SYMPOSIUM A

Amorphous and Nanocrystalline Silicon-Based Films-2003

April 21 – 25, 2003

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Hydrogenated amorphous silicon (a-Si:H) and micro- or polycrystalline silicon (µc-Si, poly-Si) are important technological materials for large-area electronics, with applications to thin film solar cells, active matrix liquid crystal displays (AMLCDs), optical sensors, and radiation imaging. The course describes the growth and preparation, basic material properties, device physics, and state-of-the-art processing issues of modern large-area array technology based on amorphous or polycrystalline thin silicon films. Special emphasis will be on the relation between material properties and device performance.

Instructors:
Siegfried Wagner, Princeton University
Joao Pedro Conde, Instituto Superior Tecnico, Lisbon

SESSION A1: NANOCRYSTALS AND PHOTONICS
Tuesday, April 22, 2003
Salon 5/6 (Marriott)

8:30 AM #A1.1
SILICON NANOCRYSTALS ELECTRONICS AND PHOTONICS
Harry A. Atwater, R.J. Whaaker, J.S. Bithen, T. Fong, J. Casperek, California Institute of Technology, Pasadena, CA; and Harvard University, Cambridge, MA; and A. Polman, FOM Institute for Atomic and Molecular Physics, Amsterdam, NETHERLANDS.

The interplay between the photophysics and electronic properties of silicon nanocrystals and nanocrystal arrays is a rich area for physics and device applications, and is currently yielding interesting surges. In this talk, I will compare and contrast the optoelectronic properties of arrays of isolated silicon nanocrystals passivated by hydrogen or oxide termination with the properties of the continuous films of nanocrystalline silicon that are more familiar to us in the thin film silicon electronics community. I will discuss the dependence of nanocrystal luminescence on electronic change state, and survey potential applications for silicon nanocrystal arrays in nonvolatile memory devices, photodectors, novel optical memory devices, and future possibilities for silicon nanocrystals in photovoltaic devices.

9:00 AM A1.2
PHONON CONFINEMENT IN Ge NANOCRYSTALS IN SILICON OXIDE MATRIX. Y.X. Jie, A.T.S. Wei, C.H.A. Huan and Z.X. Shen, Department of Physics, National University of Singapore, SINGAPORE.

Well-dispersed spherical Ge nanocrystals in silicon oxide thin film on Si substrate have been synthesized with different sizes and crystallinity using RF magnetron sputtering. Significant Raman shift and broadening have been observed from the samples annealed under different conditions. Several phenomenological phonon confinement models have been compared with our experimental data. The observed size-dependent shift and broadening is found to be well depicted by the BWL phonon confinement model combined with a Gaussian weighting function and the isotropic TO2 phonon dispersion relation introduced by Suzuki et al. The Raman shift and broadening are described by 1-d 47 and 1-d 75 power laws respectively. A three-peak fitting method of obtaining Ge nanocrystal size and crystallinity is introduced.

9:15 AM A1.3
PREPARATION OF SiOx/SiOy SUPERLATTICES FOR ORDERED Si NANOCRYSTALS. L.Y. Ju, J. Heitmann, R. Scholz, and M. Zichner, Max-Planck-Institute of Microstructure Physics, Halle, GERMANY.

The preparation of ordered, arranged Si quantum dots using a superlattice approach and reactive evaporation of SiO powder is presented. By this method, an independent size and density control is possible for Si nanocrystals [1]. The different stages of phase separation and crystallization are studied in detail by infrared absorption (IR), photoluminescence (PL), and TEM in a function of annealing temperature from 300 to 1100°C [2]. IR spectra show a continuous shift of the Si-O-Si asymmetric stretching mode from 1180 cm⁻¹ as a signature of Si and SiO₂ phase separation. Three PL bands are distinguished correlated to the three stages of phase separation. A band centered at 590 nm is present in as-prepared samples and diminishes for annealing above 700°C. The second band shifting from 700 nm to 850 nm is detected for annealing temperatures between 500°C and 550°C. A strong red luminescence is observed for annealing above 900°C. The origin of the different IR and PL bands related to different stages of phase separation of the ultra thin SiOx layers will be discussed in detail. Our results show that the different bands, seemingly contradictory, PL and X-ray diffraction features, can be understood as different stages of network reorganization during the phase separation and crystallization processes. After crystallization, the strong PL shows a blue shift with decreasing SiO layer thickness from 20 nm to 740 nm due to quantum confinement. The emission energy and power dependence of the strong room temperature PL is discussed in comparison to bulk crystalline Si. [1] M. Zichner, J. Heitmann, R. Scholz, U. Kuhler, M. Schmidt, J. Bliokh, Appl. Phys. Lett. 80 (2002) 661. [2] L.X. Yi, J. Heitmann, R. Scholz, M. Zichner, Appl. Phys. Letter in press.

9:30 AM A1.4
THE FORMATION OF Si 1-x Ge x NANOCRYSTALS AND CONTROL GATE OXIDE THROUGH THE OXIDATION OF THIN AMORPHOUS SiOxGe3 Y LAYER AND ITS ELECTRICAL PROPERTIES. Tae-Sik Yoon, Seoul National University, Research Institute of Advanced Materials, School of Materials Science and Engineering, Seoul, KOREA; Hyun-Mi Kim, Ki-Su Kim, Ki-Bum Kim, Seoul National University, School of Materials Science and Engineering, Seoul, KOREA.

It is necessary to form nanometer size quantum dots embedded in the oxides in order to fabricate a flash-type single electron memory device. In this talk, we propose a novel scheme to form Si 1-x Ge x nanocrystals and the control gate oxide (upper oxide), simultaneously, through the oxidation of the thin deposited amorphous SiOxGe3 layer. Firstly, a 5 nm thick amorphous SiOxGe3 layer is deposited by LPCVD on SiO2 substrate. Secondly, this layer is oxidized by the dry oxidation process at 600°C for 20 minutes. During this second step, not only the oxidation of Si 1-x Ge x layer occurs but also, the remaining Si 1-x Ge x layer forms an uniform nanometer size crystals. It is identified that the average size of nanocrystals is 3.7 ± 0.9 nm with a density of 5.43 × 1013 /cm² and the thickness of upper oxide was measured as 4 nm. CV characteristics were measured by fabricating Al/SiO2[300nm]/4nm-thick SiO2/Si 1-x Ge x nanocrystal/Al gate structure both before and after processing with negative bias. The plateau of flat-band voltage shift (AV FB) was clearly observed at room temperature with a magnitude of 0.223 V due to the electron charging in nanocrystals.

9:45 AM A1.5
POSSIBLE APPLICATION OF PHOTONIC CRYSTALS TO PHOTOVOLTAICS. J.G. Fleming and S.Y. Lin, Sandia National Laboratories, Albuquerque, NM.

Photonic crystals are the photonic analogues of semiconductors. The photonic band structure results when light encounters a well-defined repeating arrangement of materials with differing refractive indices. This behavior is independent of the electronic properties of the material making up the crystal as long as it does not strongly absorb. Advances in silicon processing technology have resulted in rapid progress in this field. We have recently demonstrated tunable near-infrared photonic crystals, using silicon, back end of the line processing. In the course of our work we have found that these metallic photonic crystals demonstrate thermal emission properties that device significantly from the behavior predicted by the normal derivation of the Stefan-Boltzmann law. In particular, when heated, they show anomalous thermal emission in a relatively narrow band of wavelengths at the higher energy band edge. We have observed that the bulk of the energy emitted by the structures is contained in this relatively narrow band and that the intensity of emission at these wavelengths is close to an order of magnitude greater than that emitted by a black body. The peak emission wavelength also does not blue shift as the material is heated. We believe that this behavior arises from the significant modification of the photonic density of states associated with these structures. We propose that it may be interesting to consider the integration of such a photonic crystal emitter with a band edge in the near infrared with a concentrator and absorber system. The aim of this would be the conversion of a high fraction of the solar radiation into heat and subsequently into a narrow band of wavelengths targeted at the bandgap of a semiconductor. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

SESSION A2: DEFECT SPECTROSCOPIES
Tuesday, April 22, 2003
Salon 5/6 (Marriott)

10:30 AM #A2.1
META-STABLE DEFECTS IN THE AMORPHOUS SILICON.
GERMANIUM ALLOYS. J. David Cohen, Department of Physics and Materials Science Institute, University of Oregon, Eugene, OR.

