SYMPOSIUM A

Amorphous and Nanocrystalline Silicon Science and Technology-2004

April 12 - 16, 2004

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* Invited paper
Hydrogenated amorphous silicon (a-Si:H) and nano- or polycrystalline silicon (µc-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 relationship between material properties and device performance. Existing and emerging applications will be presented and discussed.

Instructors:
Siguad Wagner, Princeton University
Jaon Pedro Conde, Instituto Superior Tecnico, Lisbon, Portugal

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


In an attempt to fulfill the predictions of Mores Law, the silicon device community has turned increasingly to SiGe alloys and 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. Rich et al., IEDM Technical Digest, IEEE 2003, pp. 777-4 and H. Shang et al., IEEE Electron Device Lett. 25(4), 245-4 (2003).

9:00 AM *A1.2/H1.2 The Role of Hydrogen in the Creation of Mottastable Defects in Hydrogenated Amorphous Silicon. P Craig Taylor,*1 Tsu,*2 G. Ganguly,*2 and D E Carlson,*2 *1Physics, University of Utah, Salt Lake City, Utah; 2PB Solar, Toano, Virginia.

The Staebler-Wronski effect, which is a decrease in the photo- and dark conductivity of 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 decrease 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 8:30 AM *A1.3/H1.3 Hydrogen in amorphous Silicon: A simple Atom in a complex Environment. Martin Stutzman, Walter Schottky Institute, Technische Universitat Muenchen, 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 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 of hydrogen in 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 Schift
Tuesday Afternoon, 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. Ting Su,*1 P. Craig Taylor,*1 Guotam Ganguly,*2 Dave Carlson*2 and Friedhelm Finger,*2 *1Physics, University of Utah, Salt Lake City, Utah; 2BP Solar, Toano, Virginia; 3Institute of Photovoltaics, Research Center Juelich, Juelich, 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 addition, 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. 89 015502 (2000).

10:45 AM A2.2 Absence of enhanced stability in deuterated amorphous silicon thin film transistors. Ralph B. Wehrspohn,*1 Martin J. Powell,*2 Shufan Lin,*2 Andrew J. Flewitt*2 and William Milne*2 *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 p+ 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 materials have lower average densities and the deuterated materials have increased stability. TFTs produced 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...
The main advantages of the technique are that it is contactless and used to study the damage induced in hydrogenated amorphous silicon (a-Si:H) by irradiation with 3-MeV electrons. We have simulated the H evolution and the temperature dependent H evolution from a-Si:H provides unique insight into the role of defects and the influence of light in degrading the material. In the past, the complete subgap absorption spectrum, \( a(h\nu) \), has been estimated to determine the defect density in the material. The electron mobility, which was estimated to be \( 10^6 \) cm\(^2\) V\(^{-1}\) s\(^{-1}\), was used to study the damage. The rate of decay of the conductivity has been 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 trapping and defect-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 SHB 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 2x10\(^{15}\) cm\(^{-2}\) irradiation.

**Defect creation and annealing in tritiated amorphous silicon: a new angle in understanding the Staebler-Wronski effect**

**Janica Whitaker**, John Viner, Stefan Zukotynski, Nazir Kherani, Erik Johnson, P Craig Taylor and Paul Stradins, 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 \( \mathrm{He}^2 \), emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction has a half-life of 12.3 years. When these samples are irradiated with \( \beta \) particles from tritium decays, the defects are induced in a controlled manner. The samples are annealed at elevated temperatures and the defects are characterized using low temperature conductivity and Hall measurements. The results show a new low temperature H-evolution peak near 10°C, which cannot be attributed to photogenerated defects. The origin of this peak is attributed to the presence of defects created by the \( \beta \) particles. The temperature evolution of the peak shows that the H-evolution is enhanced by a factor of 5 after a 2x10\(^{15}\) cm\(^{-2}\) irradiation.

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 promising crystallization method. However, the size of poly-Si grains in ELA using conventional ELA is limited due to small grain size and randomly located grain boundaries which act as potential barriers for carriers. Therefore, a technique has to be developed to control the location of GBs and avoid their formation 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-μm-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 2μm to 12μm. The etching depth was about 7nm. The film was irradiated with a XeCl excimer laser in the energy range from 420 to 460 mJ/cm² in N₂. The laser shot number was determined by Electron Backscatter Diffraction Pattern (EBSP) analysis that indicated <111>-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 <3μm-<15μm were observed in the pattern, and mainly <1μm-<3μm-<111> grains, can be realized at this low temperature site. The essentially <111> texture can be explained by the surface energy of the [111] surface, which is the lowest for all surfaces. Not only the controlled grain position but also the preferential <111> orientation leads to good device performance, particularly as regards uniformity, as the interface quality of SiO₂/Si depends on surface orientation. We fabricated n-channel TFTs whose channel was in a convex region (L/W=3μm/1μm). Field-effect electron mobility of 461 cm²/Vs, subthreshold swing of 0.6V/dec and on/off current ratio of 3x10⁷ were obtained. We simultaneously achieved position and orientation control of grains using structured a-Si films. <111>-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 3D-LSIs.

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 DPPS 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 with adequate scanning speed and laser power. Not only the electrical 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 papers regarding electrical and structural characteristics of CLC poly-Si, little has been known about the crystallization kinetics. We have studied CLC of various-shaped 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), which can be explained as pinned position 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 LEC kinetics, the crystallization kinetics of CLC can be understood. We will present an explanation on the LEC kinetics with a simple model at the symposium.
made to adhere strongly, to withstand shear caused by thermal contraction. Electronics that just need to flex can be made on substrates that are strongly coated with a polymer film using a production process that fills the grain-filter. The samples heated at 450°C were crystalized with XeCl excimer-laser with various energy densities. TFTs having W/L = 40/2 μm were fabricated inside a glass substrate with 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 Vs ranging from -10 to 10 V at a drain voltage of 0.2 V. Activation energies were calculated from an Arrhenius plot by means of current obtained at 37°, 52°, 77°, 127° and 177°C. On-state (Vs = 10V), the Ea drop to negative value (-0.01 eV), which is distinct from a typical poly-crystalline 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 Ea value at Off-state (Vs = -10V) is calculated to be 0.92 eV, which indicates that the leakage current is thermally generated at mid-gap states. In contrast, for a high laser energy density, the Ea in Off-state (-10V Vs < 0V) was nearly constant at 1.7 eV. This suggests that the leakage current coming 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 carbon-dioxide in the location-controlled grain. [1] P.C. Van der Wilt, B.D. van Dijk, G.J. Bertens, R. Ishihara and C.M. Beenakker, formation of location crystalline silicon 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. Metelsasar and C.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 A3.8/12.8
Elastic integrated circuits on elastomeric skin.
Stephanie Pendrnan Lahour 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 membrane to form a stretchable TFT circuit. They meet TFT input/output impedance requirements in the low-frequency range, can be deformed repeatedly, and thus ensure both the flexibility and the functionality of the circuits.

We then integrate amorphous silicon thin film transistors, fabricated on plastic foil with the gold interconnects on the elastomer membrane to form active low-voltage 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 A3.9/12.0
Red-to-Red 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 case, each process chamber (e.g. PECVD for SiNx, intrinsic and doped amorphous silicon, spatter deposition techniques for metallization and ITO) is physically separated from other 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-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 TFTs on to flexible substrates, which uses the inherent advantages of the cluster tool. In this, a large number of the flexible substrate material is contained within a cassette which includes a reel to reel operation. One of the key features of the cluster tool 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 so that the reel-to-reel operation can be performed. After 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, spatter 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 on the substrate to be increased. In the OFF cycle, the ions are blocked by a mask. 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 Å, low O concentration and a minority carrier diffusion length of 1.2 μm resulting in a solar cell conversion efficiency of 8% for single junction p-i-n device. The technique allows that the structure of the film can be altered from 111 to 220 in a controllable way; this has implications for fabricating nc-Si TFS 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 Roll to Roll 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, May 13, 2008
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 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 use for 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 drain (LDD) region crystallization. This paper presents poly-Si TFT with higher current density compared with a conventional LDD due to the reduction of effective channel length. However, it is well known that GOLD poly-Si TFT requires a complicated process such as poly-Si sidewall gages on an additional photolithographic process. The purpose of our work is to report a simple and self-aligned GOLD 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 drain region may be formed because a gate oxide on the GOLD region would be able to behave as the buffer layer during crystallization of the source/drain region. We also employ oblique incident ELA activation, which was performed to activate both the S/D and GOLD region simultaneously. The laser beam is irradiated with oblique incident angle of 5° in order to eliminate the implant damages considerably. The proposed poly-Si TFT with W/L=10μm/3μm shows very small anomalous leakage current ($V_{DS}=3.3V, V_{GS}=-20V$) of 0.47nA, compared with 16.8nA of conventional one due to reduction of lateral electric field in the GOLD region. The proposed poly-Si TFT also improves the electrical reliability due to hot carrier stress, such as $V_{DS}=10V$ and $V_{GS}=20V$. The proposed poly-Si TFT exhibits a high mobility of 192cm²/Vsec, compared with conventional one of 139cm²/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 without a 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. Heikyo Kanno, Takanori Wakiyama, Kenji Makihira and Tanzamasu Assano; 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 ~1 μm 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 to the final stage of thermal annealing. 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 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 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 annealing of Si ion implanted oxide. Miho Kikumoto and K. 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 ion volume and the fluence. The nanocrystal growth was considered to occur at the nucleation centers by diffusing 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 Phosphorus Doped Polycrystalline Silicon Thin Films. Rosari Saleh, 1Department of Physics, Universitas Indonesia, Depok, Indonesia; 2Photovoltaic, Hahn-Meitner Institut, Berlin.

Excimer laser crystallization is an efficient technology to produce 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 it has been 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 composition was varied from 1 to 20% of the total flow of silane. The films were recrystallized 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/μm² [2] and ending at the desired final laser fluence using steps of 40 or 20 mJ/μm² 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 SiH stretching peak at 2000 cm⁻¹ [1] is observed. Specimens doped with moderate boron and P-doped a-Si:H show a second SiH stretching peak at 2100 cm⁻¹ [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 crystallization the decrease of the bands SiH stretching peaks can be observed at 2000 cm⁻¹ [1] and at 2100 cm⁻¹ [1]. However, the decrease of the stretching peaks at 9200 cm⁻¹ [1] is enhanced compared to the one at 2100 cm⁻¹ [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 simultaneously the SiH stretching peaks disappear for completely crystallized poly-Si. The results of Raman spectroscopy will be correlated with the results obtained from hydrogen effusion measurements.
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 1.5"x1.5" Corning 7059 glass substrates. Two structures were prepared: Al (α-Si/A) 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.

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 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 1.5″ glass substrates. The sequence is intrinsic nc-Si:H seed layer / SO2 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 regions - the source/drain can be controlled by over-etching of the lift-off photoresist pattern. Atomic force micrographs show 1 mm source/drain overlap consisting of 40 nm gate length. TFTs fabricated in this structure have electron mobilities of 25 cm²V⁻¹s⁻¹. We acknowledge support by DARPA, NJCST and the Princeton Plasma Physics Lab.

