

SYMPOSIUM A

Amorphous and Nanocrystalline Silicon Science and Technology-2004

April 12 - 16, 2004

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* Invited paper

TUTORIAL

A/I: Thin-Film Silicon Materials and Devices for Large-Area Electronics
Monday April 12, 2004
8:30 AM - 4:30 PM
Room 2001 (Moscone West)

Hydrogenated amorphous silicon (a-Si:H) and nano- or polycrystalline silicon (μ c-Si, poly-Si) are the semiconductors used for large-area electronics. They are applied to thin-film solar cells, active matrix liquid crystal displays (AM-LCDs), optical scanners, and radiation imaging arrays. The tutorial describes materials growth and preparation, basic material properties, device physics, and applications. Attention is given to state-of-the-art, low-temperature processing. Special emphasis will be on the relation between material properties and device performance. Existing and emerging applications will be presented and discussed.

Instructors:

Siguard Wagner, Princeton University
Jaao Pedro Conde, Instituto Superior Technic, Lisbon, Portugal

SESSION A1/H1: Joint Session: Hydrogen in Silicon
Chairs: Norbert Nickel and Eric Schiff
Tuesday Morning, April 13, 2004
Room 2001 (Moscone West)

8:25 AM
OPENING REMARKS

8:30 AM *A1.1/H1.1

Hydrogen in Silicon and Germanium: Dopant Activation and Passivation. Eugene E. Haller, ¹MS&E, UC Berkeley, Berkeley, California; ²Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California.

In an attempt to fulfill the predictions of Moores Law, the silicon device community is turning increasingly to SiGe alloys and to elemental Ge. The inherently higher electron and hole mobilities in Germanium and certain strain induced bandstructure changes both contribute to spectacular device performance increases.* It is timely to revisit the role of hydrogen in the elemental semiconductors Si and Ge and their alloys. Discussion of dopant passivation and activation by hydrogen will be emphasized. *See for example: J. S. Rieh et al., IEDM Technical Digest, IEEE 2002, pp. 771-4 and H. Shang et al., IEEE Electron Device Lett. 24(4), 242-4 (2003). –

9:00 AM *A1.2/H1.2

The Role of Hydrogen in the Creation of Metastable Defects in Hydrogenated Amorphous Silicon. P. Craig Taylor¹, T. Su¹, G. Ganguly² and D. E. Carlson²; ¹Physics, University of Utah, Salt Lake City, Utah; ²BP Solar, Toano, Virginia.

The Staebler-Wronski effect, which is a decrease in the photo- and dark conductivities in hydrogenated amorphous silicon (a-Si:H) after irradiation with light of band gap energy, has been known for over 25 years [1]. From electron spin resonance (ESR) measurements [2], the defects responsible for the decreases in conductivity are thought to be silicon dangling bonds. Hydrogen has long been invoked as important in stabilizing these dangling-bond defects, but the experimental proof of this conjecture has been elusive. We have reported an 1H nuclear magnetic resonance (NMR) signal in a-Si:H that occurs only after light soaking for 600 hours [3]. This signal, which is attributed to a pair of hydrogen atoms, exhibits similar annealing kinetics to that of the defects created during light-soaking, and the concentration of these sites is comparable to that of the defects measured by electron spin resonance (ESR). The inescapable conclusion is that these paired hydrogen sites stabilize the silicon dangling bond defects that cause the Staebler-Wronski effect. The distance between the two hydrogen atoms in the pair is about 2.3 angstroms. The temperature dependence of the lineshape suggests that the pair may undergo some form of local motion as the temperature increases [4], but the evidence is not compelling. Recently, we have seen similar effects in samples of a-Si:H made by a technique (hydrogen dilution of silane in a PECVD reactor) that reduces the saturated densities of these defects. Some possible microscopic models for the paired hydrogen sites will be discussed. 1. D. Staebler and C. R. Wronski, Appl. Phys. Lett. 31, 292 (1977). 2. H. Dersch, J. Stuke and J. Beichler, Appl. Phys. Lett. 38, 456 (1980). 3. T. Su, P. C. Taylor, G. Ganguly, and D. E. Carlson, Phys. Rev. Lett. 89, 015502-1 (2002). 4. T. Su, P. C. Taylor, G. Ganguly, and D. E. Carlson, Symposium A, this meeting.

9:30 AM *A1.3/H1.3

Hydrogen in amorphous Silicon: A simple Atom in a complex Environment. Martin Stutzmann, Walter Schottky Institute, Technische Universität München, Garching, Germany. Historically, the scientific interest concerning hydrogen in semiconductors to a large extent has been triggered by the beneficial role which hydrogen plays in hydrogenated amorphous silicon (a-Si:H) as a chemical terminator of silicon dangling bonds. However, it was almost immediately realized that the hydrogen content in device quality a-Si:H is much larger than what would be necessary to just saturate dangling bonds. Ever since, the influence of the excess hydrogen in a-Si:H on the overall structural and electronic properties of a-Si:H has been the subject of many investigations, with very different conclusions. In the meantime, much of what we believe to know today about hydrogen in silicon has emerged from detailed studies of hydrogen in crystalline rather than amorphous silicon. Yet, a direct transfer of this knowledge back to amorphous silicon has basically failed due to the inherent disorder of the amorphous matrix. The purpose of this contribution is to emphasize the role which a-Si:H has played in our present understanding of hydrogen in silicon, and to point out some central unresolved questions concerning fundamental effects of hydrogen in a-Si:H (defect passivation, doping efficiency, metastability).

SESSION A2: Metastability
Chair: Eric Schiff
Tuesday Morning, April 13, 2004
Room 2001 (Moscone West)

10:30 AM A2.1

NMR study of Paired Hydrogen Atoms in Hydrogenated Amorphous Silicon, Microcrystalline Silicon, and Doped Amorphous Silicon Thin Films. Tining Su¹, P. Craig Taylor¹, Gautam Ganguly², Dave Carlson² and Friedhelm Finger³; ¹Physics, University of Utah, Salt Lake City, Utah; ²BP Solar, Toano, Virginia; ³Institute of Photovoltaics, Research Center Jülich, Jülich, Germany.

We have previously investigated the metastable Staebler-Wronski effect in hydrogenated amorphous silicon thin films prepared by PECVD with pure silane [1]. We found that after irradiation with light, there exist paired-hydrogen sites whose densities are consistent with those of the silicon dangling bond defects measured by ESR. These hydrogen pairs can be annealed at the same temperatures as the metastable dangling-bond defects are annealed. In this report, we extended our investigation to amorphous silicon films prepared with hydrogen dilution, as well as microcrystalline and p-type doped amorphous silicon thin films. After light-soaking, the samples prepared with hydrogen dilution exhibit a lower concentration of the paired hydrogen sites than in the sample prepared without hydrogen dilution. In addition, for both the samples with and without hydrogen dilution, the paired hydrogen sites anneal at similar temperatures, and exhibit similar temperature dependences of the spin-lattice relaxation times. For both the microcrystalline and doped samples, the 1H NMR lineshapes also exhibited signals from paired hydrogen, but the temperature dependences are very different. Within experimental error, the separation of the two paired hydrogen atoms is the same for all samples. Reference 1. T. Su, P. C. Taylor, G. Ganguly, and D. E. Carlson, Phys. Rev. Lett. v89 015502 (2000).

10:45 AM A2.2

Absence of enhanced stability in deuterated amorphous silicon thin film transistors. Ralf B. Wehrspohn¹, Martin J. Powell³, Shufan Lin², Andrew J. Flewitt² and William Milne²; ¹Department of Physics, University of Paderborn, Paderborn, Germany; ²Philips Research Laboratories, Redhill, Surrey, United Kingdom; ³Department of Electrical Engineering, University of Cambridge, Cambridge, United Kingdom.

A comparison of the threshold voltage shift after gate-bias stress in hydrogenated and fully-deuterated (zero hydrogen) amorphous silicon thin film transistors (TFTs) is presented. A series of fully deuterated bottom gate TFTs consisting of a deuterated n+ contact layer, deuterated intrinsic amorphous silicon (deposited at a range of pressures) and deuterated silicon nitride gate insulator have been produced. A similar series of fully hydrogenated bottom gate TFTs have also been produced, and the stability of the two sets of devices compared. Deuterated and hydrogenated amorphous silicon deposited under the same process conditions will not have the same material properties due to the difference in the ion energy of H and D in the plasma. However, deuterated and hydrogenated material deposited at the same growth rate have almost identical structural properties. Hydrogenated and deuterated TFTs are found to exhibit the same variation in stability as a function of growth rate. In particular, there is no evidence for increased stability in deuterated TFTs. Previous reports of more stable deuterated TFTs, by other groups, can be explained by a change in the Si network properties due to the higher ion energy of deuterium in comparison with hydrogen, when using

similar deposition conditions. The implication of our experimental results is that, for the same amorphous network and hydrogen/deuterium concentration, the stability is identical for hydrogenated and deuterated TFTs. This is consistent with the idea that Si-Si bond breaking is the rate limiting step for Si dangling bond defect creation, rather than Si-H bond-breaking (1). (1) M J Powell, S C Deane and R B Wehrspohn Phys Rev B 66 155212 (2002)

11:00 AM A2.3

Study of 3-MeV Electron Radiation Damage in Amorphous Silicon with TRMC. Arjen Klaver¹, John JM Warman², Thijs MP de Haas², Wim JW Metselaar¹ and Rene RACMM van Swaaij¹; ¹DIMES-ECTM, Delft University of Technology, Delft, Netherlands; ²Radiation Chemistry Department, Delft University of Technology, Delft, Netherlands.

The Time Resolved Microwave Conductivity technique (TRMC) was used to study the damage induced in hydrogenated amorphous silicon (a-Si:H) by irradiation with 3-MeV electrons. We aim to use these results in a computer model to predict changes in a-Si:H solar cells under electron irradiation when applied in a space environment. With this technique a single 10 ns electron pulse is used to create excess charge carriers in the material, leading to an increase in conductivity. The magnitude and decay of the radiation-induced conductivity is monitored from nanoseconds to milliseconds using 30-GHz microwave detection equipment. The sample is then subjected to a large radiation dose by repetitive pulsing after which the single-pulse measurement is repeated. This procedure was reiterated with increasing amounts of accumulated dose up to a maximum of $2 \times 10^{15} \text{ cm}^{-2}$. The main advantages of the technique are that it is contactless and the effect of accumulated dose can be studied in-situ in the TRMC sample cell. Furthermore, the measurement gives quantitative information on the electron mobility and various recombination and trapping processes in the material. The electron mobility, which was estimated to be $ca\ 2 \text{ cm}^2/\text{Vs}$, was unaffected by accumulated radiation dose. The rate of decay of the conductivity however increased by up to a factor of 10 for the highest dose, indicating an increase in defect density in the material. Information on trapping, band-to-band recombination and recombination via defects can be derived from the measurements. After high radiation doses trapping and defect-recombination appeared to be dominant over band-to-band recombination. The increase in the overall recombination and the dominance of the trapping and defect recombination over band-to-band recombination indicates a large increase in the defect density after irradiation. As expected, the irradiated a-Si:H returned to its pristine condition after annealing at 150°C for 30 minutes. A new model based on SRH recombination statistics is developed to analyze the TRMC measurements further in order to be able to distinguish between trapping and defect recombination and to get a more quantitative view of the processes involved. Preliminary results show an increase in the density of states in the mobility bandgap by a factor of 5 after a $2 \times 10^{15} \text{ cm}^{-2}$ irradiation.

11:15 AM A2.4

Defect creation and annealing in tritiated amorphous silicon: a new angle in understanding the Staebler-Wronski effect. Janica Whitaker¹, John Viner¹, Stefan Zukotynski², Nazir Kherani², Erik Johnson², P Craig Taylor¹ and Paul Stradins³; ¹Physics, University of Utah, Salt Lake City, Utah; ²Electrical and Computer Engineering, University of Toronto, Toronto, Ontario, Canada; ³National Renewable Energy Laboratory, Golden, Colorado.

The appearance of optically or electrically induced defects in hydrogenated amorphous silicon (a-Si:H), especially those that contribute to the Staebler-Wronski effect, has been the topic of numerous studies [1], yet the mechanism of defect creation and annealing is far from clarified. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He³, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction has a half-life of 12.5 years. Therefore, in these tritium-doped samples essentially each beta decay creates a defect by converting a bonded tritium to an interstitial helium, leaving behind a silicon dangling bond. We have tracked these defects through electron spin resonance (ESR) and photothermal deflection spectroscopy (PDS). Like the optically induced defects, the defects created by tritium decay also anneal out at approximately 150 °C, confirming the earlier findings from luminescence [2]. However, the observed increase in defect density is several orders of magnitude smaller than one would expect with samples that contain approximately 6 at. % of tritium. After one year, the decay of tritium to helium would be expected to yield defect densities of 10^{20} cm^{-3} without saturation, but the increases observed by ESR or PDS are much smaller. At room temperature the defect densities reach saturated values of about 10^{18} cm^{-3} within 1 to 4 months. At higher temperatures the saturated densities decrease rapidly. Therefore, a very efficient room temperature annealing process must exist in the tritiated samples.

Details concerning this efficient annealing process will be presented. These findings should clarify the hydrogen-mediated defect annealing process, and the mechanism of light-induced degradation. 1. H. Fritzsche, Ann. Rev. Mater. Res. **31**,47 (2001). 2. S. Zukotynski, F. Gaspari, N. Kherani, T. Kostas, K. Law, W.T. Shmayda, C.M. Tan, J. of Non-Cryst. Solids **299 – 302**, 476 (2002).

11:30 AM A2.5

Evolution of D⁰ and non-D⁰ Light Induced Defect States in a-Si:H Materials and Their Respective Contribution to Carrier Recombination. Joshua Pearce¹, V Vlahos¹, J Deng¹, R W Collins¹, C R Wronski¹, J Whitaker² and P C Taylor²; ¹Center for Thin Film Devices, Penn State University, University Park, Pennsylvania; ²Physics, University of Utah, Salt Lake City, Utah.

Despite over twenty-five years of scientific studies on light induced defects in hydrogenated amorphous silicon (a-Si:H) materials and solar cells there are still outstanding questions regarding their nature. The existence of distinctly different light induced gap states in a-Si:H has been clearly shown in the results on the annealing kinetics of solar cells and thin films after high intensity light degradation [1,2]. The presence of such "fast" and "slow" states is also indicated in the kinetics of the light induced changes in films and cells under 1 sun illumination at temperatures between 25 and 100°C [2]. A study has been carried out in which the significant differences in both the kinetics and the corresponding evolution of distinctly different light induced defect states are characterized. This has been accomplished by taking into account the presence of more than one type of defect state, the neutral dangling bond (D⁰), as has been generally done in the past. In this approach, the complete subgap absorption spectrum, $\alpha(h\nu)$, measured with dual beam photoconductivity (DBP), are characterized rather than the commonly used method of tracking only the magnitudes of $\alpha(h\nu)$ at a single and somewhat arbitrary energy [3]. Under 1 sun illumination, the creation of defect states has been clearly identified, one around 1.0eV and the other around 1.2eV from the conduction band, which have distinctly different creation kinetics that also depend on the microstructure of the material. To identify the D⁰ defect states, direct comparisons are made between the evolution of the full DBP spectra with that in the densities of D⁰ states measured directly with electron spin resonance (ESR). The differences in the kinetics of the two defect states created by 1 sun illumination in the diluted and undiluted a-Si:H materials at different degradation temperatures are then related to the corresponding changes in electron mobility lifetime products and fill factors in solar cells. The respective contributions of these two states to carrier recombination are discussed as are the consequences of the non-D⁰ states in controlling the stability of a-Si:H materials and solar cells as well as their importance in addressing the origin of SWE. [1] L.Yang and L. Chen, *Appl.Phys.Lett.* **63** (1993) 400. [2] J. M. Pearce, R. J. Koval, X. Niu, S. J. May, R.W. Collins, and C. R. Wronski, *17th European Photovoltaic Solar Energy Conference Proceedings*, **3**, pp. 2842-2845, 2002. [3] J. M. Pearce, J. Deng, R. W. Collins, and C. R. Wronski, *Appl.Phys.Lett.*, **83**(18), pp. 3725-3727, 2003.

11:45 AM A2.6

H evolution from nano-crystalline silicon- comparison of simulation and experiment. Rana Biswas¹ and Bica Pan^{1,2}; ¹Dept. of Physics, Microelectronics Res Ctr. & Ames Lab, Iowa State University, Ames, Iowa; ²Department of Physics, University of Science and Technology of China (USTC), Hefei, China.

The temperature dependent H evolution from a-Si:H provides unique information on the H-bonding and microstructure. Traditional undiluted a-Si:H films show a high temperature H-evolution peak near 600 C. However device-quality compact nanocrystalline silicon films grown near the phase boundary of amorphous and microcrystalline growth show a new low temperature H- evolution peak near 400C in addition to a second high temperature peak near 600C. The origin of this peak cannot be attributed to microvoids or a substantial density of dihydride species typical of porous low-temperature films. We have simulated the H evolution using a molecular dynamics generated model of nanocrystalline silicon, where nano-crystallites reside in a background amorphous matrix. An excess density of H occurs at the crystallite surface. The models are heated to successively higher temperature and the motion of H is monitored. We find a low temperature evolution peak at 250-400 C, where the H-evolution starts from the surface of the nano-crystallite. In addition there is a higher temperature peak at 700-800 C providing good agreement with H-evolution measurements. The mobile H is found to exist in both the bond-centered type of species and H₂ molecules, which has implications for H-diffusion models. We will also discuss the thermal stability of the nanocrystallites. Supported by NREL.

1:30 PM A3.1/I2.1

Novel approach to position control of Si grains for a high-performance TFT using an excimer laser. K Nakano¹, Y Hitsuda¹, M Shiomi¹, I Hatada¹, N Saotome¹, Y Negoro² and J Sato¹; ¹Materials Laboratories, Sony Corporation, Atsugi-shi, Kanagawa, Japan; ²Fusion Domain Laboratory, Sony Corporation, Ohta-ku, Tokyo, Japan.

For applications to a system on panel (SOP), a high-performance poly-Si thin film transistor (TFT) is desirable. Excimer laser annealing (ELA) of a-Si film is a promising crystallization method. However, the performance of poly-Si TFTs formed using conventional ELA is limited due to small grain size and randomly located grain boundaries (GBs) which act as potential barriers for carriers. Therefore, a technique has to be developed to control the location of GBs and avoid GBs in the TFT channel. We propose a novel approach to form position-controlled Si grains by using a-Si precursor film having convex regions of several μm . In this way, high-performance TFTs are achieved. A 47-nm-thick a-Si layer was deposited on a glass substrate. A part of the layer was etched by plasma etching to form a square convex region with sides ranging from $2\mu\text{m}$ to $12\mu\text{m}$. The etching depth was about 7nm. The film was irradiated with a XeCl excimer laser in the energy range from 420 to 460 mJ/cm^2 in N_2 . The laser shot number was 100. Electron Backscatter Diffraction Pattern (EBSP) analysis indicated that $\langle 111 \rangle$ -oriented grains are formed not only in the convex region but also around it. The size of the essentially round-shaped grains was several μm . Practically only ~ 3 GBs were observed in the $\{111\}$ grains. ~ 3 GBs are thought to be electrically inactive, unlike random GBs[1] and might not degrade TFT characteristics significantly. 2-D numerical analysis revealed that there is a concave temperature profile across the convex region and the temperature drop is estimated to be about 100K with a thickness difference of 7nm. This is because the thicker convex region has a larger heat capacity than the adjacent thinner region. Preferential nucleation, that is control of the location of grains, can be realized at this low temperature site. The essentially $\langle 111 \rangle$ texture can be explained by the surface energy of the $\{111\}$ surface, which is the lowest of all surfaces. Not only the controlled grain position but also the preferential $\langle 111 \rangle$ orientation leads to good device performance, particularly as regards uniformity, as the interface quality of SiO_2/Si depends on surface orientation. We fabricated n-channel TFTs whose channel was in a convex region ($L/W=1\mu\text{m}/1\mu\text{m}$). Field-effect electron mobility of $461\text{ cm}^2/\text{Vs}$, subthreshold swing of 0.6V/dec and on/off current ratio of 3×10^7 were obtained. We simultaneously achieved position and orientation control of grains using structured a-Si films. $\langle 111 \rangle$ -oriented Si grains of a size of several μm can be obtained at the desired positions. TFTs fabricated in position-controlled Si grains show good device performance. This position-control method can be applied to SOPs and 3-D LSI's. [1] A. Fedotov et al., J. Cryst. Growth 104, 186 (1990).

1:45 PM A3.2/I2.2

A Novel Femto-second Laser Annealing for TFT Device. Zun-Hao Chen, Jia-Min Shieh, Yi-Chao Wang, Yi-Fan Lai and Bau-Tong Daia; National Nano Device Laboratories, Hsinchu, Taiwan.

In recent years, polycrystalline silicon thin-film transistors (poly-Si TFTs) have been extensively investigated for applications in large-area electronics, especially for switching devices or peripheral driving circuits in active matrix liquid crystal display (AMLCD).^{1,2} In order to realize low-cost AMLCD with integrated peripheral circuits, it is essential to reduce the maximum process temperature for high performance TFTs. Two annealing steps are adapted in the fabrication process of TFT device: one is channel-region annealing and the other is post-implantation annealing. Active region composed of amorphous silicon (a-Si) was crystallized by femto-second laser annealing (FLA) using infrared femto-second Ti: sapphire lasers. Non-thermal melting on transparent a-Si to poly-Si was induced by the intense peak power of infrared ultrafast laser pulses which leads nonlinear photo energy absorption and generation of very dense photoexcited plasma. FLA assisted by sequential lateral solidification constitutes super lateral epitaxy that can crystallize amorphous silicon into polycrystalline silicon with large grains of $\sim 1\mu\text{m}$, even when a-Si films are irradiated at an ultralow laser fluence of 45 mJ/cm^2 , and low laser-shots. The sheet resistance of post-implant annealing of a-Si decreased from $10,000\ \Omega/\text{square}$ to $300\ \Omega/\text{square}$. The traditional TFT process typically uses a top gate self-align TFT architecture with FLA. FLA activation reduces not only the postannealing temperature but also the resistance of source and drain regions, which helps improve device turn-on characteristics compared to traditional furnace activation. FLA method also has higher breakdown voltage compared to the furnace annealing because the process time of FLA method is much shorter

than furnace annealing method.

2:00 PM A3.3/I2.3

A simple explanation on the crystallization kinetics of a CW laser crystallization of a-Si. Seong Jin Park, Sang Hoon Kang, Yu Mi Ku and Jin Jang; Advanced Display Research Center, Kyung Hee University, Seoul, South Korea.

Recently, a CW laser crystallization of amorphous silicon using DPSS laser, so called CLC, has been reported as an alternative method to get a high-quality poly-Si on glass substrate. In this method, a-Si is crystallized by the scanning of CW laser and the large (long) grains are obtained along the laser scanning direction under adequate scanning speed and laser power. Not only the electric characteristics of CLC poly-Si TFT shows nearly same as that of MOSFET on SOI wafer, but also CLC has several advantages such as simple, easy and low cost process compared to the conventional sequential lateral solidification (SLS) using an excimer laser. Although there are some of papers regarding electrical and structural characteristics of CLC poly-Si, little has been known about the crystallization kinetics. We have studied CLC of various-shape patterned a-Si on glass substrate with changing thickness of a-Si film, scanning speed and laser power. Although there are many parameters for the crystallization as referred above, microstructures of the various samples are similar. The crystallized region is composed of small (edge of the pattern), large and very large grains (center of the pattern, we called it *SequentialLateralCrystallization* region) with peculiar area distribution inside the pattern. This phenomenon can be explained as the positional difference between the heating and cooling rate of a-Si film inside the pattern during CLC. This difference decides the thermal distribution of a-Si inside the pattern, and finally the grain size is decided by the thermal distribution. By the combination of our concept for thermal distribution and the well-established ELC kinetics, the crystallization kinetics of CLC can be understood. We will give an explanation on the CLC kinetics with a simple model at the symposium.

2:15 PM A3.4/I2.4

100-nm Channel Length a-Si:H Vertical Thin Film Transistors. Isaac Chan and Arokia Nathan; Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

This paper will report on the fabrication of hydrogenated amorphous silicon (a-Si:H) vertical thin film transistors (VTFTs) with nanometer-scale channel length, $L = 100\text{ nm}$, using conventional planar TFT processing technology. The device is a fully self-aligned vertical channel structure realized through optimization of photo-etch processes. The VTFT process design presented here is unique in that it has a strategic arrangement of the drain, gate, and source electrodes in such a way that the critical dimensions of the VTFT are defined only by the intersectional area of the electrodes. This yields the smallest possible TFT size for any given photo-etching resolution. Presently, we can demonstrate VTFTs with critical dimensions of $5\text{-}\mu\text{m}$ square area using standard $5\text{-}\mu\text{m}$ lithography to yield high ON-OFF current ratio (10^7) and low leakage current (1 fA at $V_d = 1.5\text{ V}$). Extension of this design to active-matrix backplanes with competitive pixel sizes and fill factor (or aperture ratio) will be presented, along with a discussion of the contemporary performance barriers and avenues for improvement.

2:30 PM *A3.5/I2.5

Issues in processing a-Si/nc-Si TFTs on flexible substrates. Sigurd Wagner, Electrical Engineering, Princeton University, Princeton, New Jersey.

Long ago silicon migrated long ago to unconventional substrates. Amorphous silicon solar cells are made on foils of steel or organic polymers, and a-Si thin film transistors are made on glass. The tremendous technology base of silicon stimulates continued experimentation with silicon on unconventional substrates. Fascinating results can be obtained that way. Many macroelectronic concepts rely on flexible, shaped, or even elastic electronic surfaces. Integrating Si TFTs with the appropriate substrates raises many process issues. They stem largely from the fact that flexible substrates are so different from crystalline silicon and glass, for which the integrated circuit processes have been developed. The physical properties of the substrate define many process conditions. Most important is the maximum process temperature, which imposes the selection of silicon TFT materials and device processes. Techniques for substrate passivation, planarization, and film adhesion also directly flow from the choice of substrate. Often these three functions are coupled. Their choice is critical to the building of a thin film silicon structure on a flexible substrate. Dimensional instability and differential thermal expansion likewise shape process conditions. Shrinking and warping calls for pre-process bake. Layers must be

made to adhere strongly, to withstand shear caused by thermal contraction. Electronics that just need to flex can be made on substrates that remain fully coated with a passivation layer during the entire fabrication process. To the process steps this layer makes the substrate material look like the passivating material. Fortunately SiNx and SiO₂ work well as adhesion and passivating layers, and allow using standard silicon fabrication processes. Electronic surfaces that can be shaped or deformed reversibly pose a much bigger process challenge. At some point in fabrication the deformable or elastic substrate must be exposed, which means that the passivation layer must be stripped. Because the properties of the substrate can be vastly different from those of silicon TFT materials, from that point on new process chemicals, patterning techniques and metallization procedures must be employed. I will illustrate these processing issues with specific examples.

3:30 PM *A3.6/I2.6

Flexible Electronics Devices using SUFTLA and Micro Liquid Process. Tatsuya Shimoda, Technology Platform Research Center, Seiko Epson Corporation, Suwa-gun, Nagano-ken, Japan.

For fabrication of flexible electronics devices, SUFTLA technology and a micro liquid process, in which an inkjet printing is included, are very promising. We have already developed several flexible devices using these technology in Seiko Epson Corporation. They not only enable us to realize flexible devices but also give us a versatile means for a flexible production system. SUFTLA, which stands for "Surface Fee Technology by Laser Annealing/ablation, is a technology that enable TFTs and TFT devices to be transferred from the original substrate to any secondary substrate by irradiating the laser to an exfoliation layer sandwiched between the TFT and the original substrate. The advantage of this technology over a direct fabrication of TFT on a plastic substrate is that the well-matured conventional TFT fabrication process can be utilized. Therefore, properties and reliability of TFT can be guaranteed. It has been demonstrated that the TFT properties don't change before and after the transfer process. We have successfully developed a flexible AM-LCD (active matrix liquid crystal display) and AM-OLED (AM-organic EL display) by using active matrix poly Si-TFT backplanes with integrated drivers transferred onto plastic substrates. Micro Liquid Process (MLP) is a process which includes an inkjet technology as an important component. MLP is defined as using a functional liquid material as a starting one and a direct patterning method to form a patterned solid film with accurate dimension. Candidates for liquid materials include liquid metals, liquid semiconductors, liquid ceramics and organic materials in a liquid form. Devices using organic materials were first explored, and then followed by inorganic materials. In the MLP including an inkjet, the process is divided into three major steps; (1) inkjet process, which enables to make a small droplet from a solution and mechanically positions it accurately on the substrate, (2) self-assembling of the droplet by surface energy, which enable a further accurate patterning than the mechanical one and (3) solid thin film formation by controlling a movement of solute which is caused by evaporation of a solvent. As applications of MLP, we have developed a colour filter for LCD, organic EL display, organic TFTs and a micro lens for VCSEL (vertical cavity surface emitting laser) by using organic materials. As for inorganic materials, metal bus lines for a plasma display were directly inkjet printed using a silver liquid metal and an PZT piezo element was also directly patterned by inkjet so as to form epitaxial growth. Direct patterning of inorganic films is very encouraging for flexible electronics devices. I confirm SUFTLA and Micro Liquid Process are very useful both for flexible devices and a flexible production system. If combined each other, advantage would be enhanced to the nth degree.

4:00 PM A3.7/I2.7

Temperature Dependent Carrier Transport in Single Crystalline Si TFTs inside a Location-Controlled Grain.

Vikas Rana, Ryoichi Ishihara, Jan Wim Metselaar and C.I. M. Beenakker; ECTM/DIMES, Delft University of Technology, Delft, Delft, zuid-holland, Netherlands.

Precise location-control of a grain in excimer-laser crystallization process allows us to eliminate the grain boundaries from active area of thin film transistor, i.e. single-crystalline Si TFTs (c-Si TFTs). TFT fabricated inside a location-controlled grain by μ -Czochralski process [1] showed a high field effect mobility of 450 cm²/Vs and low-leakage current of 10⁻¹³ A. [2] The high performance of c-Si TFTs will allow us to integrate system circuits as well as driver circuits with display, i.e., system on glass. In present work, to understand mechanism of carrier transport of the c-Si TFTs in detail, the temperature dependence of I-V characteristics of c-Si TFTs fabricated inside a location-controlled grain by μ -Czochralski (grain-filter) process were studied. The n-channel TFTs used in this study were fabricated with μ -Czochralski process [1] as follows. A grid of cavity (grain-filter) (size 100 nm) was made in SiO₂ by photolithography. Subsequently, a 250 nm thick a-Si was deposited by LPCVD using silane at 545°C and

fills the grain-filter. The samples heated at 450°C were crystallized with XeCl excimer-laser with various energy densities. TFTs having W/L of 3.21/2.88 μ m, were fabricated inside a grain with top gate, self-align structure having LPCVD SiO₂ (120 nm) as a gate insulator. No hydrogenation was done later. Temperature dependence of transfer characteristics of TFTs were measured for gate voltage V_{gs} ranging from -10 to 10 V at a drain voltage of 0.2 V. Activation energies E_a were calculated from an Arrhenius plot by means of current obtained at 37°, 52°, 77°, 127° and 177°C. At ON-state (V_{gs} = 10V), the E_a drops to negative value (-0.01 eV), which is distinct from a typical poly-Si TFT. The value indicates that bulk trap states density is very low and TFT behaves like single-crystalline MOSFETs. This was varied for a wide range of laser energy densities. With a low laser energy density, the E_a value at OFF-state (V_{gs} = -10V) is calculated to be 0.52 eV, which indicates that the leakage current is thermally generated at mid-gap states. In contrast, for a high laser energy density, the E_a in OFF-state (-10V < V_{gs} < -3V) was nearly constant at 0.7 eV. This suggests that the defects creating mid-gap states, e.g., random grain boundaries, were diminished, as a result of the high laser energy density and hence a long melt duration. Leakage current is dominated rather by trap states located in the band tail, which may be caused by remaining coherent grain boundaries in the location-controlled grain. [1] P.C. Van der Wilt, B.D. van Dijk, G.J. Bertens, R. Ishihara and C.I.M. Beenakker, formation of location crystalline islands using substrate embedded seeds in excimer-laser crystallization silicon film, Appl. Phys. Lett. 79, 1819 (2001). [2] R. Ishihara, P.C. Van der Wilt, B.D. van Dijk, J.W. Metselaar and C.I.M. Beenakker, Property of single crystalline Si TFT fabricated by μ -Czochralski (grain-filter) process, Proc. of SPIE, Vol. 5004 (2003) Pg.10-19

4:15 PM A3.8/I2.8

Elastic integrated circuits on elastomeric skin.

Stephanie Perichon Lacour and Sigurd Wagner; Electrical Engineering, Princeton University, Princeton, New Jersey.

Elastic integrated circuits are essential for robotic sensor skin that can stretch, wrinkle or shrink while transmitting data to embedded sensors. In this paper, we demonstrate the first stretchable integrated circuits made of thin film transistors (TFTs) on elastomeric membranes, and interconnected with stretchable gold conductors. We begin by fabricating stretchable gold interconnects on the rubber-like membranes. They meet TFT input/output impedance requirements in the megaohm range, can be deformed repeatedly, and thus ensure both the electrical functionality and the stretchability of the circuits. Then we integrate amorphous silicon thin film transistors, fabricated on plastic foil with the gold conductors on the elastomer membrane to form active load inverter circuits. We describe the complete fabrication process, including the application of reliable electrical contacts on elastomeric substrates. We also present the electrical performance of the inverter circuits prior to, during, and after 3D mechanical stretching.

4:30 PM *A3.9/I2.9

Reel-to-Reel Cassette Cluster Tool System with PECVD and Pulsed PECVD Deposition Techniques. Arun Madan, MVSystems Inc., 80401, Colorado.

Cluster tool (or multi-chamber) systems are generally used in the production of amorphous silicon thin film transistors, solar cells, etc. In this, each process chamber (e.g. PECVD for SiNx, intrinsic and doped amorphous silicon, sputter deposition techniques for metallization and ITO) is physically separated from others via gate valves in order to avoid cross contamination, which is crucial in obtaining optimal performance of an electronic device. The planar substrate is transported via a robotic arm from one chamber to another. Flexible amorphous silicon p-i-n type solar cells are produced using a roll to roll approach. In this, a large roll of material (e.g. a mile long) is transported through the various process zones; an attempt is made to minimize the cross contamination, between the doping and the intrinsic process regions, via the inclusion of slits, gas curtains, differential pumping etc. As is inevitable, cross contamination of the intrinsic layer due to Phosphorous and Boron persists thus preventing an optimal performance of the resulting device. We present a new type of system architecture (1) to fabricate thin film silicon devices, such as TFT's on to flexible substrates, which uses the inherent advantages of the cluster tool. In this, a large quantity of the flexible substrate material is contained within a cassette which includes a reel to reel operation. As in the current cluster tools for planar substrates, the cassette is transported to a process chamber using a robotic arm; within the process zone (e.g. SiNx using the PECVD technique), the cassette is engaged to motors to move the flexible material in a reel-to-reel operation. When the entire roll in the cassette has been processed, it is disengaged from the motors and transported into other chambers for further processing (e.g. intrinsic or doped amorphous silicon, sputter depositions of metals, or ITO). We also discuss the use of the pulsed PECVD

deposition technique, which allows an increase in the electron density during the 'ON' cycle, thus allowing the deposition rate of amorphous silicon to exceed $>15 \text{ \AA/s}$; in the 'OFF' cycle the ions responsible for dust formation in the plasma are neutralized. We show that high quality micro- (or nano) crystalline Silicon can be produced using a modified pulsed PECVD technique. In particular, at a deposition temperature as low as 120°C , materials result with a grain size of 200 \AA , low O concentration and a minority carrier diffusion length of $1.2 \mu\text{m}$ resulting in a solar cell conversion efficiency of 8% for single junction p-i-n device. The technique allows that the structure of the films can be altered from 111 to 220 in a controllable way; this has implications for fabricating nc-Si TFT's with high field effect mobility, especially on low cost flexible substrates. (1) US patent #6,258,408B1: Semiconductor Vacuum Deposition System and Method having a Reel to Reel Substrate Cassette.

SESSION A4: Poster Session: TFT, Imagers, Detectors and Other Devices; Metal and/or Laser Assisted Crystallization

Chairs: Joao Conde and Sigurd Wagner
 Tuesday Evening, April 13, 2004
 8:00 PM
 Salons 8-9 (Marriott)

A4.1

Gate Overlapped Lightly Doped Drain Poly-Si TFTs With 45° Tilt Implant For Source and Drain. Jae-Hoon Lee, Moon-Young Shin, Hee-Sun Shin and Min-Koo Han; School of Electrical Engineering #50, Seoul National University, Seoul, South Korea.