In this talk I will first briefly review some of the early studies that established some of the salient features of light-induced degradation in a-Si,Ge:H. I will then examine a couple of complicating issues that came to light more recently; namely, the possibility that charge defects play a more central role in the alloys, and that both Si and Ge metastable dangling bonds may be involved, even up to levels above 20%. Ge. I will then discuss some of the most recent studies carried out by members of the NRL-LLNL team focusing on the details of degradation in the low Ge fraction alloys to gain insight into the fundamentals of degradation of amorphous silicon materials in general. Finally I will conclude with a brief assessment of the level of our understanding of degradation in the a-Si,Ge:H alloys and where some key issues are still remaining to be resolved.

11:00 AM A2.2 TEMPERATURE DEPENDENCE OF THE DECAY OF OPTICALLY EXCITED CHARGE CARRIERS IN AMORPHOUS SILICON. J. Whittaker and D.C. Taylor, Department of Physics, University of Utah, Salt Lake City, UT.

Modeling of the eventual recombination of optically excited electrons and holes in amorphous silicon at low temperatures (T < 40 K) involves two distinct processes, the hopping down in energy via tunneling of each individual carrier (diffusion) and recombination of electrons and holes via tunneling. At short times the hopping down process dominates, and at long times the recombination process dominates. One can define the tunneling timescales (i.e., the times the two processes compete: quantum tunneling by a single carrier to a lower energy state, and recombination of an electron and a hole via tunneling). At finite temperature where excitations that increase the effective mass provide a third mechanism for carrier trapping, a third intermediate range hopping of the charge carriers, must be considered. The optically induced electron spin resonance (EESR) signal of amorphous silicon at low temperatures has been well studied for time scales greater than about 1 ps [1]. The photoexcited spin (PL) signal, which is related to the LEESR, in amorphous silicon has also been well studied for time scales less than about 1 ns [2]. We have studied the temperature dependence of the growth and decay of the LEESR on short and long time scales (10 ps < t < 200 ns) in between the previously published photoluminescence and the LEESR data. In addition, we have examined the saturated density of charge carriers as a function of temperature and excitation intensity. These measurements lead to a better understanding of the band tail structure of amorphous silicon as well as the kinetics of the excitation and recombination processes.


11:15 AM A2.3 ELECTRON SPIN RESONANCE INVESTIGATION OF LASER CRYSTALLIZED POLYCRYSTALLINE SILICON: K. Brendel, Hahn-Meitner-Institut Berlin, Berlin, GERMANY.

Polycrystalline silicon (poly-Si) produced by excimer laser crystallization is a promising candidate for electronic devices such as TFTs and solar cells. A competitive way to produce high quality poly-Si is laser crystallization of amorphous silicon. We investigated electron spin resonance in undoped and phosphorus-doped laser crystallized poly-Si with electron spin resonance (ESR) measurements. Hydrogenated amorphous silicon was deposited in a PECD process. A step-by-step crystallization procedure was performed on the samples. In fully crystallized films a hydrogen concentration of about 5·10^{18} cm^{-3} is still remaining in the film. The spin density, N_{sp}, in fully crystallized films amounts to about 6·10^{17} cm^{-3}. The remaining hydrogen can be activated into a single vacuum anneal and reduces the defect density. A 1h anneal at 400°C results in a decrease of N_{sp} by a factor of 2. From the temperature dependence of the change in the spin density, ΔN_{sp}, an activation energy of E_{a} ≈ 0.2 eV was estimated. The number of passivated defects depends on the hydrogen concentration in the initial amorphous layer. Phosphorous and boron doping concentrations up to 100 ppm do not result in a decrease of N_{sp}. For phosphorous concentrations larger than 10 ppm the resonance of the crystalline electron (CE) emerges with a g-value of about 1.9865. The g-value decreases with increasing temperature and increasing phosphorous doping concentration. Temperature dependent ESR measurements reveal that in highly doped samples nearly all electrons show Pauli paramagnetism. For lower doping concentrations a mixture of Curie and Pauli paramagnetism can be observed. This is similar to results observed in single crystal silicon. The linewidth, ΔH_{PP}, increases with increasing doping concentration and increasing temperature. A factor 2 smaller than in microcrystalline silicon, but it exceeds the value reported for single crystal silicon by about a factor of 4.

11:30 AM A2.4 TIME-RESOLVED SWITCHING STUDIES IN a-Si:H AND a-Si:Ge:H FILMS. P. Struck, W.B. Jackson, H.M. Braun, J. Hu, C.L. Perkins, and Q. Wang, National Renewable Energy Laboratory, CO; Hewlett Packard Laboratories, Palo Alto, CA.

We report time-resolved studies of switching in hydrogenated amorphous silicon (a-Si:H), microcrystalline Si (μ-Si:H), and a-Si:Ge:H layers sandwiched between two metallic layers. Two distinct types of switching kinetics are characterized by studying the dependence of switching current on switching voltage and on the nature of the layer material, its doping, the contact metal, and switching temperature over a wide range of applied voltage pulse amplitudes. In a-Si:H and μ-Si:H, we normally see Type I switching characterized by a latency time (τ_L) followed by a sudden switching event. During the latency time, the sample current exhibits a telegraphic noise (‘pre-switching’) which may be a precursor of a permanent switching and filament formation. These pre-switching changes in I, for < τ_L are reversible but may persist for as long as milliseconds at room temperature after termination of the voltage pulse. At > τ_L, samples switch permanently to a highly conductive state. The values of τ_L follow random statistics and vary over a wide range depending on the applied voltage. Once the final switching event begins, it typically completes in microseconds.

Scanning micro-Auger microscopy confirms that Type I switching is normally accompanied by the formation of a single submicron-diameter metallic filament connecting the metallic contacts. In a-Si:H, switching with sufficient voltage, we normally observe Type II switching in which I increases gradually from t = 0. By interrupting the pulse, a continuum of stable final states with gradually variable high conductance can be reached. At low levels of current, the switching conductance saturates only at long pulse times. Both the sudden and gradual switching times depend exponentially on the applied voltage pulse amplitude with characteristic times that depend on the contact material. Triggered charge accumulation, nonlinear effects of current-induced heating, and field dependent conductivity are investigated as possible causes of the two types of switching and their voltage dependences.

11:45 AM A2.5 ADSORPTION AND OXIDATION EFFECTS IN MICROCRYSTALLINE SILICON T. Diyle,8, F. Finger,9, R. Cariss; Institut für Photovoltaik, Forschungszentrum Jülich, Jülich, GERMANY; 8Department of Physics, Syracuse University, Syracuse, NY.

The development of microcrystalline silicon (μc-Si:H) for solar cells has made good progress with efficiencies, and these are significantly larger than for comparable amorphous silicon devices. However, in-diffusion of atmospheric gases can affect the electronic transport and the stability of μc-Si:H devices and can cause significant degradation upon oxidation, or oxidation effects in μc-Si:H with different crystalline volume fractions and various degrees of porosity by electron spin resonance and conductivity measurements. The material was deposited with PECD at silane concentrations 3-5%. The material structures can be classified in three categories as (i) highly crystalline, very porous material at SC ≈ 3%, (ii) very crystalline, compact material between SC = 3-5% and (iii) crystallites diffused in an amorphous phase at SC = 6-7%. The samples were stored and measured (9G) in different environments (air, O_2, H_2O, Ar). Spin density N_S and electronic conductivity are clearly influenced by adhesion and oxidation effects. When stored in water or air, N_S of highly crystalline, porous material increases by up to a factor of three. Annealing in Ar completely restores the original N_S. These changes in N_S affect only the resonance at g ≈ 2.0052, while the second resonance at g = 2.0043 is not affected. These results indicate that the resonances represent defects in different environments of the material. With decreasing porosity the changes in N_S are less pronounced, and they are not observed at all for material with a large amorphous phase contribution. The conductivity measurements suggest that adhesion leads to a strong peculiarity of a-Si:H. The other hand, the material is annealed in pure oxygen atmosphere, a non-reversible increase of N_S with the appearance of an additional resonance is observed. Such behaviour can have serious consequences on the stability of μc-Si:H devices and should be considered when investigating spin densities of μc-Si:H of different structure compositions.