Fabrication and Characterization of Hydrogenated Amorphous Silicon Bipolar Thin Film Transistor (B-TFT). Yue Kuo, Xi-Lei and Helinda Nomumanda; 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-n junctions were prepared and examined 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+p/p/p+n were fabricated. The complete TFT was made using PECVD to deposit all doped amorphous silicon layers using 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 ± 1, which is larger than previously reported values [3]. In addition, the 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).

Advanced SLS Crystallization Method for Low Temperature Poly-Silicon Thin Film Transistors. Ji-Yong Park, I-Hyung Kim and H-Kyoon Chung; Technology Development Team 1, SAMSUNG SDI, Yongin-City, Gyeonggi-Do, Korea.


The deposition rate increased with increasing ICP power, which indicates that high power plasma can easily decompose SiH₄ and form films. For each power density, both structures were exposed to the laser beam for 10, 60 and 120 seconds. The flow rate of He, H₂ and He/H₂ mixture was fixed at 20 sccm while the ICP power was 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. The process gas was SiH₄ diluted with He as well as H₂. 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 1.5"x1.5" Corning 7059 glass substrates. Two structures were prepared: Al (α-Si/A) 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.

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 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 1.5″ glass substrates. The sequence is intrinsic nc-Si:H seed layer / SO2 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 regions - the source/drain can be controlled by over-etching of the lift-off photoresist pattern. Atomic force micrographs show 1 mm source/drain overlap consisting of 40 nm gate length. TFTs fabricated in this structure have electron mobilities of 25 cm²V⁻¹s⁻¹. We acknowledge support by DARPA, NJCST and the Princeton Plasma Physics Lab.

Fabrication and Characterization of Hydrogenated Amorphous Silicon Bipolar Thin Film Transistor (B-TFT). Yue Kuo, Xi-Lei and Helinda Nomumanda; 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-n junctions were prepared and examined 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+p/p/p+n were fabricated. The complete TFT was made using PECVD to deposit all doped amorphous silicon layers using 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 ± 1, which is larger than previously reported values [3]. In addition, the 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).
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 channel properties, such as mobility, threshold voltage, and field effect mobility on SLS 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 showed various device characteristics due to the SLS microstructures. We made the new channel direction independent TFTs of mobility about 400cm²/Vs by controlling the crystallization method and also suggest the method of designing SLS mask pattern to control these characteristics.

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 Aroika 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. In current programmed pixel circuits, lifetime measurements can last thousands of hours, hence it is desirable to develop accelerated methods of testing that can reveal 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 this paper directly explores the channel and TFT dependent stability of a-Si:H TFT 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°C. These measurements are used to develop a model of the temperature dependence of the $V_t$-shift in TFTs. The temperature acceleration factors 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 a 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] S. Sakariya, P. Servati, D. Striakhilev and A. Nathan; “AmoLED-a-Si:H TFT 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. 1325-1328, 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 a 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. To define the p-type TFT properties, such as mobility, conductivity, are related to the deposition parameters and substrate temperature. In addition, the TFT characteristics, such as threshold voltage and field effect mobility, are functions of the channel dopant species and concentration. Using this concept, 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-photon mask process on the Corning 7059 substrates [4]. Bits cannot directly be applied to TFTs and a P-doped ohmic contact layer was deposited by PECVD using the SiH₄/BCl₃:H₂ and H₂ mixture at various temperatures. The following results have been obtained: (1) The increase of B₂H₆ feed gas concentration increases the deposition rate and improves the dark conductivity. However, the film resistivity is not directly related to the B₂H₆ 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 films 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 B₂H₆ feed gas concentration can promote the formation of Si-B bonds in the film, hence, the dopant efficiency is improved, but it can also reduce the dopant efficiency through mechanisms, such as blocking the available surface for recombination or including a large number of electrically inactive dopants in the film. (2) TFT characteristics, such as mobility, threshold voltage and dark conductivity, 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.
Poly-silicon (poly-Si) thin film transistors (TFTs) 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 plastic, usually under 150°C. The doping process for source-drain contacts, as well as the various film processes, must therefore 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 (~10Å) 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 method 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 on the plasma, and the laser energy on the sheet resistance were studied. Sheet resistance values smaller than 10$^3$ 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 10$^{15}$ cm$^{-2}$, the lowest attainable sheet resistance was not affected much by the ion dose or by the substrate temperature during 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.

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 in a film will be taken up by the substrate exposed between the platforms. Earlier we demonstrated this concept with a plastic substrate that is deformed just enough to make contacts with making platforms on an elastomeric, rubber-like, substrate, which can be deformed reversibly. The substrate material is 1-mm thick polydimethylsiloxane (PDMS). We are testing amorphous silicon, silicon nitride, copper, gold, and copper 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 formation. We report the process, the maximum platform size, and the substrate aperture. This research is supported by the Packard Foundation, DARPA, and NSF.

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 Arokan Nathan; ECE, University of Waterloo, Waterloo, Ontario, Canada.

Hydrogenated nanocrystalline silicon (n-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$^+$)-Si:H films as channel layers and as ohmic contact layers, respectively, for low-temperature high-frequency TFTs. All 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 and H$_2$ dilution gas concentration were fixed at 25 W/cm$^2$ and 10%, respectively. To optimize the deposition conditions, and to study the thickness dependence and the annealing effect on n-Si:H films, electrical conductivity, optical absorption spectra, Raman scattering, and XRD measurements were carried out.

Low Temperature a-Si:H TFTs with a SiO$_2$ Gate Insulator Deposited by Liquid Phase Deposition. R.B. M. Cross, D. P. Oksley and E. M. Sandlare Nayanar; 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, there is a desire to improve process compatibility with inexpensive, flexible substrates that has initiated great efforts by many workers to develop device quality layers at reduced substrate temperatures. In this paper, we describe the device and physical properties and characteristics of a-Si:H TFTs with silicon dioxide (SiO$_2$) 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 120°C. The hydrogen fraction of the gas mixture was 0.9, the RF power density was 44 mW/cm$^2$, and the reactor pressure was 300 mTorr. The temperature of the source gas line was 400°C, which was measured and regulated by a digital temperature controller.

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 patterned, coplanar aluminium electrodes under AM 1.5 illumination. The material was found to have a hydrogen concentration of 10 at% with a dihydride (SiH$_2$) fraction, an optical bandgap of 1.70 eV as determined from Tauc plotting, and a low density of 44 mWcm$^{-2}$ 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/SiO$_2$/Si structures. Film characteristics and device performance on a-Si:H were found to be 4 x 10$^{-11}$-10$^{-13}$ cm$^2$/V/s, 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. SiO$_2$ 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.

Low tensile stress SiGe deposited at 370°C for monolithically integrated MEMS applications. Sherif S Seddy1, Kris Baer2, Chris Van Heuvel3, Yi Wang3, Omer Van Der Biezen3 and Ann Witvrouwen4; 1Physics, The American University in Cairo, Cairo, Egypt, 2MCP, IMEC, Leuven, Belgium, 3MIT, 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 silicon 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 later 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 $\text{Si}_x\text{Ge}_{1-x}$ films at temperatures lower than 400°C, by depositing films on top of thin (50 nm) metal seed layers of either Al or Ti. X-ray diffraction (XRD) and transmission electron microscopy (TEM) have been used to study the texture, grain microstructure, and stress of the Al/a-Si and Ti/a-Si films, and the stress gradient on top of Al is 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 negative) is lower 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. Coenen, 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. 2007-12, September, 2001. 3. J. Schroeder, T. Sands, R. Howes and T. J. 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 Jung1, Shawn Chang1, Grant Z Pan1 and Yahya Rahmat-Samii2; 1Microfabrication Laboratory, Department of Electrical Engineering, University of California at Los Angeles, Los Angeles, California; 2Antenna Research, Analysis, and Measurement Laboratory, Department of Electrical Engineering, University of California at Los Angeles, Los Angeles, California.

Polycrystalline silicon (c-Si) is desirable for thin film transistors (TFTs) because of its high carrier mobility compared to that of the amorphous silicon (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 times 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 deposited by low pressure 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 Al to a-Si, 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 layer on the Al side of the interface by 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 Al/a-Si structure. This is one of the possible reasons why crystallization of a-Si at a lower temperature occurs for the a-Si/Al structure compared to the Al/a-Si structure. 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 photodiodes, three 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 $10^{13}$ to $10^{14}$ cm$^{-3}$, the open-circuit voltage ($V_{oc}$) increased from 0.14V to 0.19V while short-circuit current density ($J_{sc}$) decreased from 2.45mA/cm$^2$ to 1.9mA/cm$^2$. Hydrogen passivation was carried out by using electron-cyclotron-resonance plasma with a hydrogen content of $8 \times 10^{17}$ cm$^{-2}$. The effect of substrate temperature and interface oxide layer on aluminum induced crystallization (AIC) of magnetron-sputtered amorphous silicon, M. Hossain, Husam Abu-Saife, Marwan Barghouti, Hamed 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/Oxide/Al/glass, and Al/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 525°C. On the other hand, a-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 and cross-sectional layers after annealing. The 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. Yung-Jao Zhao1, Jiangang Wang2, Eric Jan Mittemeijer2 and Yuntian Theodore Zhu1; 1Materials Science and Technology, Los Alamos National Lab., Los Alamos, New Mexico; 2Max Planck Institute for Metals Research, Stuttgart, Germany.

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 focused-ion beam microscopied techniques were used. A high compositional and microstructural analysis. A major observation was that after annealing the Al and Si sublayers had exchanged their locations 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] fiber 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.
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 277 °C has been studied. The crystallite 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 regions containing a mixture of Si and Al with Si 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 10 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.

Increase of crystallinity during electrical switching in metal/p-Si/metal structures, Jian Hu', Pauls Stradins', Craig Hayzelden, 

We report on switching phenomena in metal/p-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. Doped microcrystalline Si (p-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 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 mesoetched devices after the metal top contacts are removed. For the non-switched devices, the Raman signal indicates a uniform structure at all locations. Measured a peak at 520 cm⁻¹ is associated with the 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 of/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. Pehnt, F. Pfojtk, K. Luterov, J. Kochs, K. Kniez and J. Stepanek, Thin Solid Films 383, 101-103 (2001) [2] C. Hayzelden and J. L. Batstone J. Appl. Phys. 73, 8279 (1993)


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 microscopy observations and X-ray diffraction analysis and was found to be in close agreement.

A4.37 TRANSFERRED TO A10.10


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.

