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 silicon thin film transistors. Ralf B. Wehrspohn, Martin J. Powell, Shuuan Lan, Andrew J. Flewitt and William Milne, 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 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 D and H in the plasma. However, deuterated and hydrogenated TFTs deposited at the same stress rate have almost identical structural properties. Hydrogenated and deuterated TFTs are found to exhibit the same variation in stability as a function of gate voltage. 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.

9:30 AM *A1.3/H1.3
Hydrogen in amorphous Silicon: A simple Atom in a complex Environment, Martin Stottermann, Walter Schottky Institute, Technische Universität München, Garching, Germany.

Historically, the scientific interest concerning hydrogen in semiconductors to a large extent has been triggered by the beneficial role which hydrogen plays in hydrogenated amorphous silicon (a-Si:H) as a chemical terminator of silicon dangling bonds. However, it was almost immediately realized that the hydrogen content in device quality a-Si:H is much larger than what would be necessary to just terminate dangling bonds. Thus, the influence of 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. This purpose of this contribution is to emphasize the role which hydrogen has played in our present understanding of hydrogen in silicon, and to point out some central unresolved questions concerning fundamental effects of hydrogen in a-Si:H (defect passivation, doping efficiency, metastability).

SESSION A2: Metastability
Chair: Eric Schiff
Tuesday, 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. Timung Su, P. Craig Taylor, Goutam Ganguly, Dave Carlson and Friedhelm Finger; 2 Physics, University of Utah, Salt Lake City, Utah; 3BP Solar, Toano, Virginia; 4Institute of Photovoltaics, Research Center Jülich, Jülich, Germany.

We have previously investigated the metastable Staebler-Wronski effect in hydrogenated amorphous silicon thin films prepared by PECVD with pure silane [1]. We found that after irradiation with light, there exist paired-hydrogen sites whose densities are consistent with those of the silicon dangling bond defects measured by ESR. These hydrogen pairs can be annealed at the same temperatures as the metastable dangling-bond defects are annealed. In 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. This purpose of this contribution is to emphasize the role which hydrogen 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).

In an attempt to fulfill the predictions of Mooser Law, the silicon defect community is turning increasing increasing attention on nano- and microcrystalline silicon (Si nanowires and Si nanotubes) and the 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 2002, pp. 771-4 and H. Shang et al., IEEE Electron Device Lett. 24(4), 242-4 (2003).

8:30 AM OPENING REMARKS

8:30 AM *A1.1/H1.1
Hydrogen in Silicon and Germanium: Dopant Activation and Passivation. Eugene E. Haller, MS&E, UC Berkeley, Berkeley, California; 2Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California.

In an attempt to fulfill the predictions of Mooser Law, the silicon defect community is turning increasing increasing attention on nano- and microcrystalline silicon (Si nanowires and Si nanotubes) and the 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 2002, pp. 771-4 and H. Shang et al., IEEE Electron Device Lett. 24(4), 242-4 (2003).

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

The Staebler-Wronski effect, which is a decrease in the photo- and dark-conductivity in amorphous hydrogenated 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 to this conjecture has been elusive. We have reported an NMR signal in a-Si:H that occurs only after light soaking for 600 hours [3]. This signal, which is attributed to a pair of hydrogen atoms, exhibits similar annealing kinetics to that of the metastable dangling-bond defects. The distance between the two hydrogen atoms, exhibits similar annealing kinetics to that of the metastable dangling-bond defects. The distance between the two hydrogen atoms, exhibits similar annealing kinetics to that of the metastable dangling-bond defects. The distance between the two hydrogen atoms, exhibits similar annealing kinetics to that of the metastable dangling-bond defects. The distance between the two hydrogen atoms, exhibits similar annealing kinetics to that of the metastable dangling-bond defects. The distance between the two hydrogen atoms, exhibits similar annealing kinetics to that of the metastable dangling-bond defects.
similar deposition conditions. The implication of our experimental results is that, for the same amorphous network and hydrogen/dideuterium concentration, the mechanism induced defect is identical for hydrogenated and deuterated TFTs. This is consistent with the idea that Si-Si bond breaking is the rate limiting step for Si dangling bond defect creation, rather than Si-H bond-breaking [1].

The Time Resolved Microwave Conductivity technique (TRMC) was used to study the damage induced in hydrogenated amorphous silicon (a-Si:H) by irradiation with 3-MeV electrons. We aim to use these results in a computer model to predict the results on the annealing kinetics of solar cells under electron irradiation when applied in a space environment. With this technique a single 10 ns electron pulse is used to create excess charge carriers in the material, leading to an increase in conductivity. The magnitude and decay of the radiation-induced conductivity is monitored from nanoseconds to milliseconds using 30-GHz microwave detection equipment. The sample is then subjected to a large radiation dose by repetitive pulsing after which the single-pulse measurement is repeated. This procedure was repeated with increasing amounts of accumulated dose up to a maximum of $2 \times 10^{15}$ cm$^{-2}$. The main advantages of the technique are that it is contactless and the collected dose is monitored continuously in the TRMC sample cell. Furthermore, the measurement gives quantitative information on the electron mobility and various recombination and trapping processes in the material. The electron mobility, which was estimated to be $1500 \mathrm{cm}^2 \mathrm{V}^{-1} \mathrm{~s}^{-1}$, was not affected by the radiation dose. The rate of decay of the conductivity however increased by up to a factor of 10 for the highest dose, indicating an increase in defect density in the material. Information on trapping, band-to-band recombination and recombination via defects can be derived from the measurements. After high radiation doses trapping and defect recombination appeared to be dominant over band-to-band recombination. The increase in the overall recombination and the dominance of trapping and defect recombination over band-to-band recombination indicates a large increase in the defect density after irradiation. As expected, the irradiated a-Si:H returned to its pristine condition after annealing at 180°C for 30 minutes. A new model based on SRH recombination statistics is developed to analyze the TRMC measurements further in order to be able to distinguish between trapping and defect recombination and to get a more quantitative view of the processes involved. Preliminary results show an increase in the density of states in the mobility bandgap by a factor of 5 after a $2 \times 10^{15}$ cm$^{-2}$ irradiation.

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

Janica Whisker, John Viner, Stefan Zukotynski, Nazir Kherani, Erik Johnson, P Craig Taylor and Paul Strachan

1Physics, University of edmonton, Edmonton, Alberta Canada; 2Computer 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 of these defects 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 He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. Tritium decays to He$^3$, emitting a beta particle (average energy of 5.7 keV) and an antineutrino. This reaction occurs at a rate of $12.5 \times 10^6$ per year. We have investigated the intrinsic growth of defects in tritiated a-Si:H as an alternative approach to inducing defects optically. 

The evolution of DO and non-Do Light Induced Defect States in a-Si:H Materials and Their Respective Contribution to Carrier Recombination with John Viner, Yimin Vinger, J Deppe, R W Collins, C R Wronski, J Whisker and P C Taylor

1Center for Thin Film Devices, Penn State University, University Park, Pennsylvania; 2Physics, University of Utah, Salt Lake City, Utah.

Despite over twenty-five years of scientific studies on light induced defects in hydrogenated amorphous silicon (a-Si:H) materials and solar cells there are still outstanding questions regarding their nature. The existence of distinctly different light induced gap states in a-Si:H has been clearly shown in the results on the annealing kinetics of solar cells and thin films after high intensity light degradation [1,2]. A study has been carried out in which the significant differences in both the kinetics and the corresponding evolution of distinctly different light induced defect states are characterized. This has been accomplished by taking into account the presence of more than one type of defect state, the neutral dangling bond (D$^0$), as has been generally done in the past. In this approach, the complete subgap absorption spectrum, of(hv), measured with photocapacitance, is characterized rather than the commonly used method of tracking only the magnitudes of $(a(hv))$ at a single and somewhat arbitrary energy [3]. Under 1 sun illumination, the creation of defect states has been clearly identified, one attributed to the accumulation of DO $(a(hv))$ at the conduction band, which have distinctly different creation kinetics that also depend on the microstructure of the material. To identify the D$^0$ defect states, direct comparisons are made between the evolution of the full DBP spectra with that in the densities of D$^0$ states measured directly with electron spin resonance (ESR).


H evolution from nano-crystalline silicon- comparison of simulation and experiment, Bana Biswas and Bicai Pan

1Dept. of Physics, Microelectronics Res Ctr. & Ames Lab, Iowa State University, Ames, Iowa; 2Southwest National Laboratory, University of Science and Technology of China (USTC), Hefei, China.

The temperature dependent H evolution from a-Si:H provides unique information on the H-bonding and microstructure. Traditional undoped a-Si:H films show a high temperature H-evolution peak near 600°C. However device-quality compact nanocrystalline silicon films grown near the phase boundary of amorphous and microcrystalline silicon show a new low temperature H-evolution peak near 500°C in addition to a second high temperature peak near 600°C. The origin of this peak cannot be attributed to microvoids or a substantial density of dihydride species typical of porous low-temperature films. We have simulated the H-evolution in a molecular dynamics model of nanocrystalline silicon, where nano-crystallites reside in a background amorphous matrix. An excess density of H occurs at the crystallite surface. The models are heated to successively higher temperatures and the motion of H is monitored. We find a low temperature evolution peak at 250-400 °C, where the H-evolution starts from the surface of the nano-crystallite. In addition there is a higher temperature peak at 700-800 °C providing good agreement with H-evolution measurements. The mobile H is found to exist in both the bond-centered type of species and H2 molecules, which has implications for H-diffusion models. We will also discuss the thermal stability of the nano-crystallites. Supported by NREL.

For applications to a system on panel (SOP), a high-performance poly-Si thin-film transistor (TFT) is desirable. Excimer laser annealing (ELA) of a-Si film is a promising crystallization method. However, the performance of poly-Si TFTs formed using conventional ELA is limited due to small grain size and randomly located grain boundaries (GBs) which act as potential barriers for carriers. Therefore, a technique has to be developed to control the location of GBs and avoid GBs in the TFT channel. We propose a novel approach to form position-controlled Si grains by using a-Si precursor film having convex regions of several μm. In this way, high-performance TFTs are achieved. A 47-nm-thick a-Si layer was deposited on a glass substrate. A pattern of the laser 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 430 to 460 mJ/cm² in N2. The laser spot was scanned at 1000 Hz. "Electron Backscatter Pattern (EBSP) analysis indicated that (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 (111)-oriented grains were observed in the film. GBs are thought to be electrically inactive, unlike random GBs[1] and might not degrade TFT characteristics significantly. 2-D numerical analysis revealed that there is a concave temperature profile across the convex region and the temperature drop is estimated to be about 100K with a thickness difference of 7nm. This is because the thicker convex region has a larger heat capacity than the adjacent thinner region. Preferential nucleation, that is control of the location of GBs, 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 of 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 film is crystallized region is composed of small (edge of the pattern), large (long) grains, and very large grains (center of the pattern, we called it GBs and avoid GBs in the TFT channel). We propose a novel approach to position control of Si grains for a high-performance TFT using an excimer laser. "K. Nakano, Y. Hitadivi, M. Sinomi, N. Hatada, N. Sato, H. Minematsu, S. Kajiyama. Oita, Japan."

In recent years, polycrystalline silicon thin-film transistors (poly-Si TFTs) have been extensively investigated for applications in large-area electronics, especially for switching devices or peripheral driving circuits in active matrix liquid crystal display (AMLCD). In order to realize low-cost AMLCD with integrated peripheral circuits, it is essential to reduce the maximum process temperature for high-performance TFTs. Two annealing steps are adapted in the fabrication process of poly-Si TFTs; one is post-annealing of amorphous silicon (a-Si) and the other is post-implantation annealing. Active region composed of amorphous silicon (a-Si) was crystallized by femtosecond laser annealing (FLA) using infrared femtosecond Ti: sapphire lasers. Non-thermal melting on transparent a-Si to poly-Si was induced by the intense peak power of infrared ultrafast laser pulses which leads to non-linear photo energy absorption and generation of very dense photexcited plasma. FLA assisted by sequential lateral solidification constitutes super lateral epitaxy that can crystallize amorphous silicon into polycrystalline silicon with large grains of ~1micrometer, even when a-Si films are irradiated at an ultralow laser fluence of 45 mJ/cm², and low laser-scalets. The shear resistance of post-implant annealing of amorphous silicon decreased from 10,000 omegas/square to 300omegas/square. The traditional TFT process typically uses a top gate self-align TFT architecture with FLA. FLA activation reduces not only the postannealing temperature but also the resistance of source and drain regions, which helps improve the mobility and differential thermal expansion like shape process conditions. Shrinking and warping calls for pre-process bake. Layers must be
made to adhere strongly, to withstand shear caused by thermal contraction. Electronics that just need to flex can be made on substrates that are fabricated inside a grain (grain-filter) process using the entire fabrication process. To the process steps this later makes the substrate material look like the passivating material. Fortunately SiNx and SiO2 work well as adhesion and passivating layers, and allow using standard fabrication processes that can be shaped or deformed reversibly pose a much bigger process challenge. At some point in fabrication the deformable or elastic substrate must be exposed, which means that the passivation layer must be removed. To improve the properties of TFTs, heat treatments of various temperatures are done after fabrication. These treatments can be done at different gates, allowing for a more accurate patterning than the mechanical one and (3) solid thin film transistor, i.e. single-crystalline Si TFTs (c-Si TFTs). TFT properties don't change before and after the transfer process.

4:00 PM A3.7/12.7 Temperature Dependent Carrier Transport in Single Crystalline Si TFTs inside a Location-Controlled Grain.

Precise location-control of a grain in excimer-laser crystallization processes must be guaranteed. We present a new type of system architecture (1) to fabricate TFTs having W/L of 3.21/2.88 μm, were fabricated inside a grain with top gate, were fabricated inside a location-controlled grain by I’-Czochralski process for a flexible production system. SUFTLA, which stands for “Surface film formation by controlling a movement of solute which is caused by substrate to any secondary substrate by irradiating the laser to an substrate material look like the passivating material. Fortunately substrate. The advantage of this technology over a direct fabrication enable TFTs and TFT devices to be transferred from the original enable us to realize flexible devices but also give us a versatile means of TFT on a plastic substrate is that the well-matured conventional TFT fabrication process is divided into three major steps: (1) liquid metals, liquid semiconductors, liquid ceramics and organic materials in a liquid form. Devices using organic materials were first explored, and then followed by inorganic materials. In the MLP process which includes an inkjet technology as an important contact on elastomeric substrates. We also present the electrical performance of the inverter circuits prior to, during, and after 3D mechanical stretching.

4:30 PM A3.8/12.8 Elastic integrated circuits on elastomeric skin.