SESSION A3: SOLAR CELLS
Tuesday, April 22, 2008
Salon 5/6 (Marriott)

1:30 PM A3.1 HIGH EFFICIENCY THIN FILM SILICON SOLAR CELL AND MODULE. Kenji Yamamoto, Akiko Nakajima, Masashi Yoshimi, Toru Sawai, Saisumu Fukuda, Katsuhiko Hayashi, Takashi Suenoki, Mitsuru Ishikawa, Yohei Ko, Masahiro Go, Hiroshi Takata, and
An initial efficiency of 14.5% (Jsc=14.4mA/cm^2, Voc=1.41V, FF=71.9%) has been achieved for a-Si:H / transparent inter-layer / microcrystalline Si solar cell (total area of 1 cm^2). Both a-Si and microcrystalline Si films were fabricated by plasma chemical vapor deposition on glass substrates. The short circuit current (Jsc) was enhanced by the introduction of a transparent inter-layer without increasing the thickness of a-Si:H layer. It was also found that the internal quantum efficiency is improved due to the presence of an inter-layer of a-Si:H. The open circuit voltage (Voc) is very high in the presence of a transparent inter-layer. An initial aperture efficiency of 13.3% has been achieved for Si 0.045% 2.5% / microcrystalline Si thin film integrated large area solar cell module.

2:00 PM A3.2 BANDTAIL LIGHTS TO SOLAR CONVERSION EFFICIENCY IN A MORPHOLOGICAL SOLAR CELLS: K. Tsuchiya, T. Irie, T. Takechi, Y. Morita, T. Ohta, Y. Kondo, T. Murakami, H. Sato, and M. Takahashi

We have measured the electrical properties of amorphous silicon based solar cells in their initial, non-light-soaked state, and we conclude that in some cases these properties can be understood without reference to deep levels such as dangling bonds. Such studies are valuable because they provide relatively unambiguous information about the most fundamental aspects of the cells: the electrical bandgaps and the bandtail densities of states of their intrinsic layers. In particular, we have measured the temperature-dependent properties of these cells under uniformly absorbed incident illumination (1085 nm) over the range 200 K - 350 K. We have applied an analytical model primarily based on valence bandtail trapping. We find that this model explains the measurements well for cells thinner than 500 nm. For these thin cells, the energy band gap of the calculated electrical bandgap, \( E_G = 1.75 \text{ eV} \), and for the valence band effective density of states, \( N_V = 10^{12} \text{ cm}^{-3} \). The bandgap is somewhat smaller than that which has been inferred previously from internal photoemission measurements on similar material. Only very rough bounds on \( X_{V0} \) have been made prior to the present work. The valence bandtail model failed for thicker cells and also for expected for light-soaked cells. Using these results for inputs for charge carrier modeling, we are able to predict the initial solar conversion efficiencies for simply engineered cells (no texturing or back reflectors). A narrowing of the bandtail width from 50 meV to 40 meV increases the initial efficiency from 7% to 9% in an optimized cell; there is fragmented experimental evidence that such a narrowing may be feasible in practice. This research was supported by the Thin Film Photovoltaics Partnership of the National Renewable Energy Laboratory.

2:15 PM A3.3 NANOMETER-RESOLUTION SPECTROSCOPY OF n/p INTERFACES IN A MORPHOLOGICAL SILICON SOLAR CELLS: K. Zhu, E.A. Schiff, Department of Physics, Syracuse University, Syracuse, NY; G. Genggely, BP Solar, Toano, VA

We have studied defect and doping levels at the interfaces of amorphous silicon solar cells using charge-modulated spectroscopy. The fundamental idea is to monitor the change of the infrared transmission signal as we electrically charge and discharge the samples at n/p interfaces. Here we describe the spectra observed for interfaces of intrinsic silicon and (i) n-type amorphous silicon or (ii) n-type microcrystalline silicon. The results are far more complex than expected in the context of the "standard" doping model for amorphous silicon. More broadly, they illustrate how this spectroscopy may be used to unravel the electronic structure of device interfaces. Strongly microcrystalline silicon n-layers give a rather weak spectrum, which is consistent with the weakness of the free carrier absorption that is observed in this material. For amorphous silicon n-layers, we find three distinct spectral features in various samples. The simplest is a broad spectrum of magnitude 10^6 cm^-1; this is consistent with the standard doping model of a fourfold coordinated phosphorus atom with an electron energy level close to the conduction band edge. A second, more striking feature is a sharp spectral line near 0.75 eV, which we believe is due to an internal optical transition of a complex incorporating a fourfold coordinated phosphorus and a dangling bond. In one series of samples, this line was absent for doping levels higher than 0.5%, and was nearly fully developed for levels greater than 10%. These measurements suggest the possibility of a phase transition in the structure of phosphorus doped a-Si for sufficiently large phosphorus concentrations. We have not yet identified a third, bipolar spectrum with peaks at 0.9 and 1.2 eV; it is, of course, tempting to identify this spectrum with dangling bond level within the doped material.

This research was supported by the National Renewable Energy Laboratory.

2:30 PM A3.4 CARRIER TRANSPORT AND RECOMBINATION IN a-Si:H p-i-n SOLAR CELLS IN DARK AND UNDER ILLUMINATION: Jinglong Deng, Joshua M. Price, Vasileios Vlachos, Robert W. Collins, and Christopher R. Wronski, Center for Thin Film Devices, The Pennsylvania State University, University Park, PA

To gain a better understanding of the carrier transport and recombination mechanisms both in dark and under illumination, the drift current density - forward bias voltage curves were obtained over a wide range of light intensities for a hydrogenated amorphous silicon (a-Si:H) p-i-n solar cells. These were carried out on p-i (a-Si:H)/n/(a-Si:H) (superstrate) solar cell structures with different n intrinsic layers and n-Si:H buffer layers at the p/i interface. Results are presented and discussed which exhibit superposition between J<sub>sc</sub>, V<sub>oc</sub> and the extended regions of voltage and illumination. In these cell structures, contributions from interface and bulk recombination to the dark currents are identified and separated. It is found that the superposition is not affected by the interface recombination. However, it depends on both carrier injection from the p and n contacts and the defect densities in the bulk layers. Both first principle arguments and computer simulations are presented showing that the superposition observed experimentally here is valid until the bulk defect densities exceed about 3x10^17 cm^-3. This can explain the absence of such superposition of J<sub>sc</sub>, V<sub>oc</sub> and J<sub>sc</sub>, V<sub>oc</sub> characteristics previously reported in studies on n-Si solar cells.

2:45 PM A3.5 NANOMETER-SIZE STRUCTURE MODULATED SOLAR CELL IN A MORPHOLOGICAL Si/MICROCRYSTALLINE-Si HETEROGENEOUS MATERIAL: Motoki Ito, Norikazu Moejiri, Motoh Kondo, Atsuhiko Matsubara, and Kunitoshi Ito, Chugoku Electric Power Co., Ltd., AIST, Tsukuba, JAPAN; Motoki Shiraishi and Yukio Watanabe, Kyushu University, Department of Electronic Device Engineering, Fukuoka, JAPAN

Controlling nanometer-size structure is quite crucial in making high performance Si thin film solar cell. In this study, we have applied nanometer-size structural modulation technique in a-Si/µc-Si heterogeneous material, and demonstrated its validity by showing improved performance of the solar cells. As for a-Si based solar cell, degradation by light-soaking has been a biggest obstacle in achieving high conversion efficiency. It has been reported that inclusion of nanometer sized crystals into a-Si decreases light-induced degradation. In order to obtain this structure homogeneously in the film growth direction, SiH<sub>4</sub> flow rate was periodically varied from low hydrogen dilution ratio to high hydrogen dilution ratio and thus a-Si and µc-Si layers are stacked one by one with each layer thickness of few nm. Compared with standard a-Si solar cells whose degradation ratio is around 15%, degradation ratio of our nanometer-size structure modulation silicon solar cells is extremely low, less than 5%. Although the initial efficiency has not standard a-Si solar cells, their light-soaked efficacies (6.3%) exceed that of a-Si one (6.0%). Nanometer-size structural modulation can also be applied to p/i interface of the µc-Si solar cells. For achieving high efficiency in µc-Si solar cell, it is essential to use high open circuit voltage (V<sub>oc</sub>) and fill factor (FF), especially in a-Si/µc-Si tandem type solar cell. Substrate type solar cells were prepared at 140°C onto flat substrate with i-layer thickness of 1 μm. Both kinds of the buffer layer were examined; one is a single layer with a thickness of 5 to 30nm and the other is a-Si/µc-Si multilayers. By inserting a single 5nm thick a-Si layer, V<sub>oc</sub> increases from 0.47V to 0.63V and FF increases from 70.5% to 74.3%. Although the short wavelength response decreases slightly, efficacy increases from 6.12% to 6.30%

SESSION A4: SOLAR CELLS II
Tuesday Afternoon, April 23, 2003
Salon 5/6 (Marriott)

3:30 PM A4.1 HYDROGENATED MICROCRYSTALLINE SILICON SINGLE-JUNCTION AND MULTIJUNCTION SOLAR CELLS: Bangjie Yan, Zhouchen Yue, Jeffrey Yong, and Subhendu Guhain, United Solar Systems Corp., Troy, MI.