In-situ Aluminum-Induced Crystallization (AIC) of HWCVD Si films on Corning 7059 glass substrates above the Si-Al eutectic temperature of 277 °C has been studied. The crystallite 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 regions 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 10 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/p-Si/metal structures, Jian Hu', Pauls Stradins', Craig Hayzelden, 

We report on switching phenomena in metal/p-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. Doped microcrystalline Si (p-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 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 mesoetched devices after the metal top contacts are removed. For the non-switched devices, the Raman signal indicates a uniform structure at all locations. Measured a peak at 520 cm⁻¹ is associated with the 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 of/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. Pehnt, F. Pfojtk, K. Luterov, J. Kochs, K. Kniez and J. Stepanek, Thin Solid Films 383, 101-103 (2001) [2] C. Hayzelden and J. L. Batstone J. Appl. Phys. 73, 8279 (1993)


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 microscopy observations and X-ray diffraction analysis and was found to be in close agreement.
obtain the conductivity and the activation energy, the x variation, results in a change in the absorption coefficient, the dark conductivity at room temperature of the PL peak energy 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 uncoated micro-bolometer, due to its high Ea, and therefore, a high TCR (0.016 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 10⁴ 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 2.0-9.0E17 ions cm⁻² at energies of 50-180 keV through a pre-patterned hard mask. 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 excitation generation. Mark Klik¹, B. A. Andrews² and Tom Gregorkiewicz; ¹, Physics, Van der Waals-Zeeman Institute, Amsterdam, Netherlands; ²for 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 were 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 and Tetyana Torchynska; Science Materials Department, National Polytechnic Institute, Mexico, Mexico.

A number of groups have reported intense photoluminescence (PL) of Si nano-crystallites embedded in SiO₂ in the spectral range of 1.5-2.4 eV. The mechanism of this photoluminescence has 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 and without Si nano-crystallites (a-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 a/c - amorphous silicon systems, peaked at 0.92-0.98 eV, 1.12 eV, 1.39 eV and 1.56 eV. The intensity of the bands depends on Si concentration and size. 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.

A4.34 Change of light emission of Si wires during Si/SiOx interface formation. Francisco Guillermo Becerril-Espinosa¹, Tetyana Torchynska¹, Miguel Morales-Rodriguez³, Larisa Khomenkova² and S. Ostapenko³; ¹Ciencia de Materiales, Escuela Superior de Fisica y Matematicas-Instituto Politectnico Nacional, Mexico, Mexico; ²Inst. Semiconductor Physics at Superior de Fisica y Matematicas-Instituto Politectnico Nacional, Mexico, Mexico; ³Inst. Semiconductor Physics at National Academy of Sciences, Kiev, Ukraine; ⁴UNR-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-emissive objects fully compatible with Si processing. Different models were proposed to ascribing the visible PL, such as quantum confinement effects in Si nanocrystallites, as well as defects (oxygen vacancy or non-bonded oxygen hole centres) in silicon oxide on the PSi/SiO₂ interface. In this work the changes of Photoluminescence (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 annealing in ambient air, with the aim to reveal the PL mechanism. Fresh-prepared PSI layers created at low values of current density (Ia) is characterised by ”red” emission centred at 1.72 eV, while the prepared at higher values of Ia have ”green” PL band centred at 2.60 eV. It is possible to receive also the superposition of these two PL bands for some intermediate value of Ia , 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 eV while the ”orange” band does not change. 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 150 keV. The micro-PL results reveal that the natural layer properties of the Si-SiOx interface give the possibility to make conclusion concerning the PL and EL excitations in Si wires. This work partially supported by CONACYT Mexico (Projects 33427-U and U49346-Y, as well as Mexico-Ukraine International Project), NSF USA and CGPI-IPN.

A4.35

About the luminescence mechanisms of composite a-Si:Sic system obtained by ion-beam amorphization in a wide dose region. David Isaakovich Tetelbaum1, Alexander A. Ezhakevich2, Alexey N. Mikhailov3, Mikhail Yu. Lebedev4, Yulina A. Mendeleva5, and Sergey V. Morozov6. 1 Physics-Technical Research Institute of University of Nizhny Novgorod, Nizhny Novgorod, Russian Federation; 2 Institute of 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 line-by-line processing of the experimental results. Influence of the annealing temperature is also investigated. The work was supported by the RFBR grant 04-02-16490 and programme of the Russian Ministry of Education Scientific researches of higher school in the priority fields of science and technique, subprogram 2053. [1] D.I. Tetelbaum, S.A. Trushin, Z.F. Krushinskii, D.M. Gaponova, A.N. Mikhailov. Optical Materials. 2001, V. 17, Nos. 5-6, P. 57-59. [2] D.I. Tetelbaum, A.A. Ezhakevich, S.A. Trushin, A.N. Mikhailov, Z.F. Krushinskii, Y.A. Mendeleva, L.I. Akis, D.M. Gaponova. Material Science and Engineering B. 2003. V. 101. No.1-3, P. 279-282. [3] D.I. Tetelbaum, A.A. Ezhakevich, A.N. Mikhailov. Semiconductors. 2008. V. 43. No.11. P. 1542-1544.

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, Hunchu, 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+) characterized. The SiO2:Si+ samples with 500 A a-Si:H buffer layer due to the strong absorption of the 514 nm wavelength by the 500 A a-Si:H buffer layer. The PL peak at 1.3-1.4 eV increases after light soaking for the samples with 100 A thick Si:H buffer layer, similar to those with no buffer layer. However, such a pumping-intensity dependent red-shifted light emission is only observed for samples with 500 A a-Si:H buffer layer. The reason is that the light-induced defect generation in the thick Si:H buffer layer reduces the band tail transitions, hence the change in the micro-PL spectrum is masked. We also found that the same PL behavior is found in the interface layers between the i and a layers. Light-soaking experiments show that a thin (100 A) a-Si:H at the i/p interface does not affect the behavior of light-induced Voc increase. However, a thick (500 A) layer increases the initial Voc significantly and eliminates the light-induced Voc increase by blocking the current path through the nanocrystalline grains. The signatures of nanocrystalline grains still appears on the Raman spectra measured on certain areas of the cells with a 100 A thick a-Si:H buffer layer at the i/p interface. It completely disappears for samples with 500 A a-Si:H buffer layer due to the strong absorption of the 514 nm wavelength by the 500 A a-Si:H buffer layer. The Raman peak at 1-3-1.4 eV increases after light soaking for the samples with 100 A thick a-Si:H buffer layer, similar to those with no buffer layer. However, such a pumping-intensity dependent red-shifted light emission is only observed for samples with 500 A a-Si:H buffer layer. The reason is that the light-induced defect generation in the thick Si:H buffer layer reduces the band tail transitions, hence the change in the micro-PL spectrum is masked. We also found that the same PL behavior is found in the interface layers between the i and a layers. Light-soaking experiments show that a thin (100 A) a-Si:H at the i/p interface does not affect the behavior of 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, R. Yan, A. Banerjee, S. Guha, D. Han, K. Wang. Mater. Res. Soc. Sym. Proc. 715, 601 (2002). [2] D. Han, J. Yang, and S. Guha. Proc. of 3rd World Conf. on Photovoltaic Conversion Osakan, Japan, 2003, SP-A5-08 (in press). [3] J.M. Olszowka, D. Han, B. Yan, J. Yang, D. Han, K. Wang, Mater. Res. Soc. Symp. Proc. 762, A5.1(2003).

A4.38

Buffer-layer Effect on Mixed-Phase Cells Studied by Micro-Raman and Photoluminescence Spectroscopy. Andrea Hilchey1, 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 photoluminescence (PL) spectroscopy to study the electronic states in the mixed-phase solar cells with various interface conditions. An amorphous silicon (α-Si:H) buffer layer is inserted between the p layer and the mixed-phase intrinsic (i) layers in the n/i/p solar cells. Light-soaking experiments show that a thin (100 A) α-Si:H at the p/i interface does not affect the behavior of light-induced Voc increase. However, a thick (500 A) layer increases the initial Voc significantly and eliminates the light-induced Voc increase by blocking the current path through the nanocrystalline grains. The signatures of nanocrystalline grains still appear on the Raman spectra measured on certain areas of the cells with a 100 A thick a-Si:H buffer layer at the i/p interface. It completely disappears for samples with 500 A a-Si:H buffer layer due to the strong absorption of the 514 nm wavelength by the 500 A a-Si:H buffer layer. The Raman peak at 1.3-1.4 eV increases after light soaking for the samples with 100 A thick α-Si:H buffer layer, similar to those with no buffer layer. However, such a pumping-intensity dependent red-shifted light emission is only observed for samples with 500 A a-Si:H buffer layer. The reason is that the light-induced defect generation in the thick α-Si:H buffer layer reduces the band tail transitions, hence the change in the micro-PL spectrum is masked. We also found that the same PL behavior is found in the interface layers between the i and a layers. Light-soaking experiments show that a thin (100 A) a-Si:H at the i/p interface does not affect the behavior of 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, R. Yan, A. Banerjee, S. Guha, D. Han, K. Wang. Mater. Res. Soc. Sym. Proc. 715, 601 (2002). [2] D. Han, J. Yang, and S. Guha. Proc. of 3rd World Conf. on Photovoltaic Conversion Osakan, Japan, 2003, SP-A5-08 (in press). [3] J.M. Olszowka, D. Han, B. Yan, J. Yang, D. Han, K. Wang, Mater. Res. Soc. Symp. Proc. 762, A5.1(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 Rodriguez1, Jesus Sangrador2, Tomas Rodriguez2 and Juan Jimenez,1, 2 Fisica Materia Condensada, Universidad de Valladolid, Valladolid, Spain; 3Departamento 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 internal 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 Ge 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, of 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 on flexible polyethylene substrate. Marco Antonio Mastropasqua1, José Porto1, Dinis Cunha1, Jesus Ceballos1, Juliano Uguccioni1, 2, Domenico Fecchio2, 3. 1Instituto de Ciências do Material, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil; 2Departamento de Tecnologia Electronica, Universidad Politecnica de Madrid, Valladolid, Spain; 3IFisica Materia Condensada, Universidad de Valladolid, Valladolid, Spain.

Amorphous silicon based X-ray imagers have been studied in the last
13 years by some universities and industrial laboratories. Some prototypes have even come to the market already. For these prototypes, material is in mass production, using physical vapour deposition (PVD) or chemical vapour deposition (CVD). Thin-film transistors (TFTs) are also used for the fabrication of amorphous silicon-based image sensors. The specific layer sequence in the pixel (P) of a silicon image sensor (SI) is shown in Figure 4.41. T1 represents the phosphor layer, and the photo detector (PD) is made of a-Si:H. The photosensitive layer (PSL) is between the gate and source electrode of the SiO2-doped aSi:H transistor with a work function of 5 eV. The phosphor layer is composed of a light-emitting material with a quantum efficiency of 0.8 and a quantum yield of 0.8. The quantum efficiency is defined as the ratio of the number of photons detected to the number of photons incident on the target. The quantum yield is defined as the ratio of the number of photons emitted by a material to the number of photons absorbed by the material. The quantum efficiency of the phosphor layer is 0.8, which means that 80% of the photons absorbed by the phosphor are converted into light. The quantum yield of the phosphor layer is 0.8, which means that 80% of the photons absorbed by the phosphor are converted into light.