Polycrystalline silicon thin film transistors (poly-Si TFTs) recrystallized by excimer laser annealing (ELA) are widely used for various display applications. Poly-Si TFT with a short channel makes it possible to integrate peripheral circuits of AMLCD and AMOLED. However, poly-Si TFT with a short channel causes hot-carrier problems and large leakage current due to large lateral electric field so that various device structures, such as lightly doped drain (LDD) or gate-overlap lightly doped drain (GOLDD), have been already reported in order to reduce lateral electric field at the drain junction. Although LDD structure successfully improves the reliability and decreases the leakage current, on current is decreased due to lightly doped (n-) region. GOLDD poly-Si TFT has higher on current compared with a conventional LDD due to the reduction of effective channel length. However, it is well known that GOLDD poly-Si TFT requires a complicated process such as poly-Si sidewall gates or an additional photolithographic process. The purpose of our work is to report a simple and self-aligned GOLDD poly-Si TFT employing 45° tilt implant in order to reduce lateral electric field at the drain junction. 45° tilt implant was performed from the source and the drain by simply rotating the wafer. In our proposed method, gate overlapped lightly doped region may be formed because a gate oxide on the GOLDD region would be able to behave as the buffer layer during implantation of the source/drain (S/D) region. We also employ oblique incident ELA activation, which was performed to activate both the S/D and GOLDD region simultaneously. The laser beam is irradiated with oblique incident angle of 50° in order to eliminate the implant damages considerably. The proposed poly-Si TFT with $W/L=10\mu\text{m}/3\mu\text{m}$ shows very small anomalous leakage current ($V_{DS}=3.3\text{V}$, $V_{GS}=-20\text{V}$) of 0.47nA , compared with 16.8nA of conventional one due to reduction of lateral electric field in the GOLDD region. The proposed poly-Si TFT also improves the electrical reliability due to hot carrier stress, such as $V_{DS}=10\text{V}$ and $V_{GS}=V_{TH}+2$. The proposed poly-Si TFT exhibits a high mobility of $192\text{cm}^2/\text{Vsec}$, compared with conventional one of $139\text{cm}^2/\text{Vsec}$, because oblique incident ELA activation causes the reduction of effective channel length, as well as successfully cures the residual junction defect, which degrades the electrical characteristics of the conventional poly-Si TFT with a short channel. Our proposed poly-Si TFT with a short channel, which does not require any additional photolithographic process, improves the electrical reliability and decreases the leakage current by employing a simple 45° tilt implant and oblique incident ELA activation.

A4.2

Location Control of Crystal Grains in Excimer Laser Crystallization of Silicon Thin Films for Single-Grain TFTs. Hideya Kumomi¹, Hiroaki Wakiyama², Guo Nakagawa², Kenji Makihiro² and Tanemasa Asano²; ¹Leading Edge Technology HQ, Canon Inc., Atsugi, Kanagawa, Japan; ²Center for Microelectronic Systems, Kyushu Institute of Technology, Iizuka, Fukuoka, Japan.

The location of crystal grains is controlled in melting and recrystallization by excimer laser crystallization of amorphous Si (a-Si) thin films, by manipulating seed-crystal forming sites. The sites are small portions of the starting thin film, typically $\sim 1 \mu\text{m}$ in

diameter, where many nanometer-sized crystallites are embedded in the a-Si matrix or the amorphous state is altered. In the site, at least one crystallite survives the melting and serves as a seed crystal for the recrystallization of the surrounding molten matrix. The seed crystal at the site starts to grow immediately after the thin film cools down below the melting temperature, and grows beyond the site's area, while the molten matrix goes into super-cooling. After some period, when the super-cooling becomes substantially large, crystallites randomly nucleate outside the seed crystal at a high nucleation rate. The seed crystal at the site can grow until it impinges upon the randomly nucleated crystallites. The time lag for the random nucleation from the start of the seed crystal's growth results in the formation of large crystal grain at the site. The location of crystal grains is thus controlled at the sites. As the location of the large crystal grains is predetermined, one can fabricate any devices at the location-controlled grains. TFTs whose channels are formed in the location-controlled grains exhibit excellent performance compared with the random polycrystalline Si TFTs.

A4.3

Simulation of nucleation and growth of Si nanocrystals during thermal anneal of Si ion implanted oxide. Mihail P. Petkov and L. Douglas Bell; Jet Propulsion Laboratory, Pasadena, California.

Ion implantation profile in SiO₂ layers on Si substrate calculated by TRIM was used as initial conditions for a diffusion-driven nucleation and growth model. Nucleation was initiated at randomly chosen seeds satisfying the Poisson distribution, which were used as centers in a Voronoi tessellation of space. The volume fraction of implanted Si ions in each Voronoi polyhedron was calculated based on the polygon volume and the fluence. The nanocrystal growth was considered to occur at the nucleation centers by diffusing of Si ions, which become localized at the seeds. Zero net flux across each of the surfaces of the Voronoi polyhedra was assumed for the diffusing Si species. The calculations were by with periodic boundary conditions in the directions normal to the implantation. We report size and depth distribution of the Si nanocrystals formed under the above conditions.

A4.4

Silicon-Hydrogen Bonds in Boron and Phosphorous Doped Polycrystalline Silicon Thin Films. Rosari Saleh¹ and Norbert H Nickel²; ¹Department of Physics, Universitas Indonesia, Depok, Indonesia; ²Photovoltaic, Hahn-Meitner Institut, Berlin.

Excimer laser crystallization is an efficient technology to produced high-quality polycrystalline silicon (poly-Si) through the crystallization of amorphous silicon (a-Si:H). However, a-Si:H as starting material can contain considerable amounts of hydrogen. To avoid explosive out-diffusion of hydrogen that present in large quantities in a-Si:H laser crystallization has to be performed in a step-by-step procedure. In this paper, we investigate the influence of doping concentration of the B- and P-doped a-Si:H on hydrogen bonding in partially and completely crystallized poly-Si films using Raman and hydrogen effusion measurements. The starting materials were grown on a quartz substrate by rf-glow discharge method using hydrogen diluted silane as the reaction gases. Doping was achieved by mixing silane with phosphine or diborane. The nominal gas phase doping was varied from 1 to 2000 ppm. The films were crystallized in a step by step process using the 308-nm laser line of a XeCl excimer laser in vacuum and at room temperature. Laser crystallization starts at a fluence of 100 mJ/cm^2 and ending at the desired final laser fluence using steps of 40 or 20 mJ/cm^2 depending on the hydrogen content of the starting materials and the film thicknesses. After each crystallization step the films were characterized by Raman spectroscopy and hydrogen effusion measurements. The results show that in the first step of crystallization a structural transformation takes place. The films exhibit stratified structure with a polycrystalline silicon (poly-Si) layer at the top of an amorphous layer. A structural change is also accompanied by a change in silicon-hydrogen bonding. In high B-doped a-Si:H a single Si-H stretching peak at 2000 cm^{-1} is observed. Specimens doped with moderate boron and P-doped a-Si:H reveal a second Si-H stretching peak at 2100 cm^{-1} . However, the intensity of the lower frequency peak is still dominant for all films deposited at various doping concentrations. In the first step of the crystallization procedure a decrease of the both Si-H stretching peaks at 2000 cm^{-1} and at 2100 cm^{-1} is observed. However, the decrease of the stretching peaks at 2000 cm^{-1} is enhanced compared to the one at 2100 cm^{-1} , which is consistent with the different binding energies of the two H complexes. A further increase of laser fluence results in a further decrease of the peaks and subsequently the Si-H stretching peaks disappear for completely crystallized poly-Si. The results of Raman spectroscopy will be correlated with the results obtained from hydrogen effusion measurements.

A4.5

CW Argon-ion Laser initiated Aluminum Induced Crystallization of α -Si thin films. Sampath Kumar Paduru,

Hameed Naseem, Husam Abu-safe, Adnan Shariah and William Brown; Electrical Engineering, University of Arkansas, Fayetteville, Arkansas.

CW Argon-ion laser initiated Aluminum Induced Crystallization (AIC) of magnetron-sputtered amorphous silicon (α -Si) films was investigated. Amorphous silicon (α -Si) and Al films were deposited by sputtering on Corning 7059 glass substrates. Two structures were prepared: aluminum first (Al/ α -Si) and silicon first (α -Si/Al) sequences. A CW Argon-ion laser was used to initiate the crystallization process. Both the structures were irradiated with varying power densities and different exposure times. The power densities varied from 55 W/cm² to 125 W/cm². For each power density, both structures were exposed to the laser beam for 10, 60 and 120 seconds. Optical microscopy (OM), X-ray diffraction (XRD), Environmental Scanning Electron Microscopy (ESEM) and Raman spectroscopy (RS) were used to characterize the irradiated structures. From the OM analysis, macro-scale changes on the surface of the silicon films were observed. XRD patterns showed good polycrystalline nature of the resulting films. ESEM analysis indicated changes in the surface morphology both with increasing power density and exposure time. A strong crystalline Raman peak at 520 cm⁻¹ was observed. To study the effect of Al in the crystallization process, new set of samples were prepared with only α -Si on glass without Aluminum. In this case, no crystallization was observed even when the samples were irradiated using the highest power density. The results show that the lasers can be used as a new excitation source in the Metal Induced Crystallization (MIC) process instead of conventional thermal annealing.

A4.6

Self-aligned Thin Film Transistors of Nanocrystalline Silicon.

I-Chun Cheng and Sigurd Wagner; Electrical Engineering, Princeton University, Princeton, New Jersey.

Nanocrystalline silicon (nc-Si:H) is a candidate for CMOS on plastic substrates. Fast CMOS circuits require self-aligned gates. However, plastic demands ultralow process temperatures (150°C or less) that prohibit the conventional self-aligned process of ion implantation followed by a high temperature anneal. Here we show that direct deposition, combined with lift-off patterning of the top metal contacts, can achieve the self-aligned structure at low process temperature. We fabricated transistors in a staggered top gate, bottom source/drain geometry on 1737 glass substrates. The sequence is intrinsic nc-Si:H seed layer / SiO₂ buffer layer / Cr bottom contacts / doped nc-Si:H / intrinsic nc-Si:H channel / gate dielectric / Al top contacts. The Cr bottom contacts and the doped nc-Si:H source / drain patterns are defined in a single photolithographic step. The top gate Al contact metal is deposited on lift-off photoresist, which is patterned by exposure through the Cr source / drain contacts that function as masks. This aligns the gate metal with the doped nc-Si:H source / drain. In addition, the source / drain - gate overlap can be controlled by over-etching of the lift-off photoresist pattern. Atomic force micrographs show 1 μ m source / drain - gate overlap out of 40 μ m gate length. TFTs fabricated in this structure have electron mobilities 25 cm²V⁻¹s⁻¹. We acknowledge support by DARPA, NJCST and the Princeton Plasma Physics Lab.

A4.7

Fabrication and Characterization of Hydrogenated Amorphous Silicon Bipolar Thin Film Transistor (B-TFT).

Yue Kuo, Yu Lei and Helinda Nominanda; Thin Film Nano & Microelectronics Research Laboratory, Texas A&M University, College Station, Texas.

The conventional a-Si:H TFT is a field effect transistor (FET), which has disadvantages of a low operation speed and small current driving capability. To achieve a higher speed and larger current driving capability, a potential solution is to fabricate the a-Si:H-based bipolar thin film transistor (B-TFT) [1,2]. In this study, a-Si:H p-i-n junctions were prepared and studied with the goal of determining the proper thicknesses of various layers to minimize the tunneling current. Then, B-TFTs composed of a stacked structure of n⁺/i/p/i/n⁺ were fabricated. The complete TFT was made using PECVD to deposit all doped and undoped a-Si:H layers and SiN_x dielectrics at 250°C. RIE and wet etching methods were used to define base and emitter regions and contacts. The I-V characteristics of the complete B-TFT were investigated. The measured common-emitter current gain β was 3.5, which is larger than the literature report of 2.3 [1]. In addition, a collector current larger than the literature value was obtained [1]. Currently, a significant current noise was observed, which may be contributed by the high series resistance. In this paper, authors will discuss various process and structure influences on the B-TFT performance. This research is supported by NSF (ECS-0236835).

Authors thank Dr. J. Biard for his valuable advice and discussion. [1] Y. Nara and M. Matsumura, Japanese Journal of Applied Physics, Vol. 23, No. 9, 1984, L714-L715. [2] C.Y. Chang, B.S. Wu, Y.K. Fang, and R.H. Lee, IEEE Electron Device Letters, Vol. EDL-6, No. 3, 1985, pp. 149-151.

A4.8

Bottom-Gate TFTs with Nanocrystalline Silicon Channel Grown by Pulsed PECVD Technique. David J Grant¹, Czang-Ho Lee¹, Arokia Nathan¹, Scott Morrison² and Arun Madan²; ¹Electrical and Computer Engineering, University of Waterloo, Waterloo, British Columbia, Canada; ²MVSystems, Inc., Golden, Colorado.

Nanocrystalline silicon (nc-Si) thin-film transistors (TFTs) can deliver equal or better mobility, and more importantly, improved stability over their amorphous counterparts due to higher material crystallinity. As such, they are useful not only as switching devices in flat-panel displays (FPDs), allowing for higher resolution displays, but perhaps also in row shift registers and column multiplexers thus reducing packaging costs [1]. Recently, nc-Si films deposited using pulsed plasma-enhanced chemical vapour deposition (PECVD) for use in solar cells have been reported [2]. In pulsed PECVD, a conventional 13.56 MHz RF plasma is used, but it is pulsed with a frequency in the kHz range. This increases the growth rate while reducing the formation of powder particles in the plasma, thus material quality is not sacrificed for a high growth rate. In this paper we will investigate TFTs fabricated using nc-Si channel layers deposited by the pulsed PECVD technique. The TFTs were fabricated using a bottom-gate process with a silicon nitride gate dielectric. To investigate the effect of varying levels of crystallinity and crystal plane orientation on TFT performance, RF power and silane/hydrogen ratio were varied. In addition, Raman spectroscopy, X-ray diffraction (XRD), and AFM were carried out in order to see how material properties translate into TFT performance. Also, Van der Pauw measurements were performed on these samples to obtain the Hall effect mobility and resistivity. Results of material characterization and TFT performance will be presented and discussed. References: [1] I.D. French, S.C. Deane and P. Roca i Cabarrocas, Microcrystalline, Asia Display, IDW '01, 367 (2001). [2] U.K. Das, S. Morrison, A. Madan, Mat. Res. Soc. Proc. 715, A26.6 (2002).

A4.9

Microcrystalline-Si Thin Film deposited By Inductively Coupled Plasma Chemical vapor deposition (ICP-CVD).

Sang-Myeon Han, Min-Cheol Lee, Joong-Hyun Park and Min-Koo Han; School of Electrical Engineering, Seoul National University, Seoul, South Korea.

Microcrystalline(μ c) Si film thin film transistor (TFT) may be a promising device for various application including flat panel display due to rather simple process compared with poly-Si TFT and good performance compared with a-Si TFT. Conventional plasma enhanced chemical vapor deposition (PECVD) method has been widely reported to deposit μ c-Si film. In PECVD, the dilution ratio (SiH₄/H₂) of the process gases should be very low, so that deposition rate is not high. Furthermore the grain size of the μ c-Si film deposited by PECVD is not large (typically less than 15nm) due to inherent ion bombardment which may suppress the grain growth during the deposition. The purpose of our work is to report μ c-Si film deposited by inductively coupled plasma chemical vapor deposition (ICP-CVD) suitable for low temperature TFTs. ICP-CVD employs remote plasma, so that troublesome ion bombardment problems may be reduced. ICP-CVD may also provide a certain advantages such as high deposition rate and improved crystallinity over PECVD. We deposited μ c-Si film by ICP-CVD with various process temperatures, processing gasses and ICP power. The process temperature was varied from 150°C to 350°C. ICP power was 100W, 250W, 400W and 600W respectively. The process gas was SiH₄ diluted with He as well as H₂. The flow rate of He, H₂ and He/H₂ mixture was fixed at 20sccm while that of SiH₄ was 3sccm. The crystalline volume fractions evaluated from the Raman spectrum of the μ c-Si film were above 70% in all films. By Raman spectra, we observed the transition from amorphous phase to crystalline phase in the μ c-Si film had occurred. And the location of phase transition in the μ c-Si film was observed at the 10nm 30nm from the bottom of the μ c-Si film. The grain size of 40nm was observed in the film deposited 250°C in our experiment by SEM. The deposition rate increased with increasing ICP power, which indicates that high power plasma can easily decompose SiH₄ and result in more radicals which participate in the crystal growth. Our experimental results show that μ c-Si film deposited by ICP-CVD may be suitable for active layer of μ c-Si TFTs.

A4.10

Advanced SLS Crystallization Method for Low Temperature Poly-Silicon Thin Film Transistors.

Ji-Yong Park, Hye-Hyang Park, Ki-Yong Lee, Hye-Dong Kim and Ho-Kyoon Chung; Technology Development Team 1, SAMSUNG SDI, Yongin-City, Gyeonggi-Do,

South Korea.

Sequential lateral solidification (SLS) is known to be a promising method to make low temperature poly-Si thin film transistors with superior performance for fabrication of highly circuit-integrated flat panel displays such as TFT LCD or AMOLED. In this work we studied the dependence of TFT characteristics on SLS poly-Si microstructures and suggested an advanced crystallization method for LTPS device. We varied the length, width and shape of poly-Si grain by employing SLS crystallization mask pattern. The TFTs fabricated by this concept represented various device properties depending on the poly-Si microstructures. We made the nearly channel direction independent TFTs of mobility about $400\text{cm}^2/\text{V}\cdot\text{s}$ by controlling the crystallization method and also suggest the method of designing SLS mask pattern to achieve uniform TFT performance. From these concepts, we fabricated the AMOLED device with the application of microstructure-controlled SLS poly-Si TFT.

A4.11

Accelerated Stress Testing of a-Si:H TFT Pixel Circuits for AMOLED Displays. Kapil Sakariya, Clement K. M. Ng, I-Heng Huang, Sheng Tao and Arokia Nathan; Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

Threshold voltage (V_t) shift in amorphous silicon (a-Si:H) thin film transistors (TFTs) due to extended periods of electrical stress critically affects the performance and operational lifetime of a-Si:H based active matrix organic light-emitting diode (AMOLED) pixel circuits [1]. In current programmed pixel circuits, lifetime measurements can last thousands of hours, hence it is desirable to develop an accelerated testing method which can reliably predict the true long-term behaviour of the pixel circuits using shorter high-stress tests. Using TFTs subjected to constant voltage bias for 20 hours, Powell et al. [2] have shown that V_t -shift increases with temperature. While these results cannot directly be applied to TFTs in AMOLED pixel circuits that are subjected to constant current stress for more than 10000 hours, they do demonstrate the possibility of using temperature as an accelerating parameter in stress tests. In this work, we have characterized the V_t -shift in TFTs subjected to constant current stress at temperatures ranging from 0 to 100 celsius. These measurements are used to develop a model of the temperature dependence of the V_t -shift in TFTs. The temperature acceleration factor thus obtained varies with the stress duration due to the fact that V_t -shift is highly non-linear over time. In our analysis, we take into account that electron mobility in the a-Si:H channel increases with temperature. Thus, higher drive currents are needed at higher temperatures to maintain the same level of current stress relative to room temperature. The model developed in this paper also includes the V_t -shift accelerating effects of high current stress. Using a combination of both high temperature and high current stress, we have obtained an acceleration factors of close to 9, thereby reducing the required testing time for product lifetime of a-Si:H pixel circuits to around 1000 hours. [1] K. Sakariya, P. Servati, D. Striakhilev, and A. Nathan, "Vt-Shift Compensated a-Si:H Pixel Circuits for AMOLED Displays," Proc. EuroDisplay 2002: The 22nd International Display Research Conference, pp. 609-612, Oct. 1-4, 2002. [2] M. J. Powell, C. van Berkel, and J. R. Hughes, "Time and temperature dependence of instability mechanisms in amorphous silicon thin-film transistors," App. Phys. Lett., vol. 54, no. 14, pp. 1323-1325, April 1989.

A4.12

Channel Doping Effect on p-channel a-Si:H Thin Film Transistor Performance. Yue Kuo and Helinda Nominanda; Thin Film Nano & Microelectronics Research Laboratory, Texas A&M University, College Station, Texas.

Conventionally, a-Si:H TFTs are n-channel field-effect transistor (FET). If p-channel a-Si:H TFTs are available, the CMOS-type of circuit can be fabricated for various low-speed applications, such as sensors or detectors. The p-type a-Si:H film properties, such as conductivity, are related to the deposition parameters and substrate [1,2]. In addition, the TFT characteristics, such as threshold voltage and field effect mobility, are a function of the channel doping efficiency [1,3]. In this work, authors studied the effect of different levels of boron doping concentration on the p-channel a-Si:H TFT performance. The self-aligned, inverted staggered, tri-layer TFTs were fabricated using a 2-photomask process on the Corning 7059 substrates [4]. Both the p-type a-Si:H channel film and the p+ ohmic contact layer were deposited by PECVD using the $\text{SiH}_4/\text{B}_2\text{H}_6$ and H_2 mixture at various temperatures. The following results have been obtained: 1) The increase of B_2H_6 feed gas concentration increases the deposition rate. However, the film conductivity is not directly related to the B_2H_6 concentration. XPS results indicated that a 13-14% concentration of boron atoms in the film corresponds to the highest conductivity. The high substrate temperature favors the high conductivity. The high-rate deposited film could have a high conductivity when moderate ion bombardment energy is associated

with the process, which is probably due to the enhancement of surface reaction. A high H_2 feed gas concentration can promote the formation of microcrystals in the film and, hence, the doping efficiency [5], but it can also reduce the doping efficiency through mechanisms, such as blocking the available surface for reaction or including a large number of electrically inactive dopants in the film. 2) TFT characteristics, such as mobility, threshold voltage, and on-off current ratio, are affected by the doping gas concentration in the channel layer deposition process. They are also affected by the channel geometry, such as the length/width ratio. Both bottom and back channel interfaces are critical to the transistor performance, too. Authors acknowledge J. Lu, J.-Y. Tewg, and Y. Lei for their help in preparing TFTs and technical discussions. [1] H. Nominanda and Y. Kuo, Electrochem. Soc. Proc. Plasma Processing XIV, 2002. [2] Y. Kuo, H. Nominanda, M. Ristova, H.H. Lee, and J.-Y. Tewg, Electrochem. Soc. Proc. TFT Tech. VI, 2002 [3] T. Matsumoto, Y. Mishima, K. Yanai, and K. Oki, Appl. Phys. Lett., 54(7) 60 (1989). [4] Y. Kuo, J. Electrochem. Soc., 138 637 (1991). [5] Ch. Ross, J. Herion, R. Carius, H. Wagner, Mat. Sci. Eng., B72, 16 (2000).

A4.13

Statistical Modeling of Grain-Enhanced Polysilicon Thin-Film Transistor in Consideration of Grain Boundary Distribution. C. F. Cheng, M. C. Poon, C. W. Kok and Mansun Chan; Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Hong Kong.

Polysilicon Thin-film transistor (TFT) is a promising technology used on system-on-panel (SoP) for flat panel display application and 3-dimensional circuit integration. Grain boundary in the device channel would degrade the carrier mobility. For high-density and high-speed advanced circuit integrations, device shrinking to nano-scale and grain-enhancement technology like metal-induced lateral crystallization (MILC) are introduced to reduce the grain boundaries in the channel and improve performance of the device. Statistical variation of the device performance is also an important consideration especially when the polysilicon grain size is comparable to the transistor size. Some studies on statistical modeling have been performed with assuming that the transistor size is much larger than the grain size. However, this assumption may not be applicable for advanced TFTs with grain size similar to transistor size. As the statistical distribution of grain boundary in the channel is a key factor to the variation, a probabilistic model with an arbitrary transistor size to grain size ratio to predict the grain boundary distribution will be proposed in this work. Considering both the distribution and effect of the grain boundary in the channel, device-to-device variation can be predicted. The statistical model is not only applicable to MILC technology with parallel polysilicon grain pattern, but also appropriate to other a-Si crystallization techniques with a less regular grain structure, such as excimer laser anneal (ELA) or conventional solid-phase crystallization (SPC). It is believed that the model can provide important information of transistor size optimization for advanced circuit fabrication.

A4.14

Intrinsic and Doped $\mu\text{-Si:H}$ TFT Layers using 13.56 MHz PECVD at 250 °C. Czang-Ho Lee, Denis Striakhilev and Arokia Nathan; ECE, University of Waterloo, Waterloo, Ontario, Canada.

Undoped and n^+ hydrogenated microcrystalline silicon ($\mu\text{-Si:H}$) films were deposited at a temperature of 250 °C with 99 - 99.6 % hydrogen dilution of silane by conventional 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) in a commercial multi-chamber deposition system for thin film transistors (TFTs). High crystallinity $\mu\text{-Si:H}$ films were achieved at 99.6 % hydrogen dilution and at low RF power (10 W). An undoped 80 nm thick $\mu\text{-Si:H}$ film showed a dark conductivity of an order of 10^{-7} S/cm, a photosensitivity of an order of 10^2 , and a crystallinity of 80 %, while a 60 nm thick n^+ $\mu\text{-Si:H}$ film showed a high dark conductivity of 35 S/cm and a crystallinity of around 60 %. Hydrogenated amorphous silicon (a-Si:H) TFTs with these n^+ $\mu\text{-Si:H}$ ohmic contacts display a field effect mobility of $0.9\text{cm}^2/\text{Vs}$, a threshold voltage of 2 V, an ON/OFF current ratio of over 10^7 , a subthreshold slope of 0.5 V/dec, and a leakage current of an order of 10^{-13} A. A TFT structure with silicon nitride (a-SiN:H) gate dielectric and n^+ $\mu\text{-Si:H}$ contact layers was adopted to study the effect of intrinsic $\mu\text{-Si:H}$ channel deposition conditions on TFT performance. Detailed results pertinent to $\mu\text{-Si:H}$ material properties along with characterization of top and bottom gate TFT structures will be presented.

A4.15

Low-Temperature (<150°C) Doping Techniques for Polysilicon TFT's. Wan-Shick Hong¹, Seunghee Han², Yeonhee Lee², Youngwoo Kim², Jongman Kim¹ and Do-Young Kim³; ¹Dept. of Electronics Engineering, Sejong University, Seoul, South Korea; ²Advanced Analysis Center, Korea Institute of Science and

Technology, Seoul, South Korea; ³Materials and Devices Lab., Samsung Advanced Institute of Technology, Yongin-city, Kyunggi-do, South Korea.

Polysilicon (poly-Si) thin film transistors (TFT's) constructed on plastic substrates are an essential component for active matrix, flexible display devices. Most of the plastic materials used for flexible substrates have relatively poor thermal resistance, and the process temperature must be kept below the glass transition temperature of the plastics, usually under 150°C. The doping process for source-drain contacts, as well as the various film deposition, must be conducted below this temperature. In this work incorporation of the dopant atoms into the poly-Si film was performed using three different methods: dopant layer deposition, plasma immersion, and ion shower. The dopant layer method was to deposit a very thin (<100Å) layer of amorphous silicon containing dopant impurities on the poly-Si films by the standard PECVD (plasma-enhanced chemical vapor deposition) technique at the substrate temperature of 120°C. The plasma immersion was to place the poly-Si films in the sheath region of dopant plasma and to apply pulsed bias on the substrate to attract dopant ions. During this process the substrate temperature is held at room temperature. The standard ion shower technique was also carried out as a reference. The doped poly-Si films were then subsequently annealed with the XeCl excimer laser to electrically activate the incorporated dopant atoms. Influences of the dopant layer thickness, the ion dosage in the plasma, and the laser energy on the sheet resistance were studied. Sheet resistance values smaller than 10³ Ω/sq. could be obtained in all three processes, which was believed to be sufficient to form good source-drain contacts. It was found that the laser energy used for dopant activation was the major parameter to control the sheet resistance of the poly-Si film. For an initial ion dosage higher than 10¹⁵ cm⁻², the lowest attainable sheet resistance was not affected much by the ion dose or by the substrate temperature during the dopant incorporation. In summary, doping and activation process on poly-Si layers was successfully performed at a sufficiently low temperature so as not to cause a thermal damage to the plastic substrate, and a sheet resistance value as low as 300 Ω/sq. was accomplished.

A4.16

Making silicon device platforms on an elastomeric substrate.
Joyelle Elizabeth Jones and Sigurd Wagner; Electrical Engineering, Princeton University, Princeton, New Jersey.

Skin-like circuits may undergo elastic strains of the order of 10%, for example over the elbow of a humanoid robot. However, the fracture strain of thin-film transistor materials, including amorphous silicon, silicon nitride, and contact metals is ~1%. To prevent device fracture we are developing rigid platforms on the elastomeric substrate. Devices or subcircuits will be made on the rigid platforms to prevent excessive deformation. The greater part of the deformation strain will be taken up by the substrate exposed between the platforms. Earlier we demonstrated this concept with a plastic substrate that is deformed just once. Here we describe experiments with making platforms on an elastomeric, rubber-like, substrate, which can be deformed reversibly. The substrate material is 1-mm thick polydimethyl siloxane (PDMS). We are testing amorphous silicon, silicon nitride, silicon dioxide, typical contact metals, and composite films as the platform materials. Of all materials studied to date we have found that PE-CVD amorphous silicon forms continuous films with the highest mechanical integrity. Our study includes the development of process techniques for platform separation. We report the process, the maximum platform size, and the substrate aperture. This research is supported by the Packard Foundation, DARPA, and NSF.

A4.17

Low Temperature (75 °C) Hydrogenated Nanocrystalline Silicon Films grown by Conventional Plasma Enhanced Chemical Vapor Deposition for Thin Film Transistors.

Czang-Ho Lee, Andrei Sazonov and Arokia Nathan; ECE, University of Waterloo, Waterloo, Ontario, Canada.

Hydrogenated nanocrystalline silicon (nc-Si:H) is promising due to its relatively higher carrier mobility and higher electrical stability compared to the amorphous counterpart (a-Si:H). In addition, this material can be grown on flexible and lightweight substrates such as plastic at low temperatures (< 150 °C) without degrading its intrinsic material properties. The goal of the present work is to develop high-grade undoped and highly phosphorus doped (n⁺) nc-Si:H films as channel layers and as ohmic contact layers, respectively, for low temperature nc-Si:H thin film transistors (TFTs). All nc-Si:H films in this study were deposited on Corning 1737 glass substrates at a deposition temperature of 75 °C using a conventional 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) reactor. RF power densities applied were varied at constant H₂ dilution ratio and deposition pressure. To optimize the deposition conditions, and to

study the thickness dependence and the annealing effect on nc-Si:H films, electrical conductivity, optical absorption spectra, Raman scattering, and XRD measurements were carried out. Nanocrystallinity in film structure was observed over the entire RF power density range and optimized films were achieved with a moderate RF power density regime (< 100 mW/cm²) and growth rate (3 – 4 nm/min). The 80 – 100 nm thick undoped and n⁺ nc-Si:H films show a dark-conductivity of 3x10⁻⁷ S/cm and 0.3 S/cm, respectively, and corresponding crystallinity of 75 % and 72 %. The post-deposition annealing effect on dark- and photo-conductivities of undoped nc-Si:H was also studied. It was found that both the dark- and photo-conductivities increase after annealing in vacuum and then slowly decrease to the initial value within several hours in air. This effect seems to be independent of annealing temperature and time. Possible reasons of this metastability and details pertinent to experimental results will be presented and discussed, along with the performance of nc-Si:H TFTs fabricated at a process temperature of 75 °C.

A4.18

Low Temperature a-Si:H TFTs with a SiO₂ Gate Insulator Deposited by Liquid Phase Deposition. R. B. M. Cross, D. P. Oxley and E. M. Sankara Narayanan; Emerging Technologies Research Centre, De Montfort University, Leicester, United Kingdom.

Thin Film Transistors (TFTs) based on hydrogenated amorphous silicon (a-Si:H) are widely used as the pixel switching elements in Active Matrix Liquid Crystal Displays (AMLCDs). Conventionally, a-Si:H and the gate insulator material are deposited by plasma enhanced chemical vapour deposition (PECVD) at deposition temperatures greater than 200 °C. However, the increasing desire to improve process compatibility with inexpensive, flexible substrates has initiated great efforts by many workers to develop device quality layers at reduced substrate temperatures. In this paper, we describe the film properties and device characteristics of a-Si:H TFTs with silicon dioxide (SiO₂) as the gate insulator, deposited by liquid phase deposition (LPD). The active and doped layers of a-Si:H were deposited by pre-heating the silane and hydrogen source gases, in an in-house designed PECVD system, at a substrate temperature of 125 °C. The hydrogen fraction of the gas mixture was 0.9, the RF power density was 44 mWcm⁻¹, and the reactor pressure was 300 mTorr. The temperature of the source gas line was 400 °C, which was monitored and regulated by a digital temperature controller. The physical properties of the a-Si:H films were investigated by Fourier Transform Infrared Spectroscopy (FTIR) and ultraviolet-visible (UV/VIS) spectroscopy. Photoconductivity experiments were carried out using sputtered, coplanar aluminium electrodes under AM 1.5 illumination. The material was found to have a hydrogen concentration of 10 at% with a low dihydride (SiH₂) fraction, an optical bandgap of 1.70 eV as determined from Tauc plotting, and a dark conductivity of 6 x 10⁻¹¹ Ω⁻¹cm⁻¹. These values correlate well with a-Si:H deposited at higher substrate temperatures. SiO₂ was produced from a supersaturated solution of silicic acid, diluted with de-ionised water and heated to a temperature of 48 °C. The bonding and composition of the films were revealed using FTIR spectra, and the refractive index was determined using ellipsometry. The resistivity, fixed oxide charge and dielectric constant were evaluated from I-V and C-V characteristics measured on metal/SiO₂/Si sandwich structures. Film characterisation yielded values of 10¹⁵Ωcm for the oxide resistivity and a dielectric strength of approximately 9 MVcm⁻¹. The negative fixed oxide charge of the material was found to be 4 x 10¹¹ cm⁻², with a dielectric constant of 3.08, and a refractive index of 1.45. Results will also be presented of the performance of inverted-staggered TFTs incorporating these films, and comparisons made with layers deposited using standard deposition temperatures. SiO₂ is not extensively used as a gate insulating material for a-Si:H TFTs as a result of a high interface state density with a-Si:H. However, the feasibility of its inclusion in low temperature devices is explored in detail here.

A4.19

Low tensile stress SiGe deposited at 370°C for monolithically integrated MEMS applications. Sherif S Sedky¹, Kris Baert²,

Chirs Van Hoof², Yi Wang³, Omer Van Der Biest³ and Ann Witvrouw²; ¹Physics, The American University in Cairo, Cairo, Egypt; ²MCP, IMEC, Leuven, Belgium; ³MTM, KU Leuven, Leuven, Belgium.

Over the last decade SiGe has been proposed as a structural material for low thermal budget microelectromechanical systems (MEMS) that can be post-processed on top of standard CMOS driving and control electronics. There are several ways to decrease the deposition temperature of SiGe and at the same time preserve the desired physical properties for MEMS as low mean stress and strain gradient, low electrical resistivity, high quality factor, economical growth rate etc.. The commonly used technique to achieve the desired physical properties is to increase the Ge content to 60%, or more, using

conventional Low Pressure Chemical Vapor Deposition (LPCVD) [1, 2]. In this case highly conductive polycrystalline films can be realized at deposition temperatures as low as 400°C but the strain gradient is relatively high for most of MEMS applications. This can be reduced by either a furnace anneal [2] or by laser annealing [3]. The latter technique seems to be more promising as it locally modifies the physical properties without affecting the underlying films. In this work, we investigate the possibility of enhancing crystallization, and reducing mean stress and stress gradient of Si_xGe_{1-x} films at temperatures lower than 400°C, by depositing those films on top of thin (50 nm) metal layer of either titanium (Ti) or aluminum (Al). For this study Si_xGe_{1-x} (29% ≤ x ≤ 42%) films have been deposited by plasma enhanced chemical vapor deposition (PECVD) at temperatures varying from 300°C to 370°C on top of a Si substrate coated by 250 nm of thermal oxide on top of which there is 50 nm of either AlSi or Ti. X-ray diffraction (XRD) and transmission electron microscopy (TEM) have been used to study the texture, grain microstructure and size. XRD and TEM showed that SiGe films deposited on top of AlSi are more crystalline than those on top of Ti. The crystal quality is significantly improved if the SiGe film is sandwiched between two thin Al films, and the mean stress (around 60 MPa tensile) and the stress gradient are low enough for some micromachining applications. References: 1. A. E. Franke, J. M. Heck, T. J. King and R. T. Howe, Polycrystalline silicon-germanium films for integrated Microsystems, Journal of microelectromechanical systems, 12 (2), p. 160, April, 2003. 2. S. Sedky, A. Witvrouw, A. Saerens, P. Van Houtte, J. Poortmans and K. Baert, Effect of In-Situ Boron Doping on Properties of Silicon Germanium Films Deposited by CVD at 400°C, Journal of Materials Research, 16 (9), p. 2607-12, September, 2001. 3. S. Sedky, J. Schroeder, T. Sands, R. Howe and T. King, Pulsed Laser Annealing of Silicon-Germanium Films, Material Research Society symposium proceedings vol. 741, J4.1.2-6, Fall 2002.