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 describe the first stretchable integrated circuits made of thin film transistors (TFTs) on elastomeric membranes, and interconnected with stretchable gold conductors. We are beginning to fabricate stretchable gold conductors which are robustly connected to the electrodes. Measured TFTs made using poly-Si TFTs, which have gained the required performance, were also directly patterned by inkjet so as to form active load inverter circuits. We describe the complete fabrication process, including the application of reliable electrical contacts on elastomeric substrates. We also present the electrical performance of the inverter circuits prior to, during, and after 3D mechanical stretching.
deposition technique, which allows an increase in the electron density during the 'ON' cycle, thus allowing the deposition rate of amorphous silicon (a-Si) to remain high in the 'OFF' cycle for dust formation in the plasma are neutralized. We show that high quality micro- (or nano) crystalline Silicon can be produced using a modified pulsed PECVD technique. In particular, at a deposition temperature as low as 150 °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 films can be altered from 111 to 220 in a controllable way and is useful for fabricating nc-Si TFT's with high field mobility, especially on low cost flexible substrates. (1) US patent #5,258,408B1: Semiconductor Vacuum Deposition System and Method having a Reel to Reel Substrate Cassette.

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

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

A4.1 Gate Overlapped Lightly Doped Drain Poly-Si TFTs With 45 ° Tilt Implant For Source and Drain. Jae-Hoon Lee, Moon-Young Shin, Hee-Sun Shin and Min-Koo Han; School of Electrical Engineering #50, Seoul National University, Seoul, South Korea.

Polycrystalline silicon thin film transistors (poly-Si TFTs) recrystallized by excimer laser annealing (ELA) are widely used for various display applications. Poly-Si TFT with a short channel makes it possible to use small-sized AMLCD and AMLED. 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 (GOLD), have been 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 region. GOLD poly-Si TFT has higher on current compared with a conventional LDD due to the reduction of effective channel length. However, it is well known that GOLD poly-Si TFT requires a complicated process such as poly-Si sidewall gates or an additional photolithographic process. The purpose of our work is to report a simple and self-aligned 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 region may be formed because a gate oxide on the GOLD region would be able to behave as the buffer layer during implantation of the source/drain (S/D) region. We also employ oblique incidence 45 ° tilt implant to activate both the S/D and GOLD region simultaneously. The laser beam is irradiated with oblique angle of 50 ° in order to eliminate the implant damage considerably. The proposed poly-Si TFT with W/L=10μm/3μm shows very small anomalous leakage current (VGS=15V, VGS=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, since VDS=10 V and VGS=15V+2V. The proposed poly-Si TFT exhibits a high mobility of 92cm²/Vsec, compared with conventional one of 139cm²/Vsec, because oblique 45 ° tilt implant decreases the leakage current by using a simple 45 ° tilt implant and oblique incident ELA activation.


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 the spike-ON cycle for dust formation in the plasma are neutralized. We show that high intensity of the a-Si matrix or the amorphous state is altered. In the site, at least one crystallite survives the spike-ON cycle for dust formation in the plasma are neutralized. We show that high quality micro- (or nano) crystalline Silicon can be produced using a modified pulsed PECVD technique. In particular, at a deposition temperature as low as 150 °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 films can be altered from 111 to 220 in a controllable way and is useful for fabricating nc-Si TFT's with high field mobility, especially on low cost flexible substrates. (1) US patent #5,258,408B1: Semiconductor Vacuum Deposition System and Method having a Reel to Reel Substrate Cassette.
CW Argon-ion laser initiated Aluminum Induced Crystallization (AIC) of magnetron-sputtered amorphous silicon (a-Si) films was investigated. Amorphous silicon (a-Si) and Al films were deposited by sputtering on silicon or glass substrates. Two structures were prepared: aluminum first (Al/a-Si) and silicon first (a-Si/Al) sequences. A CW Argon-ion laser was used to initiate the crystallization process. The surfaces 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 320 cm⁻¹ was observed. To study the effect of Al in the crystallization process, new samples were prepared with only a-Si on glass without Al. In this case, no crystallization was observed even when the samples were irradiated using the highest power density. The results show that the lasers can be used as a new excitation source in the Metal Induced Crystallization (MIC) process instead of conventional thermal annealing.

**A4.6 Self-Aligned Thin Film Transistors of Nanocrystalline Silicon.**

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

Nanocrystalline silicon (nc-Si:H) is a candidate for CMOS on plastic substrates. Fast CMOS circuits require self-aligned gates. However, plastic demands ultralow process temperatures (150°C or less) that prohibit the conventional self-aligned process of ion implantation followed by a high temperature anneal. Here we show that direct deposition, combined with lift-off 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 1275 glass substrates. The sequence is intrinsic nc-Si:H seed layer / SiO₂ buffer layer / Cr bottom contacts / doped nc-Si:H / intrinsic nc-Si:H channel / gate dielectric / Al top contacts. The Cr bottom contacts and the doped nc-Si:H source / drain patterns are defined in a single photolithographic step. The top gate Al contact metal is deposited on lift-off photoresist, which is patterned by exposure through the Cr source / drain contacts that act as masks. This aligns the gate metal with the doped nc-Si:H source / drain regions, the source can be controlled by over-etching of the lift-off photoresist pattern. Atomic force micrographs show 1 mm source / drain - gate overlap out of 40 mm gate length. TFTs fabricated in this structure have electron mobilities 25 cm²/Vs. We acknowledge support by DARPA, NJCST and the Princeton Plasma Physics Lab.

**A4.7 Fabrication and Characterization of Hydrogenated Amorphous Silicon Bipolar Thin Film Transistor (B-TFT).**

Yue Kuo, Yu-Lei and Helinda Nomimanda; 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 higher speed and larger current driving capability, a potential solution is to fabricate a-doped Bi-TFT. In this study, a-Si:H p-n junctions were prepared directly 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++ were fabricated. The complete TFT was made using PECVD to deposit all doped layers using SiH₄/H₂ mixture and wet etching methods were used to define base and emitter regions and contacts. The extensive characteristics of the complete B-TFT were investigated. The measured common-emitter current gain β was 3.5, which is significantly larger than the theoretical value of 1 [1]. 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 parameters on the TFT performance. This research is supported by NSF (ECS-0236935).

**A4.8 Bottom-Gate TFTs with Nanocrystalline Silicon Channel Grown by Pulsed PECVD Technique.**


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

**A4.9 Microcrystalline-Si Thin Film deposited By Inductively Coupled Plasma Chemical vapor deposition (ICP-CVD).**

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

Microcrystalline(μc) Si thin film transistor (TFT) may be a promising device for various application including flat panel display due to rather simple process compared with poly-Si TFT and good performance compared with a-Si TFT. Conventional plasma enhanced chemical vapor deposition (PECVD) method has been widely reported to deposit μc-Si film. In PECVD, the dilution ratio (SiH₄/H₂) of the process gas would be very low, so that deposition rate is not high. Furthermore the grain size of the μc-Si film deposited by PECVD is not large (typically less than 15nm) due to inherent ion bombardment which may suppress the grain growth during the deposition. The purpose of this work is to report μc-Si TFTs grown by inductively coupled plasma chemical vapor deposition (ICP-CVD) suitable for low temperature TFTs. ICP-CVD employs remote plasma, so that trouble some ion bombardment problems may be reduced. ICP-CVD may also provide a certain advantages such as high deposition rate and improved crystallinity over PECVD. We deposited μc-Si film by ICP-CVD with various process temperatures, processing gasses and ICP power. The process temperature was varied from 150°C to 280°C. ICP power was 100W, 250W, 450W and 600W respectively. The process gas was SiH₄ diluted with He as well as H₂. The flow rate of He, H₂ and He/H₂ mixture was fixed at 20sccm while the ratio of SiH₄ was 8sccm. The crystalline volume fractions evaluated from the Raman spectrum of the μc-Si film were above 70% in all films. By Raman spectra, we observed the transition from amorphous phase to crystalline phase in the μc-Si film only have occurred. At the location of phase transition in the μc-Si film was observed at the 10nm 30nm from the bottom of the μc-Si film. The grain size of 40nm was observed in the film deposited 250°C in our experiment by SEM. The deposition rate increased with increasing ICP power, which indicates that high power plasma chemistry is used as a heat source and results in more radicals which participate in the crystal growth. Our experimental results show that μc-Si film deposited by ICP-CVD may be suitable for active layer of μc-Si TFTs.

**A4.10 Advanced SLS Crystallization Method for Low Temperature Poly-Silicon Thin Film Transistors.**

Ji-Yong Park, Hye-Hyang Park, Ki-Yong Lee, Hye-Dong Kim and He-Kyuom Chung; Technology Development Team 1, SAMSUNG SDI, Yongin-City, Gyeonggi-Do,
Sequential lateral solidification (SLS) is known to be a promising method to make low temperature poly-Si thin film transistors with superior performance for fabrication of highly circuit-integrated flat panel displays such as TFT LCD or AMOLED. In this work we studied the dependence of TFT characteristics on SLS chord length and 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 convex mask showed various properties on the poly-Si microstructures. We made the nearly channel direction independent TFTs of mobility about 400 cm²/V.s by controlling 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 mobility increases with temperature. While these results directly support the SLS poly-Si circuit pixels 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 temperature stress response of 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 mobility of the SLS TFTs. The temperature dependence of the mobility was measured over the temperature range from 0 to 100 °C. These measurements are used to develop a model of the temperature dependence of the mobility of the SLS TFTs. The temperature dependence of the mobility was measured over the temperature range from 0 to 100 °C.

**A4.11 Accelerated Stress Testing of a-Si:H TFT Pixel Circuits for AMOLED Displays.** Kapil Sakariya, Clement K. M. Ng, I-Heng Huang, Sheng Tao and Arokia Nathan; Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

Threshold voltage (Vth) shift in amorphous silicon (a-Si:H) thin film transistors (TFTs) due to extended periods of electrical stress critically affects the performance and operational lifetime of a-Si:H based active matrix organic light-emitting diode (AMOLED) pixel circuits [1].

A current programmed pixel circuits, lifetime measurements can last thousands of hours, hence it is desirable to develop an accelerated stress testing method to test the AMOLED pixel circuits. 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 Vth-shift increases with temperature. While these results directly support the SLS poly-Si circuit pixels 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 Vth-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 Vth-shift in TFTs. The temperature dependence of the Vth-shift in TFTs is measured over the temperature range from 0 to 100 °C. These measurements are used to develop a model of the temperature dependence of the Vth-shift in TFTs. The temperature dependence of the Vth-shift in TFTs is measured over the temperature range from 0 to 100 °C.

**A4.13 Statistical Modeling of Grain-Enhanced Polysilicon Thin-Film Transistor in Consideration of Grain Boundary Distribution.** C. F. Cheng, M. C. Poon, C. W. Mao and Mansun Chan; Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Hong Kong, Hong Kong.

Polysilicon thin-film transistor (TFT) is a promising technology used on system-on-panel (SoP) for flat panel display application and 3-dimensional circuit integration. Grain boundary in the device channel would degrade the performance of the TFTs. 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 Vth-shift accelerating effects of high current stress. Using a combination of both high temperature and high current stress, we have obtained a acceleration factors close to 5, thereby reducing the required testing time for product lifetime of a-Si:H pixel circuits to around 1000 hours. We have characterized the Vth-shift in TFTs subjected to constant current stress at temperatures ranging from 0 to 100 °C.

**A4.14 Intrinsically Doped μc-Si/TFT Layer Using 13.56 MHz PECVD at 250 °C.** Chang-Ho Lee, Dennis Strachilch and Arokia Nathan; ECE, University of Waterloo, Waterloo, Ontario, Canada.

Undoped and n-type hydrogenated microcrystalline silicon (μc-Si:H) films were deposited at a temperature of 250 °C with 99 + 0.6% hydrogen dilution of silane by conventional 13.56 MHz chemical vapor deposition (PECVD) in a commercial multi-chamber deposition system for thin film transistors (TFTs). High crystallinity μc-Si:H films were achieved at 99.8% hydrogen dilution and at low RF power (10 W). An undoped 80 nm thick μc-Si:H film showed a high conductivity of an order of 10⁻² S/cm, a photosensitivity of an order of 10⁻² A/cm²/V and a leakage current of an order of 10⁻¹⁰ A. A TFT structure with silicide (μc-Si:H) gate dielectric and n-type μc-Si:H contact layers was used to study the effect of intrinsic μc-Si:H character on TFT characteristics. Detailed results pertinent to μc-Si:H material properties along with characterization of top and bottom gate TFT structures will be presented.

**A4.15 Low-Temperature (<150°C) Doping Techniques for Polysilicon TFT’s.** Wan-Sick Hong¹, Seunghee Han³, Yeonhee Lee¹, Youngwoo Kim² and Jongman Kim²; ¹Dept. of Electronics Engineering, University of Seoul, South Korea; ²Advanced Analysis Center, Korea Institute of Science and
Polyisilicon (poly-Si) thin film transistors (TFTs) constructed on plastic substrates are an essential component for active matrix, flexible displays. In general, most of the flexible substrates have relatively poor thermal resistance, and the process temperature must be kept below the glass transition temperature of the plastics, usually under 150°C. The doping process for source-drain contacts, as well as the various films used, must be conducted below this temperature. In this work incorporation of the dopant atoms into the poly-Si film was performed using three different methods: dopant layer deposition, plasma immersion, and ion shower. The dopant layer method was to deposit a very thin (<0.014 μm) 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 energy was used to place the poly-Si films in the sheath region of dopant plasma and to apply pulsed bias on the substrate to attract dopant ions. During this process the substrate temperature is held at room temperature. The standard ion shower technique was also carried out as a reference. The doped poly-Si films were then subsequently annealed with the XeCl excimer laser to electrically activate the incorporated dopant atoms. Influences of the dopant layer thickness, the ion dosage in the plasma, and the laser energy on the sheet resistance were studied. Sheet resistance values smaller than 10 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 films. For an initial ion dosage higher than 1x10^15 cm^-2, the lowest attainable sheet resistance was not affected much by the ion dose or by the substrate temperature during the dopant incorporation. In summary, doping and activation process on poly-Si layers was successfully performed at a sufficiently low temperature so as not to cause a thermal damage to the plastic substrate, and a sheet resistance value as low as 300 Ω/sq. was accomplished.

A4.16 Making silicon device platforms on an elastomeric substrate. Joyelle Elizabeth Jones and Sigurd Wagner; Electrical Engineering, Princeton University, Princeton, New Jersey.