Amorphous silicon-based image sensor arrays have been fabricated using the digital-lithography method. These arrays had features as small as 40 μm by 40 μm and pixel dimensions of 300 μm by 300 μm. The resulting TFTs, with on/off ratios of 10^8 and threshold voltages of 3-5 V, are integrated with a-MOCVD-grown a-Si:H films, allowing the fabrication of an a-Si:H polysilicon gate. The sensors are fabricated using a digital-lithography method, and the pixel area is 300 μm by 300 μm. The fabricated sensor is used as an x-ray detector, and the spectral sensitivity is strongly dependent on the applied voltage. The 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 voltage 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 spectral sensitivity on the applied voltage is used to encode and decode information. In the low voltage 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 spectral sensitivity on the applied voltage is used to encode and decode information.
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 a new method 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.


The relative amount of each phase can vary, depending on the 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 up to the a→(a+µ) 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 this transition position 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 above the a→(a+µ) transition, however, both 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+µ) transition.

8:45 AM A5.2

Comparison of Deposition Phase Diagrams for Si:H Film Growth at VHF and RF Plasma Frequencies. Gelo M Ferreira1, Joshua M Pearce2, Christopher R Wronski, Robert W Collins3, and Christoph Roes1; 1Department of Physics and Astronomy, University of Toledo, Toledo, Ohio; 2Forschungszentrum Julich, Institut fur 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 be used to calculate thickness at which one phase transitions into another, based on the deposition 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 up to the a→(a+µ) 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 this transition position 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 above the a→(a+µ) transition, however, both 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+µ) 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 Painet, B Vallat-Sauvain, A Vallat and A Shah; Institut de Microtechnique, Universite 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 deposition 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 microcrystals 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. The number of all possible states and the crystalline threshold value. The outcome of the simulation are computer generated representations of the layer microstructure and its usefulness for a more fundamental understanding of the microcrystalline silicon growth dynamics.

9:15 AM **A5.4**


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 [1] and it is expected that this technique will be sensitive to dangling bonds in the a-Si:H films as well. 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 be given. 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 ~0.5 A of deposited Si has formed. Atomic H induced etching seems to have an impact on the SH signal in these experiments as well. This observation might indicate that SHG has a 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, R2777 (1995).

9:30 AM **A5.5**

Surface Processes During Growth of Hydrogenated Amorphous Silicon. Eray S. Aydil1, Dimitrios Maroudas2, Sumit Agarwal2, Srinivas Saravanapriyan2 and Mayur S. Valipa1,2; 1Chemical Engineering Department, University of California-Santa Barbara, Santa Barbara, California; 2Chemical Engineering Department, University of Massachusetts, Amherst, Massachusetts.

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 reactions which include adsorption, 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 surface/solid interaction mechanisms. We have been using in situ multiple reflection Fourier transform infrared spectroscopy and in situ spectroscopic ellipsometry in conjunction with atomistic simulations to determine the elementary 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**


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 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 can be observed, it can be surmised that microstructure in the material does result in a band-tail DOS that is more Gaussian-like than exponential. [1] M Brinzan et al., J. Non-Cryst. Solids 239, 420 (2002) [2] M Brinzan, G J Adriànes, P Roca i Cabarrocas, Thin Solid Films 427, 139 (2003)

11:00 AM **A5.7**

Interpretation of Transient Photocurrents in Coplanar and Sandwich PIN Microcrystalline Silicon Structures. Steve Reynolds, Vladimir Smirnov, Charlie Main, Friedhelm Finger and Reinhard Carus; 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 at the surface and microvoids 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 different transport mobilities, mu-tau product and defect densities in nominally identical-prepared films. These studies have been used to form the basis of a model that allows one to predict the effects of structural anisotropy on the electrical properties of such films. This model has been confirmed by a number of experimental studies which have shown a dependence of transport on the direction of measurement. The objective of this work is to interpret transient photocurrents in intrinsic a-Si:H films, to determine the role of structural anisotropy on the transient photocurrent and to examine the implications of these results for the design of solar cells. The model is used to predict the observed effects of structural anisotropy on the transient photocurrent and to examine the implications of these results for the design of solar cells.

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 Nadaczy and Wim Metelsaar, DIES, 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 places the amorphous film in the Staebler-Wronski regime and is followed by creation of neutral states around midgap, Dz, and negatively charged states below midgap, Dc. During light soaking we observe a substantial increase of Dz states in accordance with the observation of the formation of additional dangling-bond defects due to light soaking. The evolution of the Dz states is strongly affected by the electric field at the p/i interface where the Dz 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 substrates with five different thicknesses of the intrinsic layer (dl = 150, 300, 450, 600 and 1000 nm) and subjected to light soaking. The dark and illuminated J-V characteristics, current density 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. Recent, 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, kiz, ke), which control changes in the spatial distribution of density of Dz, Dc, and Dz states due to light soaking. The evolution of the spatial distribution of defect states during light soaking will be presented for the solar cells with different dl. 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 Dz states and not their formation that contributes to a decrease in the spectral response of the solar cells, and that this effect is due to the short wavelength region (λ < 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 decrease in the spectral response and in the external solar cell parameters, mainly the fill factor.

11:30 AM A5.9


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 photocconductivity in the far-infrared spectral range (~1-10 μm) 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 into this spectral range, while a time-delayed probe pulse measures the resulting change in the far-infrared optical properties, which are directly related to the ac photoc conductivity, as the carrier distribution evolves in time. We find that the frequency-dependent conductivity measured on a-Si:H at room temperature under open circuit conditions 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 temperature dependence of the photocurrent decay, 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,1,2 and Stephen K. O’Leary,1,2 Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada; 3Information 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: 29th 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, 1 Palo 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 being discovered and understood as a disordered atomic structure and yet today as the Staebler-Wronski effect (SWE). 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 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, Masakyo 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 yet enough due to their high resistance, current, voltage 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 near heat tolerant substrates such as glass or plastics. Only one attractive 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 investigating lateral ELA modes, so-called Grudient (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 microns. 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, thus 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. Matsumura, et al., Proc. SPIE, Vol. 4749, 357 (2002). 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. 693 (1998). 5. K. Ishihara et al., Jpn. J. Appl. Phys., Vol. 39, p. 3972 (2000). 6. Jpn. J. Appl. Phys., Vol. 37, p. L492 (1998). Address: 292 Yoshiha-cho, Totsukku-ku, Yokohama, 244-8817 JAPAN e-mail: matsumura.masakyo@yahoo.com

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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 reactive 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.


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 different materials, using different types 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
Chair: Subbendu 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 the 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 back 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 electrolysers 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 material system.

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 their flat band potentials and simultaneous separation 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 apparent minor mechanistic distinction results in fundamental differences in photovoltaic behavior. For example, the open circuit photovoltage, Voc, in conventional cells is limited to less than the magnitude of the band gap, while in XSCs it can be greater than the band gap, being controlled by the rate of recombination. This tutorial describes excitonic processes in general and the use of carrier-selective (energy-selective) contacts to enhance Voc. 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 photovoltage and photocurrent 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.


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 transition. An evolutionary development of crystalline 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 price reduction factor is 0.75, 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 requirements to meet the needs, 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 in the second twenty years for isolated 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 solar cells and modules have been of scientific and technological interest for more than 25 years since 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 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 we 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 polycrystalline 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 by amorphous silicon modules. We will 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 and of challenges in CdTe thin-film solar-cell technology. Alvin D. Capan, 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 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 to the polycrystalline thin-film PV community as 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: Rajeev Arya and Michio Kondo
Thursday afteroon, April 15, 2004
Room 2001 (Moscone West)

1:30 PM *A8.1

High-rate deposition technique of device grade microcrystalline silicon (µc-Si:H) is essentially required for low cost manufacturing of high current solar cells. We have developed a novel high-rate process based on high-pressure and SiH4-depletion plasmas for high-quality µc-Si:H deposition [1,2]. In this paper, we present >9% efficient µc-Si:H p-i-n (superstrate-type) solar cells fabricated by 100 MHz plasma-enhanced chemical vapor deposition (PECDV) at i-layer deposition rates of >20 nm/s. Under high-rate conditions, in particular, the deposition pressure is found to play a dominant role in determining short circuit current (Jsc) of solar cell. With an increase in deposition pressure from 2 to 6–9 Torr, the Jsc increases by more than 50% due to a significant long Richardson current density. This is supported by TCO/p interfaces, which showed Jsc increases from 0.12 mAMcm(-2) at 3.4 Torr to 0.19 mAMcm(-2) at 6 Torr. This paper presents new high-rate, low pressure (0.3 Torr) µc-Si:H processes, 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/n interfaces. As a result, we have achieved 10.3% efficiency single junction solar cells with 75.0 mA/cm(-2) power output at 2.3 Torr and 2.3 nm/s deposition rate. The rise in power output is mainly due to the increase in Jsc. For the improved solar cells, µc-Si:H film is grown by a novel high-rate process at 2.3 Torr with 2.3 nm/s deposition rate. Transmission electron microscopy and secondary-ion mass spectrometry studies reveal that samples prepared at lower pressure (4 Torr) comprise many grain boundaries due to disordered grain growth, which induces a nonuniform incorporation of atmospheric impurities (predominantly oxygen) after exposing sample to air. In contrast, the high-pressure process (2.3 Torr) provides denser grain structure combined with 111-oriented crystallites, which in turn inhibits impurities from penetrating deeper in the film. Based on these results, we propose that the low post-oxidation behavior associated with the denser microstructure of high-pressure-grown µc-Si:H is responsible for the excellent charge collection in the a-Si:H/n-Si heterojunction solar cell. [1] M. Kondo et al. Jpn. Non-Cryst. Solids, 260 – 269, 84 (2000). [2] T. Matsui et al. Jpn. J. Appl. Phys. Part 2, 42, L901 (2003).

2:00 PM A8.2

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 the detailed analysis of the four (IV) curves, determination of doping and diffusion lengths, and measurement of diffusion lengths of minority carriers and surface recombination velocities of these two approaches (i) based on manufacturing monolithically interconnected polycrystalline 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 by amorphous silicon modules. We will 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?

2:15 PM A8.3
Materials and Interface Optimization of Heterojunction Silicon (HIT) Solar Cells Using In-Situ Real-Time Spectroscopic Ellipsometry. Dean H Levy, Charles Teplin, Eugene Iwaneczko, Titu Wang, Matthew Page, Qi Wang and Howard Brunz, Sandia National Energy Laboratory, Gaithersburg, Maryland (Colorim.)