We present results on hydrogenated microcrystalline silicon (µc-Si:H) solar cells and their application in various multi-junction solar cells. Two glow discharge techniques have been used in this study.

Conventional HC glow discharge is used to deposit intrinsic µc-Si:H
cells these substrates introduce excellent light trapping and high open-circuit voltages are maintained. The ZnO development was initially performed on small areas using sputtering from ceramic targets. For the up-scaling to 300x300 cm² we additionally investigated high rate sputtering from metallic Zn targets in dynamic mode. A-Si/μc-Si:H tandem cells developed on textured ZnO coated glass yielded stable efficiencies of 11.2% on 4x4 cm². First solar modules were prepared completely in-house (including laser scribing) and yielded initial module efficiencies of 10.8% and 9.2% for aperture areas of 64 cm² and 67 cm², respectively.

4:45 PM A4.4 MICRO-RAMAN MEASUREMENTS OF MIXED-PHASE HIGHLY DOPED SILICON SOLAR CELLS: O. Omarsa and D. Han, Dept. of Phys. & Astronomy, Univ. of North Carolina at Chapel Hill, Chapel Hill, NC, B. Yoon, J. Yang, K. Lord, and S. Guha, United Solar Systems Corp., Troy, MI.

The open-circuit voltage (Voc) of mixed-phase hydrogenated-silicon solar cells has been found to increase after light soaking. Microstructural change has been proposed to account for the light-induced Voc enhancement. However, recent studies by Ramam Spectroscopy and X-ray Diffraction found no observable change before and after light soaking. In this study, we used micro-Raman to further investigate the mixed-phase solar cells. A low laser power was used to avoid possibility of laser-induced crystallization. The measurements were made using a laser beam of 3 μm in diameter on solar cells with an area of 0.25 cm². For a cell with Voc = 0.881 V, four scans on different locations of the cell showed typical broad Gaussian profiles around 480 cm⁻¹. A cell with Voc = 0.874 V showed a Lorentzian line shape around 516 cm⁻¹ by most scans, indicative of a large microcrystalline volume fraction. However, for the cells with Voc = 0.767 and 0.748 V, one of the eight scans exhibited both a broad Gaussian line shape around 480 cm⁻¹ and a sharp peak around 516 cm⁻¹, indicating a mixed-phase material. The cell with Voc = 0.767 V was further systematically scanned in steps of 600 cm⁻¹ for a total of 20 different positions. Most spectra showed a typical Gaussian line shape around 480 cm⁻¹, several spectra showed a hint of a microcrystalline shoulder around 512 cm⁻¹, and one spectrum showed a distinct microcrystalline peak. From the study, we find that the crystallite distribution in the mixed-phase material is very non-uniform even within a small area. This result and other new findings provide further insight into the light-induced phenomena of the mixed-phase solar cells.

SESSION A5: POSTER SESSION
GROWTH I
Tuesday, April 22, 2003
8:00 PM
Salon 1-7 (Meridian)

A5.1 HELIUM VERSUS HYDROGEN DIOLYSIS OF SILANE IN THE DEPOSITION OF POLYCRYSTALLINE SILICON FILMS: EFFECTS ON THE STRUCTURAL AND OPTICAL PROPERTIES.
O. Sandne et al.

Hydrogen dilution of silane has been widely used for the deposition of thin silicon films. When the plasma is operated under conditions close to powder formation, hydrogen-silane mixtures give hydrogenated polycrystalline silicon films (µc-Si:H). However, when incorporating the material in P-I-N devices, hydrogen reduces the inter-valance band and makes electronic defects at the P/I interface. This is why the effect of helium dilution on the structural and transport properties of µc-Si:H layers was studied and compared to those of µc-Si:H samples prepared by the decomposition of a silane-hydrogen mixture. Plasma diagnostics were achieved during deposition of the layers to determine the role of hydrogen versus helium in the dynamics of cluster formation. We found that helium dilution drastically reduces the IF power needed to achieve the same deposition rate as in hydrogen dilution. IF spectroscopy and hydrogen effusion experiments show that hydrogen bonding and content are quite different in each process. The films produced from He-dilution have a lower hydrogen content, which we try to link to the structure of the clusters and crystallites produced in the plasma. Transport properties were investigated by means of steady state photocurrent and steady state photocarrier gating techniques. The density of states was estimated from MPC and TPA measurements. TPA intensities were measured in the e-deposited, light-soaked and annealed states of the samples. Interestingly enough, despite of their higher deposition rate, the µc-Si:H samples prepared in this manner gave efficiencies similar to those prepared in the plasma. On the other hand, we have observed different behaviours of the evolution of the transport properties of the layers (He or H2 diluted) upon L5/annealing cycles. In this contribution we aim to draw a
A5.2 MICROCRYSTALLINE SILICON GROWN BY ELECTRON CYCLOTRON RESONANCE CHEMICAL VAPOUR DEPOSITION AT 80 DEGREE CELSIUS by Y.Y. Bu, A.J. Flevitt, C. Ducati, J. Robertson, University of Cambridge, Dept of Engineering, Cambridge, UNITED KINGDOM, M. Powell, Philips Research Lab, Redhill, UNITED KINGDOM, and W.T. Mine, University of Cambridge, Dept of Engineering, Cambridge, UNITED KINGDOM.

Microcrystalline silicon thin films were deposited using an ECR plasma at 80 degree Celsius. These films are suitable for the production of TFTs on plastic substrates. Films were characterised using Raman spectroscopy, high-resolution transmission electron microscopy and conductivity measurements. The results show that thin film properties are strongly dependent on deposition conditions, chamber pressure, hydrogen dilution and RF power.

A5.3 CHARACTERIZATION OF NANOCRYSTALLINE SILICON FILM GROWN BY LEPECVD FOR PHOTOVOLTAIC APPLICATIONS. S. Binetti, M. Bellini, M. Acciarri, A. Arcari, S. Pizzini, INFM and Dept of Material Science, Universita di Milano-Bicocca, Milan, ITALY, H. Von Kiedel, INFM and Dept. of Physics, Politecnico di Milano, Como, Italy.

Crystalline silicon is one of the most extensively used photovoltaic (PV) materials, but its high cost still limits terrestrial applications. One way to overcome this problem is to reduce the material cost, using, for example, thin silicon films deposited on low cost substrates. This is the idea behind the use of the silicon material is such that solar cells with reasonably high efficiency can be obtained. The deposition procedure should hence be able to provide films with the requested features at a low cost. Plasma enhanced chemical vapor deposition (PECVD) has been extensively used for the deposition of thin films. Its major advantage is the ability to deposit good quality layers at reasonable rates and at low substrate temperatures, as required for PV applications. In this work we have grown thin films of nanocrystalline (nc) silicon for solar cell applications using a new PECVD process based on an arc discharge plasma with inherently low ion energies, called LEPECVD (Low energy PECVD). This process permits to increase the intensity of the plasma discharge in the growth region and thus to achieve higher growth rates and while avoiding any ion-induced damage of films. The electrical properties of the LEPECVD grown films were studied as a function of the deposition parameters (substrate temperature, growth rate, hydrogen dilution), by Hall effect, resistivity and surface photovoltage measurements, while the optical ones were investigated by photoluminescence spectroscopy. The influence of process parameters on the structure of nc-Si films has been evaluated by Raman Spectroscopy and SEM analysis. The results of this work allowed us to identify the process requirements suitable for the growth of nc-Si in an amorphous matrix on both oxidized silicon and on a zinc oxide covered glass substrate. The electrical and optical properties of these films are promising for PV applications.