A4.20

Aluminum-Induced Crystallization of PECVD Amorphous Silicon. Kenneth Jenq¹, Shawn Chang¹, Grant Z Pan¹ and Yahya

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Polycrystalline silicon (c-Si) is desirable for thin film transistors (TFTs) because of its high carrier mobility compared to that of the amorphous Si (a-Si). Formation of polycrystalline silicon at a low temperature is vital for low temperature large area microelectronics. We investigated the aluminum-induced crystallization (AIC) of amorphous silicon at reaction temperatures ranging from 200 to 500 °C under N₂ environment by using transmission and scanning electron microscopy. The Al layer was deposited by E-beam evaporation and a-Si was formed by plasma enhanced chemical vapor deposition (PECVD). The structures used for the AIC investigation are a-Si/Al, Al/a-Si, a-Si/Al/a-Si and Al/a-Si/Al on Si wafers coated with 300 nm PECVD SiO₂. We found that the order of the stack of layers, in addition to the ratio of a-Si to Al, significantly influences the crystallization of a-Si and the quality of the produced c-Si. When the temperature is high enough for a sufficient amount of time, a reaction will occur, and a-Si crystallizes into c-Si inside the Al layer so that the Si and Al exchange positions by the end of the process. The crystallization for the Al/a-Si structure occurs at a temperature as low as 200 °C; however, for the a-Si/Al structure the crystallization starts at a temperature above 300 °C. The electron microscopy observations indicate that the crystallized Si films are in general porous for both a-Si/Al and Al/a-Si structures though the Al/a-Si structure gives a better c-Si uniformity than the a-Si/Al structure. The non-uniformity of c-Si films for the a-Si/Al structure comes from its microstructures. The microstructures consist of preferentially oriented <100> large grains normal to the substrate Si wafer, as well as randomly formed small grains, and due to the stress on the bottom Al layer, randomly formed bubbles. Low defect density without pores and large polycrystalline grains with possible preferential orientation for high carrier mobility are essential for TFTs. We will report the details of the differences in microstructures of c-Si films, how the differences correlate to the AIC mechanism of PECVD a-Si for both Al/a-Si and a-Si/Al structures, and discuss the suitability of AIC Si for TFTs.

A4.21

Solar Cells on Foreign Substrates Using Poly-Si Thin Films by Metal-Induced Growth. Chunhai Ji and Wayne A. Anderson; State University of New York at Buffalo, Buffalo, New York.

Thin-film microcrystalline and polycrystalline silicon on foreign substrates are useful for photovoltaic and TFT devices. In the metal-induced growth technique, device quality poly-Si thin films were produced at 625°C by using 50nm Co as the metal seed-layer. In the processing, the poly-Si was heteroepitaxially grown from CoSi₂ which formed at the early stage due to a small lattice mismatch between Si

and CoSi₂ as Si was deposited by DC magnetron sputtering. The poly-Si film was grown on tungsten substrates. Previous studies focused on the growth mechanisms and electrical properties of the poly-Si. In this paper, photovoltaic device fabrication and testing will be reported. Effects of processing parameters, e.g. doping level and hydrogen passivation, on the photo-response data will be discussed. In the fabrication of MIS Schottky photo-diodes, three high work-function metals were used on n-type poly-Si, i.e. Au, Pd and Ni. Au gave the best Schottky I-V result which had the smallest reverse leakage current among the three metals. For 4μm thick poly-Si film, increasing the doping from 10¹³ to 10¹⁴ cm⁻³ level made open-circuit-voltage (V_{oc}) increase from 0.14V to 0.19V while short-circuit-current density (J_{sc}) decreased from 2.45mA/cm² to 1.9mA/cm². Hydrogen passivation was carried out by using electron-cyclotron-resonance plasma equipment. Passivation at low hydrogen pressure (2mTorr) gave improved results for both V_{oc} and J_{sc}. In one case of hydrogenation processing, J_{sc} was greatly improved to 8 mA/cm² but with a higher reverse leakage current. The mechanism of this improvement is still under investigation. Attempts in fabricating p/n junction solar cells were carried out by first using a spin-on thermal diffusion and then ion-implantation. Spin-on diffusion of boron into n-type poly-Si caused a severe shunting problem due to the faster diffusion of boron dopants into the grain boundaries than in the Si grains. Ion implantation at 10¹³ cm⁻² dose and 200keV made p/n junctions at 0.5μm position from the film surface. Single ion implantation and double ion implantation both gave a higher photo-response for the devices. The J_{sc} reached 12mA/cm² while the V_{oc} was at 0.2V. It was found that the Voc was limited by the high forward dark current. Discussions will include methods for improving V_{oc} and further refinements in device processing.

A4.22

The effect of substrate temperature and interface oxide layer on aluminum induced crystallization of magnetron-sputtered amorphous silicon. Maruf Hossain, Husam Abu-Safe, Marwan Barghouti, Hameed Naseem and William Brown; Electrical Engineering, University of Arkansas, Fayetteville, Arkansas.

The effect of substrate temperature and interface oxide layer on aluminum induced crystallization (AIC) of magnetron-sputtered amorphous silicon (a-Si) is investigated. The effect of substrate temperature on the AIC process was studied by changing the deposition temperature of a-Si from 200 to 300°C in a Al/a-Si/glass configuration. To study the effect of interface oxide on AIC, samples with a-Si/Al/glass, a-Si/Al-oxide/Al/glass, and Al/Si-oxide/a-Si/glass configurations were prepared at a fixed substrate temperature. The samples were annealed in the temperature range from 300°C to 525°C for different periods of time. The X-ray diffraction (XRD) patterns confirmed the crystallization of the a-Si films in the various configurations. From the analysis, we report that, the crystallization of a-Si happen at 350°C annealing temperature in the Al/a-Si/glass configuration. However, with or without the presence of Si-oxide at the interface, crystallization saturated after annealing for 20 minutes at 400°C. On the other hand, when Al-oxide is present at the interface, higher annealing temperatures and longer annealing times are required to saturate the crystallization of a-Si. Environmental Scanning Electron Microscope (ESEM) and Energy Dispersive X-Ray (EDX) mapping were used to study the surface morphology as well as the layer sequence after crystallization. This analysis revealed that, Si-Al layer-exchange happens regardless of the deposited configuration.

A4.23

Interaction of Amorphous Si and Crystalline Al Thin Films during Low-Temperature Annealing in Vacuum.

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A Si(150 nm, amorphous)/Al(50 nm, crystalline, {111} fiber textured) bilayer was prepared by magnetron sputter deposition and isothermally annealed at 523 K for 60 min in a vacuum system. X-ray diffraction, Auger electron microscopy, atomic force microscopy and focussed-ion beam microscopical techniques were used for compositional and microstructural analyses. A major observation was that after annealing the Al and Si sublayers had exchanged their location in the bilayer; i.e. the Si layer was adjacent to the substrate after annealing. The amorphous Si layer had crystallized into a {111} textured polycrystal. The Al layer, now adjacent to the surface, had formed uniformly net-shaped layer. Upon this arrangement, the already initially present Al {111} fibre texture has become stronger, the Al crystallites had grown laterally and the microstrain in the Al layer had relaxed. The macrostress parallel to the surface in the Al layer had changed from the initially compressive value of -139 MPa to the tensile value of +182 MPa after annealing. An extensive analysis of thermodynamic driving forces for the transformation was made.

A4.24

In-situ Aluminum-Induced Crystallization of Si Thin-Films on Glass Substrates above the Eutectic Temperature using HW-CVD. Ozgenc Ebil, Roger Aparicio and Robert W. Birkmire; Institute of Energy Conversion, University of Delaware, Newark, Delaware.

The growth and in-situ Aluminum-induced crystallization (AIC) of HWCVD Si films on Corning 7059 glass substrates above the Si-Al eutectic temperature of 577 °C has been studied. The crystalline fraction, grain structure, and the average grain size of the films were compared as a function of growth rate and the Si/Al thickness ratio. SEM and EDS analysis revealed two domains on the surfaces of the samples varying in morphology and composition; rougher areas containing a mixture of Si and Al with Al content up to 40%, and relatively smoother areas composed of almost entirely Si. This non-uniform morphology is a result of formation of Al droplets on the substrate during deposition. For 1 μm thick Si films, micron size grains were obtained with Si/Al ratio less than 2. This is a significant increase compared to samples deposited on bare glass where the average grain size is 10-50 nm. For 5 μm thick Si films, average grain size increased with decreasing Si/Al ratio, and was independent of the growth rate. Micron size grains were obtained with a Si/Al ratio less than 5. In areas composed of almost entirely Si, Raman spectroscopy also revealed the presence of a nano-crystalline phase on the surface of 5 μm thick Si films, indicating the growth of micron size crystallites in these areas does not continue as the thickness of Si film increases and the film morphology resembles that of Si film on bare glass.

A4.25

Increase of crystallinity during electrical switching in metal/μc-Si/metal structures. Jian Hu¹, Pauls Stradins¹, Craig Perkins¹, Howard Branz¹, Qi Wang¹, J R Weinberg-Wolf², Chris Lawyer² and Daxing Han²; ¹National Renewable Energy Lab, Golden, Colorado; ²Department of Physics & Astronomy, University of North Carolina, Chapel Hill, North Carolina.

We report on switching phenomena in metal/p+μc-Si/metal thin film structures, and find that it generally requires lower applied voltage than comparable amorphous Si switches. After switching, a localized increase in crystalline fraction can be observed by micro-Raman scattering measurements. Doped microcrystalline Si (μc-Si) thin films of 30-50 nm thick are deposited on Cr metal by hot-wire chemical vapor deposition at a substrate temperature of 160 C. The devices have photolithographically-defined Ag or Al top contacts of 3 μm to 40 μm in diameter. Switching is stimulated by either a current-ramp or a voltage pulse. The resistance before switching depends inversely on the device area, with about 100 kΩ across a 10-μm device. After switching, the device resistance decreases to 100 Ω or below and becomes independent of area, suggesting formation of a conducting filament. During an applied current ramp, the surface temperature probed with a fine thermocouple shows a linear increase with current density and optical microscopy reveals a localized surface morphology change likely associated with heating and filament formation. The Si microstructure is probed by scanning micro-Raman spectroscopy on mesa-etched devices after the metal top contacts are removed. For the non-switched devices, the Raman signal indicates a uniform structure at all locations, which contains a broad 480 cm⁻¹ peak (a-Si:H) and a sharp 520 cm⁻¹ peak (crystallites); after switching, the 520 cm⁻¹ peak sharpens and the 480 cm⁻¹ broad peak shrinks in a few locations (a few microns spot) on the device, indicating local crystallization in these devices. Thus, heating or/and metallic silicide [1] or/and electric fields [2] associated with the switching process induce local crystallization. A conductive atomic force microscopy and micro-Auger spectroscopy will be used to determine whether the localized spot forms a metallic or non-metallic conducting filament. [1] I. Pelant, P. Fojtik, K. Luterova, J. Kocka, K. Knizek and J. Stepanek, Thin Solid Films 383, 101-103 (2001) [2] C. Hayzelden and J. L. Batstone J. Appl. Phys. 73, 8279 (1993)

A4.26

Modelling of Aluminum Induced Lateral Crystallization of Hydrogenated Amorphous Silicon. Mohammad Saad Abbasi, Husam Abu-Safe, Hameed Ahmad Naseem and William D Brown; Electrical Engineering, University of Arkansas, Fayetteville, Arkansas.

Metal induced lateral crystallization (MILC) of hydrogenated amorphous silicon (a-Si:H) was studied and a model was developed based on the resistance measurement of the films. Hydrogenated amorphous silicon films of 300 nm thickness were deposited using plasma enhanced chemical vapor deposition (PECVD) on oxidized p-type (100) silicon wafers. Thermally evaporated 200 nm thick aluminum layer was deposited over amorphous silicon and patterned using photolithography. The samples were annealed at different temperatures for different time periods. After annealing the resistance of amorphous silicon between aluminum pads was measured. Based on

these measurements, a model was developed to predict the lateral crystallization velocity. In this model, the resistance change due to loss of hydrogen from the film was also taken into account. For this purpose, another set of experiments was conducted. In this set hydrogenated amorphous silicon films of 300 nm thickness were deposited on corning 7059 glass. The samples were annealed for different period of time at different temperatures. After annealing, parallel bars of silver paint were formed on the samples and the resistance of each sample was measured. The theoretically determined lateral crystallization velocity was verified using optical microscope observations and X-ray diffraction analysis and was found to be in close agreement.

A4.27 TRANSFERRED TO A10.10

A4.28

Porous Silicon for Small Molecule Mass Spectrometry. Grace Credo¹, Hillary Hewitson¹, Daniel Wall¹, Jeffrey Finch¹, Christopher Benevides¹, Edouard Bouvier¹, Zhouxin Shen² and Gary Siuzdak³; ¹Waters Corporation, Milford, Massachusetts; ²Mass Consortium Corporation, San Diego, California; ³The Scripps Research Institute, La Jolla, California.

Previous work has demonstrated the utility of desorption/ionization on silicon (DIOS) in small molecule and peptide detection. In DIOS, the analyte is applied directly (no matrix) to a porous silicon surface and subject to laser desorption/ionization. Like matrix-assisted laser desorption/ionization (MALDI), the advantages of DIOS include little to no fragmentation of the analyte (easier sample identification), rapid sample preparation/analysis for high-throughput applications, and the ability to analyze complex mixtures. However, since MALDI utilizes an organic acid co-crystallized with the analyte, interference peaks are common below 700 amu. With the elimination of matrix-related ions and sample preparation effects, DIOS can facilitate the identification of analytes that are not easily detected by MALDI. Potential applications include high-throughput small molecule assays for drug discovery and high sensitivity (sub-femtomole) peptide identification for proteomics. In this work, using sample substrates manufactured in-house, 1) reproducible DIOS chips were produced, 2) the chips were shown to be sensitive to contamination, 3) a consistent cleaning procedure was used to remove contaminants, 4) small molecules and protein digests were detected without matrix-related peaks, and 5) stability, shelf life, dynamic range, sensitivity, reproducibility, quantitation and speed of analysis were explored. These parameters and characteristics are further evaluated with respect to optimized morphology, derivatization, solution composition and automated deposition.

A4.29

Amorphous Si_{1-x}Ge_x:H,F films obtained by Low Frequency PECVD for uncooled microbolometers.

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A typical bolometer is a temperature sensitive resistor, whose operation relies on the temperature increase after the device has been heated by the absorbed radiation. Measurable physics effects under IR illumination are observed in many materials, such as: metals, semiconductors and superconductors as a change of resistance. A temperature-dependent resistor and an IR absorber form a bolometer. The resistor should have a large temperature coefficient of resistance (TCR), which is defined as $TCR = \alpha = (1/R)(dR/dT)$, so a small temperature increase results in a significant change in the bolometer resistance. Metals like platinum and nickel, semiconductors like vanadium oxide, superconductors and non-crystalline material have been used as sensing element. However metals present a very low TCR, additional to vanadium oxide is not a standard material in IC technology and superconductors need special temperature conditions. Two kinds of materials: superconductors and amorphous semiconductors possess the highest TCR values. However superconductors are not compatible with silicon technology, while amorphous semiconductors are fully compatible with silicon technology. For room temperature operation, amorphous silicon (a-Si:H) has been used in commercial applications, however it presents a very high resistivity. Therefore there is a compromise between having a material with a high TCR and a low bolometer resistance. In this work, we analyze the electrical behavior of amorphous Si_{1-x}Ge_x:H,F films to be used as sensing layer in uncooled microbolometers. The films were deposited using Silane (SiH₄) and Germane Tetrafluorine (GeF₄) as source of Si and Ge respectively, by PECVD at low frequency (110 kHz), diluted in H₂ and Ar respectively. The Ge content (x) in the gas phase, was varied from 0 to 1. The films were characterized by Infrared spectroscopy for structural composition; the electrical properties were obtained by I-V measurements in temperature function (300K to 470K) in order to

obtain the conductivity and the activation energy, the x variation, results in a change in the absorption coefficient, the dark conductivity at room temperature from 1×10^{-9} to 2.1×10^{-3} ($\text{Ohm}\cdot\text{cm}$)⁻¹ and the activation energy from 0.86 eV to 0.39 eV. This results demonstrate that this material as a good candidate for the sensing element for uncooled micro-bolometer, due to its high E_a , and therefore, a high TCR (0.051 K^{-1}) and its low resistivity.

A4.30

High current density in microcrystalline and amorphous Silicon diodes. Janice Nickel, Patricia A. Beck and Peter Hartwell; Advanced Storage Department, Hewlett Packard Laboratories, Palo Alto, California.

We report on the formation and characterization of wafer-scale microcrystalline and amorphous silicon p-i-n and p-n junction diodes prepared by PECVD. Data will be presented on resulting material properties/electrical properties as a function of (a) deposition parameters: hydrogen dilution, temperature and pressure, (b) substrate conditions: base material, interface cleanliness and (c) post-deposition process: etching, anneal and passivation. Device characteristics will be presented to illustrate the various conditions. Diodes with forward currents of 100 A/cm², and rectification ratios of 10^4 at 2 V have been fabricated.

A4.31

High Quality Patterned SIMOX SOI Materials for SOC Applications. Yemin Dong, Meng Chen, Jing Chen, Xiang Wang and Xi Wang; Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai, China.

Patterned silicon-on-insulator (SOI) materials have been fabricated using patterned separation by implantation of oxygen (SIMOX) technique with doses of $2.0\text{-}9.0 \times 10^{17}$ ions cm^{-2} at energies of 50-160 keV through a pre-patterned hard mask. The microstructures of the resulting materials were assessed by cross-sectional transmission electron microscopy (XTEM). The results reveal that high quality patterned SOI materials with a high degree of surface planarity and low defect density transitions between the SOI and bulk regions can be obtained by optimization of the implant dose and energy. The physical mechanisms behind the quality improvements are discussed. These planar and low-defect-density patterned SIMOX SOI materials are desirable for system-on-a-chip (SOC) applications. Furthermore, patterned SOI materials with deep submicron bulk regions have been also synthesized successfully. It is demonstrated the feasibility of fabricating a novel quasi-SOI device applying such optimized low-dose patterned SIMOX technique.

A4.32

Selecting excitation pathways in multi-nanolayers of Si:Er with resonant exciton generation. Mark Klik¹, B.A. Andreev² and Tom Gregorkiewicz¹; ¹Physics, Van der Waals-Zeeman Institute, Amsterdam, Netherlands; ²Institute for Physics of Microstructures, Nizhny Novgorod, Russian Federation.

By using infrared and mid-infrared radiation we were able to get a unique insight in the processes of energy transfer between ions of the rare earth Erbium and its Si host. The multi-layered samples that were studied are grown with a special MBE technique that produces optical centers, which emit light in an extremely narrow spectral region. Differences were observed in the power dependence and absorption cross-section of the 1.5 micron Erbium photoluminescence when exciting the Erbium either via resonantly generated excitons or via electron-hole generation, which enables us to identify two distinct excitation pathways leading to the excitation of Erbium in these systems. Mid-infrared experiments performed with a free-electron-laser further clarified the nature of the centers involved in the two methods of excitation.

A4.33

Luminescence of Si-SiOx systems. Tetyana Torchynska¹, Alejandro Vivas-Hernandez¹, Francisco Guillermo Becerril-Espinoza¹, Y. Goldstein², I. Balberg², J. Jedrzejewski² and L. Khomenkova³; ¹Ciencia de Materiales, Escuela Superior de Fisica y Matematicas-Instituto Politecnico Nacional, Mexico, Distrito Federal, Mexico; ²Racah Institute of Physics, Hebrew University, Jerusalem, Israel; ³Institute of Semiconductor Physics, Kiev, Ukraine.

The Si-SiOx systems with nano-crystallite silicon are under intensive investigations due to their potential application in the electronics industry, in particular, for creation of light emitting devices. The latter is connected with the observation of bright photoluminescence (PL) of such materials in red-orange and green-blue spectral ranges at room temperature. Although several models, including quantum confinement effects in Si nano-crystallites, surface states of Si nano-crystallites, Si-based chemical species like siloxene and polysilane, suboxide defects in Si/SiO₂, an exciton on Si/SiO₂

interface have been proposed, the nature of visible PL of Si-SiOx systems is still being discussed. In the framework of quantum confinement model a dependence of the PL peak energy on the size of Si nano-crystallites has to exist. However, in many cases a determination of the sizes of Si nano-crystallites has not been made. Besides the different dependencies of PL peak energy on Si nano-crystallites sizes have been observed: the red and blue shifts, as well as its absence with decrease of Si crystallites sizes. One of the possible explanations of this discrepancy is the superposition of emission bands of different nature. In particular, the Si-SiOx interface can contain numerous defects due to large lattice mismatch (about 7 % or more), surface roughness and variation in surface stoichiometry (SiOx). So, the radiative transitions connected with different types of interface defects can contribute to the PL spectra as well as the defects in the SiO₂ matrix can also participate in light emission. PL spectra and their temperature dependence, as well as Raman spectra of Si-SiOx systems prepared by radio frequency magnetron sputtering method and thermal annealed at 1150 oC during 40 min for creation Si nano-crystallites were investigated as a function of Si content and the Si nano-crystallite sizes. It was shown that PL spectrum of such systems consists of five PL bands with peak positions at 1.38, 1.42-1.54 eV, 1.7 eV, 2.06 eV and 2.30 eV. The dependencies of these peak positions and their intensities on concentration and Si nano-crystallites sizes in Si-SiOx system have been investigated and analyzed. The nature of radiative optical transitions for all PL bands is revealed.

A4.34

Photoluminescence of Si nano-crystals in amorphous silicon. Alejandro Vivas and Tetyana Torchynska; Science Materials Department, National Polytechnic Institute, Mexico, Mexico.

A number of groups have reported intense photoluminescence (PL) from Si nano-crystallites embedded in SiO₂ in the spectral range of 1.5-2.4 eV. The mechanisms of this photoluminescence have been discussed extensively, but still remains to be clarified. The main problem for definition of the photoluminescence (PL) mechanism is connected with the existence of the same PL bands both in SiO₂ with and without Si nano-crystallites (n/c). The latter is the evidence, that defect-related PL in SiO₂ layers may be the reason of above mentioned PL bands. In this paper we investigated Si nano-crystallites embedded in amorphous silicon using X-ray diffraction and Raman scattering methods, as well as by the study of photoluminescence spectra. The layers were deposited by the hot-wire CVD method on glass substrates at different wafer temperature in the range of 200-500°C. Four different PL bands have been revealed in PL spectra of investigated Si n/c - amorphous silicon systems, peaked at 0.92-0.98eV, 1.12eV, 1.39eV and 1.6eV. The intensity of the bands depends on Si size and concentration. The joint analysis of PL, Raman scattering and X-ray diffraction spectra in dependence on the size of Si nano-crystallites, as well as on the existence (or absence) of Si nano-crystallites in the films are analyzed. The mechanisms of PL for all 4 bands are proposed as well.

A4.35

Change of light emission of Si wires during Si/SiOx interface formation. Francisco Guillermo Becerril-Espinoza¹, Tetyana Torchynska¹, Miguel Morales-Rodriguez¹, Larisa Khomenkova², L.V. Scherbina² and S. Ostapenko³; ¹Ciencia de Materiales, Escuela Superior de Fisica y Matematicas-Instituto Politecnico Nacional, Mexico, Distrito Federal, Mexico; ²Inst. Semiconductor Physics at National Academy of Sciences, Kiev, Ukraine; ³CNNR-University of South Florida, Tampa, Florida.

Discovery of visible light emission from porous silicon (PSi) at room temperature stimulated great interest to investigation of various Si nano-structures due to necessity to create Si-luminescent objects fully compatible with Si processing. Different models were proposed to ascribing the visible PL, such as quantum confinement effects in Si nanocrystals, as well as defects (oxygen vacancy or non-bridging oxygen hole centres) in silicon oxide on the PSi surface or at the Si-SiOx interface. In this work the changes of Photoluminescence (PL), PL excitation, Raman scattering, IR absorption spectra as well as of PSi surface morphology, were studied as a function of Si/SiOx interface formation during PSi ageing in ambient air with the aim to reveal the PL mechanism. Fresh-prepared PSi layers created at low values of current density (I_a) is characterised by "red" emission centred at 1.72 eV, while the ones prepared at high values of I_a have "orange" PL band centred at 2.00 eV. It is possible to receive also the superposition of these two PL bands for some intermediate value of I_a . The ageing leads to the decrease of PL intensity. Simultaneously the peak position of "red" PL band shifts to the high-energy up to 1.80-1.85 eV while the "orange" band does not change practically. However, if the orange PL band has not been detected in "fresh" PSi layers, after the ageing this band appears in the spectrum. To understand the effect of surface morphology the comparative analysis of PL spectra and AFM images of fresh and aged PSi layers has been

done. The highest PL intensity is measured on pSi layers prepared at $I_a=5-20$ mA/cm² that have Si low-dimensional structures with the diameter of 20-60 nm and the height of 10-30 nm. In IR absorption spectra of pSi layers the intensities of oxygen related absorption bands such as Ox-Si-H, Si-OH, Si-O are increased at the rise of values of I_a and ageing duration. The complex analysis of mentioned above parameters and their changes during formation of the Si-SiOx interface give the possibility to make conclusion concerning the PL and PL excitation mechanisms in Si wires. This work partially support by CONACYT Mexico (Projects 33427-U and U42436-Y, as well as Mexico-Ukraine International Project), NSF USA and CGPI-IPN.

A4.36

About the luminescence mechanisms of composite a-Si:nc-Si system obtained by ion-beam amorphization in a wide dose region. David Isaakovich Tetelbaum¹, Alexander A. Ezhevskii¹, Alexey N. Mikhaylov¹, Mikhail Yu. Lebedev¹, Yulia A. Mendeleva¹ and Sergey V. Morozov²; ¹Physico-Technical Research Institute of University of Nizhny Novgorod, Nizhny Novgorod, Russian Federation; ²Institute for Physics of Microstructures of Russian Academy of Science, Nizhny Novgorod, Russian Federation.

Recently [1-3], we have developed a new method of creation of luminescent nanostructured layers in silicon by ion irradiation. The method is grounded on partial amorphization with retaining in a-Si the unamorphized nanocrystalline inclusions (quantum confined regions). Here we report the results of further investigation of this layer properties. It is shown that the regularities of dose evolution are common for different ion masses ($M = 20-84$). The photoluminescence spectra (in range of 700-1100 nm) are similar for the region of relatively small ion doses (transition to the amorphization) and for the doses substantially exceeding the amorphization dose. In the latter case, the light emission is dominantly caused by the layer placed beneath the amorphized one. The data are complemented by the results of ESR and scanning probe microscopy investigations with layer-by-layer etching. Influence of the annealing temperature is also investigated. The work was supported by the RFBR grant 04-02-16493 and programme of the Russian Ministry of Education Scientific researches of higher school in the priority fields of science and technique, subprogram 205». [1] D.I. Tetelbaum, S.A. Trushin, Z.F. Krasil'nik, D.M. Gaponova, A.N. Mikhailov. *Optical Materials*. 2001. V. 17. No. 1-2. P. 57-59. [2] D.I. Tetelbaum, A.A. Ezhevskii, S.A. Trushin, A.N. Mikhaylov, A.Yu. Azov, A.K. Mukhamatullin, S.E. Akis, D.M. Gaponova. *Material Science and Engineering B*. 2003. V.101. No.1-3. P.279-282. [3] D.I. Tetelbaum, A.A. Ezhevskii, A.N. Mikhaylov. *Semiconductors*. 2003. V.37. No.11. P.1342-1344.

A4.37

Correlation between Surface Charge Accumulation and Pumping Intensity Dependent Red-Shifted Micro-Photoluminescence of Si-Implanted Quartz with Buried Si Nanocrystals. Chun-Jung Lin, Kuo-Chen Yu, Hao-Chung Kuo, Gong-Ru Lin and Miao-Jia Ou-yang; Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan.

The pumping intensity dependency of the defect- and nanocrystal-related photoluminescence (PL) and micro-PL from the multi-recipe Si-implanted quartz (SiO₂:Si⁺) is characterized. The SiO₂:Si⁺ samples with 2 % excess Si density were prepared by multi-energy implanting pure quartz silica substrate with silicon ions of 5×10^{15} ions/cm² at 40 keV, 1×10^{16} ions/cm² at 80 keV and 2.5×10^{16} ions/cm² at 150 keV. The micro-PL results reveal that the natural oxygen vacancy and the Si nanocrystal (nc-Si) precursor defects at 410 nm and 550 nm enhanced after annealing and exhibit a saturation effect due to their finite concentrations. The PL of Si-implanted quartz with nc-Si of 2.5 nm diameters was observed at wavelength of 709 nm after annealing at 1100°C for 3 hours. By increasing the power density from 5 W/cm² to 300 kW/cm², we observed that the PL of as-implanted sample exhibits negligible wavelength shift effect, whereas the nc-Si related PL from the 3-hr annealed sample have a "red-shift" phenomenon from 709 nm to 735 nm. This phenomenon can not be well explained by either the band-filling or the temperature-dependent energy shift, which is also not consistent with the previously reported coupled quantum well phenomenon. A possible hypothesis is given by the anomalous quantum stark effect due to the build-in electric field from nc-Si dots to the surface of quartz substrate under high-intensity or long-term optical pumping process. By observing the gradual accumulation of surface charge during the high-power pumping conditions, we have primarily corroborated such a pumping-intensity dependent wavelength red-shift to the unusual stark effect which is mainly caused by the surface charge accumulation induced electric-field beneath the nc-Si structure buried in the quartz substrate. With a long-term (1-hr) and high power (300 kW/cm²) illumination, the nc-Si micro-PL peak wavelength further red-shifts by at least 1 nm, which is in good agreement the aforementioned interpretations.

A4.38

Buffer-layer Effect on Mixed-Phase Cells Studied by Micro-Raman and Photoluminescence Spectroscopy. Andrea Hilechey¹, Chris Lawyer¹, Daxing Han¹, Baojie Yan², Guozhen Yue², Jeffrey Yang² and Subhendu Guha²; ¹Physics & Astronomy, UNC-Chapel Hill, Chapel Hill, North Carolina; ²United Solar Ovonic Corporation, Troy, Michigan.

We have reported the light-induced open-circuit voltage (Voc) increase in mixed-phase silicon solar cells, where very small amount of nanocrystalline grains are incorporated in the intrinsic layer [1]. A two-diode model has been proposed and explained most of the experimental results [2]. Micro-Raman provided supporting evidence with non-uniform distribution of the nanocrystalline grains [3]. In this paper, we use micro-Raman and photoluminescence (PL) spectroscopy to study the electronic states in the mixed-phase solar cells with various interface conditions. An amorphous silicon (a-Si:H) buffer layer is inserted between the p layer and the mixed-phase intrinsic (i) layer, or between the i and n layers. Light-soaking experiments show that a thin (100 Å) a-Si:H at the p/i interface does not affect the behavior of light-induced Voc increase. However, a thick (500 Å) layer increases the initial Voc significantly and eliminates the light-induced Voc increase by blocking the current path through the nanocrystalline grains. The signature of nanocrystalline grains still appears on the Raman spectra measured on certain areas of the cells with a 100 Å thick a-Si:H buffer layer at the i/p interface. It completely disappears for samples with 500 Å a-Si:H buffer layer due to the strong absorption of the 514 nm wavelength by the 500 Å a-Si:H buffer layer. The PL peak at 1.3-1.4 eV increases after light soaking for the cells with 100 Å thick a-Si:H buffer layer, similar to those with no buffer layer [1]. However, such increase is significantly reduced for the cells with 500 Å a-Si:H buffer layer. The reason is that the light-induced defect generation in the thick a-Si:H buffer layer reduces the band tail transitions, hence the change in the mixed-phase i layer is masked. We also inserted the same buffer layer into the n/i interface and found no effect either on the behavior of the light-induced Voc changes or on Raman and PL spectra. The correlation of the Raman and PL results with the mechanism of light-induced Voc increase will be discussed in the paper. [1] J. Yang, K. Lord, B. Yan, A. Banerjee, S. Guha, D. Han, K. Wang, *Mater. Res. Soc. Symp. Proc.* 715, 601 (2002). [2] B. Yan, J. Yang, and S. Guha, *Proc. of 3rd World Conf. on Photovoltaic Conversion*, Osaka, Japan, 2003, 5P-A9-06 (in press). [3] J. M. Owens, D. Han, B. Yan, J. Yang, K. Lord, and S. Guha, *Mater. Res. Soc. Symp. Proc.* 762, A4.5(2003).

A4.39

Quasi-crystalline state in A-Si and A-Si Ge induced by the combined effect of light and temperature. Pilar Martin¹, Alfredo Torres¹, Andres Rodriguez², Jesus Sangrador², Tomas Rodriguez² and Juan Jimenez¹; ¹Fisica Materia Condensada, Universidad de Valladolid, Valladolid, Spain; ²Departamento de Tecnologia Electronica, Universidad Politecnica de Madrid, Valladolid, Spain.

A quasi-crystalline state is achieved under light exposure of amorphous -Si and a-SiGe, prepared by LPCVD (Low pressure chemical vapor deposition), in the temperature range between 100 and 190 C. Both the temperature and the light intensities necessary for the structural changes are significantly lower than the ones needed for either thermal or laser crystallization. The effect is reversible in the sense that the amorphous structure is restored when the layer is either cooled down below 100 C or heated up above 190 C. This structural transformation achieved under specific conditions of light exposure and temperature differs from other light induced transformations of a-Si reported in the literature, e.g. Staebler-Wronski effect. The structural transformation described herein involves a large number of lattice sites leading to the formation of quasi crystals. It does not appear as a metastable state in the sense reported for other effects, but it is rather the consequence of the combined action of light and temperature. The Raman spectroscopy study allows to describe the main structural changes characterizing this state in either amorphous Si or SiGe alloys. This study reveals that a large number of lattice sites is involved in the formation of the ordered grains with sizes around 8 lattice parameters diameter. The Raman analysis also demonstrates that these grains are under strong internal tensile stress, approx. 3Gpa. The possible mechanisms leading to the formation of this state and the influence of the different parameters, as light intensity and temperature in the formation of these grains are discussed.

A4.40

Evaluation of an alternative technique for the fabrication of direct detector X-ray imagers: spray pyrolysis of lead iodide and mercury iodide. Marcelo Mulato, Jose Fernando Condeles and Julio Cesar Ugucioni; DFM-FFCLRP, Universidade de Sao Paulo, Ribeirao Preto, Sao Paulo, Brazil.

Amorphous silicon based X-ray imagers have been studied in the last

15 years by some universities and industrial laboratories. Some prototypes have even come to the market already. For these applications a phosphor material must be used on top of the a-Si:H pixelated active matrix imager. The phosphor is responsible for the conversion of the X-ray photons into photons with wavelengths in the visible range, which in turn are absorbed by the p-i-n a-Si:H photodetector. This method is called indirect. On the other hand, the direct method is based on the use of a photoconductor that directly converts the X-ray photons into electric charge, which is stored in each pixel. A single microcrystalline silicon TFT is also used for the addressing of each pixel in this case. Among the many material candidates for the direct detection system, lead iodide and mercury iodide are very promising. They have large atomic numbers and also large energy band gaps. Because of that, they could be used at room temperature without the need of any further cooling. The growth of large volumes of both materials has already been studied in the past for the detection of high-energy photons for nuclear applications. Nevertheless, few studies have been published regarding the fabrication of thin films of PbI₂ and HgI₂, and all of them mention the difficulty of producing high quality material at reasonable price and time for industrial applications. The main of this work is to evaluate an alternative route for the fabrication of these thin films: the spray pyrolysis technique. According to the present authors knowledge, this technique has never been used in the past for the fabrication of PbI₂ and HgI₂ thin films. We discuss the structural and electronic properties of thin films obtained under varying deposition conditions, such as substrate temperature, spray-substrate distance, purity of the starting powder, deposition time, etc. The characterization techniques are X-ray diffraction, Raman scattering, atomic force microscopy (AFM) and current versus applied voltage as a function of temperature. While the deposition technique seems to be very promising for the fabrication of high quality PbI₂ thin films, unfortunately it does not present the same success for the case of HgI₂, as will be presented and discussed. The growth process is compatible with a-Si:H technology given that the best films were obtained at a substrate deposition temperature around 200°C.

A4.41

Are the Current Models Helpful to Understanding Staebler-Wronski Degradation? Bolko von Roedern, MS3212, National Renewable Energy Laboratory, Golden, Colorado.

This contribution will review the compatibility of Staebler-Wronski models with experimental data and observations. Such review will show that neither the "bond breaking models" (originally proposed by Dersch and Stutzmann) nor the "defect conversion models" (originally proposed by Adler) can explain all observations on films and/or on solar cells. It has been well accepted for a while that experimental stress and recovery phenomena, both on films and devices, always identify both "slow" and "fast" degradation and recovery mechanisms. Those attempting characterization of material and cell performance in terms of gap states had to conclude that at least two different defects have to be involved. However, as discussed by Heck and Branz [1], experimental findings are also incompatible with defect conversion; rather, degradation and annealing experiments affect the "slow" and "fast" mechanism somewhat proportional. The exact rates (or activation energies) and proportions depend on the observable used (e.g., subgap absorption, photoconductivity, or solar cell parameters), the material properties, as well as the experimental degradation and anneal conditions. It is argued that the quintessential understanding of the Staebler-Wronski mechanisms will come from identifying a fundamental physical process that provides a quantitative understanding of the "coupling" between the slow and the fast mechanisms. Qualitatively, such coupling has helped the understanding of the long-term performance of commercial amorphous silicon photovoltaic modules [2]. From a historic perspective, it is interesting to review failed predictions of overly simplistic Staebler-Wronski models suggesting pathways for the minimization or elimination of the degradation that turned out later as not being viable. Often, materials research guided by such inadequate models was based on manipulating (reducing) the amount of degradation of a single material parameter or by improving its stabilized value. When these material schemes were tested in actual solar cells, in many instances, either cell stability was either not improved or lower stabilized efficiency resulted. [1] S. Heck and H.M. Branz, *Mat. Res. Soc. Symp. Proc.* Vol. 664 (2001), A12.2. [2] B. von Roedern and J.A. del Cueto, *Mat. Res. Soc. Symp. Proc.* Vol. 609 (2000), A10.4.