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

A4.17 Low Temperature (75°C) Hydrogenated Nanocrystalline Silicon Films grown by Conventional Plasma Enhanced Chemical Vapor Deposition for Thin Film Transistors. Czang-Ho Lee, Andrei Saxenov and Arkadi Nathan; ECE, University of Waterloo, Waterloo, Ontario, Canada.

Hydrogenated nanocrystalline silicon (nc-Si:H) is promising due to its relatively higher carrier mobility and higher electrical stability compared to the amorphous counterpart (a-Si:H). In addition, this material can be grown on flexible and lightweight substrates such as plastic films at low temperatures (<150°C). Hydrogenated nanocrystalline silicon has intrinsic material properties. The goal of the present work is to develop high-grade undoped and highly phosphorous doped (n+) nc-Si:H films as channel layers and as ohmic contact layers, respectively, for low temperature screen printed thin film transistors (TFTs). All nc-Si:H films in this study were deposited on Corning 1737 glass substrates at a deposition temperature of 75°C using a conventional 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) reactor. RF power density varied from 0.6 to 6 W/cm^2. PECVD gas mixture concentration was tuned to control the growth rate and deposition pressure. To optimize the deposition conditions, and to study the thickness dependence and the annealing effect on nc-Si:H films, electrical conductivity, optical absorption spectra, Raman scattering, and XRD measurements were carried out. Nanocrystallinity in film structure was observed over the entire RF power density range and optimized films were achieved with a moderate RF power density regime (<100 mW/cm^2) and growth rate (0.4-4.0 Å/min). The 80 nm thick undoped nc-Si:H films show a dark- conductivity of 3x10^-6 S/cm and 0.3 S/cm, respectively, and corresponding crystallinity of 75 % and 72 %. The post-deposition annealing effect on dark and photo-conductivities of undoped nc-Si:H was also studied. It was found that both the dark and photo-conductivities increased after annealing in vacuo and then slowly decrease to the initial value within several hours in air. This effect seems to be independent of annealing temperature and time. Possible reasons for this metastability and details pertinent to this phenomenon will be presented.

A4.18 Low Temperature a-Si:H TFTs with a SiO2 Gate Insulator Deposited by Liquid Phase Deposition. R. R. M. Cross, D. P. Osey and E. M. Sandeen; Nanyang Technological University, Singapore; 2Center for Nanoscience and Nanotechnology, Singapore; 3National University of Singapore; 4MCP, IMEC, Leuven, Belgium; 5IMEC, Leuven, Belgium; 6NTU, Singapore.

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). Conventional a-Si:H and the gate insulator material are deposited by plasma enhanced chemical vapor deposition (PECVD) at deposition temperatures greater than 300°C. In this work we desire to improve process compatibility with inexpensive, flexible substrates has initiated great efforts by many workers to develop device quality layers at reduced substrate temperatures. In this paper, we describe the film properties and device characteristics of a-Si:H TFTs with silicon dioxide (SiO2) as the gate insulator, deposited by liquid phase deposition (LPD). The active and doped layers of a-Si:H were deposited by pre-heating the silane and hydrogen sources gases, in an in-house designed LPD system, at a substrate temperature of 125°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 monitored and regulated by a digital temperature controller. The physical properties of the a-Si:H films were investigated by Fourier Transform Infrared Spectroscopy (FTIR) and ultraviolet-visible (UV/VIS) spectroscopy. Photoconductivity experiments were carried out using sputtered, coplanar aluminium electrodes under AM 1.5 illumination. The material was found to have a hydrogen concentration of 10 at% with a low dihydride (SiH2) fraction, an optical bandgap of 1.70 eV as determined from Tauc plotting, and a dark conductivity of 6x10^-11 Ω^-1 cm^-1. These values correlate well with a-Si:H deposited at higher substrate temperatures. SiO2 was produced from a supersaturated solution of silicic acid, diluted with de-ionised water and heated to a temperature of 48°C. The bonding and composition of the films were assessed after annealing under FTIR spectra, and the refractive index was determined using ellipsometry. The resistivity, fixed oxide charge and dielectric constant were evaluated from I-V and C-V characteristics measured on metal/SiO2/Si structures. Film characteristics and composition of the films were revealed using FTIR spectroscopy, and the refractive index of 1.45. Results will also be presented of the performance of inverted-staggered TFTs incorporating these films, and comparisons made with layers deposited using standard deposition temperatures. SiO2 is not extensively used as a gate insulating material for a-Si:H TFTs as a result of a high interface state density with a-Si:H. However, the feasibility of its inclusion in low temperature devices is explored in detail here.

A4.19 Low tensile stress SiGe deposited at 370°C for monolithically integrated MEMS applications. Sherif S Sedky1, Kris Baert 2, Chris Van Hoof 2, Yi Wang 3, Orner Van Der Biest 3 and Ann Chirs Van Hoof 2, Yi Wang 3, Orner Van Der Biest 3 and Ann Witvrouw 3, E M Sankara Narayanan; Emerging Technologies Research Centre, De Montfort University, Leicester, United Kingdom.

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 to 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...
A4.20  Aluminum-Induced Crystallization of PECVD Amorphous Silicon

Kenneth Jenq, Shawn Zhang, Grant Z Pan and Yahya Rahmat-Samii

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

A4.21  Solar Cells on Foreign Substrates Using Poly-Si Thin Films by Metal-Induced Growth

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Thin-film microcrystalline and polycrystalline silicon on foreign substrates are useful for photovoltaic and TFT devices. In the metal-induced growth technique, device quality poly-Si thin films were produced at 625°C by using 50nm Co as the metal seed-layer. In the processing, the poly-Si was heteroepitaxially grown from CoSi 2 which formed at the advanced stage to a small lattice mismatch between Si and CoSi 2 as was deposited by DC magnetron sputtering. The poly-Si film was grown on tungsten substrates. Previous studies focused on the growth mechanisms and electrical properties of the poly-Si film. 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 formation of MIS Schottky-diodes, three work-function metals were used on n-type poly-Si, i.e. Au, Pd and Ni. Au gave the best Schottky IV result which had the smallest reverse leakage current among the three metals. For 4µm thick poly-Si film, increasing the doping from 1×10 15 to 1×10 16 cm -3 level made the open-circuit-voltage (V oc) increase from 0.14V to 0.19V while short-circuit-current density (J sc) decreased from 2.45mA/cm 2 to 1.0mA/cm 2. Hydrogen passivation was carried out by using electron-cyclotron-resonance equipment. Passivation at low hydrogen pressure (20mTorr) gave improved results for both Voc and J sc. In one case of hydrogenation processing, J sc was greatly improved to 8 mA/cm 2 but with a higher reverse leakage current. The microstructure of this improvement is still under investigation. Attempts in fabricating p/n junction solar cells were carried out first using a spin-on thermal diffusion and then ion-implantation. Spin-on diffusion of boron into n-type poly-Si caused a severe shunting problem due to the faster diffusion of boron dopants into the grain boundaries than in the Si grains. Ion implantation at 10 15 cm -2 dose and 200keV made p/n junctions at 0.5µm position from the film surface. Single ion implantation and double ion implantation both gave a higher photo-response for the devices. The Voc reached 12mA/cm 2 while the Voc was at 0.2V. It was found that the Voc was limited by the forward dark current. Discussions will include methods for improving Voc and further refinements in device processing.

A4.22  The effect of substrate temperature and interface oxide layer on aluminum induced crystallization of magnetron-sputtered amorphous silicon, Murat Kosem, Hussein Abu-Safe, Marwan Barghouthi, Huseen 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 temperature of the a-Si to 600 to 700°C in a Al/a-Si/glass configuration. To study the effect of interface oxide on AIC, samples with a-Si/Al/glass, a-Si/Al-oxide/Al/glass, and Al/Si-oxide/a-Si/glass configurations were prepared at a fixed substrate temperature. The samples were annealed in the temperature range from 300°C to 500°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 500°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 700°C. On the other hand, Al-oxide is present at the interface, higher annealing temperatures and longer annealing times are required in order to saturate the crystallization of a-Si. Environmental Scanning Electron Microscope (ESEM) and Energy Dispersive X-Ray (EDX) analysis were used to study the surface morphology as well as the layer sequence after crystallization. This analysis revealed that Si-Al layer-exchange happens regardless of the deposited configuration.

A4.23  Interaction of Amorphous Si and Crystalline Al Thin Films during Low-Temperature Annealing in Vacuum

Yonghao Zhao, Jiangyong Wang, Eric Jan Mittemeijer and Yuntian Theodore Zhu


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 (FIB) techniques were used for compositional and microstructural analyses. A major observation was that after annealing the Al and Si sublayers had exchanged their locations since the bilayer was c-Si/Si-Al. This layer was annealed at 150 °C for 30 min in a vacuum system. X-ray diffraction, Auger electron microscopy, atomic force microscopy and focused-ion beam microscopied (FIB) techniques were used for compositional and microstructural analyses. A major observation was that after annealing the Al and Si sublayers had exchanged their locations since the bilayer was c-Si/Si-Al. This layer was annealed at 150 °C for 30 min in a vacuum system.
The growth and in-situ Aluminum-induced crystallization (AIC) of HWCVD Si films on Corning 7059 glass substrates above the Si-Al eutectic temperature (577°C) has been studied. The eutectic temperature of 577°C has been characterized. The crystalline 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 spectroscopy. Doped microcrystalline Si films of 30-50 nm thickness are deposited on Cr metal by hot-wire chemical vapor deposition at a substrate temperature of 160°C. The devices show photolithographically-defined Ag or Al top contacts of 3 μm to 49 μm in diameter. Switching is stimulated by either a current-ramp or a voltage pulse. The resistance before switching depends inversely on the device area, with about 100 kΩ across a 10-μm device. After switching, the device resistance decreases to 100 Ω or below and becomes independent of area, suggesting formation of a conducting filament. During an applied current ramp, the surface temperature probed with a fine thermocouple shows a linear increase with current density and optical microscopy reveals a localized surface morphology change likely associated with heating and filament formation. The Si microstructure is probed by scanning micro-Raman spectroscopy on mesa-etched devices after the metal top contacts are removed. For the non-switched devices, the Raman signal indicates a uniform structure in these devices. Thus, heating or/and metallic silicide (1) or/and electric field (2) associated with the switching process induced local crystallization. A conductive atomic force microscopy and micro-Auger spectroscopy will be used to determine whether the localized spot forms a metallic or non-metallic conducting filament. [1] I. Pelant, P. Fojtik, K. Luterova, J. Kocka, K. Knizek and J. L. Batstone J. Appl. Phys. 73, 8279 (1993)


Metal induced lateral crystallization (MCLC) of hydrogenated amorphous silicon (α-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) of silane (SiH4) and germanium tetrafluorine (GeF4) as sources of Si and Ge, respectively, by PECVD at low frequency (110 kHz), diluted in H2 and Ar respectively. The Ge content (x) in the gas phase, was varied from 0 to 1. The films were characterized by infrared spectroscopy for structural composition; the electrical properties were obtained by I-V measurements in temperature function (300K to 470K) in order to these measurements, a model was developed to predict the lateral crystallization velocity. In this model, the resistance change due to local heating was also taken into account. For this purpose, another set of experiments was conducted. In this set hydrogentamorphous 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 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 $1.1\times10^{-5}$ to $6.1\times10^{-6}$ (Ohm-cm)$^{-1}$ and the activation energy from 0.86 eV to 0.39 eV. This results demonstrate that this material as a good candidate for the sensing element for uncooled micro-bolometer, due to its high $E_a$ and, therefore, a high $TCR$ ($0.001 \text{ K}^{-1}$) and its low resistivity.

A4.30

High current density in microcrystalline and amorphous Silicon (SiOx) devices. Jacques 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-n-p 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, (b) annealing temperature, temperature and (c) 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/cm$^2$, and rectification ratios of $10^4$ at 2 V have been fabricated.

A4.31

High Quality Patterned SIMOX SOl 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 $2.0-9.0\times10^{17}$ ions cm$^{-2}$ at energies of 50-160 keV through a photoresist 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 SiEr with resonant excitation generation. Mark Kikl1, B.A. Andre2 and Tom Gregorkiewicz2; 1Physics, Van der Waals-Zeeman Institute, Amsterdam, Netherlands; 2Institute for Physics of Microstructures, Nizhny Novgorod, Russian Federation.

By using infrared and mid-infrared radiation we were able to get a unique insight in the processes of energy transfer between ions of the rare earth Erbium and its Si host. The multi-layered samples that were studied included both with a spectral scheme 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. Tetjana Torchynska1, Alejandro Vivas and Tetyana Torchynska; Science Materials Department, National Polytechnic Institute, Mexico, Mexico.

A4.34

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

A4.35

Change of light emission of Si wires during Si/SiOx interface formation. Francesco Guillermo Becerril-Espinosa1, Tetyana Torchynska2, Miguel Morales-Rodriguez2, Larisa Khomenkova3, L. V. Scherbina2 and S. Ostapenko3; 1Ciencia de Materiales, Escuela Superior de Fisica y Matematicas-Instituto Politecnico Nacional, Mexico, Mexico; 2Inst. Semiconductor Physics at National Academy of Sciences, Kiev, Ukraine; 3CNNR-University of South Florida, Tampa, Florida.

The SiOx systems with nano-crystalline silicon are under intensive investigations due to their potential application in the electronics industry, in particular, for creation of light emitting devices. The latter is connected with the observation of bright photoluminescence (PL) of such materials in red-orange and green-blue spectral ranges at room temperature. Although several models, including quantum confinement effects in Si nano-crystallites, surface states of Si nano-crystallites, Si-based chemical species like siloxene and polysilane, suboxide defects in Si/SiO2, an exciton on Si/SiO2 interface have been proposed, the nature of visible PL of Si-SiOx systems is still being discussed. In the framework of quantum confinement model a peak energy on the size of Si nano-crystallites has to exist. However, in many cases a determination of the sizes of Si nano-crystallites has not been made. Besides the different dependences of PL peak energy on Si nano-crystallites sizes have been observed: the red and blue shifts, as well as its absence with decrease of Si crystallites sizes. One of the possible explanations of this discrepancy is the superposition of emission bands of different nature. In particular, the Si-SiOx interface can contain numerous defects due to large lattice mismatch (about 7% or more), surface roughness and variation in surface stoichiometry (SiOx). So, the radiative transitions connected with different types of interface defects can contribute to the PL spectra as well as the defects detected in the SOI matrix can also participate in light emission. The PL spectra and their temperature dependence, as well as Raman spectra of Si-SiOx systems prepared by radio frequency magnetron sputtering method and thermal annealed at 1150 oC during 40 min for creation Si nano-crystallites were investigated as a function of current density and the Si nano-crystallites sizes. It was shown that PL spectrum of such systems consists of five PL bands with peak positions at 1.38, 1.42-1.54 eV, 1.7 eV, 2.06 eV and 2.38 eV. The dependences of these peak positions and their intensities on concentration and Si nano-crystallites sizes in Si-SiOx system have been investigated and analyzed. The nature of radiative optical transitions for all PL bands is revealed.