Microcrystalline silicon (mc-Si) has been receiving special attention as present because it is much cheaper to produce than crystalline silicon, and do not present the degradation problems of amorphous silicon (a-Si). Furthermore, because of its bandgap, it can be used in tandem cells with a-Si. Among the deposition methods, hot-wire chemical vapor deposition (HWCD) has the advantage of higher deposition rates when compared to other conventional techniques, such as plasma enhanced CVD. In the present work, we deposit mc-Si films at different temperatures (200° - 400°C) and ratio between hydrogen and silane (50-100%) and study the relationship between these two parameters, and their influence on the properties of the films. We also study the effects of a very thin seed layer, deposited with high concentration of hydrogen, and the use of different substrates (Si and glass). The films were characterized using several techniques, such as atomic force microscopy, grazing-angle incidence X-ray diffraction, Raman spectroscopy, and transmission and scanning electron microscopy. We will correlate the growth conditions with properties such as crystallinity, morphology, surface roughness, crystalline and amorphous phases, and development of the microstructure from the interface film/substrate to the film surface.

A5.5 STRUCTURAL AND DEPOSITION CHARACTERISTICS OF AMORPHOUS AND MICROCRYSTALLINE SiH FILMS DEPOSITED AT LOW TEMPERATURE WITH Si-H, Si-H-He AND Si-H-He CHEMISTRY. Young-Hae Park, Harvard University, Applied Physics Dept, Cambridge, MA 02138, USA, Dept of Chemical Engineering, Inha University, Incheon, KOREA. Shi Won Bae, Department of Chemical Engineering, Pohang University of Sci. and Technol., Pohang, KOREA.

Silicon films with the nanometer-scale microstructure are widely used as the active and contact layers in thin film transistor (TFT) and solar cell applications. The Si-H, Si-H(He) and Si-H-F films deposited on Si, Cr, C, and Si(100), SiO(2) films at low temperatures (<250°C) by remote plasma enhanced chemical vapor deposition (RPECVD) from SiH4-H2-He and SiH4-H2-He gash mixtures were characterized using quadrupole mass spectrometer (QMS) and optical emission spectroscopy (OES). The microstructure composition and atomic force microscopy (AFM), high resolution transmission electron microscopy (HRTEM), Raman spectroscopy, X-ray diffraction (XRD), UN-unspectrometer, and FT-IR for the thin film characterization, respectively. The Si-H and Si-H-F films were found to be a mixture of amorphous and nanocrystalline phases while most Si-H(He) films had the amorphous phase. The polycrystalline fraction of the as-deposited films was ranged from 0 to 85% depending on gas phase chemistry. The microcrystalline phase exhibited the columnar structure with needle-like grains. The grain size was ranged from 2 to 50 nm. The effects of substrates and deposition parameters on crystallinity, grain shape, size, preferred orientation, and polycrystalline fraction have been studied. The roles of hydrogen, helium and fluorine were elucidated to explain low temperature crystallization and grain boundary passivation processes. The grain sizes were measured by different characterization techniques were also compared.

A5.6 STRUCTURAL CHANGES IN NANOCRYSTALLINE SILICON by Won-Suk Kim, Jongmin Lee, Junghee Lee, Jong H. Lyon, Korea Univ, Dept of Applied Physics, Graduate School of Natural Science, Seoul, KOREA, Eui-Kwan Ko, Korea Basic Science Institute, Seoul, KOREA.

We have measured structural and optical properties of nanocrystalline silicon thin films deposited by rf magnetron sputtering and characterized the microstructure of the films with the measurements of scanning electron microscopy, transmission electron microscopy, x-ray diffraction, and Raman scattering. Amorphous and nanocrystalline silicon thin films have been widely deposited with plasma enhanced chemical vapor deposition, hot-wire chemical vapor deposition, and reactive magnetron sputtering (RMS). Especially, the RMS method is useful for the deposition of nanocrystalline silicon, because it requires a low level of reactive gas pressure for the deposition to produce few columns in the microstructure. We have controlled nanocrystals with hydrogen content which recognize that the nanocrystals are first formed when the ratio (Ar:H2) is 1. We determine size and fraction of nanocrystals in nanocrystalline silicon: the size of nanocrystals is about 5-8 nm and the fraction is about 70%.

The nanocrystalline silicon consists of not only nano-sized crystallites but also amorphous states. The fraction of nanocrystals is measured with Raman scattering and estimated with a two-component Lorentzian profile. Meanwhile, the microstructure of nanocrystalline silicon is understood with scanning electron microscopy. Combined results of SEM micrographs with Raman scattering spectra identify columns appeared in the micrographs with amorphous networks. The results also indicate that the columns regularly disappear with increasing hydrogen content for the deposition of nanocrystalline silicon films. Thus we observe that the hydrogen dilution helps the amorphous networks removed, but high density of reactive gas molecules reduces the microstructure of nanocrystalline silicon to a columnar structure. We conclude that the hydrogen dilution employed with the level of less reactive gas molecules reduces the amorphous networks in which grain boundary as well as amorphous tissues and islands are incorporated.

A5.7 ELECTRICAL PROPERTIES OF PHOSPHORUS-DOPED AND BORON-DOPED NANOCRYSTALLINE GERMANIUM THIN FILMS by William B. Jordan and Sigurd Wagner, Princeton Univ, Dept of Electrical Engineering, Princeton, NJ.

The structure (nanocrystalline vs. amorphous) of doped germanium thin films is a strong function of both temperature and source gas ratios. Intrisic films grow as an amorphous state between 150-250°C, amorphous around 250-300°C, and an amorphous state again above 300°C. The doped films generally followed this same temperature dependence of phase transition, although high doping concentrations
cause films to grow amorphous. We provide an overview of the electrical and structural properties of the deposited Ge films throughout this text. As a general guide, we note that we deposited thin films of n+ Ge-H on Corning 1737 glass substrates by RF (13.56 MHz) plasma enhanced chemical vapor deposition (PECVD) using GeH₄ and H₂ source gases. The source gases used for the p+ and n-type layers were ED₃H₂ and ED₃H₂, respectively. GeH₄ and H₂ flow rates were held constant, while the dopant gas flow rates and the substrate temperature were varied and their effects on the growth rate, crystallinity, dielectric constant, and thermal expansion energy were measured. Crystallinity was determined by UV/visible reflectance. The H, B, and P concentrations in the films were measured by secondary ion mass spectroscopy (SIMS). The thickness of the Ge films was determined by ellipsometry. Growth rates for the intrinsic and doped films, mostly a function of the hydrogen dilution, ranged between 0.20 and 0.30 Å/sec. For the intrinsic p-type films, the growth rate increased significantly from 0.25 to 0.30 Å/sec when the thickness was reduced to 500 Å. A Fermi level swing of approximately 5000 eV between the n-doped and p-doped films deposited at 150-200°C is inferred from the electrical conductivity data. At deposition temperatures above 300°C, intermixed p-type Ge:H films were found to be very strongly p-type, with an electrical conductivity of approximately 10 S/cm and a thermal activation energy of about 0.04 eV.

A5.8
Abstract Withdrawn.

A5.9

Whereas usually silicon (Si:H) is used for the plasma deposition of amorphous and microcrystalline silicon thin films for solar cells, our aim is to replace the toxic, highly flammable and relatively expensive gas silicon by a lead-free hydrogen and carbon hydrogen source. We concentrate on two silicon sources: silane/tetramer (SiC₄H₂) and tetramethylsilane (SiCH₃₂H₂), which are liquid at room temperature but can be easily converted into the gas phase. While Beyer et al. found results similar to the silicon process using SiC₄H₂/H₂ or SiCH₃₂H₂/H₂ mixtures in a high pressure regime (p = 200 Pa), regarding deposition rates, microcrystallinity/amorphous silicon transition, doping efficiency, the present experiments using SiC₄H₂/H₂ in a low pressure, low temperature regime (p = 10-50 Pa, T = 400-600 K) surprisingly show decreasing growth rates for microcrystalline silicon with increasing SiC₄H₂ concentrations in the gas mixture. For all used substrate temperatures a silicon deposition could not be realized when SiC₄H₂/H₂ was higher than 10%. Using the Raman spectroscopy, all deposited films showed crystalline fractions between 30 and 60%. A significant dependence of the crystallinity in the silicon carbon ratio Si:CH₃ was detected. TEM investigations showed the absence of an amorphous silicon layer at the substrate/film interface, which would make this process attractive for the deposition of very thin microcrystalline films. Furthermore, a completely amorphous layer could not be detected under the current process conditions. XPS and SIMS measurements of the deposited films showed chlorine concentrations < 3% with the silicon-rich film. First results for silicon deposition from [SiCH₃₂H₂]/H₂ mixtures will be presented. [1] W. Beyer et al., PV 6: Europe - From PV Technology to Energy Solutions, Rome 2002.