A4.42

Amorphous Silicon Image-sensor Arrays Fabricated by Digital Lithography. William S. Wong, Steven E. Ready, Rene A. Lujan and Robert A. Street; Electronic Materials Lab, Palo Alto Research Center, Palo Alto, California.

A promising approach to simplify large-area electronics fabrication is through digital lithography, in which an electronically generated and digitally aligned etch mask is jet-printed onto a process wafer to

define device features, replacing conventional photolithography. Amorphous silicon-based image sensor arrays have been fabricated using the digital-lithography method. a-Si:H thin-film transistor back-plane arrays were fabricated using conventional deposition methods, while etch masks defining the device structure were patterned using electronically generated images jet-printed directly onto the process wafer. The digital lithographically fabricated arrays had features as small as 40 μm with 5 μm layer-to-layer registration and pixel dimensions of 300 μm over a four-inch diameter wafer. The resulting TFTs, with on/off ratios of 10⁸ and threshold voltages of 2-3 V were then integrated with a-Si sensor media to complete the array structure. Operation of the image sensor as an x-ray detector will be shown. To further demonstrate the efficacy of the digital lithographic process, results from multi-layer patterning on flexible substrates for sensor and display applications will also be presented.

A4.43

Use of Large Area P-I-N Photodiode as a Colour Image Sensor. Paula Louro¹, M. Fernandes¹, A. Fantoni¹, A. Macarico¹, M. Vieira¹, N. Carvalho² and G. Lavareda², ¹DEETC, ISEL, Lisboa, Portugal; ²CFM, IST, Lisbon, Portugal.

Photodiodes based on p-i-n amorphous silicon structures have several applications in the field of photosensitive devices. In this work we report its use as a colour image sensor. These structures exhibit a strong dependence of the spectral response on the applied voltage, which means that the spectral sensitivity can be electrically tuned. We used several p-i-n structures based on amorphous silicon and amorphous silicon carbide produced by PE-CVD with the configuration glass/ITO/p(a SiC:H)/i(a Si:H)/n(a SiC:H)/Al-ITO. All have the same intrinsic layer and in the doped layers we changed the resistivity through the addition of methane to the doping gas. For the optical characterisation of the devices we measured the I(V) characteristics under daylight-like illumination (AM1.5) and with appropriate neutral density filters we also varied the photon flux. Interference filters with maximum transmission at wavelengths 450 nm, 550 nm and 650 nm and half width (FWHM) of 40 nm were also used in order to evaluate the I(V) characteristics under monochromatic illumination at different photon fluxes. Results show that for 650 nm illumination a higher voltage is needed for complete collection of photo-generated carriers, while for 450 nm illumination a lower voltage is sufficient to reach the wavelength-dependent saturation current. Thus, at a constant photon flux it is possible to separate different wavelengths at distinct bias voltages. The spectral response dependence on the applied voltage and on optical bias was also studied. Results show that the spectral sensitivity is strongly dependent on the applied voltage, namely the maximum spectral sensitivity shifts with the voltage, and the spectral response goes down to zero at certain wavelengths, which allows a different selectivity and enables colour recognition. In the low voltages range the red signal is suppressed allowing green recognition. The red information is obtained by tuning the voltage to higher values where the green signal goes down to zero. Combining the signal information at these voltages a colour image can be acquired. The dependence of the transport mechanism on the spectral region and on the applied bias voltage is explained taking into account the experimental data and the results obtained through a detailed numerical simulation based on the ASCA simulator.

A4.44

A Real-time Optical Signal and Image Processing P-I-N/P-I-N Device. Manuela Vieira¹, M. Fernandes¹, A. Fantoni¹, P. Louro¹, C. Mendes¹, G. Lavareda² and N. Carvalho²; ¹DEETC, ISEL, Lisboa, Portugal; ²CFM, IST, Lisbon, Portugal.

Large area (4x4 cm²) optical signal and image processing devices deposited on flexible substrates were produced at low temperatures (110°C) by PE-CVD and compared with similar sensors deposited on glass substrates. The optically addressed device consists of two stacked p(SiC:H)/i(Si:H)/n(SiC:H) write-read photodiodes with different i-layer thickness. The device operates under short circuit or slightly reverse bias. The imaging is performed in a write-read simultaneous process: the write exposure, which converts the optical image into a localized packet of charges and the optical read which performs the charge to current conversion by detecting the photocurrent generated by a light beam scanner. During the image acquisition process no charge transfer to move the packets of charge within the sensor is needed. This allows a real-time optically addressed readout. If write beam is on, the front photodetector, acting as a load, converts the optical image into a spatially varying electric field across the bottom diode. This leads to the self biasing of the bottom diode that switches to its OFF state becoming locally sensitive to the incoming read beam. In the absence of the write beam (erase operation) the sensor becomes insensitive to the read beam since the front photodiode is not conducting, and ideally the voltage drops across the bottom one is not enough to switch it to its OFF state. In this work the main emphasis will be put on analysis of the

optical characteristics. The influence of the doped and active layers characteristics (conductivity, photosensitivity, thickness) on the device performance (transfer functions, resolution, responsivity, response time) will be presented. The various design parameters tradeoffs are discussed. Results show that reducing the thickness of the back diode increases the resolution, but increases the capacitance and therefore the response time. The resistance of the doped layers is also important. Too conductive doped layers spread out the charge, reducing resolution. A trade-off between the read and the write beams wavelength and the active layers thickness are needed to minimize the cross talk between the write and the read beams and to improve the contrast ratio of the output read light. An electrical model is presented and supported by a two dimensional simulation.

A4.45

Dynamic Characteristics of a 32 A-Si:H Position Sensitive Linear Array. Rodrigo Ferrao de Paiva Martins, Elvira Fortunato, Isabel Ferreira, Hugo Aguas, Leandro Raniero and Shubin Zhang; Materials Science, FCT-UNL, Caparica, Portugal.

The increase demand in automation processes requires more and more the use of inspection methods able to supply information in real time. These methods should be installed as close as possible to the production process and they should be able to supply the required measured information in a safe and fast way, without disturbing the process itself. Simultaneously they should be free of wear and insensitive against mechanical perturbations. This approach can be reached by proper combination of the laser triangulation technique with an array of linear position sensitive detectors, able to supply information about the surface finishing of an object. The aim of this paper is to present experimental results of the dynamic performances exhibited by such array constituted by 32 elements (equivalent to 5 bits lateral resolution, combined with a continuous analogue longitudinal resolution). The analogue information supplied by this array is processed by an analogue/digital converter, directly coupled to the array and whose information is computer processed, concerning the recognition of patterns and the processing of information collected over the object to be inspected.

A4.46

Performance Analysis of a-Si:H Detectors Deposited on CMOS Chips. Clement Miazza¹, Nicolas Wyrsch¹, Sylvain Dunand¹, Gregory Choong¹, Arvind Shah¹, Nicolas Blanc², Rolf Kaufmann², Lionel Cavalier², Pierre Jarron³, Danielle Moraes³, Matheiu Despeisse³, ¹Institute of microtechnology, University of Neuchatel, Neuchatel, Switzerland; ²Optoelectronic microsystems, CSEM, Zurich, Switzerland; ³Experimental Physics Division, CERN, Geneva, Switzerland.

Image and particle sensors based on thin-film on CMOS (TFC) technology are currently being developed at our laboratory. In this technology, the detectors are vertically integrated on top of a CMOS chip. The chip is a designed specifically for the application that is envisaged. The detector is a thin film amorphous silicon (a-Si:H) diode deposited in a VHF-PECVD reactor. For both, vision and particle detection, the use of this approach will lead to enhanced performances. In fact very high fill factor, sensitivity, and integration level, coupled with extremely low dark current values can be attained. A preliminary phase of optimization of the a-Si:H layers with primary focus on reducing dark current, enabled us to reach values as low as 1pA/cm² (at -1 V for 1 micron thick detectors). These detectors have then been deposited on the CMOS readout chips, revealing unfortunately a significant increase in dark current. In this paper, the causes and remedies relating to this effect will be discussed in detail. In particular, the principal cause, the influence of chip's surface topology on final performances, will be evidenced. Some solutions to improve dark current, or at least limit the increase of dark current will be analyzed. These solutions include surface treatments, and use of alternative detector configurations. The overall characteristics and most significant results already achieved with these TFC image and particle sensors will also be presented.

SESSION A5: Growth and Properties

Chairs: Dave Cohen and Richard MCM van de Sanden
Wednesday Morning, April 14, 2004
Room 2001 (Moscone West)

8:30 AM A5.1

In-situ observation of silicon epitaxy breakdown with real-time spectroscopic ellipsometry. Charles W. Teplin, Dean Levi, Eugene Iwaniczko, Kim M. Jones, Qi Wang and Howard M. Branz; National Renewable Energy Laboratory, Golden, Colorado.

Spectroscopic ellipsometry is used for the first time to monitor, in real time, the breakdown of hot-wire chemical vapor deposition (HWCVD) epitaxial crystalline silicon (c-Si) growth to hydrogenated amorphous silicon (a-Si:H) growth. We study epitaxy on different c-Si substrate

orientations for varied growth parameters such as substrate temperature and filament current (reaction temperature), with the aim of correlating ellipsometry measurements with the progress or breakdown of epitaxy. The ellipsometry measurements, which are validated by transmission electron microscopy of selected samples, show that the breakdown of epitaxy can take various forms depending on the growth conditions. During growth from pure silane at 250 °C on (100) substrates with a 13 Å filament current, breakdown is a slow evolution (over 100 nm of deposition) of the top silicon layer from c-Si to a-Si:H. During growth at lower substrate temperature (200 °C) on both (111) and (100) substrates with a 16 Å filament current, the transition region extends over only 30 nm of deposition. The optical properties of the breakdown regions are well-described by an effective medium of a-Si:H and c-Si. Previously, HWCVD has been used to grow 140 nm of epitaxial Si at 325 °C. [Thiesen et al., APL 75, p. 993 (1999)] These new in-situ spectroscopic ellipsometry measurements provide real-time observation of surface morphology and the crystallinity of newly deposited Si. By applying this technique to epitaxial growths, we hope to develop a deeper understanding of epitaxy breakdown, allowing increased epitaxial breakdown thickness and growth rate.

8:45 AM A5.2

Comparison of Deposition Phase Diagrams for Si:H Film Growth at VHF and RF Plasma Frequencies. Gelio M Ferreira¹, Joshua M Pearce¹, Christopher R Wronski¹, Robert W Collins^{2,1} and Christoph Ross³; ¹MRI, PSU, University Park, Pennsylvania; ²Department of Physics and Astronomy, University of Toledo, Toledo, Ohio; ³Forschungszentrum Julich, Institut für Photovoltaik, Julich, Germany.

Deposition phase diagrams provide a convenient means to describe the thickness evolution of hydrogenated silicon (Si:H) film structure and phase during low-temperature plasma-enhanced chemical vapor deposition (PECVD). They can also be used to assess the electronic properties and potential device performance of Si:H films, based on established correlations. We have applied phase diagrams in a comparison of Si:H prepared by PECVD at low and high frequencies (rf: 13.56 MHz; and vhf: 60 MHz), in both low and high pressure regimes (< 0.5 Torr; and 3-4 Torr). Smooth c-Si wafers have been used to evaluate the surface roughness evolution in the amorphous silicon (a-Si:H) growth regime. Also, R=[H₂]/[SiH₄]=0 a-Si:H substrate films have been used to simulate i-layer deposition in devices. These latter substrates are used to identify relevant amorphous-to-(mixed-phase microcrystalline) transitions [a→(a+μc)] and (mixed-phase)-to-(single-phase) microcrystalline transitions [(a+μc)→μc]. This study has shown that under all explored conditions of plasma power, frequency, and pressure, yielding a range of deposition rates (0.5 - 20 Å/s), the structural evolution for a-Si:H growth improves with increasing R right up to the [a→(a+μc)] transition. This improvement is apparent through the amorphous roughening transition (denoted a→a to indicate the absence of a phase change) which increases in thickness with R under all conditions. For R values much lower than the a→(a+μc) transition for a thick film, vhf a-Si:H deposition provides a significant improvement in structural evolution (i.e., increased a→a transition thickness) over rf a-Si:H, for a given rate. For optimum a-Si:H films with R values just below the a→(a+μc) transition, however, both rf and vhf processes exhibit comparable structural evolution. In fact, highest quality 3000 Å a-Si:H at high rates (6.5 Å/s) are obtained by both rf and vhf PECVD at elevated pressure (3 Torr) and plasma power (0.5-0.7 W/cm²) with R=60 just before the a→(a+μc) transition.

9:00 AM A5.3

Phase diagrams and microstructure of microcrystalline and amorphous silicon studied by dynamical simulation of the growth of microcrystalline silicon. J Bailat, E Vallat-Sauvain, A Vallat and A Shah; Institut de Microtechnique, Université de Neuchatel, Neuchatel, Switzerland.

A simple discrete model is shown to be able to reproduce well and qualitatively explain the main characteristics of the growth dynamics and microstructure of microcrystalline silicon: conical shape of the crystalline grains, transition from amorphous to crystalline material, roughness evolution versus film thickness. The present study focuses on the microstructure and the phase diagrams of the simulated layers. The Transmission Electron Microscopy (TEM) study of microcrystalline silicon deposited by plasma enhanced chemical vapor deposition revealed that the material is a complex mixture of crystalline phase, amorphous phase, grain boundaries and voids. The typical microstructure consists in conical conglomerates of nanocrystals separated by amorphous material and possibly voids. The relative amount of each phase can vary, depending on the deposition parameters, the thickness of the layer or the underlying substrate. The model presented is a 3-dimensional discrete model on a cubic lattice. Each cubic particle falls along a randomly chosen column of the lattice towards the growing surface. When the particle

reaches the surface, it moves to the column of lowest height among the surrounding columns (first neighbors only). The state of the newly arriving particle is then chosen according to the following selection rules: the new state will be the state that is mostly represented in the neighborhood, provided the number of similar neighbors is higher than a threshold, the so-called crystalline threshold value; otherwise the state of the particle is randomly chosen among all possible states. The state of a deposited particle corresponds to its crystallographic orientation. A crystalline domain is thus defined as a domain filled with particles in the same state whereas an amorphous domain is filled with particles in different states. Thus in this model, the number of simulation parameters is reduced to two, i.e. the number of possible states and the crystalline threshold value. The outcome of the simulation are computer generated representations of the layer microstructure that compares directly with TEM micrographs. Furthermore the simulation permits to observe the time evolution of the growing microstructure. It also allows one to demonstrate the effect of preferential etching of the amorphous phase on the layer growth, by incorporating a simple etching rule. This model is the first one that simulates the microcrystalline silicon microstructure from simple selection rules. Since the first presentation of this model at the ICAMS 20 Conference (2003), the authors have added the study of the phase diagrams of the model, i.e. the study of the occurrence of the amorphous/microcrystalline phase transition versus the two model parameters: the number of possible states and the crystalline threshold value. This study demonstrates the stability of the model and its usefulness for a more fundamental understanding of microcrystalline silicon growth dynamics.

9:15 AM **A5.4**

Real-time and spectroscopic study of a-Si:H film growth by second harmonic generation. W.M.M. Kessels, C.M. Leewis, I.M.P. Aarts, J.J.H. Gielis and M.C.M. Van de Sanden; Dept. of Applied Physics, Eindhoven Univ. of Technology, Eindhoven, Netherlands.

The nonlinear optical technique of second harmonic generation (SHG) has been applied on thin films of a-Si:H both in *ex-situ* experiments as well as in-situ and real-time during a-Si:H film growth. It is expected that the application of SHG on a-Si:H can yield insight in the a-Si:H film properties and the surface processes during film growth because SHG has proven to be sensitive to surface dangling bonds on crystalline silicon. First a set of a-Si:H films with a different thickness (4-1031 nm) and deposited by rf PECVD on quartz substrates have been investigated at different polarization states and for pump photon energies between 1.10 and 1.30 eV. It is shown that the SH signal originates from an isotropic contribution at both the surface and buried interface region of the film and a distinct resonance peak is observed at a pump photon energy of ~ 1.20 eV. Close examination of this resonance peak with the spectral dependence of dangling bonds on crystalline silicon [1] reveals similarities which might indicate that the SH signal of a-Si:H is caused by dangling bonds in the interface and surface region of the films. This suggestion is also strengthened by the fact that dangling bonds in a-Si:H are generally measured by subgap absorption spectroscopy in the same energy range. A comparison between the SHG experiments and subgap absorption spectroscopy measurements - from the combination of cavity ring down spectroscopy and spectroscopic ellipsometry carried out on the same films - will therefore be given. Subsequently, SHG experiments have been performed in-situ in an ultra-high vacuum setup on a-Si:H films deposited by HWCVD. Although these films generate a somewhat lower signal, the HWCVD deposited films show the same polarization dependence and spectral signature as the a-Si:H films deposited by rf PECVD. These experiments also validate the fact that the a-Si:H itself leads to the SH signal as these films are not influenced by a native oxide which forms after exposure of Si films to air. SHG has also been applied during real-time film growth of a-Si:H for different substrate temperatures. These experiments reveal that the SH signal initially increases with increasing film thickness but starts to decrease after ~ 10 Å a-Si:H has formed. Atomic H induced etching reveals the reverse process. These initial experiments prove therefore that SHG has a great potential for monitoring a-Si:H growth and can provide real-time information on the role of dangling bonds in the a-Si:H growth process. Currently, more real-time experiments are carried out with an extended pump photon energy range. [1] K. Pedersen, and P. Morgen, Phys. Rev. B 52, R2277 (1995).

9:30 AM **A5.5**

Surface Processes During Growth of Hydrogenated Amorphous Silicon. Eray S. Aydil¹, Dimitrios Maroudas², Sumit Agarwal², Sriraman Saravanapriyan³ and Mayur S. Valipa^{1,2}; ¹Chemical Engineering Department, University of California-Santa Barbara, Santa Barbara, California; ²Chemical Engineering Department, University of Massachusetts, Amherst, Massachusetts; ³Chemical Engineering, Princeton University, Princeton, New Jersey.

Hydrogenated amorphous silicon films for photovoltaics and thin film transistors are deposited from silane containing discharges. The

radicals generated in the plasma such as SiH₃ and H impinge on the surface and lead to silicon film growth through a complex network of elementary surface processes that include adsorption, abstraction, insertion and diffusion of various radicals. More importantly, these reactions also determine H incorporation, and defect generation and passivation. Developing deposition strategies for improving the film quality requires a fundamental understanding of the radical-surface interaction mechanisms. We have been using in situ multiple total internal reflection Fourier transform infrared spectroscopy and in situ spectroscopic ellipsometry in conjunction with atomistic simulations to determine the elementary surface reaction mechanisms and their energetics. Experiments and atomistic simulations will be synergistically used to elucidate elementary processes occurring on the surface and to discuss our current understanding of the reaction mechanisms that lead to a-Si:H film growth.

10:30 AM **A5.6**

Influence of the Distribution of Tail States in a-Si:H on the Field Dependence of Carrier Drift Mobilities.

Guy J. Adriaenssens¹, Monica Brinza¹, Evguenia V. Emelianova¹, Andre Stesmans¹ and Vladimir I. Arkhipov², ¹Halfgeleiderfysica, University of Leuven, Leuven, Belgium; ²IMEC, Leuven, Belgium.

The multiple-trapping transport model has been used successfully in the past to describe the temperature and electric-field dependencies of carrier drift mobilities as they are obtained from time-of-flight (TOF) transient photocurrent measurements in hydrogenated amorphous silicon (a-Si:H). From the agreement between experimental observations and modelling predictions did follow the wide acceptance of an exponential distribution of tail states, on both the valence- and conduction-band sides of the gap, for the 'standard' a-Si:H, i.e. material prepared by plasma-enhanced chemical vapor deposition (PECVD) at ~ 250 °C. However, a-Si:H layers prepared by other techniques do not always fit into this pattern. For instance: TOF samples prepared by the expanding thermal plasma (ETP) technique have shown virtually field-independent drift mobilities [1] that can only be reconciled with an exponential band tail by assuming the presence of a pronounced band of deep traps. A weak field dependence of the mobility was also observed [2] in some polymorphous silicon samples. In this contribution, we examine in how far one may account for these data by assuming a density of tail states that decays faster than the exponential one. While it has been shown before that a linear tail does indeed lead to a field-independent mobility, a Gaussian distribution of tail states does result in similar behavior. In those cases, the insensitivity to the applied field results from the fact that in these steep distributions carrier transport more readily reaches quasi-equilibrium conditions. On the other hand, equilibrium transport implies the observation of non-dispersive transients, which is not the case for the data obtained from the ETP a-Si:H samples that show field-independent drift mobilities. Therefore, to also match the experimental data with respect to the degree of dispersion observed in the TOF signals, the problem of multiple-trapping transport in band tails is re-examined for the general case of steeply decreasing density-of-states (DOS) functions. Given the types of samples in which the weaker mobility field dependence is observed, it may be surmised that microstructure in the material does result in a band-tail DOS that is more Gaussian-like than exponential. [1] M.Brinza et al., J.Non-Cryst.Solids 299, 420 (2002) [2] M.Brinza, G.J.Adriaenssens, P.Roca i Cabarrocas, Thin Solid Films 427, 123 (2003)

11:00 AM **A5.7**

Interpretation of Transient Photocurrents in Coplanar and Sandwich PIN Microcrystalline Silicon Structures.

Steve Reynolds¹, Vladimir Smirnov¹, Charlie Main¹, Friedhelm Finger² and Reinhard Carius², ¹Computing and Advanced Technologies, University of Abertay Dundee, Dundee, United Kingdom; ²IPV, Forschungszentrum Juelich, D-52425 Juelich, Germany.

The prospect of further improvements in stable photovoltaic efficiencies continues to stimulate research on carrier transport in microcrystalline silicon films. A wide range of studies have confirmed that such films are structurally anisotropic, consisting of clusters of coherent crystalline regions often in the form of columns oriented perpendicular to the substrate, separated from each other by cracks or voids and disordered material [1]. Differences in film transport properties depending on whether measurements are made parallel or perpendicular to the substrate might therefore be anticipated. Previous studies [2,3] have identified differences in carrier mobility, μ - τ product and defect densities in nominally identically-prepared films equipped with ohmic coplanar and sandwich contacts. These results have then been used to inform the construction of transport models, in which grain size and shape and defect and barrier height distributions and cross-sections are adjustable parameters. Here, we present a comparison of transient photocurrents in intrinsic microcrystalline silicon coplanar [4] and solar cell (pin) [5] configurations, as a function of crystalline volume fraction (CVF), and

experimental temperature. Data are analysed in terms of trap-limited band transport, and while results from both structures at low CVF support this model, the temperature-dependence observed in more highly crystalline films is at variance with it. Possible reasons for this are discussed. The density of states distributions in films of low CVF deduced from photocurrent decays differ between coplanar and sandwich structures, the former suggesting a broad exponential tail but a comparatively low density of deep states, and the latter a narrower tail but somewhat higher mid-gap density. These predictions are contrasted with existing structural models. [1] L. Houben et al, Phil. Mag. A 77, 1447 (1998). [2] T. Unold, R. Brueggemann, J.P. Kleider, C. Longeaud, J. Non-Cryst. Sol. 266-269, 325 (2000). [3] K. Hattori et al, J. Appl. Phys. 94, 5071 (2003). [4] S. Reynolds et al, MRS Symp. Proc. 715, A21.2.1 (2002). [5] S. Reynolds et al, MRS Symp. Proc. 762, A4.3.1 (2003).

11:15 AM A5.8

The Role of Charged Gap States in Light-Induced Degradation of Single Junction a-Si:H Solar Cells. Miro Zeman, Vojtech Nadazdy and Wim Metselaar; DIMES, Delft University of Technology, Delft, Netherlands.

Inherent to hydrogenated amorphous silicon (a-Si:H) are the reversible changes in electronic properties of a-Si:H under light exposure, known today as the Staebler-Wronski effect (SWE). It is generally accepted that light soaking leads to the creation of additional dangling-bond defects, which deteriorate the performance of a-Si:H devices such as solar cells. Our experimental results from charge deep-level transient spectroscopy reveal that in the initial stage of light soaking of a-Si:H the annihilation of positively charged states above midgap, Dh, takes place and is followed by creation of neutral states around midgap, Dz, and negatively charged states below midgap, De. During light soaking we observe a substantial increase of Dz states in accordance with the observation of the creation of additional dangling bonds that dominates the SWE. We expect that the annihilation of the Dh states would strongly effect the charge distribution and electric field at the p/i interface where the Dh states dominate the gap-state distribution in a single junction a-Si:H solar cell. A series of single junction a-Si:H solar cells were deposited on Asahi U-type substrate with five different thicknesses of the intrinsic layer (di = 150, 300, 450, 600 and 1000 nm) and subjected to light soaking. The dark and illuminated J-V characteristics and spectral response of the cells were measured during the degradation experiments. We used the ASA (Advanced Semiconductor Analysis) program to simulate the behavior of the single junction a-Si:H solar cells during various stages of light-induced degradation. Recently, several new features were implemented into the ASA program, which enhance its capability of accurate modeling of thin-film silicon solar cells. For example, degradation of a-Si:H solar cells can be simulated by using position dependent coefficients (kh, kz, ke), which control changes in the spatial distribution of density of Dh, Dz, and De states due to light soaking. The evolution of the spatial distribution of the defect states during light soaking will be presented for the solar cells with different di. This evolution is extracted from matching the solar cell experimental data with the simulated results at different times of light soaking, which will also be presented. We demonstrate that in the initial stage of light exposure it is the annihilation of the Dh states and not their formation that contributes to a drop in the spectral response of the solar cell in the short wavelength region ($\lambda < 550$ nm) and to a slight increase of the open circuit voltage. The creation of the Dz states in the bulk of the solar cells in the later stages of light soaking is responsible for an overall drop in the spectral response and in the external solar cell parameters, mainly the fill factor.

11:30 AM A5.9

Femtosecond Far-Infrared Studies of Photoconductivity in a-Si:H. A.V.V. Nampootheri and Susan L. Dexheimer; Washington State University, Pullman, Washington.

Far-infrared, or THz, frequencies are a key spectral range for probing conductivity mechanisms, since they correspond to inverse times for important carrier processes. We present femtosecond time-resolved studies of the frequency-dependent photoconductivity in the far-infrared spectral range (1-10 meV) in PECVD a-Si:H and a-SiGe:H thin films. The experiments are carried out using an optical pump / terahertz (THz) probe technique, in which a femtosecond pump pulse excites carriers into the extended states and a time-delayed probe pulse measures the resulting change in the far-infrared optical properties, which are directly related to the ac photoconductivity, as the carrier distribution evolves in time. We find that the frequency-dependent conductivity measured on picosecond time scales shows a strongly non-Drude behavior, with components of the response fitting to a power-law frequency dependence, reflecting processes associated with localized states. This response is compared with the temporal response of the photoexcited carrier distribution, which can be successfully modeled with a simple physical model that includes both trapping into band tail states and bimolecular

recombination on picosecond time scales. This work was supported by the National Renewable Energy Laboratory and by the National Science Foundation under grant DMR-9973615.

11:45 AM A5.10

On the Einstein relation for hydrogenated amorphous silicon.

Thanh H. Nguyen^{2,1} and Stephen K. O'Leary¹; ¹Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada; ²Information Systems Management Corporation, Regina, Saskatchewan, Canada.

We present a generalized Einstein relation analysis, applicable for disordered semiconductors with exponential distributions of tail states and square-root distributions of band states. We find that there are substantial deviations from the traditional non-degenerate form of this relation, these deviations arising as a consequence of the degeneracy of the occupation statistics within disordered semiconductors. We use these results to account for some hydrogenated amorphous silicon experimental results.

SESSION A6: 20th Anniversary Session
Chairs: Arun Madan and Craig Taylor
Wednesday Afternoon, April 14, 2004
Room 2001 (Moscone West)

1:30 PM *A6.1

20 years of fundamental physics and applications of amorphous silicon. Robert Street, ¹Palo Alto Research Center, Palo Alto, California; ²Palo Alto Research Center, Palo Alto, California.

At the time of the first MRS symposium on amorphous silicon in 1984, the fundamental science of hydrogenated amorphous semiconductors was striving to understand the disordered atomic structure and to develop a consistent model to account for the electronic properties. At the same time the development of a-Si thin film transistors for active matrix liquid crystal displays (AMLCD) was just in its exploratory phase. Now, 20 years on, AMLCD fabrication is a large and growing industry and the science of a-Si:H is quite well understood. The talk will discuss some of the many ways that the field has evolved in the past 20 years, and how the fundamental physics and the technology development have informed and guided each other. Some speculations about future research and technology developments will be attempted.

2:15 PM *A6.2

Excimer-laser growth of Si large-grain arrays. Masakiyo Matsumura, ALTEDEC, Yokohama, Japan.

A-Si TFTs will be a leading star, for a long time, as the best addressing device for high impedance liquid-crystal (LC) pixels with reasonable sizes. But, various new applications have been grown recently in display fields, which include ultra-large displays such as 100-inches in diagonal size, and intelligent & fine displays (1). Much higher switching speed TFTs are strongly requested for these applications. Another technological trend toward organic EL displays want also new TFTs having higher current drivability, since EL diodes are of a forward-biased and low-impedance device. Poly-Si TFTs seem not sufficient due to their high leakage current, insufficient mobility and characteristics fluctuation. Thus single-crystal Si (x-Si) TFTs are essential for these next-generation displays. It is impossible to grow x-Si on large and non-heat tolerant substrates such as glass or plastics. Only one attractive technological way is therefore to form two-dimensional arrays of high quality x-Si grains of larger than the TFT feature size with desired spatial pitch on large substrate at low temperature. Ultra-short melt-regrowth method of Si based on high-power & pulsed lasers, such as excimer lasers, seems the best solution for this new demand. There is a 20 years history for an excimer laser annealing (ELA) method, but grain size grown by this method was remained extremely small until a lateral growth mode (2) was discovered in 1992. Now, there are many groups studying lateral ELA modes, so-called Gradient (3), SLS (4) and micro-Cz (5) methods. The SLS method is based on a step & repeat concept, and thus needs a huge number of shots for crystallizing whole substrate surface since growth length per shot is as short as a few micro-m. The micro-Cz method needs micro-fabrication technology, unacceptable for large substrate. A serious problem in the Gradient method was how to modulate microscopically a laser light intensity distribution on the substrate surface. A solution was an introduction of a phase-shift concept developed in photolithography fields, and registered as the PM (Phase-Modulated) ELA method (6). This review talk will give past, present and prospect of the PM-ELA method. References 1. H. Abe et al., To be presented at 10th International Display Workshops (2003). 2. D. Choi et al., Jpn. J. Appl. Phys., Vol.31, p.4545 (1992). 3. K. Ishikawa et al., Jpn. J. Appl. Phys., Vol.37, p.731 (1998). 4. J. Im et al., Phys. Stat. Sol., Vol.166, p.603 (1998). 5. R. Ishihara et al., Jpn. J. Appl. Phys., Vol.39, p.3872 (2000). 6. C. Oh et al., Jpn. J. Appl. Phys., Vol.37, p.L492 (1998). Address: 292 Yoshida-cho, Totsuka-ku, Yokohama, 244-0817 JAPAN e-mail: matsumura.masakiyo@nifty.com

3:30 PM *A6.3**Review on a-Si:H Deposition Sciences for Mass Production.**

Jacques Schmitt, Unaxis Management Incorporated, Pfaffikon/SZ, Switzerland.

The history of the fertile 70s is recalled and illustrated. It was when a-Si:H potential was discovered and actively explored. Then the entry in production of a-Si:H based technology is followed over the last 30 years. The industrial status of the technique is described and some trends affecting future development are derived. 25 years of active research concerning plasma sciences, deposition mechanisms and key device performance drivers in a-Si:H deposition led to some basic understanding of the process and its limitations. We also discuss some not as glamorous problems met in real production such as plasma cleaning. The multiple options for reactor design are discussed with the viewing angle of production economics. Finally a few recent developments are highlighted as they may lead to improved or new applications for amorphous and/or nano-crystalline Silicon

4:15 PM *A6.4**Amorphous and Microcrystalline Silicon based Photovoltaic.**

S. Guha, United Solar Ovonic, Auburn Hills, Michigan.

The last two decades have witnessed significant progress in the science and technology of amorphous silicon based alloys for large-scale manufacture of photovoltaic products. Development of multi-junction devices incorporating component cells absorbing different wavelengths of light have resulted in high efficiency with good stability. Innovative manufacturing technologies have been developed to facilitate large-volume production. In this paper, I shall summarize the current state of art of material research, device performance and manufacturing. I shall also discuss future trends including the use of mixed-phase and microcrystalline silicon.

SESSION A7: PV Technologies

Chairs: Subhendu Guha and Jacques Schmitt

Thursday Morning, April 15, 2004

Room 2001 (Moscone West)

8:30 AM *A7.1**Efficient Conversion of Sunlight to Electricity by Dye**

Sensitized Nanocrystalline Solar Cells. Michael Graetzel, LPI, Swiss federal Institute of Technology, Lausanne, Switzerland.

The dye sensitized solar cell (DSC) provides a technically and economically credible alternative concept to present day p-n junction photovoltaic devices. In contrast to the conventional silicon systems where the semiconductor assumes both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band gap oxide semiconductor. Charge separation takes place at the interface via photo-induced electron injection from the dye into the conduction band of the solid. Carriers are transported in the conduction band of the semiconductor to the charge collector. The use of sensitizers having a broad absorption band in conjunction with oxide films of nanocrystalline morphology permits to harvest a large fraction of sunlight. Nearly quantitative conversion of incident photon into electric current is achieved over a large spectral range extending from the UV to the near IR region. Overall solar (standard AM 1.5) to current conversion efficiencies of 10.6 % have been reached. New electrolytes based on ionic liquids have been developed that show excellent stability both under prolonged light soaking and high temperature stress. There are good prospects to produce these cells at lower cost than conventional devices. Here we present the current state of the field, and discuss the importance of mastering the interface of the mesoporous films by assisting the self-assembly of the sensitizer at the surface of the oxide nanocrystals. Literature: 1) a) B.O'Regan and M.Graetzel, Nature 335 737 (1991), b) M Graetzel Nature 414,338-344 (2001),c) U.Bach, D.Lupo, P.Comte, J.E.Moser, F.Weissoertel, J.Salbeck, H.Spreitzer and M.Graetzel, Nature, 395, 544 (1998). 2) Hagfeldt, A, Graetzel, M. Acc. Chem. Res. 33, 269-277 (2000), 3)P. Wang, S. M. Zakeeruddin, J. E. Moser, M. K. Nazeeruddin, T. Sekiguchi, M. Graetzel, Nature Mater. 2, 402 (2003). Work supported by the Swiss National Science Foundation, the Swiss Commission for Technology and Innovation, the Swiss Energy Office, the European Joule program, and the European Office of the United States Airforce.

9:00 AM *A7.2**Excitonic Solar Cells.** Brian A. Gregg, NREL, Golden, Colorado.

Existing types of solar cells may be divided into two distinct classes: conventional solar cells such as silicon p-n junctions and excitonic solar cells, XSCs. Most organic-based solar cells, including dye-sensitized solar cells, DSSCs, fall into the category of XSCs. In these cells, excitons are generated upon light absorption and, if not

created directly at the heterointerface as in DSSCs, must diffuse to it in order to photogenerate charge carriers. The distinguishing characteristic of XSCs is that charge carriers are generated and simultaneously separated across a heterointerface. In contrast, photogeneration of free electron-hole pairs occurs throughout the bulk semiconductor in conventional cells, and carrier separation upon their arrival at the junction is a subsequent process. This apparently minor mechanistic distinction results in fundamental differences in photovoltaic behavior. For example, the open circuit photovoltage, V_{oc} , in conventional cells is limited to less than the magnitude of the band bending, Φ_{bi} ; however, V_{oc} in XSCs is commonly greater than Φ_{bi} . This tutorial describes excitonic processes in general and the use of carrier-selective (energy-selective) contacts to enhance V_{oc} . Then studies of DSSCs, which provide a particularly simple example of XSCs, are described. A general theoretical description applicable to all solar cells is employed to quantify the differences between conventional and excitonic cells. The key difference is the dominant importance, in XSCs, of the photoinduced chemical potential energy gradient created by the interfacial exciton dissociation process. Numerical simulations demonstrate the difference in photoconversion mechanism caused solely by changing the spatial distribution of the photogenerated carriers. Finally, the similarities and differences are explored between the three major types of XSCs: organic semiconductor cells with planar interfaces, bulk heterojunction cells and DSSCs.

9:30 AM *A7.3**Thin Film Solar Cells Based on Cu(In,Ga)Se₂, From the**

Laboratory to the Market. John Kessler, Physics, University of Nantes, Nantes cedex 3, France.