A4.36

Change of light emission of Si wires during Si/SiOx interface formation. Francesco Guillermo Becerril-Espinosa1, Tetyana Torchynska2, Miguel Morales-Rodriguez2, Larisa Khomenkova3, L. V. Scherbina2 and S. Ostapenko3; 1Ciencia de Materiales, Escuela Superior de Fisica y Matematicas-Instituto Politecnico Nacional, Mexico, Mexico; 2Inst. Semiconductor Physics at National Academy of Sciences, Kiev, Ukraine; 3CNNR-University of South Florida, Tampa, Florida.

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About the luminescence mechanisms of composite a-Si:nc-Si films obtained by ion-beam amorphization in a wide dose region. David Isaakovich Tetelbaum, Alexander A. Ezhovskii, Alexey N. Mikhailov, Mikhail Yu. Lebedev, Yulia A. Mendeleva, Sergey V. Morozov; 1Physics-Technical Research Institute of Universities of Nizhny Novgorod, Nizhny Novgorod, Russian Federation; 2Institute for Physics of Microstructures of Russian Academy of Science, Nizhny Novgorod, Russian Federation. 

Recently [1-3], we have developed a new method of creation of luminescent nanostructured layers in silicon by ion irradiation. The method is grounded on partial amorphization with retaining in a-Si the unamorphized nanocrystalline inclusions (quantum confined regions). Here we report the results of further investigation of this layer properties. It is shown that the regularities of dose evolution are common for different ion masses (M = 20-84). The photoluminescence spectra (in range of 700-1100 nm) are similar for the region of relatively small ion doses (transition to the amorphization) and for the doses substantially exceeding the amorphization dose. In the latter case, the light emission is dominantly caused by the layer placed beneath the amorphized one. The data are complemented by the results of scanning profilometry with layer-by-layer etching. Influence of the annealing temperature is also investigated. The work was supported by the RFBR grant 04-03-40493 and programme of the Russian Ministry of Education Science researches of higher school in the priority fields of science and technique, subprogramm 2052. [1] D.I. Tetelbaum, S.A. Trushin, Z.F. Krasilnik, D.M. Gaponova, A.N. Mikhailov. Optical Materials. 2003. V. 17. No. 1-2. P. 57-59. [2] D.I. Tetelbaum, A.A. Ezhovskii, S.A. Trushin, N.M. Gaponova, A.Yu. Akis, D.M. Gaponova. Material Science and Engineering B. 2003. V.101. No.1-2. P.279-282. [3] D.I. Tetelbaum, A.A. Ezhovskii, A.N. Mikhailov. Semiconductors. 2003. V.37. No.11. P.1343-1344.
Amorphous Silicon Image-sensor Arrays Fabricated by Digital Lithography, \textit{A4.42} 

P. Louro\textsuperscript{1}, C. Mendes\textsuperscript{1}, G. Lavareda\textsuperscript{2} and N. Carvalho\textsuperscript{2}; IDEETC, ISEL, Lisboa, Portugal, \textsuperscript{2}CFM, IST, Lisbon, Portugal.

Amorphous silicon-based image sensor arrays have been fabricated using the digital-lithography method. a-Si:H thin-film back-plane arrays were fabricated using conventional deposition methods, while etch masks defining the device structure were patterned using electronically generated images jet-printed directly on the process wafer. The resulting T6F structure, with on/off ratios of 10\textsuperscript{5} and threshold voltages of 3-5 V, is an integrated sensor medium to optically triggered array structure. Operation of the image sensor as an x-ray detector will be shown. To further demonstrate the efficiency of the digital lithographic process, results from multi-layer patterning on flexible substrates for sensor and display applications will also be presented.
optical characteristics. The influence of the doped and active layers characteristics (conductivity, photosensitivity, thickness) on the device performances, resolution, responsivity, and bandwidth time) will be presented. The various design parameters tradeoffs are discussed. Results show that reducing the thickness of the back diode increases the resolution, but increases the capacitance and therefore the response time. The resistance of the doped layers is also important. Too conductive doped layers spread out the charge, reducing resolution. A trade-off between the read and the write beams wavelength and the active layers thickness are needed to minimize the cross talk between the read-out and the substrate and to improve the contrast ratio of the output read light. An electrical model is presented and supported by a two dimensional simulation.

**A4.45**


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 the experimental results of the dynamic performances exhibited by such array constituted by 32 elements (equivalent to 5 bits lateral resolution, combined with a continuous analogue longitudinal resolution). The analogue information supplied by this array is processed by an analogue/digital converter, directly coupled to the array and whose information is computer processed, concerning the recognition of patterns and the processing of information collected over the object to be inspected.

**A4.46**

**Performance Analysis of a-Si:H Detectors Deposited on CMOS Chips.** Clement Miazzu, Nicolas Wyrsh, Sylvain Dunand,1 Arjuniyas,2 Olivier Buisson, Rolf Kaufmann,2 Lionel Cavaliere,2 Pierre Jarzun,2 Danielle Moraes,3 Mathieu Despeisse,4 Isabel Ferreira, Hugo Aguas, Leandro Raniero and Shiban Zhang; Materials Science, FCT-UNL, Caparica, Portugal.

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

**SESSION A5: Growth and Properties**

**Friday 14th March 2004 Room 209 (Moscone West)**

**8:30 AM A5.1**


Spectroscopic ellipsometry is used for the first time to monitor, in real time, the breakdown of hot-wire chemical vapor deposition (HWCDV) epitaxial crystalline silicon (c-Si) growth. We study epitaxy on different c-Si substrate orientations for varied growth parameters such as substrate temperature and filament current (reaction temperature), with the aim of correlating ellipsometry measurements with breakdown of epitaxy. The ellipsometry measurements, which are validated by transmission electron microscopy of selected samples, show that the breakdown of epitaxy can take various forms depending on the growth conditions. During growth from pure Si on (100) substrates with a 13 A filament current, breakdown is a slow evolution (over 100 nm of deposition) of the top silicon layer from c-Si to a-Si:H. During growth at lower substrate temperature (200 °C) on both (111) and (100) substrates with a 16 A filament current, the transition region extends over only 30 nm of deposition. The optical properties of the breakdown regions are well-described by an effective medium of a-Si:H and c-Si. Previously, HWCDV has been used to grow 140 nm of epitaxial Si at 325 °C, [Thiesen et al., APL 75, p. 993 (1999)]

These new in-situ spectroscopic ellipsometry measurements provide real-time observation of surface morphology and the crystallinity of newly deposited Si. By applying this technique to epitaxial growths, we hope to develop a deeper understanding of epitaxial breakdown, allowing increased epitaxial breakdown thickness and growth rate.

**8:45 AM A5.2**

**Comparison of Deposition Phase Diagrams for Si:H Film Growth at VHF and RF Plasma Frequencies.** Gelio M Ferreira1, Isabel Ferreira1, Hugo Aguas, Leandro Raniero and Shibin Zhang; Materials Science, FCT-UNL, Caparica, Portugal.

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 should be used to design technological conditions and to predict the electrical, optical and mechanical properties as well as the potential device performance of Si:H films, based on well-established correlations. We have applied phase diagrams in a comparison of Si:H prepared by PECVD at low and high frequencies (rf: 13.56 MHz; and vhf: 60 MHz), in both low and high pressure regimes (< 0.5 Torr; and 3–4 Torr). Smooth c-Si wafers have been used to evaluate the surface roughness evolution in the amorphous silicon (a-Si:H) growth regime. Also, R=(H2)/[SiH4]=0 a-Si:H substrates films have been deposited to simulate layer deposition in devices. These latter substrates are used to identify relevant amorphous- to- (mixed-phase microcrystalline) transitions [a-+ (a+μ)] and (mixed-phase)- to- (single-phase) microcrystalline transitions [(a+μ)–μ]. This study has shown that under all explored conditions of plasma power, frequency, and pressure, yielding a range of deposition rates (0.5 - 20 Å/s), the structural evolution for a-Si:H growth improves with increasing R up to the [a-+ (a+μ)] transition. This improvement is apparent through the amorphous roughening transition (denoted a-→μ) to indicate the absence of a phase change) which increases in thickness with R under all conditions. For R values much lower than the μ transition for a thick film, vhf a-Si:H deposition provides a significant improvement in structural evolution (i.e., increased a-→μ transition thickness) over that of rf a-Si:H, for a given rate. For optimum a-Si:H films with R values much lower than the μ transition, however, commercial deposition 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-→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.** Jan Bialot, E Valtat-Sauvain, A Valtat and A Shah; Institut de Methode, 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, rounded evolution versus film thickness. The present study focuses on the microstructure and the phase diagrams of the simulated layers. The Transmission Electron Microscopy (TEM) study of microcrystalline silicon deposited by plasma enhanced chemical vapor deposition of silicon revealed that the material is a complex mixture of crystalline phase, amorphous phase, grain boundaries and voids. The simple microstructure consists in conical conglomerates of microcrystalline grains separated by amorphous material and porosity 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
From a-Si:H has formed. Atomic H induced films deposited by HWCVD. Although these films generate a filled with particles in different states. Thus in this model, the number starts to decrease after states and the crystalline threshold value. The outcome of the spectroscopy measurements - from the combination of cavity ring simulation are computer generated representations of the layer simple selection rules. Since the first presentation of this model at the comparison between the SHG experiments and subgap absorption on crystalline silicon [1] reveals similarities which might indicate that this resonance peak with the spectral dependence of dangling bonds has been applied on thin films of a-Si:H both in ex-situ experiments as well as in-situ and real-time during a-Si:H film growth. It is expected that the application of SHG on a-Si:H can yield insight in the a-Si:H film properties and the surface processes during film growth because SHG has proven to be sensitive to surface dangling bonds on crystalline silicon. First a set of a-Si:H films with a different thickness (4-1031 nm) and deposited by rf PECVD on quartz substrates have been investigated at different polarization states and for pump photon energies between 1.10 and 1.30 eV. It is shown that the SH signal originates from an isotropic contribution at both the surface and buried interface region of the film and a distinct resonance peak is observed at a pump photon energy of ~1.20 eV. Close examination of this resonance peak with the spectral dependence of dangling bonds on crystalline silicon [1] reveals similarities which might indicate that the SH signal of a-Si:H is caused by dangling bonds in the interface and surface region of the films. This suggestion is also strengthened by the fact that dangling bonds in a-Si:H are generally measured by subgap absorption spectroscopy in the same energy range. A comparison between the SHG experiments and subgap absorption spectroscopy measurements - from the combination of cavity ring down spectroscopy and spectroscopic ellipsometry carried out on the same films - will be shown. Subsequently, SHG experiments have been performed in-situ in an ultra-high vacuum setup on a-Si:H films deposited by HWCVD. Although these films generate a somewhat lower signal, the HWCVD deposited films show the same polarization dependence and spectral signatures as the a-Si:H films deposited by rf PECVD. These experiments also validate the fact that the a-Si:H itself leads to the SH signal as these films are not influenced by a native oxide which forms after exposure of Si films to air. SHG has also been applied during real-time film growth of a-Si:H for different substrate temperatures. These experiments reveal that the SH signal initially increases with increasing film thickness but starts to decrease after ~10 a-Si:H has formed. Atomic H induced etching prevents crystallization in these experiments, and therefore that SHG has a great potential for monitoring a-Si:H growth and can provide real-time information on the role of dangling bonds in the a-Si:H growth process. Currently, more real-time experiments are carried out with extended pump photon energy range [1].

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

**10:30 AM A5.5**


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 experiments 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 polymeric 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 was observed, 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 was observed, 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.

**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 Caraus; 1Computing and Advanced Technologies, University of Abertay Dundee, Dundee, United Kingdom, 1IPV, Forschungszentrum Juelich, Dr. H-D 29425 Juelich, Germany.

The prospect of further improvements in stable photovoltaic efficiencies continues to stimulate research on carrier transport in microcrystalline silicon (c-Si) films. The objective of studies in this area is confirmed that such films are structurally anisotropic, consisting of clusters of coherent crystalline regions often in the form of columns oriented perpendicular to the substrate, separated from each other by cracks or voids and disordered material. Different local transport properties depending on whether measurements are made parallel or perpendicular to the substrate might therefore be anticipated. Previous studies [2] have identified different mobility, mu-tau product and defect densities in nominally identically-prepared films equipped with ohmic coplanar and sandwich contacts. These results have then been used to inform the construction of transport models, in which grain size and shape and defect and barrier height distributions and cross-sections are adjustable parameters. Here, we present a comparison of transient photocurrents in intrinsic microcrystalline silicon coplanar [4] and solar cell (pin) [5] configurations, as a function of crystalline volume fraction (CVF), and...
Far-infrared spectral range (1-10 meV) in PECVD a-Si:H and support this model, the temperature-dependence observed in more spatial distribution of the defect states during light soaking will be solar cells in the later stages of light soaking is responsible for an solar cells were deposited on Asahi U-type substrate with five experimental temperature. Data are analysed in terms of trap-limited open circuit voltage. The creation of the Dz states in the bulk of the degradation. Recently, several new features were implemented into the experimental temperature. 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, Dz, takes place 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 Dc states in accordance with the observations of additional mono-exponential bimolecular band transport, and while results from both structures at low CVF are discussed. The density of states distributions in films of low CVF 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-0076615.

11:45 AM A5.10
**On the Einstein relation for hydrogenated amorphous silicon.** Thanh H. Nguyen1,2, and Karen K. O’Leary1,3
1 Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada; 2Information Systems Management Corporation, Regina, Saskatchewan, Canada.

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

SESSION A6: 29th Anniversary Session
Chair: Arun Madan and Craig Taylor
Wednesday Afternoon, April 14, 2004
Room 2001 (Moscone West)
The last two decades have witnessed significant progress in the science and technology of amorphous silicon based alloys for large-scale manufacture of photovoltaic products. Development of multi-junction devices incorporating component cells absorbing different wavelengths of light have resulted in high efficiency with good stability. Innovative manufacturing technologies have been developed to facilitate large-volume production. In this paper, I shall summarize the current state of art of material research, device performance and manufacturing. I shall also discuss future trends including the use of mixed-phase and microcrystalline silicon.