We have applied real-time spectroscopic ellipsometry (RTSE) as both an in-situ diagnostic and post-growth analysis tool for amorphous silicon (a-Si)/crystalline silicon (c-Si) heterojunction with intrinsic thin-layer (HIT) solar cells grown by hot-wire chemical vapor deposition (HWCD). 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 high-stability conversion efficiencies of nearly 14% on p-type CZ wafers coated with thin i and n layers. Open-circuit voltages above 600mV indicate effective passivation of the c-Si surface by the n-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 transient measurements. We estimate that the n-Si intrinsic layer thickness is below 100Å from RTSE. Post-growth analysis of the RTSE data enables accurate determination of the evolution of the dielectric function with time.
thickness. The dielectric function provides a measure of the bandgap and degree of crystallinity. There is a gradual transition from ordered a-Si, or microcrystalline, 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 A8.5.4
Protocrystalline Silicon at High Rate from Undiluted Silane.
Ruud E.J. Schropp1, Mariele K. van Veen1, Karine van der Werf2, Don L. Williamson3 and Harv Mahan4, 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 (FWHM) were 5.29 ± 0.10 °20 at 500°C and 5.10 ± 0.10 °20 at 600°C, respectively, indicating a template effect due to the µc-Si:H n-layer. These FWHMs are as narrow as for optimized i-layers made by H2-diluted plasma deposition, however, at a much higher deposition rate (1 nm/min). The use of a single deposition temperature (500°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 these voids in the bulk are not to be ignored. The utilization 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.
Baqiao Yan1, Jeffrey R. Carius2, Yibin Luo3, Jeffrey Goh4, Daming Hao2, D. L. Williamson3 and Chun-Sheng Jiang4, 1United Solar Ovonic 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 (Jsc) from hydrogenated microcrystalline silicon (µc-Si:H) solar cells, a thick intrinsic layer is required. However, we find that Jsc reaches a maximum with a thickness in the range between 1 and 2 µm. Increasing the thickness further leads to a decrease in Jsc, corresponding to a reduction of spectral response in the long wavelength region. Two mechanisms could be responsible for the low Jsc for thick µc-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 µc-Si:H deposited on a textured substrate grow progressively large 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 microcrystallite volume fraction (fc) and grain size with film thickness. Very high fc could cause high microvoid and microcrack densities, thus poor cell performance. We made two sets of µc-Si:H solar cells: one on a specular stainless steel (SS) substrate and another on textured AgOx BR. Both sets of cells show a saturation in Jsc for thick cells, indicating that the microcrystallite collision is not the main reason for the low Jsc in thick µc-Si:H cells. Raman and X-ray diffraction exhibit a significant increase of fc 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 microcrystallite phase with thickness is the main reason for the observed low Jsc 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 Jsc.

3:30 PM A8.6
Crystalline volume fraction in µc-Si:H: Raman spectroscopy versus X-ray diffraction.
Reinhard Carius1, Lothar Houben2, Friedhelm Finger1 and Stefan Klein1, 1IPV, Forschungszentrum Juelich, Juelich, Germany; 2FFI, Forschungszentrum Juelich, Juelich, Germany.

The crystalline volume fraction (Xc) is one of the key parameters which determines the electrical 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. 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. For Raman spectroscopy and X-ray diffraction (XRD) are most widely used methods to determine Xc. For Raman spectroscopy the common procedure to determine Xc is to evaluate the intensity of two spectral parts, (i) a narrow band at about 520 cm⁻¹ related to the crystalline phase (Icr), and (ii) a broad band at about 480 cm⁻¹ related to the amorphous phase (Ia), Xc is then determined from $I_{cr} / (I_{cr} + I_{a})$. 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 Xc. For XRD the crystalline volume fraction Xc 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. Particularly the applicability of Raman spectroscopy for the determination of Xc is questionable and impressive examples for huge errors are given. 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 depths the laser wavelength and angle of incidence in the XRD was varied. The data show a good correlation of Xc determined by both quantities taking into account the large error bars at very high and very low Xc. Surprisingly, the mean error deviation from the reference samples is found to be less than 5 % with about 40 - 60 % crystallinity. Additional measurements of Xc 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 µc-Si:H was discussed.

3:45 PM A8.7
Understanding the structure of Si nanoclusters in a/n-µc-Si:H films using spherical aberration-corrected transmission electron microscopy. Christopher Perrey1, Siri S. Thompson2, Markus Lentzen2, Uwe Kortshagen2 and C. Barry Carter2, 1Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota; 2Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota, 3Institut fur Festkorperforschung, Julich, Germany.

Recent work has shown that the electrical properties of hydrogenated nanocrystalline Si films (a/n-µc-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 electron microscopy (EM) is hindered 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/n-µc-Si:H film. By varying both the spherical aberration of the objective and the defocus, regions of crystallinity in the a/n-µc-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 two 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, J0-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 J0-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 J0-V characteristics of
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 between two amorphous silicon layers (SS/n-Si:H/i-Si:H/n-a-Si:H). The second is a microcrystalline n-i-p device (SS/n-a-Si:H/i-Si:H/p-a-Si:H). The measurements were carried out on both the 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 i-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, the TPC measurements allow us to deduce Urbach's energetic characteristic of each component individually. Moreover, by varying the measurement temperature we directly observe the minority carrier collection in the microcrystalline component greater than that in the a-Si:H component. Using the DLCP method, both the shallow dopant 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.

8:00 PM A9.0
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 Guha1. 1Physics, University of Oregon, Eugene, Oregon; 2United Solar Ovonic Inc., 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 between two amorphous silicon layers (SS/n-Si:H/i-Si:H/n-a-Si:H). The second is a microcrystalline n-i-p device (SS/n-a-Si:H/i-Si:H/p-a-Si:H). The measurements were carried out on both the 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 i-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's energetic characteristic of each component individually. Moreover, by varying the measurement temperature we directly observe the minority carrier collection in the microcrystalline component greater than that in the a-Si:H component. Using the DLCP method, both the shallow dopant 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.
Using infrared (IR) spectroscopy and x-ray diffraction (XRD), the nature of the grain boundaries in two µ-Si films deposited by hot wire CVD, displaying similar crystalline volume fractions (>65%) but very different post deposition exposure to atmospheric contaminants, is analyzed. Both films exhibit, from XRD, a preferential [110] orientation, and were deposited at similar deposition rates (7-11 Å/s) using similar H2:SiH4 ratios (H2:SiH4=12/1 to 1/1). 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 µ-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 µ-Si when these sites comprise the grain boundaries and are therefore accessible to oxygen exposure. These include dimer bonds and backbone bonds 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. The appearance and disappearance of these absorption peaks is associated with new absorption 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 minimizing oxidation and depositing µ-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 Pataner 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 150 °C. The disappearance of the Si-H stretching absorption bands 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)-(1×1) 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 dynamic simulations of the different oxygen bearing bond stages of silicon, a mean composition of the suboxide layer could be estimated. Instead of the generally used Bruggemann effective medium approximation (EMA) an improved Tauc-Lorentz parametrization 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 Inno2, 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 (S33 - 1000 nm). Silicon 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 spectroscopy and spectroscopic ellipsometry (S33 - 1000 nm) 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 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 transmission Electron Tomography (TEM) [3], which is sensitive only to the unoccupied DOS. [1] Main, C., Reynolds, S., Zrinisic, I., and Merzaga, 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., Zrinisic, I., and Merzaga, A., 2003, The Influence of Generation and Transport Processes in the Constant Photocurrent Method. J. Materials Science: Materials in Electronics, 14 (2003) 681 - 690 [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. Lianghuang Feng, Lili Wu, Wei Cai, Yaping Cai, Jiazun Zheng, Jingquan Zhang, Bing Li and Wei Li; Department of Materials Science, Sichuan University, Chengdu, 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 electric 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 a short circuit, there is almost no current 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 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-neighbor area of the cross section. Therefore, this method can be used to observe and reveal the distribution of the build-in electric potential. 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 phase transitions of the PSC were 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 ground boundary and some defects.

A0.7 Electric-Field Dependence of Photocarrier Properties in the Steady-State Photogeneration Arrangement

Badran1, and Rudolf Bruggemann2; 1Phisics Department, Hashemite University, Zarqa, Jordan, 2Institut fur Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany.

The steady-state photogenerating (SSPG) techniques have become a standard tool for 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 photogeneration 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 experiments. In this work, we explore 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 high-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 is enhanced more by the charge carrier drift than by the diffusion 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. Blos, Philos. Mag. B 72, 551 (1995).

A0.8 Transient and Modulated Photocarrier in Microcrystalline Silicon, Rudolf Bruggemann, Institut fur Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany.

We present experimental data on transient and modulated photocarrier density (TPC and MPP) in a-Si:H 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 MPP data [1, 2]. The time-dependent drift mobility in transient photocarriers shows different variations in its temperature dependence, directly related to a high or low dark conductivity type 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 MPP) the additional 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 data for the a-Si:H 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.

A0.9 Effects of FEL radiation on amorphous silicon, Branko Pivac1, Vesna Borjanovic1, Branslav Vlahovic2 and Akira Ueda1; 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 amorphous silicon for different photon energies. The effects of band 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 silicon crystal substrate and were subsequently irradiated with 5 and 4.75 um light from FEL. The effects of irradiation were monitored with FTIR and Raman spectroscopy. It is shown that the irradiation affected much more the structure attributed to Si-H2 clusters, detected by infrared 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 Si-H stretching, indicating that the change in 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.

A0.10 Metastability in Undoped Microcrystalline Silicon Thin Films Deposited by HWCVD. Saydulla Persheyev,1, Kevin O Neil1, Mervin Rose1, Vlad Smirnov2 and Steve Reynolds2; 1EET, University of Dundee, Dundee, United Kingdom; 2EPCentre, 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 processes induced by atmospheric exposure of microcrystalline silicon films. 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 surfaces and within the films, we have introduced the photoelectric measurements. Three types of metastability were observed in our films: a) long term irreversible degradation due to condensation 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 in the carrier density observed underneath bottom chromium contacts under a condition of air admittance. We propose the effect is associated with electrical field induced by accumulated charge layer created by adsorbed water vapor near film surface. 1. S. Klein, F. Finger, R. Carius, T. Dylla, Al. Thini Solid State Physics, 202-207 2. S. V. Smirnov, S. Reynolds et al presented ICAMS 202, to be published JNCS 3. F. Finger, R. Carius, T. Dylla, S. Klein, S. Okur, M. Guenee, IEE Proc. CDS 150 (2003) (in press) 4. S. K. Persheyev, S. Reynolds et al Thin Solid Films 309/310 (2001) 130-138.

A0.11 The Influence of Light-Soaking and Atmospheric Adsorption on Microcrystalline Silicon Films studied by Coplanar Transient Photoconductivity, Vladimir Smirnov1, Steve Reynolds1, Friedhelm Finger2, Charlie Main3 and Reinhard Carus2; 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 phase regions; in solar cells 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 in single-junction or multijunction devices, show degradation 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...
I'c-Si:H for the two different group IVA host: Si and Ge. Hall effect measurements were performed on these films. We have obtained highly resistive and have low conductivity Si:H films that are highly resistive and have low conductivity. Si:H, little attention is paid to the study of its underlying physics and properties. However, plasma-deposited μc-Si:H is inherently a heterogeneous material consisting of micro and nano size crystallites, amorphous materials 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 μc-Si:H, little attention is paid to the carrier transport in undoped μc-Si:H. We have obtained highly crystallized dense undoped μc-Si:H films on glass substrates by standard rf glow discharge plasma CVD technique using a mixture of SiH₄, 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 microscopic techniques. This article will basically cover the conductivity, steady state photocurrent, Hall effect and photo Hall effect studies carried out on samples having different thicknesses. The dependence of photocurrent on the temperature (T) on the temperature range of 15-250 K. Mechanisms of carrier transport and reconstruction 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 μc-Si:H, Hall effect measurements were performed in the temperature range of 300-450 K. However, several experimental limitations are associated with Hall effect measurement on undoped μc-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 usual offset voltages, which mostly arise due to misalignment of contacts. We have also studied n and p types of doped μc-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 generation by illumination. The details will be described in this paper.