There have been 25 years of R&D invested in thin film solar cells based on Cu(In,Ga)Se₂. At the laboratory and demonstrator level, these devices appear very attractive, and limited commercialization has begun. The questions of how to generate a large scale commercial success and of what relevant research activities should be undertaken are very important present issues. Behind the need to prove market readiness are the questions of what will be needed for the future. Some issues are clear, such as higher band gap material, more rapid deposition techniques, and less toxic or scarce materials. Others such as new module structures, or the real expectations of a tandem approach are still open issues. It must be remarked that the performance level of today's devices still owes much to the tolerance of the material system. It is a fact that there are many issues involved where a better fundamental understanding in both materials and devices would most probably lead to more performant, and more importantly more acceptable device structures and synthesis methods. This field has reached the level where both the investor and the scientist have important roles to play and depend on each others success. The past has shown that the know-how from quality laboratory devices has been transferred to achieve quality commercial size modules. The present and the near future must bring these commercial size modules to a point of economic and ecological acceptability. Our success will not be complete until we have reached the point where "its good, its big and its cheap". For this to happen, both applied and fundamental research still have great roles to play.

10:30 AM *A7.4**A Vision for Crystalline Silicon Photovoltaics.**

Richard Swanson, SunPower Corporation, Sunnyvale, California.

Starting with an overview of the current status of crystalline photovoltaics, this paper next presents a vision for the future via a possible set of technical requirements that will continue the historical progress. PV system prices have been decreasing roughly 50 percent per decade. We will show how crystalline silicon solar cells can continue this trend over the next decade, thus becoming cost-competitive without subsidies in many distributed grid connected applications. Significantly no "big breakthroughs" are needed for this to happen. An evolutionary development of existing silicon technology is shown to be all that is necessary. Module prices have followed a classic experience curve in cost versus cumulative volume. (Straight line on a log-log plot of price versus cumulative volume.) The experience factor is 81%, meaning that module prices reduce 19% for every doubling of cumulative volume. There is no reason to expect that the price reductions predicted by this progress ratio will cease in the near future. A survey of silicon experts at an NREL workshop in Colorado in 2002 was conducted to develop an expert consensus on how wafered silicon costs will come down over the next decade. What emerged are projections for parameters such as efficiency and wafer thickness that can serve as a guide to the industry and a projection of costs. The manufacturing cost projected for 2012 is \$1.00/W and the sales price \$1.48/W, thus meeting the necessary price for cost-effective distributed applications. The results of this workshop, along with the research required to meet the goals, will be presented. Today, grid connected markets are viable only with subsidies. As costs come down, the required subsidy will decrease. Based on the above

projection, the required subsidy will decrease to zero in ten years for grid-connected applications in the most favorable regions such as California, USA, and around twenty years for lower insolation regions such as Germany. The total required subsidy in order to "buy down" this market is straightforward to calculate using the above experience curve projections. Interestingly, the total amount required depends only slightly on the assumed market growth rate, and is in the range of \$25 billion.

11:00 AM *A7.5

Amorphous Silicon based Solar Cell Technologies: Challenges and Opportunities. Rajeewa R. Arya, Arya International, Inc., Williamsburg, Virginia.

Amorphous Silicon solar cells and modules have been of scientific and technological interest for more than 25 years because they have held the best hope for low cost module manufacturing. While there have been several attempts to pursue large scale manufacturing (still ongoing), amorphous silicon solar modules have NOT penetrated the mainstream PV power markets in any significant way. Mostly, the applications have been unique but not lower in cost/watt. Why has the promise of low cost thin film solar modules not been fulfilled? What has prevented large-scale applications? What are the technical challenges ahead? What do amorphous silicon based technologies have to achieve to penetrate and be acceptable for power applications? In this paper will examine amorphous silicon technology industry in depth from a historical perspective for the progress made over the years in device performance and module performance. We will assess the challenges and opportunities of amorphous silicon technologies for the two approaches (i) based on manufacturing monolithically interconnected thin film solar cell plates and (ii) based on the continuous web deposition on metal foil. We will also compare the cost elements from cell/plate level to finished modules for these two approaches. We will then address module reliability and field performance for amorphous silicon modules and try to answer the questions - What are the reliability challenges for the amorphous silicon modules? What is needed from performance, quality and reliability to compete with crystalline modules?

11:30 AM *A7.6

The status of and challenges in CdTe thin-film solar-cell technology. Alvin D. Compaan, Physics and Astronomy, Univ. of Toledo, Toledo, Ohio.

Polycrystalline CdTe thin-film solar cells have shown tantalizing potential for low cost large-area module fabrication, but successful large-scale commercial fabrication has been elusive. Fabrication of the basic n-CdS / p-CdTe heterojunction is possible by a wide variety of methods, including close spaced sublimation, vapor transport deposition, electrodeposition, chemical bath deposition, and magnetron sputtering. An overview of these methods will be presented as well as a description of the role of the postdeposition "activation" treatment using CdCl₂ and issues related to the difficulty of obtaining low resistance back contacts to CdTe. I shall also present some of our recent fabrication results using rf magnetron sputtering and discuss some of the advantages that appear possible with the use of sputtering methods in this class of materials. Some of these advantages are particularly relevant as the polycrystalline thin-film PV community addresses issues related to fabricating tandem cells with efficiencies over 25%. Other issues related to nonuniformities in thin-film structures will also be discussed. Supported by NREL, AFRL, NSF, and the State of Ohio.

SESSION A8: Crystalline Silicon Characterization and Solar Cells

Chairs: Rajeewa Arya and Michio Kondo
Thursday Afternoon, April 15, 2004
Room 2001 (Moscone West)

1:30 PM *A8.1

High-Rate Plasma Process for Microcrystalline Silicon: Over 9% Efficiency Single Junction Solar Cells. Takuya Matsui, Michio Kondo and Akihisa Matsuda; National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan.

High-rate deposition technique of device grade microcrystalline silicon ($\mu\text{c-Si:H}$) is essentially required for low cost manufacturing of high efficiency silicon-based thin film solar cells. Recently, we have developed a novel high-rate process based on high-pressure and SiH₄-depletion plasmas for high-quality $\mu\text{c-Si:H}$ deposition [1,2]. In this paper, we present >9% efficient $\mu\text{c-Si:H}$ $p-i-n$ (superstrate-type) solar cells fabricated by 100 MHz plasma-enhanced chemical vapor deposition (PECVD) at i -layer deposition rates of >2 nm/s. Under high-rate conditions, in particular, the deposition pressure is found to play a dominant role in determining short circuit

current (J_{sc}) of solar cell. With an increase in deposition pressure from 2 to 7-9 Torr, J_{sc} increases by more than 50% due to a significant improvement in the long wavelength ($\lambda > 600$ nm) responses, which essentially leads to high efficiency (>8%) solar cells in the 2-3 nm/s deposition rate range. Further progress in solar cell efficiency has been made by the improvement of TCO/ p and p/i interfaces. As a result, efficiency reaches 9.13% ($J_{sc}=23.7$ mA/cm², $V_{oc}=0.528$ V, $FF=0.73$) with a 2.3 μm -thick i -layer grown at 2.3 nm/s. Transmission electron microscopy and secondary-ion mass spectroscopy studies reveal that samples prepared at lower pressure (<4 Torr) comprise many grain boundaries due to disordered grain growth, which induces an anomalous incorporation of atmospheric impurities (predominantly oxygen) after exposing sample to air. In contrast, the high-pressure process (>7 Torr) provides denser grain columns coalesced with [110]-oriented crystallites, which in turn inhibits impurities from penetrating deeper in the film. Based on above results, we propose that the less post-oxidation behavior associated with the denser microstructure of high-pressure-grown $\mu\text{c-Si:H}$ is responsible for the excellent charge collection in $p-i-n$ solar cells. [1] M. Kondo *et al.* J. Non-Cryst. Solids, **266** - **269**, 84 (2000). [2] T. Matsui *et al.* Jpn. J. Appl. Phys. Part 2, **42**, L901 (2003).

2:00 PM A8.2

Device Physics of Microcrystalline Si:H Solar cells. Vikram L. Dalal, Elec. and Computer Engr., Iowa State University, Ames, Iowa.

Microcrystalline Si:H is an important material for solar cells. However, there is no unique microcrystalline Si:H material. The degree of crystallinity and the orientation of grains varies from film to film. In this paper, we present a systematic study and discussion of the device physics of various types of microcrystalline Si:H solar cells. The study involves dark I(V) curves, determination of doping and deep defects, measurement of diffusion lengths of minority carriers, effects of compensation on material properties, Hall mobilities, carrier lifetimes etc. All these factors are correlated with the degree of crystallinity and doping of the films and of base layers in cells. Diffusion and drift models are applied to understand the behavior of solar cells in these different materials. It is found that in cells made in materials with a high degree of crystallinity (Raman peak ratio of 4 or greater), the standard diode generation-recombination and diffusion controlled models can be used to explain most of the device behaviors. The relationships between J_{sc} , V_{oc} , Fill factor and thickness can be explained using the standard model. The diffusion lengths of holes and deep trap densities can be measured using low frequency capacitance and QE vs. voltage techniques. A very good correlation exists between deep defects and doping, indicating that the same element (probably oxygen) is responsible for introducing defects and dopants. A number of cells from different groups are studied, and they all show a distinct inverse correlation between doping and diffusion lengths. Diffusion lengths can be improved by compensating the base layer with ppm levels of B, indicating that B may form complexes with O and remove it from playing an active role. As the degree of crystallinity decreases, the dark diode I(V) behavior changes from the standard diode model to one controlled by a model involving multiple-defects within the bandgap. This fact indicates that the material now may be composed of grains with a significant amorphous tissue between the grains. A distinct inverse correlation is observed between QE at 800 nm and open-circuit voltage. A new device design, which includes both amorphous and microcrystalline material within the same base layer is presented, and it shows a significant improvement in current collection.

2:15 PM A8.3

Materials and Interface Optimization of Heterojunction Silicon (HIT) Solar Cells Using In-Situ Real-Time Spectroscopic Ellipsometry. Dean H. Levi, Charles Teplin, Eugene Iwaniczko, Tihu Wang, Matthew Page, Qi Wang and Howard Branz; National Renewable Energy Laboratory, Golden, Colorado.

We have applied real-time spectroscopic ellipsometry (RTSE) as both an in-situ diagnostic and post-growth analysis tool for amorphous silicon (a-Si)/crystal silicon (c-Si) heterojunction with intrinsic thin-layer (HIT) solar cells grown by hot-wire chemical vapor deposition (HWCVD). RTSE enables precise thickness control of the 5 - 25 nm layers used in these devices, as well as monitoring crystallinity and interface roughness in real time. Utilizing RTSE feedback, but without extensive optimization, we have achieved photovoltaic energy conversion efficiencies of nearly 14% on p-type CZ wafers coated with thin i and n layers. Open-circuit voltages above 630 mV indicate effective passivation of the c-Si surface by the a-Si intrinsic layer. We estimate that the surface recombination velocity (SRV) is less than 100 cm/s, and will report values of SRV derived from lifetime measurements versus i -layer thickness and crystallinity from RTSE. Post-growth analysis of the RTSE data enables accurate determination of the evolution of the dielectric function with

thickness. The dielectric function provides a measure of the bandgap and degree of crystallinity. There is a gradual transition from ordered a-Si, or mixed amorphous and nanocrystalline silicon (nc-Si), to less ordered a-Si as the film grows. The final device open circuit voltage is a function of the bandgap of the i- and n-layers, as well as the SRV. We shall report systematic correlations of device performance with these properties as determined from in-situ and ex-situ analysis.

2:30 PM **A8.4**

Protocrystalline Silicon at High Rate from Undiluted Silane. Ruud E.L. Schropp¹, Marieke K. van Veen¹, Karine van der Wert¹, Don L. Williamson² and Harv Mahan³, ¹Debye Institute, Utrecht University, Utrecht, Netherlands; ²Department of Physics, Colorado School of Mines, Golden, Colorado; ³National Renewable Energy Laboratory, Golden, Colorado.

Hot Wire Chemical Vapor Deposition (HWCVD) is shown to be a fast method for the deposition of protocrystalline silicon films from undiluted silane. Solar cells in the n-i-p configuration, incorporating hot-wire deposited protocrystalline i-layers at a substrate temperature of 250 °C, have demonstrated remarkable stability against light soaking, which appears to be correlated with a special void nature and enhanced medium range order. Intrinsic silicon-hydrogen films have been deposited by HWCVD on plain stainless steel as well as on stainless steel precoated with a n-type doped microcrystalline silicon layer. In X-ray diffraction experiments, the linewidths of the first sharp peak (FSP) were 5.29 ± 0.06 degrees and 5.10 ± 0.09 degrees, respectively, indicating a template effect due to the $\mu\text{-Si:H}$ n-layer. These FSPs are as narrow as for optimized i-layers made by H₂-diluted plasma deposition, however, at a much higher deposition rate (1 nm/s), at moderate temperature (250 °C), and without the use of H₂ dilution. In accompanying transmission electron micrographs, the layers show a large concentration of elongated small voids in the growth direction that are not interconnected. We suspect that the void nature allows the bulk of the film to be more ordered. The utilisation of such layers in solar cells leads to cells with a remarkably good stability, showing a decrease of the fill factor of less than 10 % during 1500 h of light soaking.

2:45 PM **A8.5**

Microstructure Evolution with Thickness and Hydrogen Dilution Profile in Microcrystalline Silicon Solar Cells. Baojie Yan¹, Guozhen Yue¹, Jeffrey Yang¹, Subhendu Guha¹, Daxing Han², D. L. Williamson³ and Chun-Sheng Jiang⁴, ¹United Solar Ovic Corporation, Troy, Michigan; ²Department of Physics and Astronomy, University of North Carolina, Chapel Hill, North Carolina; ³Department of Physics, Colorado School of Mines, Golden, Colorado; ⁴National Renewable Energy Laboratory, Golden, Colorado.

In order to obtain high short-circuit current density (J_{sc}) from hydrogenated microcrystalline silicon ($\mu\text{-Si:H}$) solar cells, a thick intrinsic $\mu\text{-Si:H}$ layer is required. However, we find that J_{sc} reaches a maximum with a thickness in the range between 1 and 2 μm . Increasing the thickness further leads to a decrease in J_{sc} , corresponding to a reduction of spectral response in the long wavelength region. Two mechanisms could be responsible for the low J_{sc} for thick $\mu\text{-Si:H}$ solar cells. One is microcrystallite collision due to the textured substrate, and the other microstructure evolution with thickness. It has been reported that grains in $\mu\text{-Si:H}$ deposited on a textured back reflector (BR) grow perpendicular to the local substrate surface and collide with each other when the film is over a certain thickness. The stress caused by the microcrystallite collision results in a high defect density and low cell performance. A second mechanism is the increase of microcrystalline volume fraction (f_c) and grain size with film thickness. Very high f_c could cause high microvoid and microcrack densities, thus poor cell performance. We made two sets of $\mu\text{-Si:H}$ solar cells: one on specular stainless steel (SS) substrates and another on textured Ag/ZnO BR. Both sets of cells show a saturation in J_{sc} for thick cells, indicating that the microcrystallite collision is not the main reason for the low J_{sc} in thick $\mu\text{-Si:H}$ cells. Raman and X-ray diffraction exhibit a significant increase of f_c and grain size with film thickness. Atomic force microscopy reveals an increase in the size of microstructural features and the surface roughness with increasing thickness. Based on these results, we believe that the increase of the microcrystalline phase with thickness is the main reason for the observed low J_{sc} for thick cells. To overcome this problem, we have developed a procedure of varying the hydrogen dilution ratio during deposition. Using this method, we have been successful in controlling the microstructure evolution and achieved significant improvements in the long wavelength response and J_{sc} .

3:30 PM **A8.6**

Crystalline volume fraction in $\mu\text{-Si:H}$: Raman spectroscopy versus X-ray diffraction. Reinhard Carius¹, Lothar Houben², Friedhelm Finger¹ and Stefan Klein¹, ¹IPV, Forschungszentrum Juelich, Juelich, Germany; ²IFF, Forschungszentrum Juelich, Juelich, Germany.

The crystalline volume fraction (X_c) is one of the key parameters which determines the electronic properties of microcrystalline silicon thin films. For material prepared e.g. by plasma enhanced chemical vapor deposition (PE-CVD) or hot-wire (HW-) CVD the electronic transport, optical properties and the concentration of electronic defects depend strongly on the crystalline volume fraction. Also the performance of solar cells exhibits a pronounced dependence on the crystalline volume fraction of the absorber layer. In particular a significant amount of amorphous phase seems beneficial for the open circuit voltage and the fill factor, i.e. for the efficiency. Raman spectroscopy and X-ray diffraction (XRD) are most widely used methods to determine X_c . For Raman spectroscopy the common procedure to determine X_c^{RS} is to evaluate the intensity of two spectral parts, (i) a narrow band at about 520 cm^{-1} related to the crystalline phase (I_c^{RS}) and (ii) a broad band at about 480 cm^{-1} related to the amorphous phase (I_a^{RS}). X_c^{RS} is then determined from $I_c^{RS} / (I_c^{RS} + I_a^{RS})$. Distortions of the lattice, such as structural defects and strain, lead to a broadening and an asymmetric shape of the 'ideal' crystalline spectrum. Therefore the procedure is not unambiguous and may lead to significant errors particularly at very high or very low X_c . For XRD the crystalline volume fraction X_c^{XRD} is calculated from the integration over the crystalline diffraction peaks corresponding to the [111], [220] and [311] lattice plane reflections. The amorphous contribution is derived from the two broad bands of the disordered phase close to the [111] and in between the [220] and [311] reflections [1]. Particularly the applicability of Raman spectroscopy for the determination of X_c has been questioned and impressive examples for huge errors are given [2]. In the present study, we have investigated a large number of films and solar cells by Raman spectroscopy and XRD at grazing incidence. To achieve different probe depth the laser wavelength in the Raman experiment and angle of incidence in the XRD was varied. The data show a good correlation of X_c determined by both quantities taking into account the large error bars at very high and very low X_c . Surprisingly, the most severe deviation from this correlation is found for a class of samples with about 40 - 60 % crystallinity. Additional measurements of X_c by electron diffraction on this samples give a good agreement with the Raman data but not with XRD. Based on these findings the applicability of Raman spectroscopy for the characterization of $\mu\text{-Si:H}$ will be discussed. [1] L. Houben, M. Luysberg, P. Hapke, R. Carius, F. Finger, H. Wagner, Phil. Mag. A, 1447, (1998) [2] Ossadnik, C, Veprek, S, Gregora, I; THIN SOLID FILMS 337 (1-2) 148 (1999) and references therein

3:45 PM **A8.7**

Understanding the structure of Si nanoclusters in a/nc-Si:H films using spherical aberration-corrected transmission electron microscopy. Christopher Perrey¹, Siri S. Thompson², Markus Lentzen³, Uwe Kortshagen² and C. Barry Carter¹, ¹Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota; ²Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota; ³Institut für Festkörperforschung, Jülich, Germany.

Recent work has shown that the electrical properties of hydrogenated nanocrystalline Si films (a/nc-Si:H) make this material a promising candidate for applications in solar cells. However, the analysis of the nanocrystalline content and structure of the constituent nanoparticles by transmission electron microscopy (TEM) is complicated by the presence of the surrounding amorphous matrix. The present study applies the technique of spherical aberration-corrected TEM for the identification and analysis of the crystalline content of a a/nc-Si:H film. By varying both the spherical aberration of the objective lens and the defocus, regions of crystallinity in the a/nc-Si:H film can be identified. This study reports the analysis of Si nanoparticles of approximately 1.5 nm in size. Some of these nanoparticles contain planar defects, such as twin defects and stacking faults. All particles observed were the same crystal structure as bulk Si, which agrees with theoretical cluster calculations.

4:00 PM **A8.8**

Characterization of the Bulk Recombination in Hydrogenated Amorphous Silicon Solar Cells. Jingdong Deng, Joshua M. Pearce, Vasilios Vlahos, Robert W. Collins and Christopher R. Wronski; Center for Thin Film Devices, the Pennsylvania State University, University Park, Pennsylvania.

Dark forward bias current, J_D -V, characteristics offer a probe for characterizing carrier recombination and the defect states in the intrinsic layers of hydrogenated amorphous silicon (a-Si:H) solar cells [1]. However, in order to successfully utilize these characteristics it is critical to establish the J_D -V regimes in the different cell structures being studied over which the currents are determined solely by the recombination in the bulk. Such current-voltage regimes have been identified in studies carried out on the J_D -V characteristics of p

(a-SiC:H) / i (a-Si:H) / n (μ c-Si) (superstrate) solar cell structures having different a-Si:H intrinsic layers, i-layer thicknesses and a-Si:H "buffer" layers at the p/i interfaces. From the results on cell structures with the same p/i interface regions but having different bulk i-layer thicknesses, it was possible to separate and then quantify the contributions to the J_D -V characteristics of both the p/i interface recombination and bulk recombination. Results are presented which clearly identify the differential diode quality factors, $n(V) = [kT/q]^{-1} [d(\ln J_D)/dV]^{-1}$, that corresponds to the recombination at the p/i interface and in the bulk. It is found that in the cell structures with optimized "buffer" layers carrier recombination in the bulk dominates the J_D -V characteristics over a wide voltage range. The $n(V)$ characteristics obtained on such cell structures with hydrogen diluted and undiluted i-layers are then utilized in characterizing the differences in the distribution of defect states in the two intrinsic layers both in annealed state as well as after creating light induced defects. [1] J. Deng, J. M. Pearce, R. J. Koval, V. Vlahos, R. W. Collins, and C. R. Wronski, *Appl. Phys. Lett.* **82**, pp. 3023-3025, 2003.

4:15 PM A8.9

Electronic Properties of RF Glow Discharge Intrinsic Microcrystalline Silicon near the Amorphous Silicon Phase Boundary. James J. Gutierrez¹, J. David Cohen¹, Baojie Yan², Jeffrey C. Yang² and Subhendu Guha²; ¹Physics, University of Oregon, Eugene, Oregon; ²United Solar Ovonic Corp., Troy, Michigan.

The electronic properties of microcrystalline silicon have been characterized for the first time using transient photocapacitance spectroscopy (TPC) and drive-level capacitance profiling (DLCP). Two types of microcrystalline films were deposited by the RF glow discharge method at United Solar. The first device type is a 'sandwich' structure with the microcrystalline silicon layer sandwiched by two amorphous silicon layers (SS/n a-Si:H/i a-Si:H/ μ c-Si:H/i a-Si:H). The second is a microcrystalline n-i-p device (SS/n a-Si:H/i μ c-Si:H/p uc-Si:H/ITO). For the sandwich device structure, a series of devices were fabricated under varying growth conditions. This allowed us to partially address the effects of the microcrystallite fraction on electronic properties. In addition, devices were characterized in both their initial and light degraded states to examine effects of light degradation on these microcrystalline materials. The motivation for comparing the two device types (sandwich vs. n-i-p) was to find which structure was more suitable for our characterization measurements, and also to discriminate against effects of possible oxygen contamination of the microcrystalline Si which are greatly inhibited by the a-Si:H layers in the sandwich structure. We found that the sandwich configuration definitely proved best for our TPC measurement. However, insights of carrier transport were gained from comparing the results of each structure type. The TPC measurements reveal that both a microcrystalline as well as an a-Si:H component exist in these samples. Indeed, these TPC measurements allow us to deduce Urbach energies characteristic of each component individually. Moreover, by varying the measurement temperature we directly observe that the minority carrier collection in the microcrystalline component greatly exceeds that in the a-Si:H component. Utilizing DLCP method, both the shallow doping as well as the deep defect densities were estimated. Significant effects due to light soaking on all of the above properties have been observed and will be reported.

4:30 PM A8.10

Hole Drift-Mobility Measurements in Microcrystalline Silicon. Thorsten Dylla^{1,2}, Friedhelm Finger¹ and Eric A. Schiff²; ¹Institut fuer Photovoltaik, Forschungszentrum Juelich, Juelich, Germany; ²Department of Physics, Syracuse University, Syracuse, New York.

We report temperature-dependent hole drift-mobility measurements in microcrystalline silicon prepared by radio-frequency (95 MHz) plasma deposition. The samples were *pin* diodes prepared under plasma-deposition conditions similar to those that have recently yielded 8.7% efficient solar cells. Standard photocarrier time-of-flight methods were successful in these diodes. "Raman ratio" measurements indicated a high crystalline volume fraction for these materials (ratios in the range 0.6-0.7). Hole drift-mobilities measured at room-temperature were about $1 \text{ cm}^2/\text{Vs}$. At lower temperatures, hole transport in these samples was clearly dispersive, thermally-activated, and linear with electric field. These results are somewhat different than have been reported independently for microcrystalline silicon from another laboratory. The present measurements are described well by an exponential bandtail, multiple-trapping model with a valence bandtail width of about 30 meV. We were surprised by the success of this model, which is typically applied to amorphous semiconductors. While the valence bandtail width for the present samples is narrower than has been reported for hydrogenated amorphous silicon (a-Si:H), it is still wider than the widths for conduction bandtails in a-Si:H. The "band mobility" parameter was about $1.0 \text{ cm}^2/\text{Vs}$, which is again reminiscent of values for amorphous silicon. The results offer an interesting perspective on the origins of "bandtail traps" for both

amorphous and microcrystalline silicon. This research supported by BMBF (Germany) and the National Renewable Energy Laboratory (USA).

4:45 PM A8.11

A Phase Diagram for Morphology and Properties of Low Temperature-Deposited Polycrystalline Silicon Grown by Hot Wire Chemical Vapor Deposition. Christine Esber Richardson, Maribeth Swiatek Mason and Harry A. Atwater; Applied Physics, California Institute of Technology, Pasadena, California.

The ability to fabricate low temperature polycrystalline silicon with the mobilities more closely resembling multicrystalline or single crystal silicon, but with internal surface passivation similar to that observed in deposited microcrystalline silicon is a promising direction for thin film polycrystalline silicon photovoltaics. To achieve this, large grains with passivated grain boundaries and intragranular defects are required. We investigate the low temperature (250-550 C) epitaxial growth of thin silicon films by hot-wire chemical vapor deposition (HWCVD) on Si (100) substrates and large-grained polycrystalline silicon template layers formed by selective nucleation and solid phase epitaxy (SNSPE). Using reflection high energy electron diffraction (RHEED) and transmission electron microscopy (TEM), we have observed epitaxial, twinned epitaxial, mixed epitaxial/polycrystalline and polycrystalline phases in the 50 nm - 5 micrometer thickness regime. Polycrystalline films exhibit hydrogen content similar to that observed in microcrystalline silicon deposited directly on glass. The large-grained polycrystalline silicon SNSPE layers are formed using nickel nanoparticles as nucleation sites for the solid-phase crystallization of phosphorus-doped amorphous silicon on glass or 100 nm SiO₂ on Si. Hot wire chemical vapor deposition growth on Si (100) was performed using a mixture of diluted silane (1% in He) and hydrogen at a H₂/SiH₄ ratio of 50:1 at substrate temperatures from 250-475 C. We will discuss the relationship between the microstructure and photoconductive decay lifetimes and hole mobilities of these undoped layers on Si (100) and SNSPE templates as well as their suitability for use in thin-film photovoltaic applications. Results obtained for deposition conditions using pure silane will also be discussed.

SESSION A9: Poster Session: Growth and Characterization of Materials and Devices
Chairs: Rana Biswas and Vikram Dalal
Thursday Evening, April 15, 2004
8:00 PM
Salons 8-9 (Marriott)

A9.1

Optical Properties of Transparent Conducting Oxide Sculptured Thin Films for Applications in Amorphous Silicon Photovoltaics. Chi Chen¹, Ilsin An¹, Gelio M. Ferreira¹, Mark W. Horn³, Russell Messier³ and Robert W. Collins²; ¹Material Research Institute, The Penn State University, University Park, Pennsylvania; ²Department of Physics and Astronomy, University of Toledo, Toledo, Ohio; ³Department of Engineering Science and Mechanics, The Penn State University, University Park, Pennsylvania.

Significant optical losses in thin film silicon-based solar cells arise due to reflection at the top interface between the transparent conducting oxide (TCO), tin-oxide or indium-tin oxide, and the p-type silicon film. At this interface, the index discontinuity that the light beam encounters on its way to the absorber layer is the largest. Another significant optical loss occurs in the back-reflector structure at the interface between the dielectric, zinc-oxide, and the metal, silver or aluminum. Advanced optical engineering approaches are needed to minimize these losses. One possible approach is to incorporate multilayered or graded index TCO films that can act as broadband anti-reflectors at the top of the device and narrower band reflectors at the back. Thus, it is important to be able to modulate the index of refraction of the TCO over a wide range without increasing its extinction coefficient or degrading its conductance. Here we report an investigation of sculptured SnO₂ films under initial development for this purpose. Sculptured thin films are deposited under low surface mobility conditions using stepwise or continuous variations in the polar and/or azimuthal angles of the deposition flux impinging on the surface. Through self-shadowing and columnar growth, deposition at a glancing polar angle leads to high void fractions, low indices of refraction and optical anisotropy, whereas normal incidence deposition under the same conditions leads to low void fraction, high indices of refraction, and optical isotropy. In this study, we explore the dependence of the optical properties of SnO₂, including index of refraction and birefringence spectra, on the polar deposition angle. Preliminary results will be presented for films deposited continuously with a modulated polar angle, as well. Optical modeling will explore the ability of such an approach to provide tailored TCOs for advanced optical engineering of silicon-based solar cells.

A9.2 **Identification of Possible Bonding Sites for Post Deposition Oxygen Absorption in Microcrystalline Silicon.**

Lynn M. Gedvilas¹, Archie H Mahan¹ and Don L. Williamson²;

¹NREL, Golden, Colorado; ²Colorado School of Mines, Golden, Colorado.

Using infrared (IR) spectroscopy and x-ray diffraction (XRD), the nature of the grain boundaries in two $\mu\text{-Si}$ films deposited by hot wire CVD, displaying similar crystalline volume fractions (>65%) but very different behavior upon exposure to atmospheric contaminants, is analyzed. Both films exhibit, from XRD, a preferential (220) orientation, and were deposited at similar deposition rates (9-11 Å/s) using similar H₂ dilution ratios (H₂/SiH₄=12/1 to 14/1). For the film which exhibits no post deposition oxidation, the IR peak centered at 2100 cm⁻¹ is rather broad and featureless, with a full width at half maximum (FWHM) of 50 cm⁻¹ which is characteristic of bulk material. For the film exhibiting significant post deposition oxidation, the IR absorption in this region contains two sharp and very narrow peaks centered at 2084 and 2097 cm⁻¹, with FWHM's of 36 and 9 cm⁻¹ respectively. These features suggest that the crystallites have been incorporated into the $\mu\text{-Si}$ film with their hydrogenated surfaces relatively intact. By comparing these peak frequencies to those for Si-H bonding on various c-Si surfaces, we identify specific absorption sites for post deposition oxidation in $\mu\text{-Si}$ when these sites comprise the grain boundaries and are therefore accessible to oxygen exposure. These include dimer bonds and backbonded sites on the Si (100) surface and 'edge' sites on the Si (111) stepped surface. The presence of both of these crystallite surfaces are detected by XRD measurements, and the oxidation is confirmed by the appearance of new peaks in the IR spectrum upon exposure of this film to atmospheric contaminants. We further suggest that the distribution of H within this grain boundary/crystallite surface region is crucial for depositing $\mu\text{-Si}$ films with good electronic properties and minimal post deposition oxidation.

A9.3 **FTIR and Ellipsometric Analysis (VIS-UV) of Low-Temperature Oxidation of Amorphous and Crystalline Silicon.** Peter Hess, Patrik Patzner and Andrey Osipov; Physical Chemistry, University of Heidelberg, Heidelberg, Germany.

The low-temperature oxidation behavior of various forms of silicon is a topic of fundamental interest in silicon technology. With strong oxidants, such as ozone and/or atomic oxygen atoms, high growth rates can be achieved. The mechanism of self-limited VUV-radiation-induced growth of ultrathin oxide layers was characterized by in situ FTIR spectroscopy and real-time spectroscopic ellipsometry (VIS-UV). Both spectroscopic methods were implemented in one UHV chamber. Pulsed F₂-laser radiation (157 nm) was used to study the pulse-by-pulse oxidation of H-terminated amorphous and well-defined crystalline silicon surfaces at low oxygen partial pressures of about 0.01 mbar between room temperature and 200 C. The disappearance of the Si-H surface bonds and the formation of a suboxide interface layer and subsequent growth of the silicon-dioxide layer of about 1-2 nm thickness at room temperature could be monitored with monolayer sensitivity, e.g. for Si(111)-(1x1):H, by FTIR spectroscopy. A characteristic blue shift of the silicon-oxide phonon bands was observed during oxide growth. Characteristic differences in the oxidation behavior were found between Si(111) or Si(100) crystal surfaces and amorphous silicon surfaces by spectroscopic ellipsometry. The ellipsometric results for the crystalline surfaces could only be simulated, with low mean squared error, by assuming a denser monolayer covered by a 0.5-0.9 nm thick suboxide layer as additional transition layers between silicon and silicon oxide. On the other hand, the oxidation process for the a-Si surface could be simply modeled by a silicon-oxide layer with low error. The formation of an ultrathin denser transition layer is in agreement with recent theoretical calculations performed for Si(100) by molecular modeling. By taking into account the different oxidation stages of silicon, a mean composition of the suboxide layer could be estimated. Instead of the generally used Brueggemann effective media approximation (EMA) an improved Tauc-Lorentz parameterization was employed in the ellipsometric analysis.

A9.4 **Optical and Electronic Characterization of a-SiGe:H Thin Films Prepared by a Novel Deposition Technique.**

Rodney J. Soukup¹, Natale Ianno¹, Christopher Exstrom² and Scott Darveau²; ¹Electrical Engineering, University of Nebraska, Lincoln, Nebraska; ²Chemistry, University of Nebraska, Kearney, Nebraska.

Using a novel hollow cathode plasma-jet reactive sputtering system in which an intense plasma, ignited in an Ar/H₂ flow, is directed through silicon and germanium nozzles, a series of a-SiGe:H thin films have been prepared on silicon and glass substrates. These films have

been optically characterized by infrared (IR) spectroscopy, surface Raman spectroscopy and spectroscopic ellipsometry (335 - 1000 nm). Si-H and Ge-H stretching absorption bands from monohydride (SiH, GeH) and dihydride (SiH₂, GeH₂) moieties were observed in the 2150 cm⁻¹ region. No trihydride groups (SiH₃, GeH₃) were formed in the deposition process. Stretching bands were deconvoluted and hydrogen concentrations were calculated using previously reported methods. Total hydrogen concentration varied with deposition conditions and ranged from 2.5 x 10²¹ to 1.6 x 10²² atoms per cm³ and correlate with secondary ion mass spectroscopy (SIMS) elemental analysis to within 10%. Surface Raman measurements of linewidth broadening of the vibrational peaks have been used to determine the crystalline/amorphous nature of the films and to develop a correlation with the efficiency of the solar collection capability. The ellipsometric spectra of the films have been fit with a modified Tauc-Lorentz model for the determination of film properties, including thickness (ranging from 400 to 1000 nm), the optical functions (η and κ), and the film uniformity and surface roughness. Conductivity measurements in the dark and under one sun (simulated) illumination have indicated that the films electronic properties are very good. The light to dark conductivity ratio has consistently been greater than 1000 for films with band gaps down to 1.3 eV. Relationships between deposition parameters, light and dark conductivity properties and chemical structural features are presented.

A9.5 **Extension of the Constant Photocurrent Method to Determine Densities of Occupied and Unoccupied Localised States.** Charles Main¹, Stephen Reynolds¹, Ivica Zrinscak¹ and Amar Merazga^{2,1}; ¹School of Computing and Advanced Technologies, University of Abertay Dundee, Dundee, United Kingdom; ²Faculte des Sciences et Sciences de l'ingenieur, Universite Mohammed Khidir, Biskra, Algeria.

This paper examines the use of Constant Photocurrent (CPM) measurements on thin film semiconductors, employing steady (DC) and modulated (AC) sub-gap illumination, to determine the density of localised states (DOS) in the bandgap. AC and DC measurements often result in different apparent absorption spectra. It is demonstrated that it is possible not only to extract information from the respective 'absorption' spectra, on the DOS below the Fermi level - i.e. occupied states, but also on the density of unoccupied states above the Fermi level. The ability to discriminate between these two groups of states by using DC and AC modulated sub-gap light arises from the frequency dependence of the different excitation pathways by which free electrons can be produced [1, 2]. AC modulated excitation will reveal absorption associated with transitions from occupied states into the conduction band, while DC excitation will include transitions from the valence band into unoccupied defect states, followed by slow thermal emission to the conduction band. A simple analysis of the different absorption spectra allows the two regions of the DOS, above and below the Fermi level, to be determined. We report on the use of this method in studying the effects of light soaking on different regions of the DOS in a-Si:H, and also validate the results against transient photocurrent DOS spectroscopy [3], which is sensitive only to the unoccupied DOS. [1] Main, C., Reynolds, S., Zrinscak, I., and Merazga, A., 2003, Determination of Defect Densities by Constant Photocurrent Method - Comparison of AC and DC Methods, Mat. Res. Soc. Symp. Proc. 762, A19.12.1-A19.12.6. [2] Main, C., Reynolds, S., and Zrinscak, I., 2003, The Influence of Generation and Transport Processes in the Constant Photocurrent Method. J. Materials Science: Materials in Electronics. 14 (2003) 681 - 684 [3] Main, C., 2002, Interpretation of Photocurrent Transients in Amorphous Semiconductors, J Non-Cryst Solids 299-302 (P1) 525-530.