**SESSION A7: PV Technologies**

**Chairs: Subhendu Guha and Jacques Schmitt**

**Thursday Morning, April 15, 2004**

**Room 2001 (Moscone West)**

**8:30 AM **

**A7.3 Efficient Conversion of Sunlight to Electricity by Dye Sensitized Nanocrystalline Solar Cells. Michael Graetzel, LPI, Swiss Federal Institute of Technology, Lausanne, Switzerland.**

The dye sensitized solar cell (DSC) provides a technically and economically credible alternative concept to present day p-n junction photovoltaic devices. In contrast to the conventional silicon systems where the semiconductor assumes both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band gap 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 conducting oxide and back to the charge collectors. 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 developments are highlighted as they may lead to improved or new applications for amorphous and/or nano-crystalline silicon.

**9:00 AM **

**A7.2 Excitonic Solar Cells. Brian A. Gregg, NREL, Golden, Colorado.**

Existing types of solar cells may be divided into two distinct classes: conventional solar cells such as silicon p-n junctions and excitonic solar cells, XSCs. Most organic-based solar cells, including dye-sensitized solar cells, DSSCs, fall into the category of XSCs. In these cells, excitons are generated upon light absorption and, if not created directly at the heterointerface as in DSSCs, must diffuse to it in order to photogenerate charge carriers. The distinguishing characteristic of XSCs is that charge carriers are generated and simultaneously separated across a heterointerface. In contrast, photogeneration of free electron-hole pairs occurs throughout the bulk semiconductor in conventional cells, and carrier separation upon their arrival at the junction is the subsequent process. This greatly simplifies 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 built-in potential, Phi.bi, but in DSSCs it can be larger than Phi.bi. This tutorial describes exciplex processes in general and the use of carrier-selective (energy-selective) contacts to enhance Voc. Then studies of DSSCs, which provide a particularly simple example of XSCs, are described. A general theoretical description applicable to all solar cells is employed to quantify the differences between conventional and excitonic cells.

**9:30 AM **

**A7.4 A Vision for Crystalline Silicon Photovoltaics. Richard Swanson, SunPower Corporation, Sunnyvale, California.**

Starting with an overview of the current status of crystalline photovoltaics, this paper next presents a vision for the future via a possible set of technical requirements that will continue the historical progress. PV system prices have been decreasing roughly 50 percent per decade. We will show how crystalline silicon solar cells can continue this trend over the next decade, thus becoming cost-competitive without subsidies in many distributed grid connected applications. Significantly no "big breakthroughs" are needed for this to happen. An evolutionary development of crystalline photovoltaics technology is shown to be all that is necessary Module prices have followed a classic experience curve in cost versus cumulative volume. (Straight line on a log-log plot of price versus cumulative volume.) The experience factor is 85%, meaning that prices have fallen 15% 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 2002 was conducted to develop an expert consensus on how wafered silicon costs will come down over the next decade. What emerged are projections for parameters such as efficiency and wafer thickness that can serve as a guide to the industry and a projection of costs. The manufacturing cost projected for 2012 is $1.00/W and the sales price $1.48/W, thus meeting the necessary price for cost-effective distributed applications. The results of this workshop, along with the research required to meet the goals, will be presented. Today, grid connected markets are viable only with subsidies. As costs come down, the required subsidy will decrease.
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 some of the high insolation regions such as Germany. The total required subsidy in order to "buy down" this market is straightforward to calculate using the above experience curve projections. Interestingly, the total amount required depends only slightly on the assumed market growth rate, and is in the range of $25 billion.


Amorphous Silicon solar cells and modules have been of scientific and technological interest for more than 25 years because they have held the best hope for low cost module manufacturing. While there have been several attempts to pursue large scale manufacturing (still ongoing), amorphous solar modules have NOT yet met 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 will examine amorphous silicon technology industry in depth from a historical perspective for the progress made over the years in device performance and module performance. We will assess the challenges and opportunities of amorphous silicon technologies for the two approaches (i) based on manufacturing monolithically interconnected amorphous silicon solar cells 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 solar cells. 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 of and challenges in CdTe thin-film solar-cell technology. Alvin D. Compaan, Physics and Astronomy, Univ. of Toledo, Toledo, Ohio.

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

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


High-rate deposition technique of device grade microcrystalline silicon (µc-Si:H) is essentially required for low cost manufacturing of high efficiency amorphous based thin film solar cells. Recently, we have developed a novel high-rate process based on high-pressure and SiH4-depletion plasmas for high-quality 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 °C plasma-enhanced chemical vapor deposition (PECVD) at i-layer deposition rates of >2 nm/s. Under high-rate conditions, in particular, the deposition pressure is found to play a dominant role in determining short circuit current (Jsc) of solar cell. With an increase in deposition pressure from 2 to 7-9 Torr, Jsc increases by more than 50% due to a significant long wavelength (λ > 1.2 μm) photovoltaic response, which essentially leads to high efficiency (8%) solar cells in the 2-3 nm/s deposition rate range. Further progress in solar cell efficiency has been made by the improvement of TCO/p and p/i interfaces. As a result, efficiency of 9.13%, which is in tune with the above results, we propose that the less post-oxidation behavior associated with the denser microstructure of high-pressure-grown μc-Si:H is responsible for the lower contact resistance of the a-Si:H - n solar cells. [1] M. Kondo et al. J. Non-Cryst. Solids, 260 – 264, 84 (2000). [2] T. Matsui et al. Jpn. J. Appl. Phys. Part 2, 42, L901 (2003).

2:00 PM A8.2 Device Physics of Microcrystalline Si:H Solar Cells. Vikram L. Dalal, Elec. and Computer Engr., Iowa State University, Ames, Iowa.

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


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 photovoltaic conversion efficiencies of nearly 14% on p-type C2 wafer coated with thin i and layers. Open-circuit voltages above 620 mV 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 lifetime measurements versus layer thickness and crystallinity from RTSE. Post-growth analysis of the RTSE data enables accurate determination of the evolution of the dielectric function with
thickness. The dielectric function provides a measure of the bandgap and degree of crystallinity. There is a gradual transition from ordered a-Si, or mixed amorphous and nanocrystalline silicon (nc-Si) to less ordered a-Si as the film grows. The final device open circuit voltage is a function of the bandgap of the i- and n-layers, as well as the SRV. We shall report systematic correlations of device performance with these properties as determined from in-situ and ex-situ analysis.

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 line-widths of the first sharp peak (FSP) were found to be between 0.06 degrees and 5.10 ± 0.09 degrees, respectively, typically being a half-integer function of the microcrystalline n-layer. These FSPs are as narrow as for optimized i-layers made by H2-diluted plasma deposition, however, at a much higher deposition rate (1 nm/s), 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 this void density accounts for the better cell performance. 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.

To obtain high short-circuit current density (Jsc) from hydrogenated microcrystalline silicon (μc-Si:H) solar cells, a thick μc-Si:H 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 regime. The mechanisms responsible for the low Jsc for thick μc-Si:H solar cells. One is microcrystallite collision due to the textured substrate, and the other microcrystalline evolution with thickness. It has been reported that grains in μc-Si:H deposited on a textured wafer tend to grow perpendicularly to the surface and collide with each other when the film is over a certain thickness. The stress caused by the microcrystallite collision results in a high defect density and low cell performance. A second mechanism is the increase of microcrystalline volume fraction (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 specular stainless steel (SS) substrates and another on textured BR. Both sets of cells showed a decrease 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 microcrystalline 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 A8.5

Microstructure Evolution with Thickness and Hydrogen Dilution Profile in Microcrystalline Silicon Solar Cells.

In order to obtain high short-circuit current density (Jsc) from hydrogenated microcrystalline silicon (μc-Si:H) solar cells, a thick μc-Si:H 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 regime. Several mechanisms can 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 microcrystalline evolution with thickness. It has been reported that grains in μc-Si:H deposited on a textured wafer tend to grow perpendicularly to the surface and collide with each other when the film is over a certain thickness. The stress caused by the microcrystallite collision results in a high defect density and low cell performance. A second mechanism is the increase of microcrystalline volume fraction (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 specular stainless steel (SS) substrates and another on textured BR. Both sets of cells showed a decrease 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 microcrystalline 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

Crystallinity Volume Fraction in μc-Si:H: Raman spectroscopy versus X-ray diffraction.

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

4:00 PM A8.8

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

Dark forward bias current, Jp-V characteristics offer a probe for characterizing carrier recombinations 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 Jp-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 Jp-V characteristics of p

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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 thin-film microcrystalline silicon layers were deposited by the RF glow discharge method at United Solar. The first device type is a sandwich structure with the microcrystalline silicon layer sandwiched by two amorphous silicon layers (SS/n-Si:H/a-Si:H) or (a-Si:H)/n-Si:H/a-Si:H. Thus, this sandwich layer is characterized in both its 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 is most suitable 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 n-Si:H component exist in these samples. Indeed, these TPC measurements allow us to deduce Urbach energies characteristic of each component individually. Moreover, by varying the measurement temperature we directly observe that the minority carrier collection in the microcrystalline component grows with temperature of the measurement. Unlike DLCP method, both the shallow doping as well as the deep defect densities were estimated. Significant effects due to light soaking on all of the above properties have been observed and will be reported.

A9.1 Optical Properties of Transparent Conducting Oxide Sculptured Thin Films for Applications in Amorphous Silicon Photovoltaics, Chi Chen1, Bin An1, Gerd Voelkl2, Park Han1, Russell Messier2 and Robert W. Collins2. 1Material Research Institute, The Pennsylvania State University, University Park, Pennsylvania; 2Department of Physics and Astronomy, University of Toledo, Toledo, Ohio; 3Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, Pennsylvania.

Significant optical losses in thin film silicon-based solar cells arise due to absorption at the top interface between the transparent conducting oxide (TCO), tin-oxide or indium-tin oxide, and the p-type silicon layer. Significant optical loss occurs in the back-reflector structure at the interface between the dielectric, zinc-oxide, and the metal, silver or aluminum. Advanced optical engineering approaches are needed to minimize these losses. One possible approach is to incorporate multi-layered or graded-index TCO films that can be used to tailor the reflectance of broadband anti-reflectors at the top of the device and narrow band reflectors at the back. It is important to be able to modulate the index of refraction of the TCO over a wide range without increasing its extinction coefficient or degrading its conductance. We report on an investigation of sculpted SnO2 films under initial development for this purpose. Sculpted thin films are deposited under low surface mobility conditions using stepwise or continuous variations in the polar and/or azimuthal angles of the deposition flux impinging on the surface. Structural and optical properties will be presented for films deposited continuously with a modulated polar angle, as well. Optical modeling will explore the ability of such an approach to provide tailored TCOs for advanced optical engineering of silicon-based solar cells.
To be provided.
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 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-neighbored area of the cross section. Therefore, this method can be used to observe and record the details of the build-up potential in solar cells. The cross sections of a-Si and CdTe solar cells have been observed by this method. We study the AFM images in both conditions of open circuit and short circuit and compare the performance of the solar cells. In addition, the absence of the samples is observed in the two conditions, which obtains the different images of two kinds. The image in open circuit displays a map of electrical potential on the surface, and shows the grain boundary and some defects.


The steady-state photoconductivity grating (SSPG) technique has become a standard tool for the characterisation of the minority carrier properties in amorphous and microcrystalline silicon. In the standard application the photocurrent response under the presence of spatially modulated photogeneration is measured at low electric fields. The diffusion length in relation to the modulation period determine how the influence of diffusion smears out the photocurrent grating. Analysis of the experimental data allows the extraction of the ambipolar diffusion length from these low field data. Abel et al. derived a theory for the influence of space charge effects and drift on the measured photocurrent. The authors suggested to study the electric-field dependence of the parameters, measured in the SSPG experiment. If we exploit the electric-field dependence 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 field values 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 measured diffusion length is almost entirely determined by drift contributions. Analysis of our data with the theory by Abel et al. shows good corelation 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. CD. Abel, G.H. Buser, W. Blois, Philos. Mag. B 72, 591 (1995).

A9.8 Transient and Modulated Photoconductivity in Microcrystalline Silicon. Rudolf Bruggemann, Institut fur Physik, Carl von Ossietzky Universitat Oldenburg, Oldenburg, Germany.

We present experimental data on transient and modulated photoconductivity (TPC, MPC) in microcrystalline silicon in which the dark conductivity was varied deliberately in order to study Fermi level effects on the recombination and trapping kinetics. Thus change in dark conductivity was achieved by annealing in vacuum at higher temperature and has a strong influence on the measured TPC and MPC data [1,2].

The time-dependent drift mobility in transient photoconductivity shows distinct variations in its temperature dependence, directly related to a high or low dark conductivity value of the microcrystalline silicon sample. We relate the thermalisation process of excess carriers to reaching the Fermi level before thermalisation is complete. For the determination of the density-of-states distribution from TPC (and also from MPC) data the assumption that empty states below the conduction 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 samples, nominally undoped microcrystalline silicon can thus be achieved [1]. R. Bruggemann, J. Mat. Sci. Mat. Electr. 14, 629 (2003) and S. Reynolds et al., J. Non-Cryst. Solids, in print.

A9.9 Effects of FEL irradiation on amorphous silicon. Branko Pivac1, Vesna Borjanovic2, Branimir 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. The photoductive band bond and hydrogen redistribution were reported but the mechanism leading to structural relaxation were not clear. Samples with the amorphous silicon structure rich in hydrogen were grown on single crystal substrates at temperatures of about 750°C and were subsequently irradiated with 5 and 7.5 nm light from FEL. The effects of irradiation were monitored with FTIR and Raman spectroscopy. It is shown that the irradiation affected much more the structural changes attributed to Si-H2 clusters, detected by IR vibration band at 2100 cm-1, than Si-H bonds, enhancing the former significantly. At the same time the effect of irradiation on Raman TO band did not affect its position or half-width indicating that the short range order was preserved. However changes in the ratio, changes in the medium range order. These results support the attribution of the 2100 cm-1 bond to the hydrogen clustered at structural defects in amorphous matrix. Although the coupling of Si-H vibration to the lattice seems to be weak it is shown that FEL irradiation could produce significant structural changes at room temperatures.

A9.10 Metastability in Undoped Microcrystalline Silicon Thin Films Deposited by HWCVD. Sayedulla Persheyev,1 Kevin O Neill2,3, Mervin Rose3, Vlad Smirnov4 and Steve Reynolds5, 2E&EP, University of Dundee, Dundee, United Kingdom; 3EPICentre, School of Computing and Advanced Technologies, University of Abertay, Dundee, Dundee, United Kingdom.