A5.10
EVALUATION OF CRYSTALLINITY IN n+Si-PEEH-FASE (n+µ-Si:H) AS DETERMINED BY REAL TIME SPECTROSCOPIC ELLIPSOMETRY. A. F. Bentsen, G. M. Ferrera, R. J. Koval, J. M. Pearce, C. R. Wanzlick, and W. M. Collins, Materials Research Institute, Center for Theoretical and Applied Physics, Pennsylvania State University, University Park, PA, M. A. Jassim and K. M. Jones, National Renewable Energy Laboratory, Golden, CO.

In the RF plasma-enhanced chemical vapor deposition (PECVD) process, the optimum hydrogenated amorphous silicon films [n+Si:H] for the intrinsic layers of solar cells are obtained at the n+m/n+m possible value of the H₂-dilution ratio R=[H₂]/[SiH₄] using silicon without introducing the hydrogenated microcrystalline silicon (n+µ-Si:H) film growth regime. Furthermore, it appears that the optimum µ-Si:H-layers for solar cells are deposited using the n+m/n±µ possible R value while maintaining predominantly n+Si:H, in other words, entering the (n+µ-Si:H) film growth regime. Owing to the critical importance of Si:H deposition near the boundaries defining the (n+µ-Si:H) film growth regime, the development and application of in situ, real time techniques that can provide the phase evolution of such films is of critical importance. We have adopted several real time spectroscopic ellipsometry (RTSE) using compensator configuration for this purpose. Using a novel interferometric approach, RTSE spectra on Si:H films that cross the (n+µ-Si:H) and (n+µ-Si:H)-µ transitions during growth can be interpreted in detail to obtain the bulk layer thickness, the Ge:H₁⁻→µ-Si:H transition, as well as the thickness at which evolving microcrystallites make contact and coalesce (the µ-Si:H transition). In addition, the fraction of crystallites f_c within the top 30 Å of the film can be deduced as a function of bulk layer thickness; as a result, a depth profile in f_c for the final film can be obtained. The outcome of such RTSE analyses, expressed succinctly in terms of the nucleation density and cone angles that define growth of crystallites, is in excellent agreement with direct structural measurements. The origin of the "delayed" crystalline nucleation, in which nucleation occurs from the bulk n+Si:H film after a critical thickness (rather than directly from the substrate) remains an important issue that will also be addressed in this paper.

A5.11
P- AND N-TYPE MICROCRYSTALLINE SiC FABRICATED BY RF PLASMA CVD WITH ETHANE GAS. T. Taya, Y. Nakano, T. Kosuge, A. Asano, O. Okumoto, Osaka University, Dept. of Physical Engineering, Graduate School of Engineering Science, Toyonaka, JAPAN.

P- and n-type microcrystalline Si-C-C (µ-SiC) films with x > 0.1 are fabricated by a conventional rf (13.56 MHz) plasma CVD method with a use of a new carbon source of C₂H₆ at low substrate temperatures on a glass substrate. Highly conductive p-type µ-SiC is one of the most promising material for optoelectronic devices such as thin-film solar cells [1] and light-emitting diodes [2]. The µ-SiC were formerly developed by electron cyclotron resonance (ECR) plasma CVD with a C₂H₆ gas source [1,2], however, the deposited by ECR plasma CVD has some disadvantages especially significantly slow deposition rate of ~0.01 nm/sec or less. On the other hand, some trials have been performed for fabrication of µ-SiC films by conventional rf (15.50 MHz) plasma CVD with a mixture of SiH₄ and C₂H₆ gases. However, they have not shown an excellent results because the crystalline volume fraction of SiC films made by rf plasma CVD markedly decreases with an increase in carbon content of the film even if the carbon content is only 10% at % [3]. Here we will demonstrate the results on p- and n-type µ-SiC fabricated by rf plasma CVD with a new carbon source of C₂H₆ gas [4]. Typical substrate temperature was 280°C. The deposited µ-SiC with a carbon content of about 10 to 20% shows high conductivities on the order of 10³ S/cm as well as an optical energy gap, Eq, of more than 2.0 eV. Additionally the deposition rate is ~0.01 nm/sec or higher. [1] Y. Hatsukade et al., Proc. 19th IEEE PVSC (1987) p. 255 [2] D. K. Morgan et al., J. Non-Cryst. Solids, 37 & 38 (1980) 295. [3] T. Wada et al., Sol. Energy Mat. & Sol. Cells, 74 (2002) 333. [4] T. Itch et al., J. Non-Cryst. Solids, 298/299 (2002) 880.

A5.12
HIGH-REMARK (> 1 NM/S) MICROCRYSTALLINE SILICON FILM GROWTH STUDIED BY IN-SITU SPECTROSCOPIC ELLIPSOMETRY AND ATTACHED THERMAL INFRARED REFLECTION SPECTROSCOPY. J. J. Hauston, J. Hong, P. van den Oever, W. M. Kessel, and M. C. M. van de Sanden, Dept. of Applied Physics, Eindhoven Univ. of Technology, Eindhoven, THE NETHERLANDS.

The growth of µ-Si:H deposited using the expanding thermal plasma (ETP) technique has been extensively studied using in situ spectroscopic ellipsometry (SE). Previous investigations using X-ray diffraction (XRD) and Raman spectroscopy have shown that this technique is capable of producing material with a crystalline fraction of over 60% at growth rates of over 2 mm/s. In situ spectroscopic ellipsometry was used to monitor the evolution of the surface roughness and surface roughness of the material, as well as the optical properties. The results from this were verified using atomic force microscopy (AFM). SE has also been used to investigate the occurrence of an amorphous incubation layer which forms on the surface prior to µ-Si:H growth. This has been done for various conditions where the hydrogen dilution R = [H₂]/[SiH₄] was varied. In particular, SE has shown that a significant incubation layer is present for deposition of Si:H using a value of 200°C. This was confirmed by transmission electron microscopy (TEM) which shows that any amorphous incubation layer in this case (which results in our crystalline material) is limited to a few nanometers.

Fourier transform infrared (ATR-FTIR) spectroscopy has also been applied to study the manner in which hydrogen is bonded within the bulk and on the surface of the material. ATR-FTIR has shown that the surface-like SiH₄ modes occur within the bulk of the µ-Si:H material and this is indicative of the characteristic columnar growth associated
with microcrystalline material. These new results confirm that the ETP technique is capable of producing microcrystalline material with different silicon fractions (amorphous material up to almost polycrystalline material) at high growth rates which is comparable to material that is grown using other techniques.

A5.13 POLYMORPHOUS SILICON FILMS PRODUCED IN LARGE AREA REACTORS BY PECVD AT 27.12 MHZ AND 13.56 MHZ.


Polymorphic silicon has gradually earned the attention of the scientific community due to their improved transport properties and stability when compared to the standard amorphous silicon material. In spite of this growing interest, electronic grade material was obtained on both silicon and glass substrates by ETP at an excitation frequency of 13.56 MHz. This work presents a study performed concerning the deposition of polymeric silicon at excitation frequency of 27.12 MHz in a large area PECVD reactor. Apart from this, large area films produced at 13.56 MHz were also investigated, aiming to compare their performances with the ones of the films produced at 27.12 MHz. The plasma was characterized by impedance probe measurements, aiming to identify the plasma conditions that lead to produce polymeric films, under quasi-isothermal conditions. The films produced were characterized by spectroscopic ellipsometry, infrared and Raman spectroscopy and hydrogen etch experiments, which are techniques that permit the structural characterization of the polymeric films and to study the possible differences between the films deposited at 27.12 MHz and 13.56 MHz. Conductivity and density of steps measurements were also performed to determine the transport properties of the films produced. The set of data obtained shows that by using the 27.12 MHz excitation frequency the hydrogen dilution needed to produce polymeric silicon films can be reduced by more than 50% , and the power density has also been reduced, otherwise the films obtained are microcrystalline. Apart from the growth rates above 3:1, both films were obtained using deposition pressures of 240 Pa, being the films more dense and chemical stable, with improved transport properties than the usually ones obtained with the standard 13.56 MHz.

A5.14 SURFACE ROUGHNESS STUDY OF LOW-TEMPERATURE PECVD n-SiH: Ge, T. E. Brown, General Electric Global Research Center, Niskayuna, NY; Joel L. Pilsukay, Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, NY; Alexey Filin, Peter D. Persans, Department of Physics, Rensselaer Polytechnic Institute, Troy, NY.