A9.16
Study of steady state photocurrent and electron mobility in highly crystallized doped and undoped microcrystalline Si films, Sanjay K. Rani, Satyendra Kumar, R. Vanderhaghen, B. Drevillon and P. Rocca i Cabarrocas; 2Physics, 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.

Hydrogenated microcrystalline silicon (μc-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, larger carrier mobility and better stability against light induced changes. However, plasma-deposited μc-Si:H is inherently a heterogeneous material consisting of micro and nano size crystallites, amorphous materials 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 μc-Si:H, little attention is paid to the carrier transport in undoped μc-Si:H. We have obtained highly crystallized dense undoped μc-Si:H films on glass substrates by standard rf glow discharge plasma CVD technique using a mixture of SiH₄, 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 microscopic techniques. This article will basically cover the conductivity, steady state photocurrent, Hall effect and photo Hall effect studies carried out on samples having different thicknesses. The dependence of photocurrent on the temperature (T) on the temperature range of 15-250 K. Mechanisms of carrier transport and reconstruction 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 μc-Si:H, Hall effect measurements were performed in the temperature range of 300-450 K. However, several experimental limitations are associated with Hall effect measurement on undoped μc-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 usual offset voltages, which mostly arise due to misalignment of contacts. We have also studied n and p types of doped μc-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 generation by illumination. The details will be described in this paper.

A9.17
Characteristic temperature for magnetically doped amorphous semiconductors, Li Zeng, John Cherry, Erik Helgren and Frances Hellman; 2Materials 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 (MI) 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 Gd₅Si₁₋ₓGeₓ and Gd₄Ge₁₋ₓSₓ, 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% [4] and is found to be the same for Gd-Ge. We compare the results of DC conductivity, T(4.2 K) and T(295 K) for the two different group VIA host materials doped with magnetic impurities, while also comparing to results from the non-magnetic counterpart Y₆Si₁₋ₓGeₓ. A characteristic temperature scale T* at which the magnetically doped samples deviate strongly from their non-magnetic counterparts is found to follow the form . A similar dependence is found for the magnitude of the magnetoresistance as a function of temperature. We also find that this 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, 552 (1996) [2] W. Teixeira, Phys. Rev. Lett. 84, 808 (2000) [3] D. N. Basov et al., Europhys. Lett. 57, 240 (2002)

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A9.18 Local ferromagnetic ordering and charge localization in amorphous Gd,Si$_{1-x}$, Nikolai Chumakov, Victor Tugushev, Stanislav Gudenko, Alexander Inyushkin, Olga Nikolaeva, Alexander Dasyukov, Valery Ozhogin, Li Zeng, Erik Helgren and Frances Hellman, 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 quantum confinement. The model takes into 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 strongly self-favoured by the drops. 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,Si$_{1-x}$, 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 temperatures below 50 K, as well as the observed 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 observations we have estimated the typical size 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 in-plane 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. B 57 (1998) 4692 [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. Bezirganyan, Halob (Aloq) P. Bezirganyan, Hayk H. Bezirganyan Jr and Petros H. Bezirganyan Jr, 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 (MOSFET), or a silicon-insulated gate metal-oxiﬁde-semiconductor (MOS) device 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 deposition, also produce 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 crystalline regions grow is strongly self-favoured by the drops. Crystalline positions in the solid phase epitaxial growth or SPegas (e.g. see [2]). The investigations of crystal-amorphous state transitional layer can be performed using the Grazing-Angle Incidence X-ray Backdiffraction technique (see translations [3,4] of 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 amorphous-crystalline state transitional layer. Images of the X-ray reflectivity coefficient of silicon amorphous-crystal interface computed for the GIXB concentration dependence of crystallization. Drastic increasing of Bragg angle are presented. [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.郝, North-Holland, 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 SiH$_3$ radicals with amorphous silicon surfaces, Sumit Agarwal, Mayur S. Valipa, Srasannapriya Srinanan, M. van de Sanden, D. Thorne, M. M. Marsenasrda  and S. A. Aydin, 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 SiH$_3$ 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 SiH$_3$ radicals, (ii) occurrence of SiH$_3$ insertion into surface Si-Si bonds simultaneously with surface D abstraction over a substrate temperature range from 500°C up to 1200°C and (iii) dissociation of some fraction of the adsorbed SiH$_3$ on the a-Si:D films and release of H into the subsurface. In addition, our MD simulations show that SiH$_3$ 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 SiH$_3$ radicals are highly mobile on the amorphous silicon surface and diffuse through overcoordinated 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 closely coupled with the surface morphology and reactivity. Due to this chemical potential gradient, radicals impinging on the surface means migrate to the valleys, whereas radicals impinging in the valleys remain in the valleys leading to surface smoothing. Based on our experimental and computational studies, we propose a deposition mechanism for a-Si:H from SiH$_3$, which explains both the temperature-independent reaction probability of SiH$_3$ with a-Si:H surfaces and the temperature-dependent surface smoothing mechanism.

A9.21 Spectroscopic Ellipsometry study of high rate a-Si:H growth by ion beams 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 i-layer, which is not coupled with the surface morphology and reactivity. The high rate a-Si:H growth without and with external RF substrate bias 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 not from the initial stage in which more voids are incorporated. The roughness results obtained from SE are compare with the roughness morphology obtained from AFM. Results on 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.  


A0.22

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

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$Department of Chemical Engineering, Princeton University, Princeton, New Jersey; 2Department of Chemical 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 SiH$_4$/H$_2$ discharges crystalize at temperatures much lower than those required for thermal annealing. The flux of H atoms need only be rastered either during post treatment with an H$_2$ plasma, or when the SiH$_4$ feed gas is diluted heavily with H$_2$. 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 H$_2$ plasma.

The a-Si:H films used in the simulations were grown through MD with SiH$_4$ 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 K ≤ T ≤ 773 K), much lower than those required for thermally-induced crystallization. The analysis showed that H atoms diffuse into the a-Si:H film and break the Si-Si bond. This leads to formation of an 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 definition of a universal curve of H insertion energies 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 K ≤ T ≤ 773 K) to analyze the effects of hydrogen post treatment on the chemical composition of the H-exposed films; for the analysis, the evolution of 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.

A0.23

High-quality hydrogen diluted SiNx films deposited by hot-wire chemical vapor deposition.


We have studied the effect of H-dilution on silicon nitride films deposited by the hot wire chemical vapor deposition technique using SiH$_4$, NH$_3$, and H$_2$ gases. We found that H-dilution significantly enhances silicon nitride films properties. The N content in the film increases above 45% when compared to films without H-dilution, as determined from FTIR measurement. As a result, we can achieve high-quality SiNx films at low substrate temperature using a much lower gas ratio of NH$_3$/SiH$_4$ (about 1) in comparison 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 SiNx films at high deposition rate can be deposited. As a result, Electric Break-down measurement shows a well-insulated film with a few MV/cm for the break-down field.

A0.24

New ultrahigh vacuum setup and advanced diagnostic techniques for studying a-Si:H film growth by radicals.


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 numerically simulated. a-Si:H film growth can take place by a hot wire source while an electron-cyclotron resonance (ECR) remote plasma operated on H$_2$ can produce a rather pure SiH$_3$ beam. An atomic H source based on thermal dissociation of H$_2$ in a hot capillary provides 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 a-Si:H, amorphous carbon and silicon films under different operating conditions of the H$_2$ operated sources. By linking the etch rates to the one obtained by the quantified atomic H source, absolute efficiencies of the different sources have been obtained. The setup is equipped 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 (ATR) spectroscopy to study the H depth profile, thermal hydride (-SiH$_4$) composition of the a-Si:H, spectroscopic second harmonic generation for measuring the dangling bonds on the a-Si:H surface and eventually resonance-enhanced cavity ringdown to measure dangling bonds on the a-Si:H during film growth. The setup will be designed to study this setup on a-Si:H film growth including 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.

A0.25

Energetics of Surface Transport During Amorphous Silicon Deposition.


Mechanisms in hydrogenated amorphous silicon growth are of interest for improved materials and for understanding low temperature deposition is known that only a fraction of the radicals on the growth surface. Species transport mechanisms in agreement with the observed scaling will be discussed.

A0.26

Structural and Electronic Properties of SiCl$_4$-based Microcrystalline Silicon Films.

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 (SiCl$_4$) which is less expensive and less dangerous. For deposition we applied pulsed and landing for high deposition rate, for high solar cell efficiencies [1], namely a high dilution of SiCl$_4$ by hydrogen, a high pressure of 4 mbar and a high rf (13.56 MHz) power of 60 W (1 W/cm$^2$). While the flow rate of hydrogen was kept constant at 100 sccm, the flow of SiCl$_4$ 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 SiCl$_4$ 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 SiCl$_4$ flow rate rises from 1 to 7 sccm, the Raman crystallinity of undoped material decreases continuously from 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 transition regime of crystallinity of 5-10%. While undoped films have their Fermi-level typically near midgap, high room temperature (RT) conductivities exceeding 100 (ohm cm)-1 are achieved for boron doping at a (solid state) doping level of about 2%. For phosphorus-doped films, the maximum RT conductivity activity about 10-1 (ohm cm)-1 was obtained. The relation between SiCl4 flow, doping, crystallinity and RT conductivity was studied. J. T. Roschek, B. Rech, W. Beyer, P. Werner, F. Edelman, A. Schack, R. Weil and R. Beesmer, MRS Symp. Proc. 664 (2001) A 25.5.

A9.27 Atomic-Scale Analysis of Fundamental Mechanisms of Surface Microcrystallization on Plasma-Doped mc-Si:H Films, Mayur V. Valipis1,2, Sarvanapriyan Srijamn3, 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 adorning 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 (001)-(2X 1) surfaces. The calculated 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 SiH2, diffuse into passive 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. Jianguo 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 Si1-xGe x (poly-Si1-xGe x : x < 0.05) at 450°C and its application to TFTs. The TFTs we fabricated with 200nm thick films exhibited high mobility over 20cm 2 /Vs and 30cm 2 /Vs in bottom and top-gate-TFTs, respectively, even though the fabrication process had been optimized yet. In this study, we prepared poly-SiGe thin films with variable germanium content (Ge=3% 30%). The films were analyzed using Raman and X-ray diffraction. 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 fraction of poly-Si1-xGe x governed an evolutionary selection process of growth. In advance, the (100) and (111) facet growth velocities were calculated. The other three growth parameters were estimated as the calculated average with the experiments. The a-Si growth 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 relative orientation of the surface morphology from the SEM observations of mc-Si films. We thank Dr. K. Suto 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 Bhunus2 and Bernd Schroeder1, 1Department of Physics / Center of Optical Technologies and Laser Controlled Processes, University of Kassel/Lautern, Kassel/Lautern, 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 amorphous silicon (a-Si). Some models using Kinetic Monte Carlo method reproduced the evolution of the whole 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 model for 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 on the surface, determine a grain basic growth form. (110) or (111)-oriented appears on condition that the facet growth velocities of (100) and (111) on the grains are nearly equal. We assume only the (110) or (111) on the film 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 large, the grains finally dominate near the film surface. (5) Micro-twins generate in the grain, which affects film-preferred orientations. Fact scale 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. 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 fraction of poly-Si1-xGe x governed an evolutionary selection process of growth. In advance, the (100) and (111) facet growth velocities were calculated. The other three growth parameters were estimated as the calculated average with the experiments. The a-Si growth 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 relative orientation of the surface morphology from the SEM observations of mc-Si films. We thank Dr. K. Suto 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).
Advantage of this new graphite catalyst is its higher chemical and electrical stability as compared to that of Ta and W. After several tens of hours of operation, the IV characteristics of the cells showed that the fill factors were found to be virtually unchanged. However, their mechanical strength is of some concern since the fillaments 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 Shiratori, Kazunori Koga, Naoto Kaguchi and Yukio Watanabe, Dept. of Electronics, Kyushu Univ., Fukuoka, Japan.