Microcrystalline silicon deposited by HWCVD has a number of advantages as a material for photovoltaic applications [1]. It is also known that properties of microcrystalline silicon films can be changed by atmospheric ageing processes. [2, 3] In the present work we report on investigation of metastable effects induced by atmospheric exposure of microcrystalline silicon. Films deposited by Hot Wire CVD method were studied by means of dark conductivity and SS photoconductivity, FTIR, Hydrogen Evolution, SEM characterization [4]. To investigate metastable processes on surfaces and nucleation layer two different coplanar (top and bottom) contacts have been introduced for the photoelectrical measurements. Three types of metastability were observed in our films: a) long term irreversible degradation due to oxidation processes on the film surface, b) reversible degradation determined by uncontrolled water adsorption, c) transient conductivity field effect in the film bulk. Oxygen and hydrogen content in 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 of the fast increase of dark current conductivity bottom chromium contacts under a condition of air admittance. We propose the effect is associated with electrical field induced by accumulated layer created by adsorbed water vapor near film surface. 1. S. Klein, F. Finger, R. Carius, T. Dylla et al. Thin Solid Films 430 (2003) 202-207 2. V. Smirnov, S. Reynolds et al presented ICAMS20, to be published 39. S. Finger, R. Carius, T. Dylla, S. Klein, S. Okur, M. Guise, IEE Proc. 150 (2003) (in press) 4. S.K. Persheyev, S. Reynolds et al Thin Solid Films 365 (2001) 130-135.

A9.11 The Influence of Light-Soaking and Atmospheric Adsorption on Microcrystalline Silicon Films Studied by Coplanar Transient Photoconductivity. Vladimir Smirnov1, Steve Reynolds2, Friedhelm Finger3, Charlie Maun4 and Reinhard Carius5,1Computing 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 a shorter response time 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 phases, with the so-called PECVD grown microcrystalline silicon can thus be achieved. R. Bruggemann, J. Mat. Sci. Mat. Electr. 14, 629 (2003) S. Reynolds et al., J. Non-Cryst. Solids, in print.

In this paper, we exploit the electric-field variation this work was to study the effect of FEL radiation at resonant frequency on undoped amorphous silicon. The selective absorption of the incident FEL radiation could produce significant structural changes at room temperatures.

A9.12 Surface potential and surface photovoltage of oxide and nitride coated multicrystalline silicon solar cells using a scanning Kelvin probe. Inan D. Buikie, Kelvin Research, KP Technology, Wick, Caithness, United Kingdom.

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

A9.13 PECVD grown polymeric hydrodendrified silicon (pm-Si:H) studied using current transient spectroscopies in PIN Diodes. vibha Tripathi, Y N Mohapatra and P Roca i Cabarrocas, Dept. of Physics, Indian Institute of Technology, Kanpur, India, LPICM, Ecole Polytechnique, Palaiseau Cedex, France.

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

A9.14 Abstract Withdrawn


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

A9.16 Study of steady state photoconductivity and electron mobility in highly crystallized doped and undoped microcrystalline Si films. Sanjay K. Ram, Satyendra Kumar, R. Vanderhagen, B. Drevillon and P. Rocca i Cabarrocas, 2Physics, Indian Institute of Technology, Kanpur, Kanpur, Uttar Pradesh, India; 2Laboratoire de Physique des Interfaces et des Couches Minces (UMR 7647 du CNRS), Ecole Polytechnique, 91128 Palaiseau Cedex, France.

Hydrogenated microcrystalline silicon (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, large 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 tissues and voids. Understanding carrier transport in such a system is undoubtedly a challenging task. Though there are several reports on the electronic transport in doped 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 SiF4, Ar and H2 at low temperature (200 °C). Structural properties of the films were well characterized by in-situ spectroscopic ellipsometry, Raman scattering, Neutron reflectometry and atomic force microscopy techniques. This article will basically cover the conductivity, steady state photoconductivity, Hall and photo Hall effect studies carried out on samples having different thicknesses. The dependence of photoconductivity (σph) on the temperature (T) and the intensity of light were measured in a temperature range 15-295 K. Mechanisms of carrier transport and recombination governing these temperature and intensity dependences will be discussed in the paper. In order to evaluate the properties like free carrier concentration and mobility in undoped µc-Si:H, Hall effect measurements were performed in the temperature range 300-450 K. However, several experimental limitations are associated with Hall effect measurement on undoped 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 optimized to reduce unusual offset voltages, which mostly arise due to misalignment of the 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 generated by illumination. The details will be described in this paper.

A9.17 Characteristic temperature for magnetically doped amorphous semiconductors. W. Z. Zhou, Z. Z. Guo, E. Z. Lee, M. L. Torment, T. V. H. Li, A. G. Bennett, V. E. Heiligen, and I. B. Miller, 1Materials Science, UCSD, La Jolla, California; 2Dept. of Physics, UCSD, La Jolla, California.

Recent results have shown that the magnetically doped amorphous films near the metal-insulator (M-I) transition are extraordinarily sensitive to magnetic field and temperature, with a negative magnetoresistance of many orders of magnitude. This sensitivity is likely due to correlation effects stemming from interactions between the conduction electrons and the magnetic impurities [1-3]. We have grown a series of thin films for each of the amorphous metallic semiconductor alloys Gd1-xSi2+1-x and Gd1-xGe2+1-x covering a broad range of dopant concentrations on the metallic side of the MIT in order to investigate correlation effects in the metallic regime, and to determine the effect of the semiconducting matrix. The critical concentration (x_c) for Gd-Si occurs at x_c=14% [1] and is found to be the same for Gd-Ge. We compare the results of DC conductivity, σ(T) (4.2 K -750 K) for the two different IVA host materials doped with magnetic impurities, while also comparing to results from the non-magnetic counterpart Y1-xSi2+1-x. A characteristic temperature scale T^* at which the magnetically doped samples deviate strongly from their non-magnetic counterparts is found to follow the form . A similar dependence is found for the magnitude of the magnetoresistance as a function of temperature. We also find that the effective characteristic temperature, for any given 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. 72, 685 (1994) [2] W. Teizer et al., Phys. Rev. Lett. 85, 848 (2000) [3] D. N. Basov et al., Europhys. Lett. 57, 240 (2002).
A9.18 Local ferromagnetic ordering and charge localization in amorphous Cd,Sn,Ge films. Nikolai Chumakov, Victor Tugushev

We present a new theoretical model, which describes the anomalous transport and magnetic properties of amorphous gadolinium silicon alloys [1] by local ferromagnetic ordering. 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 occurs more favorably in these drops than in the amorphous matrix. 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 Cd,Sn,Ge films have been performed. The temperature dependence of magnetization has been obtained by a double integrated ESR line intensity. According to the standard BKKY theory, local FM ordering of Cd,Sn,Ge monomers appears in the drops at temperatures below 50 K. That corresponds to an effective Curie temperature, estimated from measurements of magnetization at high T. Drastic increasing of magnetization obtained from ESR data below 50 K directly indicates the appearance of FM drops in the sample. Based on our experimental data and estimations we have estimated that typically the drops are to be about 1.5–2.5 nm. The Hall effect and conductivity data demonstrate that the conductivity variations on temperature and magnetic field are proportional to the itinerant electron concentration. The itinerant character of electron transport is also confirmed by the thermo EMF experiments. Such behavior seems to be in accordance with the developed theoretical model. The work was supported by grant of CRDF (RP2–5405-MO–02) and the NSF DMR [1]. F. Helmman et al. Phys. Rev. Lett. 84 (2000) 5411

A9.19 Quantitative analysis of average crystallization rate by growing-angle incidence X-ray backdiffraction technique. Siranush E. Bezirganyan1, Hakob (Akop) P. Bezirganyan2, Hayk H. Bezirganyan Jr3 and Petros H. Bezirganyan Jr4

Advanced technologies require more detailed investigations of amorphous-crystal interfaces. Many integrated circuits include a type of transistor known as a metal-oxide-semiconductor, field-effect transistor, or MOSFET, which has an insulated gate metal layer 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 transitions 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 forming a structure that continues directly from the amorphous phase to the solid crystal phase. The process by which the interface moves is the subject of much research. We suggest that the shape of the drops remains constant as they move to crystalline positions is called solid phase epitaxial growth or SPEG (e.g. see [2]). The investigations of crystal-amorphous state transitional layer can be performed using the Grazing-Angle Incidence X-ray Backdiffraction Technique (see [3] of original papers). In presented paper the theory of GIXD is extended for the investigations of the averaged rate of crystallization, and is considered theoretically an opportunity for the fine determination of the rate of the crystallization in various cases of crystal-amorphous state transitional layer. Images of the X-ray reflectivity coefficient of silicon amorphous-crystal interface computed for the GIXD configuration of crystalizing deposition technique are shown.

A9.20 Interaction of SiH₃ radicals with amorphous silicon surfaces. Sumit Agarwal1, Mayur S. Valpule1, Sarevanapriyan Sranam1, M.C.M. van de Sanden2, Dimitrios Maroudas2 and Eray S. Aydil3

Interactions of SiH₃ radicals with surfaces of hydrogenated (deuterated) amorphous silicon (a-Si:H(D)) films were studied using surface-sensitive attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy and molecular-dynamics (MD) simulations based on a recently developed many-body interatomic potential. We present experimental evidence for a-Si:H films regarding (i) occurrence of SiH₃ abstraction of surface D atoms by SiH₃ radicals, (ii) occurrence of SiH₃ insertion into surface Si-Si bonds simultaneously with surface D abstraction over a substrate temperature range of 70°C to 300°C, and (iii) dissociation of some fraction of the adsorbed SiH₃ on the a-Si:D films and release of H into the substrate. In our MD simulations show that SiH₃ radicals abstract surface hydrogen through an Eley-Rideal mechanism; the corresponding abstraction energetics are in excellent agreement with average density-functional-theory calculations and predict a very low activation energy barrier. Furthermore, according to detailed analysis of MD trajectories, the SiH₃ radicals are highly mobile on the amorphous silicon surface and diffuse through 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 the surface morphology and reactivity. Due to this chemical potential gradient, radicals impinging on the surface mesas migrate to the valleys, whereas radicals impinging in the valleys remains in the valleys leading to surface smoothing. Based on our experimental and computational studies, we propose a deposition mechanism for a-Si:H from SiH₃, which explains both the temperature-dependent reaction probability of SiH₃ 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 means of the remote expanding thermal plasma and an additional ion bombardment. Arno Smets, Erwin Kessels and Richard van de Sanden; Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

In the recent years it has been demonstrated that the remote expanding thermal plasma (ETP) is a depositions 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 surface roughness evolution during growth[1,2]. At present the maximum exposure temperature of a pin-device during processing is limited by the p-layer, which dictates the pin’s performance is maintained up to an intrinsic a-Si:H deposition rate of 1 nm/s using the ETP technique (Tdep=250 °C). Additional RF biasing of the substrate is a possible tool to reduce the substrate temperature while maintaining a sufficiently activated surface diffusion. The high rate a-Si:H growth without and with external RF substrate biasing has been studied by means of spectroscopic ellipsometry (SE). The SE technique shows extrinsic structural information from the initial growth, due to the high growth rate. Nevertheless, in the early stage of the growth, up to 50 nm, an evolving a-Si:H dielectric function has been observed. This initial growth phase is also observed in IR transmission measurements and originates from initial growth in which more voids are incorporated. The roughness results obtained from SE are compared with the roughness morphology obtained from AFM. Results on an additional RF-substrate bias at low substrate temperature of 100 °C show smoother surfaces accompanied with a thinning of the a-Si:H film, i.e. the incorporation of less voids.

A9.22
Molecular-Dynamics Modeling of Hydrogen Post Treatment of Hydrogenated Amorphous Silicon Thin Films.
Saravananpryan Sirimanon 1 , 3 , Mayur S. Valpa 1 , 2 , Eray S. Aydil 1 and Dimitrios Maroudas 2 . 1 Chemical Engineering, Princeton University, New Jersey; 2 Chemical Engineering, University of California, Santa Barbara, California; 3 Chemical Engineering, University of Massachusetts, Amherst, Massachusetts.

When exposed to a flux of H atoms, hydrogenated amorphous silicon (a-Si:H) thin films grown by plasma deposition from SiH4/H2 discharges crystalize at temperatures much lower than those required for thermal annealing. The flux of H atoms is generated either during post-treatment in a plume of atomic H radicals or by a remote-plasma source. The SiH4 feed gas is diluted heavily with H2. Understanding the fundamental physical-chemical mechanisms responsible for film crystallization is crucial for controlling the film structural and electronic properties. Toward this end, this presentation discusses atomic-scale modeling results for hydrogen post treatment of a-Si:H films. Using molecular-dynamics (MD) simulations of repeated H atom impingement on a-Si:H films, we modeled their post treatment by H2 plasma. The MD simulations were grown through MD with SiH4 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 form Si-H bonds to form intermediate bridging and bond-centered H (Si-H-H) configurations, which have been verified experimentally through in situ infrared (IR) spectroscopy. Systematic investigation of the H insertion pathways has led to derivation of a universal correlation of H insertion energetics with the strain of the corresponding Si-Si bonds for all the insertion mechanisms identified. Furthermore, a parametric study was conducted over a range of substrate temperatures (500 K < T < 773 K) to study the effect of hydrogen post treatment on the chemical composition of the H-exposed films; for the analysis, the evolution of the film surface hydride composition was monitored over the duration of the MD simulations. Our study predicts that etching occurs only at lower substrate temperatures, which is in good agreement with experiments based on in situ IR spectroscopy.

A9.23
High-quality hydrogen diluted SiNx films deposited by hot-wire chemical vapor deposition.
Fengxiao Liu 1 , 3 , Lynn Gedvilas 1 , Errol Sanchez 2 , Shulin Wang 2 and Qi Wang 2 . 1 NREL, Golden, Colorado; 2 Applied Materials, Inc, Sunnyvale, California.

We have studied the effect of H-dilution on silicon nitride films deposited by the hot wire chemical vapor deposition technique using SiH4, NH3, and H2 gases. We found that H-dilution significantly enhances silicon nitride films property. The N content in the film increases about 10% compared to H2 without H-diluted films from FTIR measurement. As a result, we can achieve high-quality films with a well-defined radicals beams such that the a-Si:H deposition process is improved for improved materials and for understanding low temperature deposition. A new ultrahigh vacuum setup has been designed and built for atomic H etching and of atomic H synergistic effects during the a-Si:H growth. It has been used to study both batch and continuous deposition processes. a-Si:H deposition using a low pressure hot-wire setup on a-Si:H films has 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 0.095 Si atoms per incoming H atom. Furthermore, no substrate temperature dependence of the etch efficiency is observed for substrate temperatures between 85 and 250 °C. Currently this Si etch process is studied with atomic deuterium using attenuated total reflection infrared experiments.