Surface topology of n-Si thin films, deposited at 75°C by Plasma-enhanced Chemical Vapor Deposition (PECVD) has been examined using x-ray (He and Ar)/albumin feedstock mixtures under different substrate bias conditions. Notable differences in the surface roughness evolution are shown for films deposited in cathodic versus anodic mode where the substrate is placed on the powered and grounded electrodes respectively. Small-scale (terabit levels) surfaces result from deposition on the RF powered electrode, upon which a self-bias induces high-energy ion bombardment. Rougher surfaces result from films deposited on the anode. These amorphous films show almost no surface roughness, line edge roughness, with processing time, exhibiting mound-type growth as evidenced by power spectral density functions of surface height measurements. Growth of this nature has not been previously reported for n-SiH. Mound growth as a linear function of time is not predicted by growth models that assume directional deposition conditions and sticking coefficients less than one. We will discuss our observations on the behavior of growth assuming the film precursors sticking coefficient of one and random angle approach of film precursor species.

A5.15 STRUCTURAL CHARACTERIZATIONS OF AMORPHOUS AND MICROCRYSTALLINE SILICON FILMS USING LADDER-SHAPED ELECTRODE.

Takamasa Ababiyama, Hiroshi Seohe, Yoshihiko Takachi, Mitsuhide Nishida, Akira Yamada, Hiroko Takakura, Nagasaki Research & Development Center, Mitsubishi Heavy Industries, Ltd., Nagasaki, JAPAN.

We have succeeded in getting high deposition rate and high quality for preparing hydrogenated amorphous silicon (a-Si:H) films, as well as micro-crystalline silicon (μc-Si) films, by very high-frequency (VHF) plasma CVD using a ladder-shaped electrode. Recently, VHF plasma CVD technique has become one of the topics in the field of the fabrication of solar cell and thin film transistors, because its high plasma density enables high-speed deposition. However, in the large area deposition, which is needed in the application of commercial production, the effective gas flow rate fed into the plasma leads the deposition rate and the film qualities because the gas depletion condition leads to the degradation of the film quality. We have developed a VHF plasma CVD device using the ladder-shaped electrode, which has an advantage over a conventional parallel-plate electrode in the controllability of the gas flow. The experiments were performed using a ladder-shaped electrode consisted of stainless-steel rods about 550 mm × 450 mm in external dimension. The material growth was introduced into the plasma region through an end of the electrode. By using the VHF-SiH 6 plasma at the frequency of 60 MHz,
we got a $n$-Si:H film at the averaged deposition rate of 0.7 nm/s ± 15.2% on 570h20 substrate with the ratio of photo conductivity/dark conductivity of 106. We also applied this electrode to fabricate the mc-Si film and succeed high-speed of 1.1 nm/s ± 13.2% using the plasma of SiH4 diluted with H2 at the frequency of 60 MHz. Furthermore, we employed this technique for fabricating the $n$-Si/mo-Si tandem solar cell of about 10% efficiency. It was demonstrated that this electrode is highly suitable for the production.

**A5.18 AMORPHIZATION OF ALPHA-QUARTZ CRYSTAL USING FAST ELECTRONS.** Ju-Yin Cheng, Department of Material Science and Engineering, Rensselaer Polytechnic Institute, Troy, NY; Michael Tracy, NEC Laboratory USA, Inc., Princeton, NJ; Pawel Kneblinski, Department of Electrical Science and Engineering, Rensselaer Polytechnic Institute, Troy, NY.

We study the phase transition of alpha-quartz crystal using transmission electron microscopy. The phase of alpha quartz can be transformed into a completely amorphous phase by electron irradiation. However, the transformation is mediated with some topological crystalline state, which loses the long-range order of the parent crystalline phase. We monitored the dependence of the structure transition on electron dose in the microscope. Our results are based on the analysis of image variance in dark field. This study is a prerequisite of doing fluctuation electron microscopy for amorphous silicon in high frequency plasma. Since the structure of the probe peak (FSID) for amorphous silicon is located around 15-18 nm.

**SESSION A6 POSTER SESSION**
**GROWTH II**
Tuesday, April 22, 2003
8:00 PM
Salon 1-7 (Merritt)

**A6.1 THE RELIABILITY OF MEASUREMENT ON ELECTRON ENERGY DISTRIBUTION FUNCTION IN SILANE RF GLOW DISCHARGES.** Kuixun Lim, Xinying Ling, Lingfei Chi, Chuying Yu, Yungpeng Yu, Department of Physics, Shantou University, Shantou, CHINA.

Plasma enhanced chemical vapor deposition in parallel-plate silane radio frequency glow discharges is the most widespread method in deposition of silicon-based thin films. To a large extent, the relation between plasma properties and material properties is still unknown. Electron energy distribution function (EEDF) in silane rf glow discharges is a key parameter for studying the spatial reaction process in a plasma and the surface reaction process on the substrate. EEDF is directly related to electron energy and density, which determines the characteristics of reaction. Because of an amplifying effect of the unavoidable noises in the experimental probe LV currents on the second derivative of the probe characteristics, it is very difficult to measure the EEDF accurately and relatively. It is the first time, so far as we know, to measure the EEDF parameters simultaneously by means of both the numerical and circuit derivative methods under the same discharge conditions on the same discharge equipment. The deviation between two groups of mean electron energy (E) and electron density (n) obtained by the above different methods is within about 7%. This apparently improves the reliability of the measurements on the EEDF parameters.

**A6.2 HIGH RATE GROWTH OF MICROCRYSTALLINE SILICON BY VHF-PECVD FOR SOLAR CELLS.** Xuesen Zhang, Guofu Hou, Peng Zhu, Wenjun Xiong, Huidong Yang, Chuan Xu, Junming Xue, Ying Zhao, Xiuwen Geng and Shouchen Xiong.

*Institute of Photonics: Thin Film Device and Technology, Nanke University, Tianjin, CHINA; *Institute of Thin Films and Nano-materials, Wuyi University, Guangdong, CHINA.

High rate growth of hydrogenated microcrystalline silicon (mc-Si:H) thin films for solar cells is crucial for cost reduction. In this paper, very-high-frequency plasma-enhanced chemical vapor deposition (VHF-PECVD) was employed to deposit microcrystalline silicon in order to increase the deposition rate. The relatively high power was combined with the relatively high excitation frequency to further improve the deposition rate. It was found that the properties of the deposited films were different from the traditional properties of the deposition rate, the films are unique in high silicon concentration SC ($\text{SiH}_4$/$\text{SiH}_2$). The deposition rate varied from 1.5 A/s to above 20 A/s, accordingly crystalline fraction increased from 30% to 90%. The phase transition from $n$-Si to mc-Si was observed when the silicon concentration was around 7%.

In addition, the dependence of the deposition rate and photo-electronic properties of the samples on working pressure were studied. The microstructures of silicon are analyzed by X-ray diffraction (XRD) and X-ray photo-electron spectroscopy (XPS), respectively. Thin film solar cells using hydrogenated silicon sputtered at high deposition rate were also fabricated. Some interesting results were discussed in detail.

**A6.3 HIGH RATE DEPOSITION OF STABLE HYDROGENATED AMORPHOUS SILICON IN TRANSITION FROM AMORPHOUS TO MICROCRYSTALLINE SILICONE.** Guofu Hou, Xinhua Geng, Ying Zhao, Xiaodan Zhang, Junming Xue, Huizhi Ren, Jian Sun, Dekun Zhang, Institute of Photonics, Nanke University, Tianjin, CHINA.

It is well known that the diphane films, prepared in the region adjacent to the phase transition from amorphous to microcrystalline state, can gain both high optical transparency and high mobility. The hydrogenated amorphous silicon (a-Si:H) and high stability amorphous microcrystalline silicon (mc-Si:H) films have been investigated. Now this diphane films have drawn much attention. In this paper, high rate deposition of high quality and stable a-Si:H films were performed near the threshold of amorphous-to-microcrystalline phase transition using a very high frequency plasma enhanced chemical vapor deposition (VHF-PECVD) method combined with a high working pressure. The deposition parameters included a plasma excitation frequency of 60 MHz, a working pressure of 1900Pa and a substrate temperature of 250°C. It was found that under the high pressure this kind of $n$-Si:H films could be deposited over a large range of glow power. Besides, the phase transition depended on not only hydrogenation but also glow power and substrate temperature. A series of high quality and stable a-Si:H films were obtained at deposition rates above 20 A/s by changing plasma density, substrate temperature and substrate temperature. The hydrogenation and crystallization were obtained in the high density, low frequency plasma deposition and low temperature conditions (through $\text{SiH}_4$/$\text{SiH}_4$ to H2) from 15% to 30%. The hydrogenation and crystallization of the a-Si:H films, deposited in the phase transition region ($i$-e crystalline volume fraction Xc=30%), were investigated by the infrared absorption spectroscopy, Raman scattering spectra and constant photocurrent method (CPM). The experiment results were also discussed in detail.