Reduction of hydrogen content $C_{\text{H(Si-H)2}}$ associated with Si-H bonds in hydrogenated amorphous silicon (a-Si:H) films has been pointed out to be an important key to reduction of light induced degradation. We have studied the relation between the hydrogen content and volume of clusters incorporated into a-Si:H films by using a cluster-suppressed plasma CVD method $2^{nd}$ 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 $C_{\text{H(Si-H)2}}$ value decreases from 1 to 0.65 atomic $\%$, while a hydrogen content associated with Si-H bonds decreases from 7 to 3 atomic $\%$. FT-IR measurements show that many Si-H 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-H bonds in the films. E. Takahashi, et al., J. Electron. Mater. 209 (2002) 1116. K. Koga, et al., Appl. Phys. Lett. 77 (2000) 1946.


The pulse laser annealing (PLA) method is effective to produce polycrystalline silicon (poly-Si) films with high carrier mobility on a glass substrate, but 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 suitable for grain growth. Then, we proposed the modulated PLA method to use periodic temperature distribution spontaneously induced by irradiating 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 materials was 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 ridge 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/cm$^2$ and the frequency and amplitude of the ultra sonic oscillator were 36 kHz and about 5 mm, 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 C. Gilmore, Joel Plawsky and Peter Persans; 1 Chemical Engineering, Rensselaer Polytechnic Institute, Troy, New York; 2Physics, 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. 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 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 effects 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 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 Lee, Chang-Hee Han, Un-Jung Kim, Chong-Ook Park, Su-Kyun Rha and Won-Jun Lee; Materials Science and Engineering, Korea Advanced Institute of Technology, Deajeon, South Korea; Materials Engineering, Hanbat National University, Deajeon, South Korea; Advanced 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 limited to 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 effect of process parameters of the film properties were investigated. Tetrachlorosilane(TEOS), Si(OClH)$_4$ and dichlorosilane(DCS, SiCl$_2$H)$_2$ were used as the silicon source gas. Ozone(O$_3$) and water vapor (H$_2$O) 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, reaction exposure of the precursors, and number of cycle. Properties of the deposited films were characterized by the electrical parameters, 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 process operated on Ar+N$_2$H$_2$:SiH$_4$ and Ar+NH$_3$:SiH$_4$ 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 SiH$_4$/NH$_3$ and SiH$_4$/N$_2$ 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 observed. The model based on the real time spectroscopic ellipsometry data for each film thickness has been used to describe the thin films. For the RTSE measurements, a good agreement with the static ellipsometry measurements for films thicker than 75 nm. For thinner films however the sensitivity of the RTSE measurements is limited.
the AFM images has been obtained. Furthermore, also the influence of the substrate temperature has been investigated and the deposition rate increase with 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 the n-Si:H could be observed.

A9.35

Growth study of highly crystallized undoped microcrystalline Si films. Sanjay K. Ram1, Dinesh Deva2, Satyendra Kumar2, R. Vanderhagen3, B. Devillon4 and P. Rocca 1 Caparrascos1,1, Physics, Indian Institute of Technology, Kanpur, Kanpur, Uttar Pradesh, India. 

The development of high quality intrinsic microcrystalline silicon (µc-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 µc-Si:H films compatible with a-Si:H deposition technologies for large area electronics applications. In this work, we have concentrated on obtaining large area crystalline silicon films. This includes smooth crystallized surfaces using a standard rf PECVD system at low substrate temperatures. We have obtained highly crystallized dense undoped µc-Si:H films on glass substrates by standard rf glow discharge plasma enhanced chemical vapor deposition of H2 and SiH4 at low temperatures (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=H2/SiF4) by AFM and in-situ spectroscopic Ellipsometry. In this study, root mean square surface roughness (σrms) of the samples obtained from the AFM images are found in agreement with the surface roughness layer thickness (σrms) 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. Thickness dependent studies show the increase of average grain size with the increase in film thickness. The electrical conductivity measurements carried out on these samples are in good agreement with the film microstructure.

A9.36

Growth and Properties of Insulators For Nanocrystalline Si:H TFT Devices. Vikram L. Dalal and Jarred MacDonald; Elect 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 oxynitride, which is grown using a combination of in-situ plasma oxidation with oxygen and fluorine and a simultaneous deposition of silicon nitride. MOS capacitor and MOSFET devices were investigated for both p and n-type nanocrystalline Si:H. Nanocrystalline Si:H was investigated at different temperatures, <111> and <220>, 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 2E10/cm2.

A9.37

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

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, combined with its relatively low operational cost. Heavily-doped p- and n-type silicon films were deposited on silicon and glass substrates at temperatures below 400 degrees Celsius with pulsed deposition rates up to 400 nanometers in 1.5 milliseconds pulse width with 20 kHz frequency. 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 p- and n-type silicon 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, Damien Grenau, Bernd Schroeder 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 µc-Si:H for high efficiency solar cells was demonstrated by Klein et al. [1]. Integration of high-quality intrinsic µc-Si:H into all-hot-wire n-type solar cells, prepared close to the transition to amorphous growth, 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 deposition rates of p-type 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 filament size 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 deposition relationships on the catalyzer surface. For these modified conditions, deposition rates in the range of 2.5-10 Å/s could be achieved for µc-Si:H due to the fact that a higher silane fraction of the process gas could be used. For different wire diameters, the optimized deposition rate was experimentally determined, i.e., the electrical conductivity measurements carried out on these samples are in good agreement with the catalyzer microstructure.
temperatures, the films present good optical-properties. No powder formation was detected although some oxygen contamination was still observed. Our preliminary results show that the narrowed 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.

A0.41 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 (μc-Si:H) as a long wavelength absorber in the bottom 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 reports [1], we have shown an initial active-area efficiency of 11.9% for an a-Si:H/μc-Si:H double-junction cell. The small-area cells have an initial active-area efficiency of 13% for an a-Si:H/μc-Si:H double-junction cell. In this paper, we will present our recent progress on the development of large-area μc-Si:H single-junction and μc-Si:H/μc-Si:H double-junction solar cells. We first optimize μc-Si:H films using the conventional RF glow discharge technique on an area of 35 x 33 cm² at a relatively low rate 1 Å/s. The thickness uniformity is well within ± 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 cm² on the p layer of one large-area a-Si:H/μc-Si:H double-junction cell. The small-area cells have an efficiency distribution in the range from 10% to 12% with a peak position around 11.5%. Preliminary results from large-area a-Si:H/μc-Si:H double-junction structures show initial aperture-area efficiencies of 11.8% and 11.3% for 45 cm² and 461 cm² size-encapsulated solar cells, respectively. The 11.3% cell became 10.6% after encapsulation. Currently, we are investigating the deposition rate and reducing the μc-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).

A0.42 Measurement of the Potential Distribution in Silicon-Based Thin Film Solar Cells by Scanning Kelvin Probe Microscopy. Chen-Xun Li, Paul W. Power, Barry K. Schwarzkopf, Zhenyu Li, and K. M. Preisig; MEMS, Montgomery, PA 19066; and Institute for Polymer Science, The Ohio State University, Columbus, OH 43210.

Scanning Kelvin probe microscopy 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 (μc-Si:H). By measuring the change of the potential distribution with an externally applied electric field to the device, we are able to exclude the effect of surface Fermi level pinning and deduce 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 calculated 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 interface 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.

A0.43 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 (μc-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, especially the relatively thick intrinsic μc-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 μc-Si:H solar cells at high rates and achieved respectable results [1]. In this paper, we will report progress made in the optimization of μc-Si:H single-junction and multi-junction solar cells. An initial active-area efficiency of 10.2% has been achieved using an a-Si:H/μc-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 10.5%. Recently, we started to make a-Si/H/a-SiGe:H/μc-Si:H triple-junction cells. This structure should have a better stability than the single top cell which is much thinner than that in the a-Si:H/μc-Si:H double-junction structure. Preliminary work resulted in an initial active-area efficiency of 10.5% 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).

A0.44 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, Roy Capapangaman and Massi Izu; Energy Conversion Devices,Inc, Troy, Michigan.

The use of Al/ZnO back reflectors in the commercial manufacturing of a-Si:H based solar cells has been advocated due to the improved front and 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 d.c. sputtering under a variety of deposition conditions to achieve the desired indices of refraction and optical enhancement from the multi-layer stack while maintaining high conductivity. Both material properties for the TCO layers and the solar cell performance with this new back reflector structure will be reported.

A0.45 Dominant effect of p/i interface on dark J-V characteristics in p-i-n nano-crystalline Si solar cells. Ujwal K Das1, Andreas Bozans2, Scott W Morrison1 and Arun Madan2; 1MVSystems Inc, Golden, Colorado; 2Institut fuer Physikalische Elektronik, Universitat Stuttgart, Stuttgart, Germany.

Nanocrystalline silicon (nc-Si) based p-i-n (nc-Si:H p/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), AISI supplied Ga doped ZnO (textured) and MVS developed Al doped ZnO (textured). Dark J-V characteristics of these devices 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 = J0 [exp(eV /nkT) -1]) decreases with increase in i-layer thickness (n=1.68 for 0.9 µm to n=1.45 for 2.1 µm) for the devices deposited on Asahi TCO, suggesting an inferior i-layer quality for thinner device presumably due to grain collision [1]. On the contrary, the opposite dependence of n with device 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 µm for the devices grown on AISI/MT/SiO2 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 our nc-Si 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-Si layer and hence the whole device performance. [1] U. Das, S. Morrison, E. Centurioni, and A. Madan, IEEE Circuits Devices Symp. Proc., Vol. 150 p. 282-286 (2003). [2] S. Klein, F. Finger, R. Carius, B. Rech, L. Houben, M. Lysberg, M. Stutzmann, Mat. Res. Soc. Symp. Proc. Vol. 715 p. A26.2.1 (2002).
The thickness of the doped contact A, further increase in Ar dilution, and light soaking caused mild degradation in efficiency, indicating that optimal quality of both the superstrate and the substrate is crucial for the formation of excellent tunnel junctions for multi-junction solar cells. We demonstrated 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 mm diameter 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 (Si3N4), to protect against edge currents through passivation of the sidewalls. Contact holes were etched through the Si3N4 to the Cr and SnO2 contacts, and larger Al contacts were evaporated to form ohmic contact to 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 in previous work. In this paper, we report on the growth 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 100 to 450 Å, while the thickness of the doped i-layer 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 (120°C) and 200°C, as previous work has shown the light response of nc-Si:H to be very sensitive to the fabrication conditions. The p-i-n structures show rectification in the p-n junction i-n-i-sat, with an enhanced 'enhanced wavelength response' compared to the devices incorporating i-layers grown by HWCVD only. The nc-Si:H solar cells with Ar2, doped i-layers exhibit no light-induced degradation. Using an Ar-rich plasma, in a process much simpler than the traditional nc-Ge:H technique, doped n-Si thin layers can be prepared to form excellent tunnel junctions for multi-junction solar cells. We demonstrated 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.