A9.6 **Observation on the Surface and the Cross Section of Thin Film Solar Cells by AFM.** Lianghuan Feng, Lili Wu, Wei Cai, Yaping Cai, Jiagui Zheng, Jingquan Zhang, Bing Li and Wei Li; Department of Materials Science, Sichuan University, Chengdu, 610064, Sichuan Province, China.

It is very significant to observe the cross sectional morphology of thin film solar cells. As a result of collecting signals by the force, the information obtained with atomic force microscope (AFM) is different from that with scan electronic microscope (SEM) and scan tunnel microscope (STM). However, there are some difficulties in this observation because the interaction between the tip of AFM and the cross section of solar cells might include an electrostatic force due to the build-in electrical field in the cells. The electrostatic force must strongly influence the information and images acquired from AFM. In this paper, the AFM equipment has been improved: the tip has been covered with gold and connected with the former electrode of the solar cell so that they have been at the same electrical potential. The solar cell samples are either in open circuit or in short circuit. When they are in short circuit, there is almost no electrostatic force between the tip and the samples. In highness-mode, the cross sectional morphology

of solar cells can be clearly observed. When solar cells are in open circuit, the electrostatic force appears between the tip and cross section, and it is much larger than the Van der Waals' force according to our studies. The strength of the recorded force depends upon the potential difference between the tip and the near-neighbored area of the cross section. Therefore, this method can be used to observe and record the distribution of the built-in electrical potential in solar cells. The cross sections of a-Si and CdTe solar cells have been observed by this method. We study the AFM images in both conditions of open circuit and short circuit and compare the performance of the solar cells. In addition, the surfaces of the samples are observed in the two conditions, which obtains the different images of two kinds. The image in open circuit displays a map of electrical potential on the surface, and shows the grain boundary and some defects.

A9.7

Electric-Field Dependence of Photocarrier Properties in the Steady-State Photocarrier Grating Experiment. Rashad I. Badran¹ and Rudolf Bruggemann², ¹Physics Department, Hashemite University, Zarqa, Jordan; ²Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany.

The steady-state photocarrier grating (SSPG) technique has become a standard tool for the characterisation of the minority carrier properties in amorphous and microcrystalline silicon. In the standard application the photocurrent response under the presence of spatially modulated photogeneration is measured at low electric fields. The diffusion length in relation to the modulation or grating period determine how the influence of diffusion smears out the photocarrier grating. Analysis of the experimental data allows the extraction of the ambipolar diffusion length from these low field data. Abel et al. [1] derived a theory for the influence of space charge effects and drift on the measured photoresponse. The authors suggested to study the electric-field dependence of the parameters, measured in the SSPG experiment. In this paper, we exploit the electric-field variation experimentally for microcrystalline silicon samples. The experimental results show a variation in the influence that the electric field imposes on the excess charge carriers, depending on the individual sample. For poor-quality samples there is hardly any influence in the measured SSPG parameter, even at electric field values of about 10^4 V/cm. In contrast, samples with high diffusion lengths in the range of 200 nm show a large variation in the SSPG parameters. At high electric fields the response for these samples is almost completely dominated by drift contributions. Analysis of our data with the theory by Abel et al. shows good correlation between experimental and theoretical values for a wide range of electric field, in particular in the transition region between diffusion dominated and drift-dominated transport. Application of this theory to our experimental data allows the extraction of information on the diffusion length and on the trapped charge carrier density which determines the space charge density. 1. C.D. Abel, G.H. Bauer, W. Bloss, Philos. Mag. B 72, 551 (1995).

A9.8

Transient and Modulated Photoconductivity in Microcrystalline Silicon. Rudolf Bruggemann, Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany.

We present experimental data on transient and modulated photoconductivity (TPC, MPC) in nominally undoped microcrystalline silicon in which the dark conductivity was varied deliberately in order to study Fermi level effects on the recombination and trapping kinetics. This change in dark conductivity was achieved by annealing in vacuum at higher temperature and has a strong influence on the measured TPC and MPC data [1,2]. The time-dependent drift mobility in transient photoconductivity shows distinct variations in its temperature dependence, directly related to a high or low dark conductivity value of the microcrystalline silicon sample. We relate the thermalisation process of excess carriers to reaching the Fermi level before thermalisation is complete. For the determination of the density-of-states distribution from TPC (and also from MPC), the usual assumption that empty states between the conducting band and the Fermi level are probed may be not met, depending on the Fermi level position in the n-type nominally undoped microcrystalline silicon. Then, the constructed density-of-states does not represent the true distribution but shows a kind of Fermi-level related cut-off. However, numerical simulation which takes full account of the occupancy of states can reveal the underlying features in the density-of-states. Analysis of the observed experimental TPC and MPC data for n-type nominally undoped microcrystalline silicon can thus be achieved. [1] R. Bruggemann, J. Mat. Sci. Mat. Electr. 14, 629 (2003) [2] S. Reynolds et al., J. Non-Cryst. Solids, in print.

A9.9

Effects of FEL radiation on amorphous silicon. Branko Pivac¹, Vesna Borjanovic², Branislav Vlahovic² and Akira Ueda³; ¹Materials Physics, R. Boskovic Institute, Zagreb, Croatia; ²Physics, North

Carolina Central University, Durham, North Carolina; ³Physics, Fisk University, Nashville, Tennessee.

The effect of laser light irradiation on structural changes in amorphous silicon, have been studied for some time. The purpose of this work was to study the effect of FEL irradiation at resonant frequency on undoped hydrogenated amorphous silicon. The selective bond breaking and hydrogen redistribution were reported but the mechanism leading to structural relaxation were not clear. Samples with the amorphous silicon structure rich in hydrogen were grown on single crystal substrate at suitable temperatures and were subsequently irradiated with 5 and 4.75 μm light from FEL. The effects of irradiation were monitored with FTIR and Raman spectroscopy. It is shown that the irradiation affected much more the structures attributed to Si-H₂ clusters, detected by IR vibration band at 2100 cm⁻¹, than Si-H bonds, enhancing the former significantly. At the same time the effect of irradiation on Raman TO band did not affect its position or half-width indicating that the short range order was preserved. However, changes in the ratio I(TO)/I(TA) showed changes in the medium range order. These results support the attribution of the 2100 cm⁻¹ band to the hydrogen clustered at large structural defects in amorphous matrix. Although the coupling of Si-H vibration to the lattice seems to be weak it is shown that FEL irradiation could produce significant structural changes at room temperatures.

A9.10

Metastability in Undoped Microcrystalline Silicon Thin Films Deposited by HWCVD. Saydulla Persheyev¹, Kevin O'Neill¹, Mervin Rose¹, Vlad Smirnov² and Steve Reynolds²; ¹EE&P, University of Dundee, Dundee, United Kingdom; ²EPICentre, School of Computing and Advanced Technologies, University of Abertay Dundee, Dundee, United Kingdom.

Microcrystalline silicon deposited by HWCVD has a number of advantages as a material for photovoltaic applications [1]. It is also known that properties of microcrystalline silicon films can be changed by atmospheric ageing processes. [2, 3] In the present work we report on investigation of metastable effects induced by atmosphere in microcrystalline silicon. Films deposited by Hot Wire CVD method were studied by means of dark conductivity and SS photoconductivity, FTIR, Hydrogen Evolution, SEM characterization [4]. To investigate metastable processes on films surface and nucleation layer two different coplanar (top and bottom) contacts have been introduced for the photoelectrical measurements. Three types of metastability were observed in our films: a) long term irreversible degradation due to oxidation processes on the film surface, b) reversible degradation determined by uncontrolled water adsorption, c) transient conductivity field effect in the film bulk. Oxygen and hydrogen content and its bonding configurations have been analyzed by hydrogen evolution and infrared spectroscopy methods on the films deposited on glass substrates and silicon wafers subsequently. It has been found that metastable processes close to the film surface are stronger than in the bulk. The transient switching effect is the fast increase of charge carrier density observed on bottom chromium contacts under a condition of air admittance. We propose the effect is associated with electrical field induced by accumulated layer created by adsorbed water vapor near film surface. 1. S. Klein, F. Finger, R. Carius, T. Dylla et al. Thin Solid Films 430 (2003) 202-207 2. V. Smirnov, S. Reynolds et al presented ICAMS20, to be published JNCS 3. F. Finger, R. Carius, T. Dylla, S. Klein, S. Okur, M. Gunes, IEE Proc. CDS 150 (2003) (in press) 4. S.K. Persheyev, S. Reynolds et al Thin Solid Films 395 (2001) 130-133

A9.11

The Influence of Light-Soaking and Atmospheric Adsorption on Microcrystalline Silicon Films studied by Coplanar Transient Photoconductivity. Vladimir Smirnov¹, Steve Reynolds¹, Friedhelm Finger², Charlie Main¹ and Reinhard Carius²; ¹Computing and Advanced Technologies, University of Abertay Dundee, Dundee, United Kingdom; ²IPV, Forschungszentrum Juelich, D-52425 Juelich, Germany.

It is now widely accepted that microcrystalline silicon thin films and solar cells exhibit greater resistance to light-induced defect creation (Staebler-Wronski effect) than their amorphous silicon counterparts [1]. There has been considerable recent interest in carrier transport in films prepared at compositions bordering the transition from microcrystalline to amorphous growth regimes, as solar cell absorber layers prepared under these conditions yield optimum photovoltaic conversion efficiencies [2]. However, there is evidence that these compositions, whether as coplanar films [3] or photovoltaic absorber layers [4], may in fact show degradation in optoelectronic properties on prolonged exposure to light. We report a study of these effects by transient photocurrent density of states spectroscopy (TPC), coupled with steady-state photoconductivity and dark-current measurements, in coplanar films prepared by PECVD over a range of crystalline

volume fractions. It is shown that confusion may result, particularly when measuring thinner films, unless effects due to light-soaking are identified and separated from those arising from the adsorption of atmospheric components [5]. For the series of films studied here, the dark conductivity generally decreases on removal of adsorbates and increases on removal of light-induced defects. Furthermore, the influence of adsorption and light-soaking on the transient photocurrent decay, and hence the density of localized states, is quite different. We examine the possibility of employing specific annealing regimes under vacuum to distinguish between these effects. The distribution of metastable defects in films of varying crystallinity as determined by TPC is compared with that in fully amorphous samples, with a view to elucidating the nature of defect creation in both materials. [1] M. Goerlitz et al, MRS Symp. Proc. 457, 301 (1997). [2] O. Vetterl et al, Solar Energy Materials & Solar Cells 62, 97 (2000). [3] S. Ray, S. Mukhopadhyay, T. Jana and R. Carius, J. Non-Cryst. Solids 299-302, 761 (2000). [4] S. Klein et al, Thin Solid Films 430, 202 (2003). [5] V. Smirnov, S. Reynolds, C. Main, F. Finger, R. Carius, ICAMS 20 (Brazil, August 2003).

A9.12

Surface potential and surface photovoltage of oxide and nitride coated multicrystalline silicon solar cells using a scanning Kelvin probe. Iain D Baikie, Kelvin Research, KP Technology, Wick, Caithness, United Kingdom.

We have applied a high resolution scanning Kelvin probe to perform dark surface potential topographies of multicrystalline silicon solar cells having thin coatings of Si₃N₄ and SiO₂. We clearly observe the electrical characteristics of the screen printed bus-bar and associated fingers, grain boundaries, together with characteristic structures on the oxide and nitride, coupled to significant surface potential variations across larger sections of the wafer. Associated surface photovoltage measurements can be unambiguously decoded to show coating and bulk contributions. The nitride coating exhibits carrier trapping lifetimes in excess of 13 minutes at 300K.

A9.13

PECVD grown polymorphous hydrogenated silicon (pm-Si:H) studied using current transient spectroscopies in PIN Diodes. vibha Tripathi¹, Y N Mohapatra¹ and P Roca i Cabarrocas²; ¹Dept. of Physics, Indian Institute of Technology, Kanpur, India; ²LPICM, Ecole Polytechnique, Palaiseau Cedex, France.

Polymorphous Silicon (pm-Si:H) thin films have emerged as alternative to conventional a-Si:H due to their better transport properties, and improved stability. These improvements in properties are attributed to the presence of nano-crystalline inclusions in the amorphous matrix when grown under controlled conditions by PECVD. Possible changes in the density of gap states due to the presence of crystallites is of central importance in understanding steady state and dynamic characteristics of devices using these materials. We have studied a-Si:H and pm-Si:H grown by PECVD at different pressures. We monitor the steady state reverse current and their transients in PIN devices fabricated using these materials. The transients are analyzed using isothermal spectroscopic techniques such as Time Analyzed Transient Spectroscopy (TATS), and high resolution Laplace DLTS as a function of temperature. In case of a-Si:H, we obtain expected signature of emission from a broad density of states in the form of stretched exponentials. In contrast the corresponding spectra for pm-Si:H are dominated by nearly exponential fast current decay processes with discrete energies between 0.25 and 0.36 eV from E_c. It is shown that the study of density of states by dynamic methods such as transient techniques reveal features not accessible to steady state measurements. The origin of multiple discrete traps in presence of disorder is discussed.

A9.14

Abstract Withdrawn

A9.15

Polycrystalline Silicon-Single Crystal Silicon Junctions: DC I-V and AC Conductance Measurements.

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Thermal Spray processing of materials offers a practically viable means to make large area coatings. In this work thermal sprayed Polycrystalline Silicon films have been prepared. Characterization of both the films and devices made using them have been carried out extensively. DC Current-Voltage characteristics of Polycrystalline Silicon-Single Crystal Silicon junctions have been explored over a wide range of temperatures (85 K - 300 K). Preliminary analysis indicates multi-step tunneling as the current transport phenomena across the device structure. AC Conductance measurements reveal the presence of interface states which aid the multi-step tunneling process. The DC

conductivity measurements on polycrystalline silicon films indicate different activation energies in effect in two different temperature ranges, rather than a single thermally activated process commonly observed in Polycrystalline Silicon films.

A9.16

Study of steady state photoconductivity and electron mobility in highly crystallized doped and undoped microcrystalline Si films. Sanjay K. Ram¹, Satyendra Kumar¹, R. Vanderhagen², B.

Drevillon² and P. Rocca i Cabarrocas²; ¹Physics, Indian Institute of Technology, Kanpur, Kanpur, Uttar Pradesh, India; ²Laboratoire de Physique des Interfaces et des Couches Minces (UMR 7647 du CNRS), Ecole Polytechnique, 91128 Palaiseau Cedex, France.

Hydrogenated microcrystalline silicon ($\mu\text{c-Si:H}$) thin films have become a promising candidate in the field of large area opto-electronic devices like solar cells, sensors and thin film transistors (TFT's) based flat panel displays. This material has drawn more attention compared with hydrogenated amorphous silicon due to higher conductivity, large carrier mobility and better stability against light induced changes. However, plasma-deposited $\mu\text{c-Si:H}$ is inherently a heterogeneous material consisting of micro and nano size crystallites, amorphous tissues and voids. Understanding carrier transport in such a system is undoubtedly a challenging task. Though there are several reports on the electronic transport in doped $\mu\text{c-Si:H}$, little attention is paid to the carrier transport in undoped $\mu\text{c-Si:H}$. We have obtained highly crystallized dense undoped $\mu\text{c-Si:H}$ films on glass substrates by standard rf glow discharge plasma CVD technique using a mixture of SiF₄, Ar and H₂ at low temperature (200 °C). Structural properties of the films were well characterized by in-situ spectroscopic ellipsometry, Raman scattering, X-ray diffraction and atomic force microscopy techniques. This article will basically cover the conductivity, steady state photoconductivity, Hall and photo Hall effect studies carried out on samples having different thicknesses. The dependences of photoconductivity (σ_{ph}) on the temperature and the intensity of light were measured in a temperature range 15–325 K. Mechanisms of carrier transport and recombination governing these temperature and intensity dependences will be discussed in the paper. In order to evaluate the properties like free carrier concentration and mobility in undoped $\mu\text{c-Si:H}$, Hall effect measurements were performed in the temperature range 300–450 K. However, several experimental limitations are associated with Hall effect measurement on undoped $\mu\text{c-Si:H}$ films that are highly resistive and have low carrier concentration. To overcome these difficulties the samples were designed in 6-pole contact geometry by lithography technique and experimental set-up was optimised to reduce unusual offset voltages, which mostly arise due to misalignment of the contacts. We have also studied n and p types of doped $\mu\text{c-Si:H}$ films. Further, the photo-Hall measurements were also carried out on these samples to observe the effect of illumination on mobility of excess carriers generated by illumination. The details will be described in this paper.

A9.17

Characteristic temperature for magnetically doped amorphous semiconductors. Li Zeng¹, John Cherry², Erik

Helgren² and Frances Hellman²; ¹Materials Science, UCSD, La Jolla, California; ²Dept. of Physics, UCSD, La Jolla, California.

Recent results have shown that the magnetically doped amorphous films near the metal-insulator (M-I) transition are extraordinarily sensitive to magnetic field and temperature, with a negative magnetoresistance of many orders of magnitude. This sensitivity is likely due to correlation effects stemming from interactions between the conduction electrons and the magnetic impurities [1-3]. We have grown a series of thin films for each of the amorphous metal semiconductor alloys Gd_xSi_{1-x} and Gd_xGe_{1-x} covering a broad range of dopant concentrations on the metallic side of the MIT in order to investigate correlation effects in the metallic regime, and to determine the effect of the semiconducting matrix. The critical concentration (x_c) for Gd-Si occurs at $x_c=14\%$ [1] and is found to be the same for Gd-Ge. We compare the results of DC conductivity, $\sigma(T)$, ($4.2\text{ K} < T < 295\text{ K}$) for the two different group IVA host materials doped with magnetic impurities, while also comparing to results from the non-magnetic counterpart Y_xSi_{1-x}. A characteristic temperature scale T* at which the magnetically doped samples deviate strongly from their non-magnetic counterparts is found to follow the form $T^* \propto x^{-1/2}$. A similar dependence is found for the magnitude of the magnetoresistance as a function of temperature. We also find that the relative characteristic temperature, for any given dopant concentration, is larger in Gd-Si as compared to Gd-Ge. These results suggest a dependence on electron screening that will be discussed in the framework of M-I theory. [1] F. Hellman et al., Phys. Rev. Lett. 77, 4652 (1996) [2] W. Teizer et al., Phys. Rev. Lett. 85, 848 (2000) [3] D. N. Basov et al., Europhys. Lett. 57, 240 (2002)

A9.18

Local ferromagnetic ordering and charge localization in amorphous Gd_xSi_{1-x} . Nikolai Chumakov¹, Victor Tugushev¹, Stanislav Gudenko¹, Alexander Inyushkin¹, Olga Nikolaeva¹, Alexander Davydov¹, Valery Ozhogin¹, Li Zeng², Erik Helgren² and Frances Hellman²; ¹RRC Kurchatov Institute, Moscow, Russian Federation; ²Dep. of Phys. UCSD, San Diego, California.

We present a new theoretical model, which describes the anomalous transport and magnetic properties of amorphous gadolinium silicon alloys [1,2] by local ferromagnetic transition. The model takes in to account large non-uniformity of the system caused by its amorphous nature. This leads to a redistribution of electron density and appearance of the regions with high electron concentration (drops). Magnetic ordering is more favorable in the drops than in the volume. We suggest that spin polarization of electron states, caused by local ferromagnetic ordering, leads to the splitting of energy sublevels for electrons with spin up and down inside the drops. The lowering of occupied spin-up sublevel increases total spin polarization of the drop and also results in lowering of the Fermi level. The Fermi energy decreases with temperature and reduces itinerant electron concentration outside the drops. The model has been verified by a series of experiments. Study of electron spin resonance (ESR), electrical conductivity, the Hall and Seebeck effects of Gd_xSi_{1-x} have been performed. The temperature dependence of magnetization has been obtained by a double integrated ESR line intensity. According to the standard RKKY theory, local FM ordering of Gd moments appears in the drops at temperatures below 50K. That corresponds to an effective Curie temperature, estimated from measurements of magnetization at high T. Drastic increasing of magnetization obtained from ESR at temperature below 50 K as well as the obvious increasing of ESR resonance field for normal orientation of magnetic field relative to the sample surface have been observed. This behavior directly indicates the appearance of FM drops in the sample. Based on our theoretical model we have estimated the typical diameter of the drops to be about 1.5-2.5 nm. The Hall effect and conductivity data demonstrate that the conductivity variations on temperature and magnetic field are proportional to the itinerant electron concentration. The itinerant character of electron transport is also confirmed by the thermo EMF experiments. Such behavior seems to be in accordance with the developed theoretical model. The work was supported by grant of CRDF (RP2-2402-MO-02) and the NSF DMR. [1] F. Hellman et al. Phys. Rev. Lett. 77 (1996) 4652 [2] F. Hellman et al. Phys. Rev. Lett. 84 (2000) 5411

A9.19

Quantitative analysis of average crystallization rate by grazing-angle incidence X-ray backdiffraction technique. Siranush E. Bezirganyan¹, Hakob (Akop) P. Bezirganyan¹, Hayk H. Bezirganyan Jr.² and Petros H. Bezirganyan Jr.³; ¹Dept of Solid State Physics, Yerevan State University, Yerevan, 375025, Armenia; ²Faculty of Informatics and Applied Mathematics, Yerevan State University, Yerevan, 375025, Armenia; ³Dept of Computer Science, State Engineering University of Armenia, Yerevan, 375009, Armenia.

Advanced technologies require more detailed investigations of amorphous-crystal interfaces. Many integrated circuits include a type of transistor known as a metal-oxide-semiconductor, field-effect transistor, or "MOSFET" which has an insulated gate member that controls its operation (e.g. see [1], in which a gate structure consisting of stacked-amorphous-silicon film is proposed). All of the techniques used to make amorphous silicon can lead to the formation of an amorphous-crystal interface between it and an underlying crystal lattice. Of particular technological importance is ion implantation, where dopants are implanted into a thin layer at one surface of the substrate, making it electrically active. At low temperatures, high doses (high density of implanted atoms), or high dose rates this can cause the formation of an amorphous layer which must be converted back into crystal for the device to be functional. The other common methods of producing amorphous silicon, low temperature deposition and pulsed laser melting, also produce such a phase interface between the newly formed amorphous layer and the crystalline silicon substrate. When heated up above a few hundred degrees Celsius the mobility of the atoms in the amorphous phase increases enough that they can transform into the lower energy diamond structure crystal phase. The crystal grows epitaxially, with the newly crystalline atoms continuing the existing lattice, directly from the solid amorphous phase to the solid crystal phase. The process by which the interface moves as the amorphous atoms rearrange themselves to move into crystalline positions is called solid phase epitaxial growth or SPEG (e.g. see [2]). The investigations of crystal-amorphous state transitional layer can be performed using the Grazing-Angle Incidence X-ray Backdiffraction (GIXB) technique (see translations [3, 4] of our original papers). In presented paper the theory of GIXB is extended for the investigations of the averaged rate of crystallization, and is considered theoretically an opportunity for the fine determination of the rate of the crystallization in various cases of crystal-amorphous

state transitional layer. Images of the X-ray reflectivity coefficient of silicon amorphous-crystal interface computed for the GIXB configuration depending on the rate of crystallization and on Bragg angle are presented. References: [1]. S.L. Wu, C.L. Lee, T.F. Lei, J.F. Chen, L.J. Chen, IEEE Electron Device Letters, 15(5) (1994) 160-162. [2]. G.L. Olson, J.A. Roth, Solid Phase Epitaxy, in Handbook of Crystal Growth, edited by D.T.J. Hurle, North-Holland-Elsevier, Amsterdam, Elsevier, 1994, Vol.3, Chap. 7. [3]. A.P. Bezirganyan and P.A. Bezirganyan, Phys. Stat. Sol. (a), 105 (1988) 345-355. [4]. A.P. Bezirganyan, Phys. Stat. Sol. (a), 109 (1988) 101-110.

A9.20

Interaction of SiH₃ radicals with amorphous silicon surfaces. Sumit Agarwal¹, Mayur S. Valipa^{1,4}, Saravanapriyan Sriraman², M.C.M. van de Sanden³, Dimitrios Maroudas¹ and Eray S. Aydil⁴; ¹Chemical Engineering, University of Massachusetts - Amherst, Amherst, Massachusetts; ²Chemical Engineering, Princeton University, Princeton, New Jersey; ³Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands; ⁴Chemical Engineering, University of California - Santa Barbara, Santa Barbara, California.

Interactions of SiH₃ radicals with surfaces of hydrogenated (deuterated) amorphous silicon (a-Si:H(D)) films were studied using surface-sensitive attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy and molecular-dynamics (MD) simulations based on an extensively tested many-body interatomic potential. We present experimental evidence for a-Si:D films regarding: (i) abstraction of surface D atoms by SiH₃ radicals, (ii) occurrence of SiH₃ insertion into surface Si-Si bonds simultaneously with surface D abstraction over a substrate temperature range from 60 to 300 °C, and (iii) dissociation of some fraction of the adsorbed SiH₃ on the a-Si:D films and release of H into the subsurface. In addition, our MD simulations show that SiH₃ radicals abstract surface hydrogen through an Eley-Rideal mechanism; the corresponding abstraction energetics are in excellent agreement with accurate density-functional-theory calculations and predict a very low activation energy barrier. Furthermore, according to detailed analysis of MD trajectories, the SiH₃ radicals are highly mobile on the amorphous silicon surface and diffuse through overcoordination defects on the surface. Radical diffusion is driven by surface chemical potential gradients determined by the distribution of Si-Si bond strain on the surface, which is strongly coupled with the surface morphology and reactivity. Due to this chemical potential gradient, radicals impinging on the surface mesas migrate to the valleys, whereas radicals impinging in the valleys remain in the valleys leading to surface smoothening. Based on our experimental and computational studies, we propose a deposition mechanism for a-Si:H from SiH₃, which explains both the temperature-independent reaction probability of SiH₃ with a-Si:H surfaces and the temperature-dependent surface smoothening mechanism.

A9.21

Spectroscopic Ellipsometry study of high rate a-Si:H growth by means of the remote expanding thermal plasma and an additional ion bombardment. Arno Smets, Erwin Kessels and Richard van de Sanden; Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

In the recent years it has been demonstrated that the remote expanding thermal plasma (ETP) is a deposition tool, which has easily access to ultra-high hydrogenated amorphous silicon (a-Si:H) deposition rates up to 10 nm/s. However, preservation of the material quality of a-Si:H material deposited by the ETP technique at high deposition rates, requires higher substrate temperatures. The need for higher substrate temperatures originates from the competition between the deposition rate and the surface diffusion processes during growth, as observed by means of vacancy and void incorporation and the surface roughness evolution during growth^{1,2}. At present the maximum exposure temperature of a pin-device during processing is limited by the p-layer, which means that the pin performance is maintained up to an intrinsic a-Si:H deposition rate of 1 nm/s using the ETP technique (T_{dep}=250 °C). Additional RF biasing of the substrate is a possible tool to reduce the substrate temperature while maintaining a sufficiently activated surface diffusion. The high rate a-Si:H growth without and with external RF substrate biasing has been studied by means of spectroscopic ellipsometry (SE). The SE technique shows experimental limitations in its sensitivity to the initial growth, due to the high growth rate. Nevertheless, in the early stage of the growth, up to 50 nm, an evolving a-Si:H dielectric function has been observed. This initial growth phase is also observed in IR transmission measurements and originates from initial growth in which more voids are incorporated. The roughness results obtained from SE are compared with the roughness morphology obtained from AFM. Results on an additional RF-substrate bias at low substrate temperature of 100 °C show smoother surfaces accompanied with a densification of the a-Si:H films, i.e. the incorporation of less voids

and more vacancies. The results can be explained in terms of an ion bombardment enhanced surface diffusion process. ¹ A.H.M. Smets, W.M.M. Kessels and M.C.M. van de Sanden, Appl. Phys. Lett. 82, 865 (2003) ² A.H.M. Smets, W.M.M. Kessels and M.C.M. van de Sanden, Mat. Res. Soc. Symp. Proc. Vol. 762, A10.3.1 (2003)

A9.22

Molecular-Dynamics Modeling of Hydrogen Post Treatment of Hydrogenated Amorphous Silicon Thin Films.

Saravanapriyan Sriraman^{1,2}, Mayur S. Valipa^{2,3}, Eray S. Aydil² and Dimitrios Maroudas³; ¹Chemical Engineering, Princeton University, Princeton, New Jersey; ²Chemical Engineering, University of California, Santa Barbara, California; ³Chemical Engineering, University of Massachusetts, Amherst, Massachusetts.

When exposed to a flux of H atoms, hydrogenated amorphous silicon (a-Si:H) thin films grown by plasma deposition from SiH₄/H₂ discharges crystallize at temperatures much lower than those required for thermal annealing. The flux of H atoms is generated either during post treatment with an H₂ plasma, or when the SiH₄ feed gas is diluted heavily with H₂. Understanding the fundamental physicochemical mechanisms responsible for film crystallization is crucial for controlling the film structural and electronic properties. Toward this end, this presentation discusses atomic-scale modeling results for hydrogen post treatment of a-Si:H films. Using molecular-dynamics (MD) simulations of repeated H atom impingement on a-Si:H films, we modeled their post treatment by H₂ plasmas. The a-Si:H films used in the simulations were grown through MD with SiH₃ as the sole radical precursor for deposition. The film structure and properties were characterized in detail. Structural analysis of the H-exposed a-Si:H film revealed disorder-to-order transitions upon exposure to H atoms at temperatures, T ($500 \text{ K} \leq T \leq 773 \text{ K}$), much lower than those required for thermally-induced crystallization. The analysis showed that H atoms diffuse into the a-Si:H film and insert into strained Si-Si bonds to form intermediate bridging and bond-centered H (Si-H-Si) configurations, which have been verified experimentally through *in situ* infrared (IR) spectroscopy. Systematic investigation of the H insertion pathways has led to derivation of a universal correlation of H insertion energetics with the strain of the corresponding Si-Si bonds for all the insertion mechanisms identified. Furthermore, a parametric study was conducted over a range of substrate temperatures ($500 \text{ K} \leq T \leq 773 \text{ K}$) to analyze the effects of hydrogen post treatment on the chemical composition of the H-exposed films; for the analysis, the evolution of the film surface hydride composition was monitored over the duration of the MD simulations. Our study predicts that etching occurs only at lower substrate temperatures, which is in good agreement with experiments based on *in situ* IR spectroscopy.

A9.23

High-quality hydrogen diluted SiNx films deposited by hot-wire chemical vapor deposition. Fengzhen Liu¹, Lynn Gedvilas¹, Errol Sanchez², Shulin Wang² and qi wang¹; ¹NREL, Golden, Colorado; ²Applied Materials, Inc, Sunnyvale, California.

We have studied the effect of H-dilution on silicon nitride films deposited by the hot wire chemical vapor deposition technique using SiH₄, NH₃, and H₂ gases. We found that H-dilution significantly enhances silicon nitride films property. The N content in the film increases above 2 times in compared to the film without H-dilution from FTIR measurement. As a result, we can achieve high-quality SiNx films at low substrate temperature using a much lower gas ratio of NH₃/SiH₄ (about 1) in compared to a ratio of about 100 for a conventional deposition condition. More remarkable, H-diluted SiNx films are conformal. SEM measurement shows a near 100 percent surface coverage over a sharp object. H-dilution normally decreases the deposition rate. However, by increasing the processing pressure, high-quality films have been deposited at 4 Å/s. Electric break-down measurement shows a well-insulated film with over a few MV/cm for the break-down field.

A9.24

New ultrahigh vacuum setup and advanced diagnostic techniques for studying a-Si:H film growth by radical beams. MCM Van de Sanden, JPM Hoefnagels, E Langereis and WMM Kessels; Dept. of Applied Physics, Eindhoven Univ. of Technology, Eindhoven, Netherlands.

A new ultrahigh vacuum setup has been designed and built for studying the surface science aspects of a-Si:H film growth. The setup is equipped with several plasma and radical sources which produce well-defined radicals beams such that the a-Si:H deposition process can be mimicked. A-Si:H film growth can take place by a hot wire source while an electron-cyclotron resonance (ECR) remote plasma operated on H₂ can produce a rather pure SiH₃ beam. An atomic H source based on thermal dissociation of H₂ in a hot capillary produces a pure beam of atomic H with a quantified H flux and can be used for

studies of atomic H etching and of atomic H synergistic effects during a-Si:H growth. These sources have extensively been characterized by several means such as by measuring the atomic H etch rate of amorphous carbon and silicon films under different operating conditions of the H₂ operated sources. By linking the etch rates to the one obtained by the quantified atomic H source, absolute efficiencies of the radical sources have been obtained. The setup is designed with several diagnostic ports such that the growing a-Si:H films can be probed with several advanced optical techniques: spectroscopic ellipsometry to monitor film growth, attenuated total reflection infrared spectroscopy to study the H depth profile and surface hydride (-SiH_x) composition of the a-Si:H, spectroscopic second harmonic generation for measuring the dangling bonds on the a-Si:H surface and eventually evanescent-wave cavity ringdown to measure dangling bonds in the a-Si:H during film growth. The first studies with this setup on a-Si:H film growth include the deposition of a-Si:H films by the hot wire and ECR source while real-time monitoring film growth by spectroscopic ellipsometry and second harmonic generation. Furthermore atomic H etching experiments of a-Si:H have been carried out for different atomic H fluxes and substrate temperatures. It has been found that the Si etch rate is linear in the atomic H flux with an etch efficiency of 0.005 Si atoms per incoming H atom. Furthermore, no substrate temperature dependence of the etch efficiency is observed for substrate temperatures between 85 and 250 °C. Currently this Si etch process is studied with atomic deuterium using attenuated total reflection infrared experiments.

A9.25

Energetics of Surface Transport During Amorphous Silicon Deposition. Gregory N. Parsons and Kevin R Bray; Chem. Eng, NC State Univ, Raleigh, North Carolina.

Mechanisms in hydrogenated amorphous silicon growth are of interest for improved materials and for understanding low temperature deposition in general. Although it is known that other species may contribute toward growth, silyl radicals (SiH₃) are considered to have a high surface mobility and contribute to the observed conformal smooth surfaces. Surface roughness evolution, characterized by atomic force microscopy, has been used to characterize static and dynamic scaling coefficients (α and β) and trends used to extract values for energetic barriers associated with surface smoothening. Transport barrier values obtained are not consistent with some previous models for silyl adsorption and hopping, so other approaches are considered. We find that under some plasma deposition conditions, scaling analysis provides a self-consistent set of parameters for a self-similar surface structure defined by surface diffusion. In other conditions, roughening mechanisms, such as ion bombardment, can dominate. For diffusion-dependent growth, the saturation roughness depends on film thickness, and the dynamic scaling coefficient is independent of growth temperature between 25 and 350C. Within this temperature range, the lateral correlation length is observed to be independent on film thickness, but the value is thermally activated with a barrier of 0.2eV. In this same temperature range, the dynamic scaling coefficient is found to be near 0.25, independent of temperature, consistent with a low energetic barrier for surface transport related to smoothening. The transport barrier is smaller than the binding energies for silyl radicals on the growth surface. Species transport mechanisms in agreement with the observed scaling will be discussed.

A9.26

Structural and Electronic Properties of SiCl₄-based Microcrystalline Silicon Films. Wolfrard Beyer, Reinhard Carius, Michael Lejeune and Uwe Zastrow; Institute of Photovoltaics, Forschungszentrum Juelich, Juelich, Germany.

Microcrystalline silicon films are of interest for application in thin film solar cells and other devices. While silane is commonly used as the precursor gas, we explored the application of silicon tetrachloride (SiCl₄) which is less expensive and less dangerous. For deposition we applied conditions leading for silane to high deposition rates and high solar cell efficiencies [1], namely a high dilution of SiCl₄ by hydrogen, a high pressure of 4 mbar and a high rf (13.56 MHz) power of 60 W (1 W/cm²). While the flow rate of hydrogen was kept constant at 100 sccm, the flow of SiCl₄ was varied between 0.5 and about 10 sccm. For doping, flows of diborane or phosphine were added. Typical substrate temperature was 250°C. The deposition rate was found to increase with rising SiCl₄ flow and at a flow of 4 sccm a deposition rate of about 3 Å/s was obtained for undoped material. For high phosphorus doping, the deposition rate was somewhat higher, for high boron doping more than a factor of two lower. The film structure was characterized by Raman spectroscopy, infrared absorption and gas effusion measurements, the chemical composition by infrared absorption and SIMS, and the electronic properties by conductivity and thermoelectric power measurements. As the SiCl₄ flow rate rises from 1 to 7 sccm, the Raman crystallinity of undoped material decreases continuously from near 90 % to less than 10 %. Infrared absorption measurements show an increase of the chlorine and

hydrogen content with increasing SiCl₄ flow. The post-deposition oxygen uptake attributed to the presence of a porous structure shows a minimum near the Raman crystallinity of 70%. While undoped films have their Fermi-level typically near midgap, high room temperature (RT) conductivities exceeding 100 (ohmcm)⁻¹ are achieved for boron doping at a (solid state) doping level of about 2%. For phosphorus-doping, only a maximum RT conductivity of about 10⁻¹ (ohmcm)⁻¹ was obtained. The relation between SiCl₄ flow, doping, crystallinity and RT conductivity was studied. I. T. Roschek, B. Rech, W. Beyer, P. Werner, F. Edelman, A. Chack, R. Weil and R. Beserman, MRS Symp. Proc. 664 (2001) A 25.5

A9.27

Atomic-Scale Analysis of Fundamental Mechanisms of Surface Smoothing in Plasma-Deposited Amorphous Silicon Thin Films. Mayur S Valipa^{1,2}, Saravanapriyan Sriraman³, Eray S Aydil¹ and Dimitrios Maroudas²; ¹Department of Chemical Engineering, University of California, Santa Barbara, Santa Barbara, California; ²Department of Chemical Engineering, University of Massachusetts, Amherst, Massachusetts; ³Department of Chemical Engineering, Princeton University, Princeton, New Jersey.