A9.25
Energetics of Surface Transport During Amorphous Silicon Deposition. Gregory N. Parsons and Kevin H Bray; Chem. Eng, NC State Univ, Raleigh, North Carolina.

Mechanisms in hydrogenated amorphous silicon growth are of interest for improved materials and for understanding low temperature deposition. It is known that only a few atomic layers can contribute toward growth, silyl radicals (SiH3) are considered to have a high surface mobility and to contribute to the observed conformal smooth surfaces. Surface roughness evolution, characterized by atomic force microscopy, has been used to characterize static and dynamic scaling coefficients (and trends used to extract values for energetic barriers associated with surface smoothing. Transport barrier values obtained are not consistent with previous models for silyl adsorption and hopping, so other approaches are considered. We find that under some plasma deposition conditions, scaling analysis provides a self-consistent set of parameters for a self-similar surface structure defined by surface diffusion. In other conditions, roughening mechanisms, such as ion bombardment, can dominate. For diffusion-dependent growth, the saturation roughness depends on film thickness, and the dynamic scaling coefficient is independent of growth temperature between 25 and 300°C. Within this temperature range, the lateral correlation length is observed to be independent on film thickness, but the value is thermally activated with a barrier of 0.2eV. In this same temperature range, the dynamic scaling coefficient is found to be near 0.25, independent of temperature, which is a low energetic barrier for surface transport related to smoothing. The transport barrier is smaller than the binding energies for silyl radicals on the growth surface. Species transport mechanisms in agreement with the observed scaling will be discussed.

A9.26
Structural and Electronic Properties of SiClx-based Microcrystalline Silicon Films.
David H. Allred, Reinhard Carus, Michael Lejune and Uwe Zastrow; Institute of Photovoltaics, Forschungszentrum Juelich, Juelich, Germany.

Microcrystalline silicon films are of interest for application in thin film solar cells and other devices. While silane is commonly used as the precursor gas, we explored the application of silicon tetrachloride (SiCl4) which is less expensive and less dangerous. For deposition we applied conditions leading for silane to high deposition rates and high solar cell efficiencies [1], namely a high dilution of SiCl4 by a high pressure of 4 mbar and a high rf (13.56 MHz) power of 60 W (1 W/cm²). While the flow rate of hydrogen was kept constant at 100 sccm, the flow of SiCl4 was varied between 0.5 and 10 sccm. For doping, dosing of diborane or phosphine were added. Typical substrate temperature was 250°C. The deposition rate was found to increase with rising SiCl4 flow and at a flow of 4 sccm a deposition rate of about 1 Å/min was obtained for undoped material. For high boron or 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 thermodiffusion power measurements. As the SiCl4 flow rate rises from 1 to 7 sccm, the Raman crystallinity of undoped material decreases continuously from nearly 97% to 90.7%, whereas the absorption measurements show an increase of the chlorine and...
Under conditions of low SiH 4 dissociation during the plasma-assisted deposition of hydrogenated amorphous silicon (a-Si:H) thin films, the dominant deposition precursor is the SiH 3 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 aligns valleys after adsoption onto the film. However, the fundamental atomic-scale processes that determine the surface morphology of a-Si:H films during deposition are not well understood.

In this presentation, we discuss such atomic-scale processes and provide a detailed fundamental analysis based on atomistic simulation. Using molecular-dynamics (MD) simulations of repeated impingement of SiH 4 radicals on the growth surface, we studied the deposition of a-Si:H films on initially H-terminated (110)- and (111)-oriented (110) surfaces. The simulated evolution of the film's structure, surface morphology, roughness, and surface reactivity was investigated systematically. The surfaces of these MD-grown films were found to be remarkably smooth due to a valley-filling mechanism where mobile precursors such as SiH 3 and SiH 2 diffuse and passivate dangling bonds present in surface valleys or at the valley edges. The mechanisms of SiH 3 precursor diffusion on the a-Si:H surface were studied placing special emphasis on elucidating the role of the a-Si:H substrate and the role of mobile hydrogen in modifying the valley-filling phenomena. The transport of the SiH 3 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 SiH 3 radical migration paths revealed the development of tensile strain regions along these paths, which typically lead to dangling bonds. Adsorbed SiH 3 radicals follow these tensile strain paths and passivate dangling bonds present in valleys or at valley edges, thus leading to valley filling.

A9.29 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 prepared atgrown high crystallinity polycrystalline Si1-xGe x (poly-Si1-xGe x : x < 0.05) at 450°C and its application to TFTs. The TFTs fabricated with 200Å thick films exhibited high mobility over 50cm 2 /Vs and 20cm 2 /Vs in bottom and top-gate-TFTs, respectively, even though the fabrication process had not been optimized yet. In this study, we prepared poly-SiGe thin films with variable germanium content (Ge5% to 20%). The films were analyzed using Raman spectroscopy, SEM, TEM and fourier-transform infrared (FTIR) measurement techniques. The content of Ge was determined by Raman peak intensity ratio of Si and Ge. We found that the gas flow ratio of Si/Ge of Ge/H 4 is one of the most important parameter to influence not only the Si/Ge content but the crystallinity. Only amorphous film can be deposited when no Ge/H 4 gas was introduced, while just increasing a small flow ratio of Ge/H 4 induced the crystalline film deposition. Further increase of Ge/H 4 flow resulted in raising of c-Ge and SiGe phase. The film growth rate varies in silicon-doped a-SiGe: H and the content of Ge increases. In order to investigate the influence of Ge for crystal growth, the films at early stage of film growth were also investigated with Raman spectroscopy and TEM. The nucleation formation was confirmed on glass substrate and the Ge content changed with increasing the film thickness. The growth mechanism associated with the Ge, its influences on growth rate, incubation time, crystallinity and conductivity of the films will be discussed in detail.

A9.28 A numerical model for microcrystalline silicon growth. Yasuyuki Kobayashi and Koji Satake; Advanced Technology Research Center of Mitsubishi Heavy Industries, Ltd., Yokohama, Japan.

Microcrystalline silicon (mc-Si:H) films, intensively investigated for solar cells, commonly made by low-temperature plasma enhanced CVD, have complicated structures that consist of mc-Si and amorphous silicon (a-Si). Some models used kinetic Monte Carlo method reproduced the evolution and 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 determine the growth conditions and the electrical properties. In this study, we present a three-dimensional numerical model for mc-Si:H growth, based on cell automata to predict the film properties. Our growth model of mc-Si:H has the following sequential process: (1) Facet growth velocities, governed by growth conditions such as reactive species fluxes onto a substrate, determine a grain basic growth form, (110) or (111)-oriented grains appear on condition that the facet growth velocities of (100) and (111) on the grains are nearly equal, so we assume only the (100) and (111) facets on the grain growth form. (2) An a-Si layer first appears on the growth surface and grows isotropically. (3) Crystaline nuclei generate, grow and prevail on the amorphous layer. (4) An evolutionary selection process of the grain growth selects preferable oriented grains to be larger, the grains finally dominate near the film surface. (5) Micro-twins generate in the grain, which affect film-preferred orientations. Facet growth velocities, n-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. These calculated results are converted into X-ray diffraction and Raman spectra to compare with experiments. We fit the growth parameters to agree with the experiments. The growth velocities of the crystalline facets were determined on a-Si-grown on an amorphous a-Si:H substrate using the facet growth velocities in advance. The (100) and (111) facet growth velocities were calculated. The other three growth parameters were estimated as the calculation agreed with the experiments. The a-Si growth velocity had to be slower than the facet growth velocities to form mc-Si films. The structure agrees with cross-sectional TEM images of the (110) oriented mc-Si films. And we have found the facet growth velocities affect the preferable orientation and also the surface morphology. Our model consistently explains the experimental data and the surface morphology from the SEM observations of mc-Si films. We thank Dr. K. Kamiya of Tokyo Institute of Technology for helpful discussions and suggestions. [1] S. W. Levine and P. Clancy, Modelling Simul. Mater. Sci. Eng. 8, 761(2000). [2] A. van der Drift, Philips Res. Repts. 22, 267(1967).
advantage of this new graphite catalyzer is its higher chemical and electrical stability as compared to those of Ta and W. After several tens of hours of deposition, the I-V characteristics and the surface morphologies of the films formed were monitored by ellipsometry and the root mean square roughness determined from atomic force microscopy (AFM). We have also found that low-temperature deposition (ULPCVD) or by plasma-enhanced chemical vapor deposition (PECVD). However, high process temperature of LPCVD and poor film quality of PECVD are being expected to limit the performance and the reliability of the next-generation semiconductor and display devices. Therefore, we are concerned with Atomic Layer Deposition (ALD) to solve these problems. In this study, silicon oxide films were deposited by self-fabricated ALD system, and effects of process parameters of the film properties were investigated. Tetraethoxysilane (TEOS, Si(OCH₂)₃H₄) and dichlorosilane (DCS, SiCl₂H₂) were used as the source gas and Oxygen (O₂) and water vapor (H₂O) were used as the Oxygen source and, nitrogen was used as the purging gas between the pulse of silicon and oxygen sources. Using each precursors, Silicon oxide thin films were deposited controlling process parameters, such as temperature, reactant exposures of the precursors, and number of cycle. Properties of the deposited films were characterized by 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.

**A9.34**

**Enhanced Surface Diffusion in Low-temperature a-Si:H Processing.** Peter van den Oever, Richard van de Sanden and Erwin Kessels; Deparment of Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

Besides the applications in microelectronics, plasma deposited silicon nitride (a-SiNₓ: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-SiNₓ:H can also accomplish bulk and surface passivation. In order to make the a-SiNₓ:H deposition process economically viable for these applications, a considerable increase in the deposition rate - up to several hundreds of angstroms per second - is needed. Other important issues are: control of the optical properties of the a-SiNₓ:H, control of the initial film growth in terms of film density and surface roughness, and a sufficiently low processing temperature. The expanding thermal plasma operated on Ar-N₂-H₂-SiH₄ and Ar-NH₃-SiH₄ gas mixtures has been used to deposit a-SiNₓ:H at rates up to 18 nm/s. Spectroscopic ellipsometry measurements have shown that the optical properties of the films can be accurately controlled by changing the flow ratio of SiH₄/ NH₃ and SiH₄/N₂ in the plasma and that films with similar optical constants can be deposited from both types of plasmas. The growth process of the films at high deposition rates has been monitored by real-time spectroscopic ellipsometry (RTSE) and the time evolution of the dielectric functions, bulk thickness, and surface roughness has been obtained using an optical model. In this model the dielectric response of the a-SiNₓ:H is described by the Tauc-Lorentz formalism. The highly transparent and non-absorbing character of a-SiNₓ:H and the high deposition rates make this material a very promising candidate for high-speed deposition of a-SiNₓ:H layers, especially for very thin films. To validate the real-time data, a series of films with different thickness has been analyzed by the combination of static ellipsometry and atomic force microscopy (AFM). It is found that the RTSE measurements show good agreement with the static ellipsometry measurements for films thicker than 75 nm. For thinner films however the sensitivity of the RTSE measurements is a limitation for resolving both the optical properties and thickness information of the films. Good agreement between the surface roughness determined by ellipsometry and 3D roughness determined from
the AFM images has been obtained. Furthermore, also the influence of the substrate temperature has been investigated and the deposition rate increased with increasing the substrate temperature from 400 to 100 °C. On the basis of the refractive index and the absorption coefficient it is concluded that the film density is significantly lower at these reduced temperatures but nevertheless no indication of oxidation of the n-Si$_{3}$N$_{4}$H$_{2}$ could be observed.

**A9.36**

The development of high quality intrinsic microcrystalline silicon (µc-Si:H) films at low substrate 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 µ-Si:H films compatible with the µ-Si:H deposition technologies for large area electronics applications. In this work, we have concentrated on obtaining large grains and high crystallinity at low temperatures in order to grow 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 (PECVD) technique. 

We have studied the crystallinity and hydrogen content of the films by using Raman spectroscopy and X-ray diffraction, respectively. The hydrogen content was found to be lower than 30% in all the films, and the crystallinity was between 30% and 45%. The films were also found to be very smooth with a root mean square roughness of less than 0.2 nm. The deposition rate was found to be between 0.5 and 1 Å/s, with a maximum at a substrate temperature of 150 °C. The films were found to be highly resistive, with a resistivity of around 10$^{4}$ Ω·cm. The deposition rate and resistivity were found to be independent of the substrate temperature, indicating that the films were deposited in a region far away from the growing surface.

**A9.37**
Growth and Properties of Insulators For Nanocrystalline Si:H TFT Devices. Viskram I. 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 glass insulators as well as plasma oxidized silicon oxide and F-doped silicon oxide. We also investigate silicon oxynitride which is known to improve the film quality of both plasma oxidized silicon oxide and F-doped silicon oxide. MOS capacitor and MOSFET devices were investigated for both p- and n-type nanocrystalline Si:H. Nanocrystalline Si:H capacitors with capacitance and conductance of less than 0.1 and 0.01, respectively, were used for these studies. It was found that the interface state density was a strong function of the carrier concentration in the film. The lower defect density obtained was in the range of 2-3E10/cm$^2$.

**A9.38**
Hot-temperature Silicon films deposition by pulsed cathodic arc process for microsystem technology. Hui Xie$^a$, Yan Yang$^a$, and Paul L. Bergstrom$^b$; $^a$Department of Material Science and Engineering, Michigan Technological University, Houghton, Michigan; $^b$Department of Electrical and Computer Engineering, Michigan Technological University, Houghton, Michigan.

The deposition of silicon films ranging from tens of nanometers to tens of microns for microelectromechanical system (MEMS) devices was investigated by pulsed cathodic vacuum arc process. This method has been employed to take the advantages of its low deposition temperature, high deposition rate, and high-energy capabilities, compared with its relative low operational cost.

In this study, we focused on the growth of high-quality silicon films at low processing temperatures. Silicon films were deposited on silicon and glass substrates at temperatures below 400 degrees Celsius with pulsed deposition rates up to 75 nanometers per second. Pulsed arc currents up to 400 amperes and 1.5 milliseconds pulse width with 20 300 pulses per second were studied. Compared with continuous DC cathodic vacuum arc, numerous possibilities exist for pulsed arc to suit specific targeted film growth. Deposition temperature and film stress can be controlled by adjusting arc pulse frequency and pulse width. However, the characterization of the films was carried out by X-ray diffraction (XRD), atomic force microscopy (AFM) and scanning electron microscopy (SEM) in terms of materials morphological and structural properties. The production of MEMS device quality silicon films at low temperature would further enable the integration of microsystems with microelectronics.
temperatures, the films present good electro-optical properties. No powder formation was detected although some oxygen contamination was still of concern. The results show that the p/i interface maintains its confinement outside the growing surface gives to this PE-CVD system the ability of producing good quality films at low temperatures, with high deposition rates.