**A9.48**

**Deposition of Optimal a-Si:H and a-SiGe:H by Hot Wire CVD**

Using the same Filament Temperature and Substrate Temperature, Madhav Mani1, 2, 3, X. Xu, Y. Xu, L. M. Gedvilis, and B. Yoon4, 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 i/p interface. Therein lies the difficulty in this approach, as the material needs to be profiled over a wide range of Ge content, the i-layer alloy with varied compositions, including that of n-Si:Ge (no Ge), which should have optimal quality and should be deposited under somewhat non-optimized deposition conditions.

In the present study, we employed ECR ( Electron cyclotron resonance)-CVD for enhanced deposition of a-Si:H at low Tb by using a tantalum (Ta) filament operating at low Tf. We gauge the material quality of the present films by comparing infrared, optical absorption and conductivity results to those presented earlier [1], and fabricate single junction as well as tandem n-i-p solar cells devices using these i-layers.

A9.49

**Passivation schemes for amorphous silicon (a-Si:H)/crystalline silicon (c-Si) heterojunctions for photovoltaic applications,**


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 have employed ECR (Electron cyclotron resonance)-CVD for enhanced deposition of silicon to grow undoped a-Si:H and mc-Si on crystalline substrates to form a heterojunction. A characterization reveals revealing 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 have 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 ambient, photon-assisted deposition and incorporation of excess atomic hydrogen during deposition. The paper discusses the influence of each passivation scheme 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) films. The qm-Si:H films and solar cells fabricated under ambient dilution 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 (104 cm2/Vs) as well as at light-soaked state (106 cm2/Vs), 10^4 cm2/Vs and 10^5 cm2/Vs) and the incorporation of high Ge in the structure is very fast (saturation occurs within 20 to 30 hours at 1600 mv/cm, white light at 50°C). 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 characteristics of qm-Si:H films by FTIR, XRD, SAXS, UV-VIS ellipsometry, mechanical density measurements, these films have compact nanostructure (density deficit from c-Si, 4%), very low nanovoid density (below detection limit), low H-content (CH < 8 at%) and narrow (111) peak in XRD. However, there is no amorphous silicon 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. The film is a-Si:H and the structure is hydrogenated quasi-amorphous silicon. 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/cm\(^2\) and open-circuit voltage, \( V_{oc} \), 0.90 - 0.91 Volts have been obtained for 150 - 170 nm thick i-layer, cured red 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 considered, however, the bandgap of the 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 (\( \alpha \)) of aSi:H absorber layers in solar cell configuration by infrared photo current (IRPC) measurement will be reported. The nanostructure of the films and the bandgap and optical properties and metastability will be presented. I. A. R. Middya, S. Hamma, S. Huzara, S. Ray and C. Longeaud, Mat. Res. Soc. Proc. Vol. 664 (2001) p. A9.5.1.

A9.5.1 Devices Fabrication with Narrow Bandgap a-SiGe:H Alloys

Department of Electronics, AVDI, Yueqin Xu, Boqie Yan, Brent P. Nelson, Qi Wang, Eugenio Iwaniczko and R. C. Reedy, 1 National 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 HWCVDF(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:H alloys with a narrow Taue band gap of 1.25 - 1.30 eV. These materials have a Ge content in the range of 20 - 30% at the front of the ETP, 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. %) 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/cm\(^2\) with a poor fill factor (FF) of 38%, this is due to excessive recombination. Therefore we 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. 400 (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. 702 (2003), A10.2.

A9.5.2 Microstructure and Thickness Optimization of a-nc-Si:H Tandem Solar Cells.

Andrzej Kolodziej and Pawel Krewnicki, Department of Electronics, AGH University of Science and Technology, Krakow, Poland.

In this paper we present the latest experiments on the field of amorphous and microcrystalline silicon thin film tandem solar cell constructions. The deposition of microcrystalline film structure was performed at high pressure and high plasma power resulting in high (up to 6A/s) deposition rates on ZnO covered glass substrates. The structure of crystalline fraction of ETP was studied by Cross Section Transmission Electron Microscopy and Grazing Incidence X-Ray Analysis. It was carried out analyzes of FF, \( V_{oc} \), \( J_{sc} \), and the FF of these cells, cured red 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 considered, however, the bandgap of the 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 (\( \alpha \)) of qm-Si:H absorber layers in solar cell configuration by infrared photo current (IRPC) measurement will be reported. The nanostructure of the films and the bandgap and optical properties and metastability will be presented. I. A. R. Middya, S. Hamma, S. Huzara, S. Ray and C. Longeaud, Mat. Res. Soc. Proc. Vol. 664 (2001) p. A9.5.1.

A9.5.3 Correlation of Material Microstructure and Device Performance in Nanocrystalline Silicon Solar Cells.

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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. We used 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 to probe the electronic 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.
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 Si waveguide laser. Amorphous Si-incorporate much higher concentrations of Er, and its continuous random network structure enables the structural flexibility to engineer the local environment of the Er magnetic ions by coordination with oxygen. The Er-O bonds, in this amorphous Si matrix, transform 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 Er-doped laser devices. Thermal annealing of the material provides the proper coordination for Er, enabling a high luminescence quantum efficiency and no temperature quenching. The Si quantum dots serve as a source for their amplification, which are located in the growing oxide and the buried oxide and the size and spatial density of the nanocrystals is determined by the conditions of thermal oxidation. 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/SiGe/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. 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 locally determined. These 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 cm2) could be achieved by selective oxidation of Si0.85Ge0.15/SiO2 structures. 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 Si nanocrystal sensitized Er-doped Si nanocrystal waveguide laser, based on both linear waveguide or microresonator designs.

9:00 AM A10.2
Fabrication and Characterization of a Germanium Quantum-dot Transistor Formed by Selective Oxidation of SiGe/On-In-Sulator. Pei-Wen Li and Wei-ming Liao; Electrical Engineering, National Central University, ChungLi, Taiwan.

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 electronic 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 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. Jing-Ping Lu, K. Van Schaeybroeck, J. Ho, Y. Wang, C.W. Shih and R. A. Street; Palo Alto Research Center, Palo Alto, California.

Flat panel imagers (FPs) have become an important application in the arena of large, 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 complete two-stage single pixel level amplifiers. Each individual pixel imager consists of a 128 by 128 array of 150 μm 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, together with the pixel level amplifier, 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.

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) electrical crosstalk is a major concern in their acceptance, due to degraded spatial contrast and color fidelity. If the SWE is a fundamental mechanism of an a-Si:H, solutions to this issue must look to ways of mitigating the SWE on devices and processes other than the 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 component of the crosstalk signal. In addition, a CMOS-compatible structure to suppress electrical crosstalk was designed and fabricated. Results from these structures demonstrate suppression of crosstalk up to lateral electric fields of at least 2 x 10^5 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 pixel sensors.
Nicolas Wyrsch¹, Clement Miazza¹, Sylvain Dunand¹, Arvind Shah¹, Danielle Moraes², Giovanni Anelli³, Matthieu Despeisse³, Pierre Jarran³, Guenther Dissertori³, and Gert Vierdt³, ¹Institute 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 silicon-based 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 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 50um) have been developed. They have been first deposited on glass substrates and subsequently on several different types of CMOS readout circuits. 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, we report the results obtained on the first of these detectors, with novel, vertically-integrated a-Si:H sensors will be presented. Their performance, limits and future potential will be discussed. [1] S. Benthien et al. 10th Workshop on Silicon and Silicon Compounds, University of Neuchatel, Neuchatel, Switzerland. [2] N. Wyrsch 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 backbone with polymer MEMS structures for electroplating displays. Jürgen Daniel¹, Brent Krusor², Naveen Chopra³, 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 electroplating 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 electroplating media there are important tasks to solve regarding the packaging and the electronic addressing of the electroplating ink. Addressing issues become more important the more sophisticated the displayed image has to be. Direct addressing is 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 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) a change in the alignment of the cells to the pixels is achieved with the lithography tool. The photore sist pattern separates the electroplating ink into cells which prevent settling and clogging of the small 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 electroplating ink. As an alternative, photolithography we have employed micromolding to form the cell pattern. The counter electrode for the display was ITO coated glass. In contrast to microcapsulated electroplating displays, our approach allows us to vary cell geometry in relation to the effect on the visual appearance of the display. Furthermore, we were able to test the interaction of the electroplating ink with various surface coatings. Concerning the amorphous silicon backbone, the effect of a black surface coating was investigated. Although the electroplating 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 Gaspar¹, Virginia Chu¹ and Joao Condé¹, 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 inorganic and functional nanomaterials. A range of MEMS structures is fabricated from thin-film amorphous silicon (a-Si:H) or micro bridges 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 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 f0*, and Q-dependences on the geometrical dimensions of the structures 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-n nc-Si:H fabricated at 100° C by hot-wire CVD, and using a polymer sacrificial layer (f0* up to 25 MHz and Qvalues as high as 1200). The performances and dissipation mechanisms of the nc-Si:H and nc-Si:H-based resonators are compared.

11:45 AM A10.10
Threshold Voltage and Field for Metal Filament Formation in Hydrogenated Amorphous Silicon. Paul Strading¹, Howard M Branz¹, Warren B Jackson², Richard S Cran dall², Jian Hu² and Qi Wang²; ¹National Renewable Energy Laboratory, Golden, Colorado; ²Howlett Packard Laboratories, Palo Alto, California.

Electrical switching due to metallic filament formation in metal/hydrogenated amorphous silicon/metal structures is an interesting nonlinear phenomenon that could be used as a basis for new electronic 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) a change in the alignment of the cells to the pixels is achieved with the lithography tool. The photore sist pattern separates the electroplating ink into cells which prevent settling and clogging of the small 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 electroplating ink. As an alternative, photolithography we have employed micromolding to form the cell pattern. The counter electrode for the display was ITO coated glass. In contrast to microcapsulated electroplating displays, our approach allows us to vary cell geometry in relation to the effect on the visual appearance of the display. Furthermore, we were able to test the interaction of the electroplating ink with various surface coatings. Concerning the amorphous silicon backbone, the effect of a black surface coating was investigated. Although the electroplating 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.