Under conditions of low SiH₄ dissociation during the plasma-assisted deposition of hydrogenated amorphous silicon (a-Si:H) thin films, the dominant deposition precursor is the SiH₃ radical. The remarkable smoothness of device-quality a-Si:H films grown under these conditions has been used to conclude that the deposition precursor is very mobile and that it can fill surface valleys after adsorbing onto the film. However, the fundamental atomic-scale processes that determine the surface morphology of a-Si:H films during deposition are still not well understood. In this presentation, we discuss such atomic-scale mechanisms as derived through a detailed fundamental analysis based on atomistic simulation. Using molecular-dynamics (MD) simulations of repeated impingement of SiH₃ radicals on the growth surface, we studied the deposition of a-Si:H films on initially H-terminated Si(001)-(2×1) surfaces. The simulated evolution of the film's structure, surface morphology, roughness, and surface reactivity was investigated systematically. The surfaces of these MD-grown films were found to be remarkably smooth due to a valley-filling mechanism where mobile precursors, such as SiH₃ and Si₂H₆, diffuse and passivate dangling bonds present in surface valleys or at the valley edges. The mechanisms of SiH₃ precursor diffusion on the a-Si:H surface were studied placing special emphasis on elucidating the role of the surface bond strain in mediating the valley-filling phenomena. Surface transport of the SiH₃ precursor was found to be driven by the Si-Si bond strain distribution on the surface, which is strongly coupled with the surface morphology and reactivity. Analysis of the MD trajectories for numerous SiH₃ radical migration paths revealed the development of tensile strain regions along these paths, which typically lead to dangling bonds. Adsorbed SiH₃ radicals follow these tensile strain paths and passivate dangling bonds present in valleys or at valley edges, thus leading to valley filling.

A9.28

Growth and Characterization of Poly-SiGe prepared by Reactive Thermal CVD. Jianjun Zhang, Kousaku Shimizu and Jun-ichi Hanna; Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, Yokohama, Japan.

We have reported preparation of high crystallinity polycrystalline Si_{1-x}Ge_x (poly-Si_{1-x}Ge_x: x < 0.05) at 450°C and its application to TFTs. The TFTs we fabricated with 200nm thick films exhibited high mobility over 50cm²/Vs and 20cm²/Vs in bottom and top-gate-TFTs, respectively, even though the fabrication process had not been optimized yet. In this study, we prepared poly-SiGe thin films with variable germanium content (Ge=5% 30%). The films were analyzed using Raman spectroscopy, SEM, TEM and four-point probe measurements. The content of Ge were determined by Raman peak intensity ratio of Si and Ge. We found that the gas flow rate ratio of Si₂H₆/GeF₄ is one of the most important parameter to influence not only the Si/Ge content but also the crystallinity. Only amorphous film can be deposited when no GeF₄ gas was introduced, while just introducing a small flow rate of GeF₄ induced the crystalline film deposition. Further increase of GeF₄ flow rate resulted in arising of c-Ge and Ge-Si peak at about 296cm⁻¹ and 410cm⁻¹ in the Raman spectra. In order to investigate the influence of Ge for crystal growth, the films at the early stage of film growth were also investigated with Raman spectroscopy and SEM: the nuclei formation was confirmed on glass substrate and the Ge content changed with increasing the film thickness. The growth mechanism associated with the Ge, its influences on growth rate, incubation time, crystallinity and conductivity of the films will be discussed in detail.

A9.29

A numerical model for microcrystalline silicon growth. Yasuyuki Kobayashi and Koji Satake; Advanced Technology Research Center, Mitsubishi Heavy Industries, Ltd., Yokohama, Kanagawa-ken,

Japan.

Microcrystalline silicon (mc-Si) films, intensively investigated for solar cells, commonly made by low-temperature plasma enhanced CVD, have complicated structures that consist of mc-Si and amorphous silicon (a-Si). Some models using Kinetic Monte Carlo method reproduced the evolution and the structure [1], however the film properties and facets exposed on the surface have not been considered. It is important to reproduce all the properties in order to connect between the growth conditions and the electrical properties. In this study, we present a three-dimensional numerical model of mc-Si growth, based on cell automata to predict the film properties. Our growth model of mc-Si has the following sequential process: (1) Facet growth velocities, governed by growth conditions such as reactive species fluxes onto a substrate, determine a grain basic growth form, (110) or (111)-oriented grains appears on condition that the facet growth velocities of (100) and (111) on the grains are nearly equal, so we assume only the (100) and (111) facets on the grain growth form. (2) An a-Si layer first appears on the substrate and grows isotropically. (3) Crystalline nuclei generate, grow and prevail on the amorphous layer. (4) An evolutionary selection process of the grain growth selects preferable oriented grains to be larger, the grains finally dominate near the film surface. (5) Micro-twins generate in the grain, which affect film-preferred orientations. Facet growth velocities, a-Si growth velocity, a grain nucleation rate and a micro-twin generation rate have to be prepared as input for our model. The evolutionary selection process selects growing grains faster normal to the substrate. The process deforms grain basic growth forms as the grains collide with each other and the process finally selects the preferable oriented grains in the mc-Si film structure [2]. The calculated results are converted into X-ray diffraction and Raman spectra to compare with experiments. We fit the growth parameters to agree with the experiments. The growth velocities of the crystalline facets and a-Si governed an evolutionary selection during the film growth. In advance, the (100) and (111) facet growth velocities were calculated. The other three growth parameters were estimated as the calculation agreed with the experiments. The a-Si growth velocity had to be slower than the facet growth velocities to form mc-Si films. The structure agrees with cross-sectional TEM images of the (110) oriented mc-Si films. And we have found the facet growth velocities affect the preferable orientation and also the surface morphology. Our model consistently explains the relation between the orientation and the surface morphology from the SEM observations of mc-Si films. We thank Dr. Kamiya of Tokyo Institute of Technology for helpful discussions and suggestions. [1] S. W. Levine and P. Clancy, Modelling Simul. Mater. Sci. Eng. 8, 751(2000). [2] A. van der Drift, Philips Res. Repts. 22, 267(1967).

A9.30

Growth of hydrogenated microcrystalline silicon films by cat-CVD using a graphite catalyzer. Prabhat Kumar¹, Dhananjay Bhusari² and Bernd Schroeder¹; ¹Department of Physics / Center of Optical Technologies and Laser Controlled Processes, University of Kaiserslautern, Kaiserslautern, Germany; ²Department of Chemical Engineering, Georgia Institute of Technology, Atlanta, Georgia.

In recent years, there has been considerable interest in evaluating new materials as catalyzer for HW deposition of a-Si:H and μ c-Si:H because of the limited lifetime (due to silicide formation) of the tungsten (W) and tantalum (Ta) wires. We report here on the microstructural and electrical properties of intrinsic μ c-Si:H layers prepared near the transition regime between a-Si:H and μ c-Si:H, where usually high quality μ c-Si:H material is obtained, using a graphite catalyzer. In order to optimise the growth conditions, the deposition parameters were varied. The dark (σ_d) and photo-conductivity (σ_p) were found to be in the range of 10⁻⁹-10⁻⁶ Ω cm⁻¹ and 10⁻⁶-10⁻³ Ω cm⁻¹ respectively. With increase in substrate temperature (T_s) from 120 to 240 °C, the μ c Raman peak at 520 cm⁻¹ continuously became more prominent compared to the amorphous peak at 480 cm⁻¹, indicating increasingly microcrystalline films. For variations in silane concentration, the films were highly microcrystalline at 6 and 8% silane, and almost amorphous at 12% and beyond. The films in the so called transition regime occurred near $T_s = 1850^\circ\text{C}$ and 10% silane in H₂. For variations in the deposition pressure (p), the film was predominantly amorphous at lower p, while the μ c-fraction increased rapidly with increase in p. The transition regime films were obtained over a very broad range in p but narrow range in silane concentration. The dark- and photo-conductivities were found to vary in a complex manner with variations in p, indicating different growth regimes at low and high pressures. The highest photo-sensitivity of the order of 10³ was obtained at 185°C, 10% silane and two different pressures 7.5 Pa and 70 Pa, with μ c-fractions greater than 50%. Good photoelectrical quality of the intrinsic μ c-Si:H films is achieved. However, it should be pointed out that the deposition rate with graphite catalyzer is significantly lower (almost by a factor of 10) than using W and Ta catalyzer in the same deposition system with similar deposition parameters. The major

advantage of this new graphite catalyzer is its higher chemical and electrical stability as compared to those of Ta and W. After several tens of hours of deposition, the I-V characteristics and shape of the filaments were found to be virtually unchanged. However, their mechanical strength is of some concern since the filaments are highly brittle which results in breakage even with small amounts of residual stresses in the fixtures.

A9.31

Relation between hydrogen content in a-Si:H films and clusters incorporated into the films. Masaharu Shiratani, Kazunori Koga, Naoto Kaguchi and Yukio Watanabe; Dept. of Electronics, Kyushu Univ., Fukuoka, Japan.

Reduction of hydrogen content $C_{H(Si-H_2)}$ associated with Si-H₂ bonds in hydrogenated amorphous silicon (a-Si:H) films has been pointed out to be an important key to reduction of light induced defects in the films.¹ We have studied the relation between hydrogen content and volume of clusters incorporated into a-Si:H films by using a cluster-suppressed plasma CVD method² together with a newly developed downstream-cluster-collection method, which provides information on size distribution, density, shape and structure of clusters formed in silane discharges. With decreasing a volume of clusters above 1 nm in size by a factor of 1/20, the $C_{H(Si-H_2)}$ value decreases from 1 to 0.05 atomic %, while a hydrogen content associated with Si-H bonds decreases from 7 to 3 atomic %. FT-IR measurements show that many Si-H₂ bonds exist in clusters. These results suggest that the incorporation of clusters above 1nm in size into a-Si:H films is one of the most important origins of Si-H₂ bonds in the films. ¹T. Nishimoto, *et al.*, J. Non-Crys. Solids. **299** (2002) 1116. ²K. Koga, *et al.*, Appl. Phys. Lett. **77** (2000) 196.

A9.32

Formation of periodic grain boundary in an Si thin film crystallized by a linearly polarized Nd:YAG pulse laser with an ultra sonic oscillator. Hirokazu Kaki, Takehiko Ootani and Susumu Horita; Materials Science, Japan Advanced Institute of Science and Technology, Tatsunokuchi, Ishikawa, Japan.

The pulse laser annealing (PLA) method is effective to produce polycrystalline silicon (poly-Si) films with high carrier mobility on a glass substrate. In order to obtain the large grain and control the location of grain boundary, it is necessary to make the temperature distribution in the melted Si film to be suitable for grain growth. Then, we proposed the modulated PLA method to use periodic temperature distribution spontaneously induced by irradiation of a linearly polarized laser beam. This period space is formulated by Rayleigh's diffraction conditions. In fact, by using this method, we obtained the periodic grain boundaries with the space as large as the wave length of the laser beam. However, over 4 irradiation pulses are needed to control the grain boundary location stably. Reducing the number of the irradiation pulse is desired from a viewpoint of the mass-production. On the other hand, we found that the surface height or roughness of the irradiated material was a main factor for the generation of the periodic temperature distribution. Also, it was found that the periodic grain boundaries were formed in the Si film crystallized only at 1 pulse irradiation on the oxidized Si substrate with the periodic ripple surface structure. According to the above results, in order to form the periodic grain boundary stably only with 1 pulse irradiation, we propose a novel technique in which the irradiated surface is vibrated by an ultra sonic oscillator. The ultra sonic oscillator can make pseudo surface roughness tentatively. Before irradiating the laser beam to an amorphous Si (a-Si) film on a Pyrex glass substrate, the ultra sonic oscillator was set up beneath the sample and vibrated. The laser irradiation conditions were as follows: The laser was a linearly polarized Nd:YAG pulse laser (wavelength: 532 nm, repetition frequency: 10 Hz and pulse width: 6-7 ns), the a-Si film thickness was 60 nm, the laser fluence was 170 mJ/cm² and the frequency and amplitude of the ultra sonic oscillator were 36 kHz and about 2.5 μm, respectively. The substrate was not heated intentionally during the laser irradiation. By using this technique, we can obtain the periodic grain boundary structure in the Si film crystallized only at 1 pulse irradiation.

A9.33

Enhanced Surface Diffusion in Low-temperature a-Si:H Processing. George Dalakos¹, Joel Plawsky² and Peter Persans³; ¹General Electric Global Research Center, Niskayuna, New York; ²Chemical Engineering, Rensselaer Polytechnic Institute, Troy, New York; ³Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute, Troy, New York.

Glow discharge a-Si:H prepared at near room temperature typically results in inhomogeneous growth, which is undesirable for a number of thin film applications. Most obvious features of which can include columnar morphology and surface roughness. This typically results from anodic deposition, where substrates are placed on the grounded

electrode. We have discovered that placing substrates on the powered electrode (cathodic deposition) offers a much wider processing range for homogenous growth. We have also found that low-temperature homogeneous growth, resulting from anodic and cathodic deposition conditions is proportional to D/F , where D is the surface diffusion and F is the adatom flux, though anodic and cathodic deposition affect these global parameters differently. Surface processes unique to cathodic deposition can enhance adatom surface diffusion, while diffusion for anodic deposition is fixed and cannot attain homogeneous growth at high adatom fluxes. Low-temperature processing a-Si:H on the cathode associated with enhanced adatom surface diffusion allows homogeneous growth even at high deposition rates, which has benefits for a number of applications.

A9.34

An Investigation of Silicon Oxide Thin Film by Atomic Layer Deposition. Joo-Hyoen Lee¹, Chang-Hee Han², Un-Jung Kim³, Chong-Ook Park¹, Sa-Kyun Rha² and Won-Jun Lee³; ¹Materials Sciences and Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea; ²Materials Engineering, Hanbat National University, Daejeon, South Korea; ³Advanced Materials Engineering, Sejong University, Seoul, South Korea.

Silicon oxide films have been widely used as gate dielectrics in Thin Film Transistor Liquid Crystal Display(TFT-LCD) fabrication and the spacer in Dynamic Random Access Memory (DRAM) transistor processing. These are deposited by low-pressure chemical vapor deposition (LPCVD) or by plasma-enhanced chemical vapor deposition (PECVD). However, high process temperature of LPCVD and poor film quality of PECVD are being expected to limit the performance and the reliability of next-generation semiconductor and display devices. Therefore, we are concerned with Atomic Layer Deposition(ALD) method to solve these problems. In this study, silicon oxide films were deposited by self-fabricated ALD system, and effects of process parameters on the film properties were examined. Tetraethoxysilane(TEOS, Si[OC₂H₅]₄) and dichlorosilan (DCS, SiCl₂H₂) were used as the silicon source gas. Ozone(O₃) and water vapor (H₂O) were used as the oxygen source gas, and nitrogen was used as the purging gas between the pulse of silicon and oxygen sources. Using each precursor, silicon oxide thin films were deposited controlling process parameters, such as temperature, reactant exposures of the precursors, and number of cycle. Properties of the deposited films were characterized by various techniques-film thickness, refractive index, wet etch rate, composition, surface morphology etc. - and compared with other deposition methods. Based upon the leakage current data, we optimized the ALD process parameters for the silicon oxide deposition.

A9.35

Real time spectroscopic ellipsometry on high-rate deposited amorphous silicon nitride films. Peter van den Oever, Richard van de Sanden and Erwin Kessels; Department of Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

Besides the applications in microelectronics, plasma deposited silicon nitride (a-SiN_x:H) has recently been used as an encapsulation material for polyLEDs and as an antireflection coating (ARC) in solar cells. In the latter case, the a-SiN_x:H can also accomplish bulk and surface passivation. In order to make the a-SiN_x:H deposition process economically viable for these applications, a considerable increase in the deposition rate - up to several nm/s - is needed. Other important issues are: control of the optical properties of the a-SiN_x:H, control of the initial film growth in terms of film density and surface roughness, and a sufficiently low processing temperature. The expanding thermal plasma operated on Ar-N₂-H₂-SiH₄ and Ar-NH₃-SiH₄ gas mixtures has been used to deposit a-SiN_x:H at rates up to 18 nm/s. Spectroscopic ellipsometry measurements have shown that the optical properties of the films can be accurately controlled by changing the flow ratio of SiH₄/NH₃ and SiH₄/N₂ in the plasma and that films with similar optical constants can be deposited from both types of plasmas. The growth process of the films at high deposition rates has been monitored by real time spectroscopic ellipsometry (RTSE) and the time evolution of the dielectric functions, bulk thickness and surface roughness has been obtained using an optical model. In this model the dielectric response of the a-SiN_x:H is described by the Tauc-Lorentz formalism. The highly transparent and non-absorbing character of a-SiN_x:H and the very high deposition rates complicate the data analysis of the RTSE measurements considerably, especially for very thin films. To validate the real time data, a series of films with different thickness has been analyzed by the combination of static ellipsometry and atomic force microscopy (AFM). It is found that the RTSE measurements show good agreement with the static ellipsometry measurements for films thicker than 75 nm. For thinner films however the sensitivity of the RTSE measurements is a limitation for resolving both the optical properties and thickness information of the films. Good agreement between the surface roughness determined by ellipsometry and the root mean square roughness determined from

the AFM images has been obtained. Furthermore, also the influence of the substrate temperature has been investigated and the deposition rate increased when reducing the substrate temperature from 400 to 100 °C. On the basis of the refractive index and the absorption coefficient it is concluded that the film density is significantly lower at these reduced temperatures but nevertheless no indication of oxidation of the a-SiN_x:H could be observed.

A9.36

Growth study of highly crystallized undoped microcrystalline Si films. Sanjay K. Ram¹, Dinesh Deva², Satyendra Kumar¹, R.

Vanderhaghen³, B. Drevillon³ and P. Rocca i Cabarrocas³, ¹Physics, Indian Institute of Technology, Kanpur, Kanpur, Uttar Pradesh, India; ²Chemical Engineering, Indian Institute of Technology, Kanpur, Kanpur, Uttar Pradesh, India; ³Laboratoire de Physique des Interfaces et des Couches Minces (UMR 7647 du CNRS), Ecole Polytechnique, 91128 Palaiseau Cedex, France.

The development of high quality intrinsic microcrystalline silicon ($\mu\text{-Si:H}$) films at low processing temperatures is crucial to the advances in technologies for thin film transistors (TFT) based display devices and stable solar cells. In particular, one requires different deposition strategies for TFTs involving top gate or bottom gate designs. For top gate structures, the top surface of the as grown material should be highly crystallized and should have minimum surface roughness. On the other hand, in the bottom gate structures, the interface of microcrystalline silicon with the gate insulator is critical. Therefore, there is an urgent need to produce high quality $\mu\text{-Si}$ films compatible with a-Si:H deposition technologies for large area electronics applications. In this work, we have concentrated on obtaining large grain, highly crystallized $\mu\text{-Si:H}$ material having smooth crystallized surfaces using a standard rf PECVD system at low substrate temperatures. We have obtained highly crystallized dense undoped $\mu\text{-Si:H}$ films on glass substrates by standard rf glow discharge plasma CVD technique using a mixture of SiF₄, Ar and H₂ at low temperature (200 °C). Structural properties of the films were well characterized by in-situ spectroscopic ellipsometry, Raman scattering, X-ray diffraction and atomic force microscopy (AFM) techniques. This article will cover the growth studies carried out on samples having different thicknesses and different hydrogen dilution ratio ($R=\text{H}_2/\text{SiF}_4$) by AFM and in-situ spectroscopic Ellipsometry. In this study, root mean square surface roughness (σ_{rms}) of the samples obtained from the AFM images are found in agreement with the surface roughness layer thickness ($\sigma_{ellipso}$) determined by ellipsometry. Different types of variation in roughness with film thickness is observed for different values of R. Thickness dependent studies show the increase of average grain size with the increase in film thickness. From the AFM data we are able to calculate the size distribution of the grains. The distribution is found to be log normal in nature. Further, it is found that the films are rougher for higher values of R. Average grain size also increases with the increase of R. This shows that the nucleation is favorable for higher values of R. The electrical conductivity measurements carried out on these samples are in good agreement with the film microstructure.

A9.37

Growth and Properties of Insulators For Nanocrystalline Si:H TFT Devices. Vikram L. Dalal and Jarred MacDonald; Elec. and Computer Engr., Iowa State University, Ames, Iowa.

Nanocrystalline Si:H is an important new material for low temperature thin film transistors. In this paper, we investigate the growth and properties of various insulators for top-gate TFT devices in nanocrystalline Si:H. The insulators include both deposited insulators such as silicon nitride and grown insulators such as plasma oxidized silicon oxide and F-doped silicon oxide. We also investigate silicon oxy-nitride, which is grown using a combination of in-situ plasma oxidation with oxygen and fluorine with a simultaneous deposition of silicon nitride. MOS capacitor and MOSFET devices were investigated for both p and n type nanocrystalline Si. Nanocrystalline Si Films with different orientations, $\langle 111 \rangle$ and $\langle 220 \rangle$, were used for these studies. It was found that the interface state density was a strong function of how the different insulators were grown, and also a strong function of the chemistry of the insulator. The lowest defect density obtained was in the range of 2-3E10/cm².

A9.38

Low-temperature silicon films deposition by pulsed cathodic arc process for microsystem technology. Hui Xia¹, Yan Yang² and Paul L. Bergstrom²; ¹Department of Material Science and Engineering, Michigan Technological University, Houghton, Michigan; ²Department of Electrical and Computer Engineering, Michigan Technological University, Houghton, Michigan.

The deposition of silicon films ranging from tens of nanometers to tens of microns for microelectromechanical system (MEMS) devices was investigated by pulsed cathodic vacuum arc process. This method

has been employed to take the advantages of its low deposition temperature, high deposition rate, and high-energy capabilities, coupled with its relatively low operational cost. Heavily-doped p-type and n-type silicon films were deposited on silicon and glass substrates at temperatures below 400 degrees Celsius with pulsed deposition rates up to 75 nanometers per second. Pulsed arc currents up to 400 amperes in 1.5 milliseconds pulse width with 20-300 pulses per second were studied. Compared with continuous DC cathodic vacuum arc, numerous possibilities exist for pulsed arc to suit specific targeted film growth. Deposition temperature and film stress can be controlled by adjusting arc pulse frequency, pulse width and peak current. The characterization of the films was carried out by X-ray diffraction (XRD), atomic force microscopy (AFM) and scanning electron microscopy (SEM) in terms of materials morphological and structural properties. The production of MEMS device quality silicon film materials at low temperature would further enable the integration of microsystems with microelectronics.

A9.39

Influence of catalyzer area and design on the growth of intrinsic hot-wire CVD thin-film silicon for photovoltaic applications. Markus Kupich, Dmitry Grunsky, Bernd Hofferberth and Bernd Schroeder; Department of Physics / Center of Optical Technologies and Laser Controlled Processes, University of Kaiserslautern, Kaiserslautern, Germany.

Abstract: Recently, hot-wire deposited microcrystalline silicon has attracted increasing attention. The use of hot-wire deposited intrinsic $\mu\text{-Si:H}$ for high efficiency solar cells was demonstrated by Klein et al. [1]. Integration of high-quality intrinsic $\mu\text{-Si:H}$ into all-hot-wire nip solar cells, prepared close to the transition to amorphous growth using a tantalum catalyzer, resulted in initial and stable efficiencies of 5.4 % on simple stainless steel substrates [2]. However, the deposition rates for such material remained low, at values around 1 Å/s. In the present study we report on the dependence of deposition rate and material quality on the design and area of the tantalum catalyzer. It was found that different filament geometries require considerable changes in certain the deposition conditions to optimize material properties. So, for example, enlarging the catalyzer surface made it necessary to decrease the hydrogen dilution of the process gas, in order to obtain the desired microcrystalline material close to the phase transition. These changes might be understood in terms of alterations of the gas decomposition relations on the catalyzer surface. For these modified conditions, deposition rates in the range of 2.5-10 Å/s could be achieved for $\mu\text{-Si:H}$ due to the fact that a higher silane fraction of the process gas could be used. For different wire geometries, the optimized intrinsic layers were incorporated into solar cells. Preliminary results show that using a catalyzer with modified geometry and enlarged surface area, conversion efficiencies $\eta > 4\%$ could be achieved at a rate of 3 Å/s. References: [1] Klein, S.; Finger, F.; Carius, R.; Dylla, T.; Rech, B.; Grimm, M.; Houben, L.; Stutzmann, M.; Thin Solid Films 430 (2003), 202-207. [2] Kupich, M., Grunsky, D., Kumar, P., Schröder, B.; Solar Energy Materials and Solar Cells, in press.

A9.40

Low defectuous thin films produced at low temperatures: a tradeoff between the RF power and the hydrogen dilution. A. Macarico, D. Brida, P. Sousa, P. Louro, M. Fernandes, Manuela Vieira and R. Schwarz; DEETC, ISEL, Lisbon, Portugal.

A PE-CVD deposition system where the rf plasma is induced and confined in a region far away from the growing surface is developed. In this system the induced species, main reactions and their transport towards the growing surface are controlled by an electric field that confines the plasma at a plane, outside the deposition region, that includes the rf electrodes and the ground. During the deposition process the plasma is used to create a strong beam of excited species that react mutually at a rate that depends on the electric field profile near the electrodes. Plasma diagnostic and deposition mechanism analysis will be presented. Results obtained show that in the plasma region, the main reaction is the direct fragmentation of SiH₄ by electron impact whilst near the growing surface the substrate temperature controls the species reactions. Hydrogenated amorphous silicon films (a-Si:H) were deposited at low temperatures. Structural and optoelectronic characterization of the films were performed by conventional IR and VIS/NIR spectroscopy, CPM measurements and conductivity dependence on the temperature. To support the deposition mechanism proposed, the role of the deposition condition on the structural (hydrogen content, bond configuration, microstructure), electrical (conductivity, activation energy) and optical (optical gap, absorption coefficient, Urbach energy, defect density) properties are presented. The films properties are studied as a function of the r.f. power density (dp), temperature (125°C -300°C) and hydrogen dilution on the gas mixture. First results show that a tradeoff between the hydrogen dilution and the temperature is needed to deposit thin films with low density of defects. At high dp and low hydrogen dilution the deposition rate is high and, even at low

temperatures, the films present good electro-optical properties. No powder formation was detected although some oxygen contamination was still observed. Preliminary results show that the plasma confinement outside the growing surface gives to this PE-CVD system the ability of producing good quality films at low temperatures, with high deposition rates.

A9.41

Large-Area Hydrogenated Amorphous and Microcrystalline Silicon Double-Junction Solar Cells. Baojie Yan, Guozhen Yue, Arindam Banerjee, Jeffrey Yang and Subhendu Guha; United Solar Ovonic Corporation, Troy, Michigan.

Hydrogenated microcrystalline silicon ($\mu\text{-Si:H}$) as a long wavelength absorber layer in the bottom cell of hydrogenated amorphous silicon (a-Si:H) based multi-junction solar cells has attracted significant attention because of its higher current capability and better stability against light soaking. In our previous report [1], we have shown an initial active-area efficiency of 13% for an a-Si:H/ $\mu\text{-Si:H}$ double-junction cell. In this paper, we will present our recent progress on the development of large-area $\mu\text{-Si:H}$ single-junction and a-Si:H/ $\mu\text{-Si:H}$ double-junction solar cells. We first optimize $\mu\text{-Si:H}$ films using the conventional RF glow discharge technique on an area of $35 \times 33 \text{ cm}^2$ at a relatively low rate 1 \AA/s . The thickness uniformity is well within $\pm 10\%$, which is similar to the uniformity of the a-Si:H deposition. The reproducibility is very good. Many small-area cells were obtained by depositing Indium-Tin-Oxide dots with an active-area of 0.25 cm^2 on the p layer of one large-area a-Si:H/ $\mu\text{-Si:H}$ double-junction cell. The small-area cells have an efficiency distribution in the range from 10% to 12% with a peak position at 11.5%. Preliminary results from large-area a-Si:H/ $\mu\text{-Si:H}$ double-junction structures show initial aperture-area efficiencies of 11.8% and 11.3% for 45 cm^2 and 461 cm^2 size un-encapsulated solar cells, respectively. The 11.3% cell became 10.6% after encapsulation. Currently, we are working on increasing the deposition rate and reducing the $\mu\text{-Si:H}$ layer deposition time. Aspects related to module fabrication and light-soaking stability will be discussed. [1] B. Yan, G. Yue, J. Yang, and S. Guha, Mat. Res. Symp. Proc. 762, A4.1 (2003).

A9.42

Measurement of the Potential Distribution in Silicon-Based Thin Film Solar Cells by Scanning Kelvin Probe Microscopy. Chunsheng Jiang¹, Helio Moutinho¹, Qi Wang¹, Mowafak Al-Jassim¹, Baojie Yan², Jeffrey Yang² and Subhendu Guha²; ¹National Renewable Energy Laboratory, Golden, Colorado; ²United Solar Ovonic Corporation, Troy, Michigan.

Scanning Kelvin probe microscopy technique is a useful tool to directly measure the spatial distribution of electrical potential in a solar cell. We have measured the potential distribution on cross sections of the solar cells of hydrogenated amorphous silicon (a-Si:H), hydrogenated amorphous silicon germanium (a-SiGe:H) alloy with flat and profiled band gaps, and hydrogenated microcrystalline silicon (mc-Si:H). By measuring the change of the potential distribution with an external bias voltage applied to the device, we are able to exclude the effect of surface Fermi level pinning and deduced the distribution of electrical potential in the bulk, which is related to the photovoltaic performance of the device. The electric field distribution in the cells was further deduced by taking the first derivative of the potential distributions. We found that the electric field is not uniformly distributed in the devices for all the solar cells studied above, showing stronger fields at the n/i and i/p interfaces than in the middle of the i-layer. The region close to the i/p layer generally has a higher electric field than the region near the n/i interface. This phenomenon is more obvious in a-SiGe:H cells than in a-Si:H cells. A bandgap profiling with an increase of germanium content from the n to p layers enhances the electric field in the region close to the i/p interface while reducing its value in the region near the n/i interface. The enhanced field in the i/p interface region helps the collection of photo-generated holes and improves the fill factor. Detailed results on the correlation of cell performance and field distribution will be presented.

A9.43

Microcrystalline Silicon Solar Cells Deposited Using Modified Very-high-frequency Glow Discharge and Its Application in Multi-junction Structures. Guozhen Yue, Baojie Yan, Jessica M Owens, Jeffrey Yang and Subhendu Guha; United Solar Ovonic Corporation, Troy, Michigan.

Hydrogenated microcrystalline silicon ($\mu\text{-Si:H}$) has attracted remarkable attention due to its low light induced degradation and potential low cost. However, many manufacturing related issues need to be addressed. The relatively thick intrinsic $\mu\text{-Si:H}$ layer requires a very high deposition rate to meet the throughput requirement. We have used the modified very-high-frequency (MVHF) glow discharge technique to deposit $\mu\text{-Si:H}$ solar cells at high rates and achieved respectable results [1]. In this paper, we will report progress made in

the optimization of $\mu\text{-Si:H}$ single-junction and multi-junction solar cells. An initial active-area efficiency of 12.5% has been achieved using an a-Si:H/ $\mu\text{-Si:H}$ double-junction structure. With the constraint of limiting the bottom cell deposition time to less than 40 minutes, we have achieved an initial active-area efficiency of 11.9%. Recently, we started to make a-Si:H/a-SiGe:H/ $\mu\text{-Si:H}$ triple-junction cells. This structure should have a better stability since the top cell is much thinner than that in the a-Si:H/ $\mu\text{-Si:H}$ double-junction structure. Preliminary work resulted in an initial active-area efficiency of 11.6% for the triple junction structure. Stability of single and multi-junction solar cells will be discussed. [1] B. Yan, G. Yue, J. Yang, and S. Guha, Mat. Res. Symp. Proc. 762, A4.1 (2003).

A9.44

Development of transparent conductive oxide materials for improved back reflector performance for amorphous silicon based solar cells. Scott J Jones, David Tsu, Tongyu Liu, Jeff Steele, Rey Capangpangan and Masat Izu; Energy Conversion Devices, Inc, Troy, Michigan.

The use of Al/ZnO back reflectors in the commercial manufacturing of amorphous Si-based modules has limited the current collection and overall performance of these products. Use of the Ag/ZnO back reflectors leads to improved initial module performance in R&D studies but electromigration of Ag causes module failures with long term light exposure and thus can not be used for commercial products. In the studies whose results are reported here, a new back reflector comprised of an Al/(multi-layered stack)/ZnO structure is being developed to replace the Al/ZnO and boost module efficiencies with improved back reflector performance. The results from studies of different transparent conductive oxides (TCOs) which comprise the multi-layered stack are reported with emphasis on ZnO alloys. The TCOs were prepared by dc sputtering techniques under a variety of deposition conditions to achieve the desired indices of refraction for optical enhancement from the multi-layer stack while maintaining high conductivity. Both material properties for the TCO layers and the cell performance with this new back reflector structure will be reported.

A9.45

Dominant effect of p/i interface on dark J-V characteristics in p-i-n nano-crystalline Si solar cells. Ujjwal K Das¹, Andreas Bozza², Scott W Morrison¹ and Arun Madan¹; ¹MVSystems Inc, Golden, Colorado; ²Institut fuer Physikalishe Elektronik, Universitaet Stuttgart, Stuttgart, Germany.

Nanocrystalline silicon (nc-Si) based p-i-n (nc-Si:H p/nc-Si:H i/a-Si:H n) solar cells were fabricated using modified pulsed plasma enhanced chemical vapor deposition technique. The devices were deposited onto various substrates, e.g., Asahi 'U'-type SnO₂ (textured), AIST supplied Ga doped ZnO (textured) and MVS developed Al doped ZnO (textured). Dark J-V characteristics of nc-Si p-i-n solar cells were found to depend strongly on the substrate materials and are studied at different i-layer thicknesses and varying the p/i interface structures. In our earlier work, we have found that the diode quality factor, n (estimated from $J = J_0 [\exp(eV/nkT) - 1]$ decreases with increase in i-layer thickness ($n=1.68$ for $0.9 \mu\text{m}$ to $n=1.45$ for $2.1 \mu\text{m}$) for the devices deposited on Ashai TCO, suggesting an inferior i-layer quality for thinner device presumably due to grain collision [1]. On the contrary, the opposite variation of n with device (grown on textured ZnO) thickness was reported by Klein et al. [2]. In this work, we report an almost constant diode quality factor ($n = 1.2 - 1.3$) up to the thickness of $3.8 \mu\text{m}$ for the devices grown on AIST/MVS textured ZnO substrates. The rather insensitive variation of n with i-layer thickness suggests that the dark J-V characteristics are not dominated by bulk recombination for the devices grown on 'suitably textured substrate', which prevents the grain collision in the i-layer. In contrast to that, a significant change of n ($1.8 - 1.3$) was found while changing the p/i interface structure by different surface treatment procedures during PECVD deposition. The result suggests that the p/i interface primarily dictates the device performance. The p/i interface structure in nc-Si p-i-n device plays the crucial role either by changing the p/i interface defects or the film structure at p/i interface determines the quality of subsequently grown nc-i layer and hence the whole device performance. [1] U. Das, S. Morrison, E. Centurioni, and A. Madan, IEE Proc. Circuits Devices Syst., Vol. 150, p. 282-286 (2003). [2] S. Klein, F. Finger, R. Carius, B. Rech, L. Houben, M. Luysberg, M. Stutzmann, Mat. Res. Soc. Symp. Proc. Vol. 715 p. A26.2.1 (2002).

A9.46

Evaluation of Ar Diluted Silane PECVD for Thin Film Si:H Based Solar Cells. J. A. Anna Selvan, Yuan-Min Li, Liwei Li and Alan E. Delahoy; Energy Photovoltaics, Inc., Princeton, New Jersey.

Dilution by Ar of silane plasma has been reported to increase the stability of a-Si:H films. A critical question is whether Ar diluted i-layers offer higher stabilized solar cell efficiencies than the hydrogen dilution method. We have fabricated a-Si:H solar cells with PECVD

i-layers by Ar dilution of silane. Ar dilution ratio (ADR), RF power, pressure, and i-layer thickness were varied. At low ADR (<20), such solar cells show comparable initial efficiencies and stability as those devices having H₂-diluted i-layers of similar thickness. For cells made with ADR > 20, the initial efficiency decreases dramatically with further increase in Ar dilution, and light soaking caused mild degradations or increases in efficiencies. The stabilized efficiencies of cells made with high ADR are inferior to the cells with low ADR or cells prepared by H₂ dilution. Further, V_{oc} of the solar cells made with high ADR (> 50) decreases substantially in ambient, indicating a porous microstructure susceptible to oxidation. While thermal annealing improves the V_{oc}, a complete recovery of V_{oc} is obtained by accelerated light soaking. The combination of high power and high Ar dilution can lead to nanocrystalline Si (nc-Si) growth, although it has been found that nucleation is much more difficult by Ar dilution compared to hydrogen dilution. We have succeeded in fabricating nc-Si solar cells using the Ar dilution approach. The double dilution by Ar and hydrogen leads to nc-Si:H i-layer with enhanced long wavelength spectral response compared to the devices incorporating i-layers grown by H₂ dilution only. The nc-Si:H solar cells with Ar H₂ diluted i-layers exhibit no light-induced degradation. Using energetic Ar-rich plasma, in a process much simpler than the traditional nc-Si technique, doped a-Si thin layers can be prepared to form excellent tunnel junctions for multi-junction solar cells. We demonstrate such a novel, non-contaminating tunnel junction for a-Si/a-Si and a-Si/nc-Si tandem solar cells entirely fabricated in a single-chamber, all-stationary RF-PECVD system.