A9.41 Large-Area Hydrogenated Amorphous and Microcrystalline Silicon Double-Junction Solar Cells, Baoshe Yan, Guozhen Yue, Aristarchos Bapstige, 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 cell of hydrogenated amorphous silicon (a-Si:H) based multiple-junction solar cells has attracted significant attention because of its higher current capability and better stability against light soaking. In our previous report [1], we have shown an initial active-area efficiency of 13% for an a-Si:H/Aµc-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 a-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 35 cm² at a relatively low rate 1 Å/s. The thickness uniformity is well within ± 10%, which is similar to the uniformity of the n-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 efficiency at 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 un-encapsulated solar cells, respectively. The 11.3% cell became 10.6% after encapsulation. Currently, we are working on increasing the deposition rate and reducing the 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. 702, A4.1 (2003).

A9.42 Measurement of the Potential Distribution in Silicon-Based Thin Film Solar Cells by Scanning Kelvin Probe Microscopy, Chun Shing Moutinho, Momenzadeh, Baojie Yan², Jeffrey Yang² and Subhendu Guha²; National Renewable Energy Laboratory, Golden, Colorado; United Solar Ovonic Corporation, Troy, Michigan.

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

A9.43 Microcrystalline Silicon Solar Cells Deposited Using Modified Very-high-frequency Glow Discharge and Its Application in Multi-junction Structures, Guozhen Yue, Baojie Yan, Jessica M Owens, Jeffrey Yang and Subhendu Guha; United Solar Ovonic Corporation, Troy, Michigan.

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

A9.44 Development of transparent conductive oxide materials for improved back reflector performance for amorphous silicon based solar cells, Scott J Jones, David Tau, Tongyu Liu, Jeff Steele, Roy Capangpangan and Massi Izu; Energy Conversion Devices, Inc., Troy, Michigan.

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

A9.45 Dominant effect of p/i interface on dark J-V characteristics in p-i-n nano-crystalline Si solar cells, Ujwal K Das¹, Andreas Bozán², Scott W Morrison¹ and Arun Madan³; MVSystems Inc, Golden, Colorado; "Institut für Mikrostrukturplanung Elektronik, Universität Stuttgart, Stuttgart, Germany.

Nano crystalline silicon (nc-Si) based p-i-n (nc-Si:H/p/i-nc-Si:H/p/i-nc-Si:H) 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 Sn02 (textured), AIST supplied Ga doped ZnO (textured) and MVS developed Al doped ZnO (textured). Dark J-V characteristics of nc-Si p-i-n solar cells were found to depend strongly on the substrate materials and are studied at different i-layer thicknesses and varying the p/i interface structures. In our earlier work, we have found that the diode quality factor, n (measured from J = J0 [exp(V/MnKFT)]-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 variation of n with i-layer 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 AIST/MVS textured ZnO substrates. The rather insensitive variation of n with i-layer thickness suggests that the dark J-V characteristics are not dominated by bulk recombination for the devices grown on "suitably textured substrate", which prevents the grain collision in the i-layer. In contrast to that, a significant change of n (1.8 - 1.3) was found while changing the p/i interface structure by different surface treatment procedures during PECVD deposition. The result suggests that the p/i interface primarily dictates the device performance. The p/i interface structure in the thin-film silicon 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 i-layer and hence the whole device performance. [1] U. Das, S. Morrison, E. Centurioni, and A. Madan, Mat. Res. Soc. Symp. Proc. Vol. 715 p. A26.2.1 (2002).


Dilution by Ar of silane plasma has been reported to increase the stability of a-Si:H films. A critical question is whether Ar diluted i-layers offer higher stabilized solar cell efficiencies than the hydrogen dilution method. We have fabricated a-Si:H solar cells with PECVD
The I-V curves of A. and 3000 further increase in Ar dilution, and light soaking caused mild degradation found in efficient tunnel junctions of cells made with high ADR are inferior to the cells with lower ADR or cells prepared by H2 dilution. Further, V oc of the solar cells made with high ADR (> 50) decreases substantially in ambient, indicating a porous structure and film microstructure is a major contributor to the degradation compared to hydrogen dilution. We have succeeded in fabricating nc-Si solar cells using the Ar dilution approach. The double dilution by Ar and hydrogen leads to nc-Si:H-i-layer with enhanced electrical properties compared to the devices incorporating i-layers grown by H2 dilution only. The nc-Si:H solar cells with Ar 37% diluted i-layers exhibit no light-induced degradation. Using energetic Ar-rich plasma, in a process much simpler than the traditional nc-Si technique, doped nc-Si thin layers can be prepared to form excellent tunnel junctions for multi-junction solar cells. We demonstrate such a novel, non-contaminating tunnel junction for a-Si/a-Si and a-Si/nc-Si tandem solar cells entirely fabricated in a single-chamber, all-stationary RF-PECVD system.

A9.47

Nanocrystalline Germanium p-i-n Structures


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 enhanced chemical vapor deposition (PECVD) using GeH4 and H2 source gases, with PH1 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 p- and n-layers to improve electron sheet resistance through the solar cell. The p-layers were deposited on the SnO2 in a superstrate configuration. Circular, 3 mm diameter, 3 mm2 area, solar cells containing 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 schemes on the photovoltaic properties of the completed structures. Finally, the insertion of a thin buffer layer at the interface between a-Si:H and mc-Si:H is addressed.

A9.48

Deposition of Optimal a-Si:H and a-SiGe:H by Hot Wire CVD Using the Same Film Temperature and Substrate Temperature

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

A9.49

Passivation schemes for amorphous silicon (a-Si:H)/crystalline silicon (c-Si) heterojunctions for photovoltaic applications.
and carrier collections of these cells, high short-circuit current, \( J_{sc} \), 12.5 - 13.5 mA/cm² and open-circuit voltage, \( V_{oc} \), 0.90 - 0.91 Volts have been obtained for 150 - 170 nm thick i-layers, compared to 270 - 280 nm absorber layer for best single junction a-Si:H solar cells of BP Solar for the same range of values of \( J_{sc} \) and \( V_{oc} \). This apparent contradictory results can only be reconciled, if the optical absorption of the a-Si:H layer is enhanced, however, the huge number of the above hundred \( A \) 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 SiSi 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 photocurrent (IRPC) measurement will be reported. The nanostructure of amorphous films and its correlation with optical properties and metastability will be presented. 1. A. R. Middya, S. Hamma, S. Hozu, S. Ray and C. Longeau, Mat. Res. Soc. Proc. Vol. 694 (2001) p. A5.1.2.

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 HWCDP[1]. By lowering tungsten (W) filament temperature more than 0.180°C and at the same time, lowering substrate temperature from more than 350°C to 250°C, we obtained high quality a-SiGe alloys with a narrow Taue band gap of 1.25 - 1.30 eV. These materials have a Ge content in the range of 30 - 40 atomic percent, with activation energy of 0.64 eV and Urbach energy of 53 meV. We found that about 40 percent of the total hydrogen content (10 at. percent) is in Ge-H bonding configuration and no observable silicon dihydride bonding, the films are very compact with low heterogeneity. In this paper, we will report the results of incorporation of these materials into single-junction n-i-p solar cells to verify the high material quality. In previous reports [1,2], a single-junction n-i-p device, with a 120 nm thick narrow gap a-SiGe:H alloy intrinsic layer, produced a short circuit current density of up to 20 mA/cm² with a poor fill factor (FF) of 38 percent due to an abrupt bandgap transition between doped layers and the a-SiGe:H alloy intrinsic layer at the n/i and i/p interfaces. To avoid this problem and improve the collection for holes, we have used the bandgap profiling in the narrow band gap a-SiGe-H layer and improved both the open circuit voltage and FF significantly without any loss in short-circuit density. As a result, we have improved the solar cell efficiency from 3.55 percent to 5.85 percent. This improved a-SiGe:H cell has a quantum efficiency of 0.48 at 800 nm and 0.15 at 900 nm. We will present details of the bandgap profiling and the effect on device performance. 1. Yuejin Xu, Brent P. Nelson, Lynn M. Gedvilas, and Robert C. Reedy. Tech. Dig. 1999 Mat. Res. Soc. Symp. Proc. 597, 197-201. 2. Yuejin Xu, Brent P. Nelson, D.L. Williamson, Lynn M. Gedvilas, and Robert C. Reedy. Mat. Res. Soc. Symp. Proc. Vol. 702 (2003). A0.1.2.

A0.53

Correlation of Material Microstructure and Device Performance in Nanocrystalline Silicon Solar Cells. Anthony Canning,1 J R Weinberg-Wolf,1 E C T Harley,1 Kenda Wang,2 Daan Han,2 Bojie Yan2, Guozhen Yue3, Jeffrey Yang1 and Subhendu Guha1,2 Science & Astronomy, UNC-Chapel Hill, Chapel Hill, North Carolina; 1United Solar Ovonics Corporation, Troy, Michigan.

We use Raman and photoluminescence (PL) spectroscopy to study the relationship between the material properties and device performance of hydrogenated nanocrystalline silicon (nc-Si:H) solar cells made using conventional RF, modified VHF and microwave glow discharge. Raman measurements were made directly on solar cells using 514.5-nm line from an argon-ion laser under ambient conditions. Crystalline volume fraction (fc) in the region near the i/p interface was deduced from the Raman transverse optical (TO) mode. PL spectra were measured at various temperature using 632.8 and 412 nm wavelengths to observe as excitation the electronic transitions in the bulk of the intrinsic nc-Si:H layer and the top layer near the i/p interface, respectively. In general, the experimental results show that a high fc in the intrinsic nc-Si:H leads to a high short circuit current density (Jsc) and low open circuit voltage (Voc). Most of nc-Si:H cell show two PL peaks at 80 K. One peak at 1.36 eV is from the band tail recombination in the amorphous region and another one 0.87 eV from the band tail recombination in the crystalline region. A possible orientation of the band tails in the crystalline region is discussed. 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 an 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.
photoluminescence and electroluminescence have been observed from a-Si:H:Er:O. A new material that has recently attracted considerable attention is a-SiGe:Er:O. Upon optical excitation, material transforms into a quantum dot solid, with silicon nanocrystals randomly dispersed in a SiO$_2$ matrix. This material, which can be made by CVD, sputtering, or ion implantation, is an interesting host for the fabrication of high-quality Er:SiGe waveguides. The host material provides the proper coordination for Er, enabling a high luminescence quantum efficiency and no temperature quenching. The Er quantum dots serve as sensitizers for Er; upon their optical excitation, they rapidly and efficiently transfer their exciton recombination energy to Er. As the quantum yield of Er in a-SiGe:Er:O is calculated to be about 7 nm, which agrees well with the TEM observation. In conclusion, we have demonstrated a simple and efficient way to transfer the exciton recombination energy to Er. As the size control of a-SiGe:Er:O is possible and a promising method for the realization of silicon-based photonic devices based on Si:Er.

We have studied the growth of amorphous silicon quantum dot (a-Si QDs) and the optical and electrical properties for their application to light-emitting and memory devices. a-Si QDs embedded in silicon nitride were grown by plasma-activated chemical vapor deposition using silane and nitrogen gases and were found to emit various colors including red, green, and blue 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 a-Si QDs is considered to play a dominant role in the charging properties such as electron storage and charge-loss rate in the a-Si QDs. Long-term charge storage was observed in the fully charged a-Si QDs and this was attributed to a suppression of the discharge process by electrostatic repulsion among the charged dots. Size-dependent charge storage was also observed and this was attributed to the changes of tunneling barrier due to a quantum confinement effect in the a-Si QDs. We will further present our recent results on the use of ammonia instead of nitrogen gas in the growth of a-Si QDs and the hydrogen passivation effect on the emission and charge storage of a-Si QDs.

Novel Flat Panel Imager with a Two-Stage Charge Amplifier in Each Individual Pixel

Flat panel imagers (FPIs) have become an important application in the arena of large area, thin-film electronics aside flat panel displays. Conventional flat panel imagers, are simple arrays of photo-sensors connected to active matrix networks of amorphous Si Thin Film Transistors (TFTs). The integration of gate line drivers, data line multiplexers, and pixel level amplifiers are made possible by the recent development of high-performance, excimer-laser annealed (ELA) poly-Si TFTs, further improves imagers performance and sensitivity. Among these new integrated functions, the pixel level amplifiers are probably the most interesting since they fundamentally improve the imager sensitivity. The ELA poly-Si TFTs, further improves imagers performance and sensitivity. Among these new integrated functions, the pixel level amplifiers are probably the most interesting since they fundamentally improve the imager sensitivity.

In this paper, we report on the first successful demonstration of an imager with complete two-stage charge amplification circuitry, consisting of one pixel. The 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 photodiode. The pixel level charge amplifier includes five poly-Si TFTs, n-channel amplifier, and p-channel amplifier, which are connected in a cascode configuration. The imager, believed to be the most sophisticated currently available on a glass substrate, provides a constant optimal sensor bias at all times, because of the virtual ground nature of the charge amplifier input, as well as the potential of even further 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, Stuebler-Wronski Effect (SWE) in exchange of a non-ideal surface shown has been a major concern in their acceptance, due to degraded spatial contrast and color fidelity. Since the SWE is a fundamental mechanism of a-Si:H, solutions to this issue must look to ways of mitigating the SWE on diode and improve performance. Instead of thin film active layer, 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 observed signal. In addition, a CMOS-compatible structure to suppress electrical crosstalk was designed and fabricated. Results from these structures demonstrates suppression of crosstalk up to lateral electric fields of at least 2 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


In particle physics, the increasing accelerating energies and fluences used in experiments call for radiation-hard particle detectors. In this context, amorphous silicon (a-Si:H) has been suggested as a promising candidate for the next generation of particle sensors. Using an approach developed for vision applications, a-Si:H sensors may be directly deposited on a CMOS readout chip. This method of vertical integration is also called the "Thin Film on CMOS (TFM)" technology. It considerably reduces the cost compared with the 2-D a-Si:H pixels 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 500 nm) have been developed. They have been deposited on glass substrates and subsequently on several different types of CMOS readout chips. Using these sensors, CERN have achieved detection of single low-energy beta particles [2] and of betas at the minimum ionizing energy [3].