A9.47

Nanocrystalline Germanium p-i-n Structures.

William B. Jordan and **Sigurd Wagner**; Electrical Engineering, Princeton University, Princeton, New Jersey.

Nanocrystalline germanium (nc-Ge:H) has attracted interest for device applications due to its low optical gap and high carrier mobilities, especially holes. Previous work has quantified and optimized nc-Ge:H materials properties, for both intrinsic material, and material doped with phosphorus and boron. This paper reports on the construction and measurement of p-i-n structures fabricated entirely from nc-Ge:H. We grew the nc-Ge:H p-i-n structures on tin oxide-coated glass substrates by RF (13.56 MHz) plasma enabled chemical vapor deposition (PECVD) using GeH₄ and H₂ source gases, with PH₃ and B₂H₆ as dopant gases. The GeH₄ and H₂ flows for all layers were 0.5 and 210 sccm, respectively, for a hydrogen dilution of 420. A thin amorphous germanium (a-Ge:H) buffer layer, achieved by reducing the hydrogen dilution, was added to both the i-p and i-n interfaces. The p-layer was deposited against the SnO₂ in a superstrate configuration. Circular, 3 mm² chromium contacts were thermally evaporated on top of the n-layer and subsequently used as etch masks during plasma etch down to the SnO₂ coating. The entire sample was encapsulated in silicon nitride (SiN_x), to protect against edge currents through passivation of the sidewalls. Contact holes were etched through the SiN_x to the Cr and SnO₂ contacts, and larger Al contact pads were thermally evaporated to contact the device without the possibility of punch-through. The deposition temperature of the p-layer was approximately 200°C, while the deposition temperature of the subsequent intrinsic layer was varied between approximately 120°C and 200°C, as previous work has shown the light response of intrinsic films to vary with deposition temperature. The deposition temperature of the n-layer was identical to that of the i-layer for each structure. The thickness of the intrinsic layer was also varied between about 1500 Å and 3000 Å, while the thickness of the doped contact layers was held constant at approximately 400 Å. The I-V curves of the p-i-n structures were measured in both the dark and light at room temperature and at 77 K. Light measurements were done under a simulated AM1.5 spectrum, and with the AM1.5 spectrum showing through a-Si and c-Si filters. The p-i-n structures show rectification in the dark and in the light. A modest light response is seen at room temperature. This work is supported by EPA and NSF.

A9.48

Deposition of Optimal a-Si:H and a-SiGe:H by Hot Wire CVD Using the Same Filament Temperature and Substrate Temperature. **Archie H Mahan**¹, **Y. Xu**¹, **L. M. Gedvilas**¹ and **B. Yan**²; ¹NREL, Golden, Colorado; ²USSC, Troy, Michigan.

The incorporation of high Ge content a-SiGe:H into a low bandgap solar cell device structure commonly involves the use of bandgap (Ge) profiling. In such a device, the lowest bandgap (highest Ge content) material is placed somewhere near the i/p interface in order to have an improved collection for holes and avoid an abrupt bandgap transition at the n/i and p/i interfaces. Since in this approach the material needs to be profiled over a wide range of Ge content, the i-layer alloy with varied compositions, including that of a-Si:H (no Ge), should have optimal quality and should be deposited under somewhat similar deposition conditions. Such conditions include the same substrate temperature (Ts), filament temperature (Tf), and

filament geometry. In a previous work of using the hot wire (HWCVD) technique, low bandgap a-SiGe:H films with superior quality were deposited at low Ts (150 C) using a thin (0.38 mm dia.) W filament operating at 1800 C [1]. However, lower Ge content (higher bandgap) films deposited under the same (Tf, Ts) condition were of decidedly inferior quality to those deposited using higher temperatures [2]. Although a single junction n-i-p solar cell with an efficiency 6 percent was fabricated using these materials, it is clear that our best materials were not used in this device. In addition, filament alloying at this low Tf severely limits the reproducibility and lifetime of the W filament [3]. This work explores the possibility of depositing optimum quality low bandgap a-SiGe:H and optimum quality a-Si:H at low Ts by using a tantalum (Ta) filament operating at low Tf. We gauge the material quality of the present films by comparing infrared, optical absorption (film bandgap), SIMS, and conductivity results to those presented earlier [1], and fabricate single junction as well as tandem n-i-p solar cell devices using these i-layers. [1]. **Y. Xu, B.P. Nelson, D.L. Williamson, L.M. Gedvilas, and R.C. Reedy**, MRS Symp. Proc. 762 (2003) A10.2. [2]. **B.P. Nelson, Y. Xu, D.L. Williamson, B. von Roedern, A. Mason, S. Heck, A.H. Mahan, S.E. Schmitt, A.C. Gallagher, J. Webb, and R.C. Reedy**, MRS Symp. Proc. 507 (1998) 447. [3]. **A.H. Mahan, A. Mason, B.P. Nelson, and A.C. Gallagher**, MRS Symp. Proc. 609 (2000) A6.6.

A9.49

Passivation schemes for amorphous silicon (a-Si:H)/crystalline silicon (c-Si) heterojunctions for photovoltaic applications. **shahrukh akbar khan** and **Wayne Anderson**; Electrical Engineering, State University of New York at Buffalo, Amherst, New York.

Hydrogenated amorphous silicon (a-Si:H)/crystalline silicon (c-Si) and microcrystalline silicon (mc-Si)/crystalline silicon (c-Si) heterojunctions have gained much attention for their unique photovoltaic conversion capabilities. However, the usual multi-junction approach employing a-Si:H/c-Si structures sometimes compromises the commercial viability of such devices. Our efforts have been concentrated on single junction a-Si:H/c-Si and mc-Si/c-Si devices with the "low-cost, light-weight" theme in mind. We've employed ECR (Electron cyclotron resonance)-CVD for enhanced decomposition of silane to grow undoped a-Si:H and mc-Si on crystalline substrates to form a heterojunction. Electrical characterization reveal good photoconductive quality of the resulting films. Despite the highly photoconductive nature of the films, it is the hetero-interface which greatly influences the photocarrier collection of these devices. Thus, optimization of the interface is critical for desirable photovoltaic properties. With this end, we've investigated several passivation schemes during deposition. Among the techniques tried are plasma treatment of the interface before film deposition as well as post deposition plasma treatment of the films, sequential deposition of films followed by a hydrogen plasma treatment in an inert gas ambience, photon-assisted deposition and incorporation of excess atomic hydrogen during deposition. The paper discusses the influence of each passivation schemes on the photovoltaic properties of the completed structures. Finally, the insertion of a thin buffer layer at the interface between a-Si:H or mc-Si and c-Si is addressed.

A9.50

Quasi-Amorphous Silicon Thin Films and Solar Cells.

Abdul Rafik Middya, Physics, Syracuse University, Syracuse, New York.

In this paper, we report a new class of amorphous silicon, quasi-amorphous silicon (qm-Si:H) films, which offers significantly improved stability and higher optical absorption compared to standard amorphous silicon (a-Si:H). The qm-Si:H films and solar cells have been developed under helium diluted silane plasma and high chamber pressure (1 - 4 Torr) regime of plasma enhanced chemical vapor deposition. These films have very high mobility-lifetime product at annealed state (10⁻⁴ cm²/V) as well as at light-soaked state (10⁻⁶ cm²/V) (G = 10¹⁸ cm⁻³s⁻¹) and kinetics of light-induced degradation is very fast (saturation occurs within 20 to 30 hours under 100 mw/cm² white light at 50°C)¹. The reproducibility of qm-Si:H type of films has been confirmed by two other laboratories. The improved stability of qm-Si:H films is most likely linked to its more ordered network; complimentary structural characterizations of qm-Si:H films by FTIR, XRD, SAXS, UV-VIS ellipsometry, mechanical density measurement reveals, these films have compact nanostructure (density deficit from c-Si 4%), very low nanovoid density (below detection limit), low H-content (C_H < 8 at%) and narrow (111) peak in XRD and no nanocrystalline Si inclusion has been observed. UV-VIS ellipsometry reveals Si-Si network structure in qm-Si:H has a distinct feature, which has not been observed before for a-Si:H. In BP Solar, hydrogenated quasi-amorphous silicon solar cells have been fabricated by DC PECVD, where intrinsic layers were prepared under high helium and hydrogen diluted silane plasma and high chamber pressure (2 - 4 Torr) and p & n layers were a-SiC:H and a-Si:H respectively. Astonishing properties has been observed in the optical absorption

and carrier collections of these cells, high short-circuit current, J_{sc} 12.5 - 13.5 mA/cm² and open-circuit voltage, V_{oc} 0.90 - 0.91 Volts have been obtained for 150 - 170 nm thick i-layer, compared to 270 - 280 nm absorber layer for best single junction a-Si:H solar cells of BP Solar for the same range of values of J_{sc} and V_{oc} . This apparent contradictory results can only be reconciled, if the optical absorption of the i-layer is enhanced, however, the bandgap of the initial few hundred Å of the absorber layer close to the p/i interface has to be same as a-Si:H otherwise V_{oc} can not be similar to that of a-Si:H solar cells. Such enhancement in optical absorption of Si:H materials is possible, if Si-Si network structure is different than that of a-Si:H, which will be discussed. The enhancement of optical absorption (α) of qm-Si:H absorber layers in solar cell configuration by infrared photocurrent (IRPC) measurement will be reported. The nanostructure of qm-Si:H films and its correlation with optical properties and metastability will be presented. 1. A. R. Middy, S. Hamma, S. Hazra, S. Ray and C. Longeaud, Mat. Res. Soc. Proc. Vol. 664 (2001) p. A9.5.1.

A9.51

Devices Fabrication with Narrow Bandgap a-SiGe:H Alloys Deposited by Hot Wire CVD. Yueqin Xu¹, Baojie Yan², Brent P Nelson¹, Qi Wang¹, Eugene Iwaniczko¹ and R. C. Reedy¹; ¹National Renewable Energy Laboratory, Golden, Colorado; ²United Solar Ovonic Corporation, Troy, Michigan.

ABSTRACT Last year, we reported the optimization of narrow bandgap hydrogenated amorphous silicon germanium alloy (a-SiGe:H) alloys by adjusting the filament temperature and substrate temperature using the HWCVD[1,2]. By lowering tungsten (W) filament temperature from more than 2000°C to less than 1850°C, and at the same time, lowering substrate temperature from more than 350°C to 250°C, we obtained high quality a-SiGe alloys with a narrow Tauc band gap of 1.25 - 1.30 eV. These materials have a Ge content in the range of 60 to 65 percent, with activation energy of 0.64 eV and Urbach energy of 53 meV. We found that about 40 percent of the total hydrogen content (10 at. percent) is in Ge-H bonding configuration and no observable silicon dihydride bonding, the films are very compact with low heterogeneity. In this paper, we will report the results of incorporation of these materials into single-junction n-i-p solar cells to verify the high material quality. In the previous reports [1,2], a single-junction n-i-p device, with a 120nm thick narrow gap a-SiGe:H alloy intrinsic layer, produced a short circuit current density of up to 20 mA/cm² with a poor fill factor (FF) of 38 percent due to an abrupt bandgap transition between doped layers and the a-SiGe:H alloy intrinsic layer at the n/i and i/p interfaces. To avoid this problem and improve the collection for holes, we have used the bandgap profiling in the narrow band gap a-SiGe:H i-layer and improved both the open circuit voltage and FF significantly without any loss in short-circuit density. As a result, we have improved the solar cell efficiency from 3.55 percent to 5.85 percent. This improved a-SiGe:H cell has a quantum efficiency of 0.48 at 800 nm and 0.15 at 900 nm. We will present details of the bandgap profiling and the effect on device performance. 1. Yueqin Xu, Brent P. Nelson, Lynn M. Gedvilas, and Robert C. Reedy, Thin Solid Films, Vol. 430 (2003) 197-201. 2. Yueqin Xu, Brent P. Nelson, D.L. Williamson, Lynn M. Gedvilas, and Robert C. Reedy, Mat. Res. Soc. Symp. Proc. Vol. 762 (2003), A10.2.

A9.52

Microstructure and Thickness Optimization of a/ μ c-Si:H Tandem Solar Cells. Andrzej Kolodziej and Pawel Krewniak; Department of Electronics, AGH University of Science and Technology, Krakow, Poland.

In this paper the latest experiments on the field of amorphous and microcrystalline silicon thin film tandem solar cell constructions are presented. The deposition of microcrystalline film structure was performed at high pressure and high plasma power resulting in high (up to 5Å/s) deposition rates on ZnO covered glass substrates. The structure of p-i-n-p-i-n Si:H was studied by Cross Sectional Transmission Electron Microscopy and Grazing Incidence X-Ray Analyzing. It was carried out analyzes of FF, V_{oc} and I_{sc} of the structures with respect to the low temperature crystallization. We illustrate the relation of microstructure and efficiency of the tandem solar cells. From other side proper choice of layer thicknesses and current matching between the series connected top and bottom cell is required to obtain optimum energy conversion efficiency. The equivalent model of a-Si:H/ μ c-Si:H tandem solar cell is presented.

A9.53

Correlation of Material Microstructure and Device Performance in Nanocrystalline Silicon Solar Cells. Anthony Canning¹, J R Weinberg-Wolf¹, E C T Harley¹, Keda Wang¹, Daxing Han¹, Baojie Yan², Guozhen Yue², Jeffrey Yang² and Subhendu Guha²; ¹Physics & Astronomy, UNC-Chapel Hill, Chapel Hill, North Carolina; ²United Solar Ovonic Corp, Troy.

We use Raman and photoluminescence (PL) spectroscopy to study the relationship between the material properties and device performance of hydrogenated nanocrystalline silicon (nc-Si:H) solar cells made using conventional RF, modified VHF and microwave glow discharge. Raman measurements were made directly on solar cells using 514.5-nm line from an argon-ion laser under ambient conditions. Crystalline volume fraction (fc) in the region near the i/p interface was deduced from the Raman transverse optical (TO) mode. PL spectra were measured at various temperature using 632.8 and 442 nm wavelengths as excitation sources to probe the electronic properties in the bulk of the intrinsic nc-Si:H layer and the top layer near the i/p interface, respectively. In general, the experimental results show that a high fc in the intrinsic nc-Si:H leads to a high short circuit current density (J_{sc}) and low open circuit voltage (V_{oc}). Most of nc-Si:H cells show two PL peaks at 80 K. One peak at 1.36 eV is from the band tail recombination in the amorphous region and another one 0.87 eV from the band tail recombination in the crystalline region. A possible origin for the band tails in the crystalline region is grain boundary states. Solar cells made under similar conditions show an increase of low energy PL peak with increase of fc. However, for some cells made under different conditions such as at very high deposition rate, the low energy PL peak does not appear. This could be due to the non-radiative recombination from defect states. For most nc-Si:H cells the intensity ratio of the low to high energy PL peaks is higher for 442 nm excitation than that 632.8 nm excitation, indicating the increase of crystallinity along the growth-direction. However, for the two cells with hydrogen dilution profiling by reducing hydrogen dilution with time, the ratio decreases from the bulk to the i/p interface. The improved cell performance with hydrogen profiling suggests that a reduced crystallinity in the i/p interface layer could be beneficial for nc-Si:H solar cell performance.

A9.54

Hydrogen Injection in ETP Plasma Jet for Fast-Deposition of High-Quality a-Si:H. Amhn Petit^{1,2}, M.C.M. van de Sanden² and Racmm van Swaaij¹; ¹DIMES-ECTM, Delft University of Technology, Delft, Netherlands; ²Department of Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

We have used a cascaded-arc expanding thermal plasma (ETP) to produce thin film solar-cell grade amorphous silicon at high growth rates (> 2 nm/s). Here, we present a study of the effect on material quality of hydrogen injection in the nozzle, i.e. at the exit of the arc where the plasma expands into the reactor chamber. The advantage of using extra H₂ in the nozzle is that the plasma chemistry and pressure in the arc remain unchanged whilst higher growth rates and a material with a remarkably low defect density are obtained. We found that the addition of H₂ in the plasma jet reduces the Urbach energy and the sub band gap absorption ($\sim 2 \text{ cm}^{-1}$ at 1.2 eV), as well as the microstructure of the material. It also improves the photoconductivity of the material, especially when grown at high temperatures ($\geq 300^\circ\text{C}$). In our opinion the addition of H₂ in the nozzle further quenches the remaining Ar-ion density coming from the arc, which consequently diminishes the cluster formation and therefore reduces the creation of defects in the material. In addition, the H₂ injection also increases the atomic hydrogen density in the reactor. The increased abundance of atomic hydrogen probably improves the material quality. Finally, we present the results of solar cells prepared with this material. It appears that the quantum efficiency in the blue part of the spectrum at zero bias voltage is higher for the cell deposited with H₂ injected in the nozzle. We think that, with H₂ injected in the nozzle, the initial growth of the ETP i-layer is improved, leading to a better p-i interface and increasing the performance of the solar cell.

SESSION A10: Silicon Nanoparticles and Devices

Chairs: Reinhard Carius and Robert Collins

Friday Morning, April 16, 2004

Room 2001 (Moscone West)

8:30 AM *A10.1

Towards an erbium-doped silicon laser. Albert Polman, FOM-Institute AMOLF, Amsterdam, Netherlands.

Erbium is a rare-earth element that, when embedded in a solid, shows well-defined narrow-band optical emission at 1.5 μm , an important telecommunication wavelength. When embedded in a semiconductor, Er can be excited through an impurity-Auger process, in which optically or electrically induced carriers recombine at an Er-related trap state, followed by excitation of Er³⁺. In the last decade, an enormous effort has been undertaken to understand, improve, and engineer the optical properties of erbium-doped silicon. In this talk we review the fundamental limiting factors determining the light emission efficiency of Er in Si and describe several critical breakthroughs that have recently been made. In single-crystalline Si, efficient emission from Er is limited by its low solubility and by temperature quenching effects due to phonon-assisted back transfer and Auger quenching to

free carriers. These effects, in combination with the high free-carrier absorption in Si waveguides has so far made impossible the fabrication of an Er-doped crystalline Si waveguide laser. Amorphous Si can incorporate much higher concentrations of Er, and its continuous random network structure enables the structural flexibility to engineer the local environment of the Er³⁺ ions by coordination with oxygen. The Er-O₆ moieties in amorphous Si show small luminescence quenching and indeed, Er-related room-temperature photoluminescence and electroluminescence have been observed from a-Si:H:Er,O. A new material that has recently attracted considerable attention is silicon-rich SiO₂. Upon thermal annealing, this material transforms into a quantum dot solid, with silicon nanocrystals randomly dispersed in a SiO₂ matrix. This material, which can be made by CVD, sputtering, or ion implantation, is an interesting host for the fabrication of a Si-based Er laser. The SiO₂ matrix provides the proper coordination for Er, enabling a high luminescence quantum efficiency and no temperature quenching. The Si quantum dots serve as sensitizers for Er: upon their optical excitation, they rapidly and efficiently transfer their exciton recombination energy to Er. As the nanocrystal absorption cross section is four orders of magnitude higher than Er, this leads to a large improvement in the Er excitation efficiency. The presence of the Si nanocrystals also causes an anomalous increase in the intrinsic intra-4f Er emission and absorption cross sections, which will enhance the achievable gain per unit length. We will discuss the prospects for a Si nanocrystal sensitized Er-doped Si nanocrystal waveguide laser, based on both linear waveguide or microresonators designs.

9:00 AM A10.2

Fabrication and Characterization of a Germanium Quantum-dot Transistor Formed by Selective Oxidation of SiGe/Si-on-Insulator. Pei-Wen Li and Wei-ming Liao; Electrical Engineering, National Central University, ChungLi, Taiwan.

We explored a simple method for forming nanoscale germanium (Ge) quantum-dots (QDs) and demonstrated clear Coulomb-blockade oscillations as well as Coulomb staircase effects at room-temperature in the Ge single-electron transistors (SETs). The formation of Ge QDs is realized by selective oxidation of Si/Si_{1-x}Ge_x/Si (x=0.05-0.15) nanowires on a SOI substrate. Thermal oxidation was performed to oxidize the Si/SiGe/Si multilayer, which would induce Ge atom's segregation out of the growing oxide and hence, the formation of Ge nanocrystals by the subsequent Ge agglomeration. An agglomeration involves movements of atoms that are driven by a driving force to achieve lower levels of energy in an entire system in which the atoms are located. Factors that determine such atomic movements include a magnitude of the driving force in thermodynamic point of view and a mobility of the atoms in kinetic point of view. TEM micrographs clearly showed that Ge nanocrystals were embedded between the growing oxide and the buried oxide and the size and spatial density of the Ge QDs are determined by conditions of thermal oxidation process and Ge content in SiGe alloys. An average Ge-dot size of 5.1 nm with standard deviation of 1.79 nm and a comparatively uniform spatial distribution (density of 7.9E11 cm⁻²) could be obtained by selective oxidation of Si_{0.85}Ge_{0.15}/SOI structure. After the formation of Ge QDs by selective oxidation of SiGe/Si nanowires, a polysilicon gate was deposited and the rest of the device process is similar to a standard MOSFET fabrication. A large Coulomb-blockade oscillation with the peak-to-valley current ratio (PVCr) of 1.92 is observed in the Id-Vg characteristics at room temperature and the constant gate voltage separations ($\Delta V_g = 0.5V$) between these current peaks strongly suggests that these major peaks come from the same dot. A large Coulomb gap of around 130 mV is observed in the Id-Vd characteristics, which corresponds to the sum of drain-dot (Cd) and source-dot (Cs) capacitances of 1.23 aF. Clear Coulomb staircases and negative differential conductances (NDCs) are observed even at room temperature, which originates from the discrete nature of the dot states due to quantum mechanical effects. The electronic structure in the Ge QDs is extracted from a contour plot of the differential conductance as a function of Vg and Vd. Large single-electron addition energy of 130 meV, Coulomb charging energy of 96 meV, and quantized level spacing of 34 meV were estimated. Assuming a spherical Ge dot embedded in a silicon-oxide matrix, the dot diameter calculated to be about 7 nm, which agrees well with the TEM observation. In conclusion, we have demonstrated a simple and CMOS-compatible method for fabricating Ge QD and Ge SET. Using this technique, the total capacitance of a SET is about 1.67 aF, which enables Coulomb-blockade oscillations, Coulomb staircase, and negative differential conductances (NDC's) observable even at room temperature.

9:15 AM A10.3

Spectroscopic Characterization of a Single Type of ER-Related Optical Center Preferentially Formed in Selectively Doped Silicon. Nguyen Vinh¹, Boris Andreev² and Tom Gregorkiewicz¹; ¹Van der Waals-Zeeman Institute, University of Amsterdam, Amsterdam, Netherlands; ²Institute for Physics of

Microstructures, Nizhny Novgorod, Russian Federation.

Emission from the Er-1 center dominates photoluminescence (PL) spectrum of selectively Er doped Si/Si:Er multilayer structures grown by the MBE sublimation method [1]. Recently, the symmetry of this optically active Er related center, labeled Er-1, has been investigated in a magneto-optical experiment [2] and established to be orthorhombic I, with a slight distortion from cubic. Further investigations prove that all the major spectral features appearing in luminescence from the nanolayers originate from the Er-1 center. In that way the preferential formation of a single type of an Er-related optically active center in crystalline Si is realized. This represents a major step toward development of photonic devices based on Si:Er. Low-temperature high-resolution time-resolved spectroscopy shows that the Er-1 spectrum is characterized by an ultra-narrow linewidth of $\Delta E = 10$ microeV, i.e., three orders of magnitude smaller than commonly observed in Si:Er and the decay time which is considerably shorter than the usual 1 ms value. The extremely small linewidth has important consequences for theoretical estimates on the possibility of optical amplification in Si:Er. [1] M.V. Stepihova et al., Thin Solid Films 369, 426 (2000). [2] N.Q. Vinh et al. Phys. Rev. Lett. 90, 066401(2003).

9:30 AM *A10.4

Growth of Amorphous Silicon Quantum Dots and Device Applications. Seong-Ju Park, Department of Materials Science and Engineering, KJIST, Gwangju, South Korea.

We have studied the growth of amorphous silicon quantum dots (a-Si QDs) and the optical and electrical properties for their application to light-emitting source and flash memory devices. a-Si QDs embedded in silicon nitride were grown by plasma-enhanced chemical vapor deposition using silane and nitrogen gases and were found to emit various colors including red, green, blue, and white light in the photoluminescence, depending on the dot size. The fabrication of light-emitting diodes (LEDs) using a-Si QDs was demonstrated and these results clearly showed that the size control of a-Si QDs is possible and a promising method for the realization of silicon based full-color LEDs. Electron charging and discharging were observed in metal-insulator-semiconductor structures containing a-Si QDs. The charging behavior suggests that a-Si QDs in the silicon nitride are positively charged due to nitrogen dangling bonds. The surface state of the a-Si QDs is considered to play a dominant role in the charging properties such as electron storage and charge-loss rate in the a-Si QDs. Long-term charge storage was observed in the fully charged a-Si QDs and this was attributed to a suppression of the discharge process by electrostatic repulsion among the charged dots. Size-dependent charge storage was also observed and this was attributed to the changes of tunneling barrier due to a quantum confinement effect in the a-Si QDs. We will further present our recent results on the use of ammonia instead of nitrogen gas in the growth of a-Si QDs and the hydrogen passivation effect on the emission and charge storage of a-Si QDs.

10:30 AM A10.5

Novel Flat Panel Imager with a Two-Stage Charge Amplifier in Each Individual Pixel. JengPing Lu, K. Van Schuylenbergh, J. Ho, Y. Wang, C.W. Shih and R. A. Street; Palo Alto Research Center, Palo Alto, California.

Flat panel imagers (FPIs) have become an important application in the arena of large area, thin-film electronics aside flat panel displays. Conventional flat panel imagers, are simple arrays of photo sensors connected to active matrix networks of amorphous Si Thin Film Transistors (TFTs). The integration of gate line drivers, data line multiplexers, and pixel level amplifiers are made possible by the recent development of high performance, excimer-laser annealed (ELA) poly-Si TFTs, further improves imager performance and sensitivity. Among these new integrated functions, the pixel level amplifiers are probably the most interesting since they fundamentally improve the imager sensitivity, potentially beyond the thermal noise limits of conventional imagers. We previously reported on the successful implementation of imager prototypes with the simplest of pixel level amplifiers, the three-transistor source-follower. In spite of the circuit simplicity with only one transistor involved in the signal amplification, a noise level as low as 800 eRMS was achieved. In this paper, we report on the first successful demonstration of an imager with a complete two-stage charge amplifier in each individual pixel. The imager consists of a 128 by 128 array of 150µm square pixels, each comprising the aforementioned amplifier and a high optical fill factor a-Si:H PIN photosensor. The pixel level charge amplifier includes five poly-Si TFTs, n-channel as well as p-channel. This imager, believed to be the most sophisticated currently available on a glass substrate, provides a constant optimal sensor bias at all times, because of the virtual ground nature of the charge amplifier input, as well as the potential of even better noise performance. A detailed characterization will be presented.

10:45 AM A10.6

Suppression of Staebler-Wronski Effect Induced Electrical Crosstalk in a Si:H-Based Image Sensors. Jeremy Theil, Agilent Technologies, Santa Clara, California.

Hydrogenated amorphous silicon photodiodes have been considered for use in array-based image sensors. They promise to significantly reduce the size and cost of CMOS image sensors, while offering the promise of improved pixel sensitivity. However, Staebler-Wronski Effect (SWE) based electrical crosstalk degradation has been a major concern in their acceptance, due to degraded spatial contrast and color fidelity. Since the SWE is a fundamental mechanism of a-Si:H, solutions to this issue must look to ways of mitigating the SWE on diode array performance rather than elimination of SWE. In order to study electrical crosstalk, a novel device structure was designed and fabricated that can directly measure interpixel leakage currents. Results from these structures indicate that edge leakage can be a significant contributing component to the measured signal. In addition, a CMOS-compatible structure to suppress electrical crosstalk was designed and fabricated. Results from these structures demonstrates suppression of crosstalk up to lateral electric fields of at least 2×10^4 V/cm. Such suppression is adequate for densely packed minimum size pixel arrays. Aspects of the design and implementation of the structure will also be discussed.

11:00 AM A10.7

Vertically integrated amorphous silicon particles sensors. Nicolas Wyrsh¹, Clement Miazza¹, Sylvain Dunand¹, Arvind Shah¹, Danielle Moraes², Giovanni Anelli², Matthieu Despeisse², Pierre Jarron², Guenther Dissertori^{3,2} and Gert Viertel^{3,2}, ¹Institut de Microtechnique, University of Neuchatel, Neuchatel, Switzerland; ²CERN, Geneva, Switzerland; ³Labor fuer Hochenergiephysik, ETHZ Zurich, Zurich, Switzerland.

In particle physics, the increasing accelerator energies and fluences used in experiments call for radiation-hard particle detectors. In this context, amorphous silicon (a-Si:H) is seen as a promising candidate for the next generation of particle sensors. Using an approach developed for vision applications, a-Si:H sensors may be directly deposited on a CMOS readout chip. This method of "vertical integration" is also called the "Thin Film on Application-specific integrated circuits (TFA)" or "Thin Film on CMOS (TFC)" technology. It greatly improves the sensitivity [1] and reduces the dead area between the pixels. It offers, furthermore, a large potential for cost reduction, in view of system integration. At IMT Neuchatel, thick a-Si:H detectors (with thicknesses up to 50 μ m) have been developed. They have been first deposited on glass substrates and subsequently on several different types of CMOS readout chips. Using these sensors, CERN have achieved detection of single low-energy beta particles [2] and of betas at the minimum ionizing energy [3]. In this paper, the latest results on particle detection with these novel, vertically-integrated a-Si:H sensors will be presented. Their performance, limits and future potential will be discussed. [1] S. Benthien et al., IEEE Journal of Solid State Circuits, vol. 35, No. 7, pp. 939-945, 2000. [2] N. Wyrsh et al., MRS Proc. Vol. 762, in print. [3] G. Anelli et al, J. of Non-Cryst. Solids, (ICAMS-20), in print.

11:15 AM A10.8

Amorphous silicon backplane with polymer MEMS structures for electrophoretic displays. Jurgen Daniel¹, Brent Krusor¹, Naveen Chopra², Robert Street¹, Steve Ready¹ and Jackson Ho¹; ¹EML, Palo Alto Research Center (PARC), Palo Alto, California; ²Xerox Research Centre of Canada, Mississauga, Ontario, Canada.

After significant research in the 1970s electrophoretic displays (EPDs) have recently again received increasing attention due to their promising properties for applications such as electronic paper. These properties include the excellent visual appearance under various lighting conditions, the low power consumption due to their intrinsic bistability and the suitability for flexible displays. Apart from developing the electrophoretic media there are important issues to solve regarding the packaging and the electronic addressing of the electrophoretic ink. Addressing issues become more important the more sophisticated the displayed image has to be. Direct addressing is sufficient for relatively simple message boards. However, since we try to display arbitrary images or text, as required for electronic books or newspapers, we have to employ a matrix-addressing scheme. Since the current electrophoretic ink does not exhibit a well-defined threshold an active matrix driving method was chosen. We used a backplane based on amorphous silicon technology that was originally fabricated for prototyping X-ray image sensors. The pixel pitch is 100 microns and the whole array consists of 512 x 512 pixels with amorphous silicon thin film transistors fabricated on a 4-inch glass wafer. The array is based on an independent storage capacitor design. Polymeric cell structures (10-50 microns high) from the photoepoxy SU-8 were directly patterned onto the active matrix backplane. In this way the

alignment of the cells to the pixels is achieved with the lithography tool. The photoresist pattern separates the electrophoretic ink into cells which prevent settling and agglomeration of the charged particles in the ink. SU-8 which has become a valuable material for MEMS (Micro-Electro-Mechanical Systems) structures provides narrow (to assure a high fill factor), high-aspect-ratio walls and it is chemically inert towards the electrophoretic ink. As an alternative to photolithography we have employed micromolding to form the cell pattern. The counter electrode for the display was ITO coated glass. In contrast to microencapsulated electrophoretic displays, our approach allows us to vary the cell geometry in order to study the effect on the visual appearance of the display. Furthermore, we were able to test the interaction of the electrophoretic ink with various surface coatings. Concerning the amorphous silicon backplane, the effect of a black surface coating was investigated. Although the electrophoretic ink absorbs a major part of the ambient light a light-blocking layer improves the shielding of the transistor array. The columns and rows were addressed with bi-level drivers and the potential on the counter electrode was variable. All voltage levels were below 25V.

11:30 AM A10.9

MEMS Microresonators Based on Nanocrystalline Silicon. Joao Gaspar^{1,2}, Virginia Chu¹ and Joao Conde^{2,1}; ¹INESC Microsistemas e Nanotecnologias, Lisbon, Lisbon, Portugal; ²Department of Materials Engineering, Instituto Superior Tecnico, Lisbon, Lisbon, Portugal.

Thin-film microelectromechanical systems (MEMS) extend the applications of MEMS to inexpensive, large-area and flexible substrates. In particular, MEMS microresonators are of great technological importance for applications such as sensitive mass detectors and radio-frequency (RF) filters. High-performance hydrogenated amorphous silicon (a-Si:H) based microresonators, fabricated at temperatures below 110°C, have been demonstrated on glass and plastic substrates. Resonance frequencies, f_{res} , up to 70 MHz and quality factors, Q , as high as 5000 have been achieved in vacuum for microbridges fabricated on glass substrates. Surface losses are identified as the dominant energy dissipation mechanism in these a-Si:H resonators, which is evidenced by a decrease of Q with the surface-to-volume ratio, S/V , of the structures. In this work, MEMS microbridge resonators with nanocrystalline silicon (nc-Si:H) structural layer are fabricated and characterized. The resonator structures consist of nc-Si:H microbridges suspended over a gate electrode, fabricated using thin-film technology and surface micromachining. The nc-Si:H films are deposited either by RF plasma-enhanced chemical vapor deposition (PECVD) or hot-wire CVD. The microstructures are electrostatically actuated by applying a voltage between the bridge and the gate, and the resulting movement at resonance is optically detected. A detailed study of the f_{res} - and Q -dependences on the geometrical dimensions of the bridges and on the measurement pressure is presented and the results are analyzed with an electromechanical model. The effect of the nc-Si:H deposition temperature on the resonator properties is also studied. So far, the best performance was measured for a resonator with a structural layer of p⁺-nc-Si:H fabricated at 100°C by hot-wire CVD, and using a polymeric sacrificial layer (f_{res} up to 23 MHz and Q -values as high as 1200). The performances and dissipation mechanisms of the a-Si:H- and nc-Si:H-based structures are compared.

11:45 AM A10.10

Threshold Voltage and Field for Metal Filament Formation in Hydrogenated Amorphous Silicon. Paul Stradins¹, Howard M Branz¹, Warren B Jackson², Richard S Crandall¹, Jian Hu¹ and Qi Wang¹; ¹National Renewable Energy Laboratory, Golden, Colorado; ²Hewlett Packard Laboratories, Palo Alto, California.

Electrical switching due to metallic filament formation in metal/hydrogenated amorphous silicon/metal structures is an interesting nonlinear phenomenon with potential applications in memory devices. The mechanisms of switch initiation and subsequent filament formation [1-2], however, remain unrevealed. We have therefore examined the conditions for initiating the switching, including dependences on film thickness, applied voltage, metal contact material, applied voltage pulse polarity, and contact interface properties. We have established that the switching voltage applied to the contacts must be large enough to establish: 1) a minimum threshold voltage of about 2V at the contacts and 2) an additional bias field of about 1 MV/cm in the bulk. As a result, switching in very thin (<10nm) films requires a minimum bias voltage of about 2V, while in thick (\approx 100nm) films the minimum bias voltage of 12 V mainly produces the required bulk electric field. When the bias pulse polarity between the bottom Cr and top Ag contacts is reversed, the relationship between voltage and switching speed changes dramatically, but the two constraints on the minimum switching voltage still hold. The initiation of switching appears always to involve formation of a high-field domain near a contact. The critical

contact region is examined by selectively modifying the contact material and its interface properties. Carrier tunneling from the contact, defect creation, near-surface charge accumulation, localized instability and Joule heating may all contribute to conductive filament formation and switching. 1. M. Jafar and D. Haneman, *Phys. Rev. B* 49 (1994) 4605. 2. P. Stradins, W. B. Jackson, H. M. Branz, J. Hu, C. L. Perkins and Q. Wang, *Mat. Res. Soc. Proc.* 762 (2003) A2.4.