**A6.4 GROWTH AND PROPERTIES OF MICROCRYSTALLINE (Ge,C):H MATERIALS AND SOLAR CELLS.** Xuefen Liu, Vikram Dahly, Iowa State University, Dept. of Electrical and Computer Eng., Ames, IA.

We report on the growth and properties of microcrystalline (Ge,C):H materials and solar cells using mixtures of germane, ethylene and hydrogen. The use of ethylene allows for a higher C:Ge ratio in the solid than the use of methane under similar growth conditions. The materials and cells were grown using a remote ECR plasma apparatus. Hall mobilities in the material were measured using a specially designed high-resistance Hall apparatus, and were found to be in the range of ~3 cm2/V-s. Both p and n type materials could be grown using appropriate doping with diborane and silane. Raman and x-ray measurements indicated crystallinity in the material. Spectral photoconductivity also revealed a crystalline type absorption coefficient. Grain sizes were in the 20-50 nm range. Solar cells were made in the $p/n$ configuration on steel substrates, and used amorphous interfaces between both n and i layers and p and i layers to obtain better results. The open circuit voltages were found to decrease as the bandgap of the material increased. Some measurements confirmed that as ethylene content was increased, the bandgap also increased. Both Raman measurements on cells and the QE spectrum indicated that the i layers were indeed microcrystalline and not amorphous.

**A6.5 STRUCTURAL EVOLUTION OF NANOCRYSTALLINE GERMANIUM THIN FILMS WITH FILM THICKNESS AND SUBSTRATE TEMPERATURE.** William B. Jordan, Eric D. Carlson, Todd R. Johnson, Sigurd Wagner, Princeton Univ, Dept of Electrical Engineering, Princeton, NJ.

Nano-crystalline germanium (nc-Ge:H) has attracted interest for possible use in low gap solar cells or photodetectors due to its low optical gap and high optical absorption. The crystallinity of Ge thin films is a strong function of both deposition temperature and hydrogen dilution. At high hydrogen dilutions, Ge films grow amorphous at room temperature, nano-crystalline between 81250°C, amorphous around 256330°C, and nano-crystalline again above 300°C. Varying the hydrogen dilution maintains the same phase sequence, but at different transition temperatures. We measured the growth rate, crystallinity, and surface roughness of the Ge films throughout their $nc/nc$/$nc$ phase range, and as a function of film thickness, substrate temperature, and hydrogen dilution. We deposited thin films of nc-Ge:H on Corning 1737 glass substrates by
HF (13.56 MHz) plasma enhanced chemical vapor deposition (PECVD) using GeH₄ and H₂ source gases. The deposition pressure, power, and H₂ to GeH₄ flow rate were held constant at 20 mTorr, 8.5 W, and 0.8:1, respectively. The substrate thickness, hydrogen dilution, and the substrate temperature were varied. The substrate temperatures ranged from 30°C to 310°C, while the hydrogen dilution ratio ranged from 20 to 60%. Crystallinity was determined by UV-visible reflection and Raman spectroscopy. The surface roughness was characterized by atomic force microscopy (AFM) and field emission scanning electron microscopy (SEM). The thickness of the Ge films ranged from approximately 250 Å to 1600 Å, while the growth rate was 0.3 Å/sec. The thickness series ranged between 0.20 and 0.30 Å/sec. The surface roughness of the Ge films increased with film thickness and substrate temperature, decreasing with hydrogen dilution. The thicker films developed a fully nucleated surface at a thickness of 200 Å. This work is supported by EPA and NSF.

A6.6 INFLUENCE OF FILAMENT AND SUBSTRATE TEMPERATURES ON STRUCTURAL AND OPTOELECTRONIC PROPERTIES OF NARROW GAP (≥SiGe) ALLOYS DEPOSITED BY HfCVD


We have found narrow band gap (1.25 < Eg, Gap < 1.50 eV) amorphous silicon germanium (a-SiGe:H) alloys grown by HfCVD can be improved by lowering both the substrate temperature and film thickness. Simulation study films deposited with a tungsten (W) film at a fixed substrate temperature (T[substrate]) and standard temperature of 2150°C down to 1750°C, fixing all other deposition parameters. By decreasing T[substrate] at a fixed substrate temperature, the hydrogen dilution ratio increased from 20% to 45% of the total hydrogen, while the SiH₂ content decreases from 20% to zero. Films with more Ge-H bonding and less Si-H bond have improved photoconductivity up to an order of magnitude higher. For this reason, a higher hydrogen dilution was fixed at 35%, but the energy where the optical absorption is 1×10⁴ (E) drops from 1.54 to 1.41 eV with decreasing T[substrate]. This is attributed to a combination of increasing Ge content, decreasing H content, and an improved compactness due to significant microvoid reduction. They also observed a series of films grown by decreasing the substrate temperature (T[substrate]) from our previous standard temperature of 350°C down to 125°C, fixing all other deposition parameters including T[substrate] at 180°C. By decreasing T[substrate], the fraction of hydrogen bonded to Ge, which preferentially exists as Ge-H bonding, increased from 27% to 42%, while the Si-H content is not measurable in the T[substrate] range from 300-200°C. The E increases from 1.40 to 1.50 eV as T[substrate] decreases from 350°C down to 125°C, mainly due to increasing H content. At the same time, the photo-to-dark conductivity ratio increases almost three orders of magnitude over this range of T[substrate] at the fixed T[substrate].

A6.7 PROCESS PARAMETERS FOR POLY-SILICON DEPOSITION AT A HIGH GROWTH RATE (1-7 mm/s) BY HOT-WIRE CHEMICAL VAPOR DEPOSITION (CVD) DEPOSITED ON SOI WAFERS

P. van de Venne, M. L. van der Waar, P. T. M. van Veenendaal, M. Y. Ruscha, and R. E. Schropp, Utrecht University, Utrecht, THE NETHERLANDS

The lack of a high density of atomic hydrogen in the gas phase is considered to be the advantage of Hot-wire chemical vapour deposition (HWCVD) (also called CVD-CVD) compared to PECVD for poly-silicon growth. We have already reported that compact polysilicon films can be made at a high deposition rate of 0.5 mm/s, which is already comparably high, and solar cells implementing this truly polycrystalline material (with no amorphous phase) have shown 4.1% efficiency. These results suggest that compromise between high growth rate and high crystallinity can be reached. This dense polycrystalline material is thus expected to fill a niche in the market. As polycrystalline materials have a high density of grain boundaries, a high amount of hydrogen is needed to reduce the concentration of defects. We have investigated the effect of hydrogen dilution on the growth of high-quality polycrystalline silicon films using a four-wire hot-wire deposition system. Our work consists of the development of a high-density polycrystalline silicon film, using a four-wire hot-wire deposition system, and from XRD, infrared, and conductivity measurements, establish a detailed correlation between the film crystallinity, porosity, and electronic quality as a function of film thickness. The film crystallinity increases with increasing film thickness, while the porosity decreases. The electronic quality remains high and shows a linear decrease with increasing film thickness. To conclude, we have observed the ability to grow polycrystalline silicon films with high crystallinity and low porosity at a high deposition rate. The results show that the use of hydrogen dilution is crucial for the growth of high-quality polycrystalline silicon films.

Microcrystalline Si is a promising material for photovoltaic applications. It can improve stability against light degradation in solar cells and provide for more effective doping than amorphous Si.

We report observation of microcrystalline Si obtained by the d.c. saddle-field glow discharge deposition method [1]. The films have been deposited on glass, coming glass, and fused silica substrates. The source gas was a mixture of silane and hydrogen, with silane concentration varying from 100% to 5%. Substrate temperature was 250°C. The presence of microcrystallinity was confirmed by Raman spectroscopy, with our peak at 510-517 cm^-1 [2]. The deposition conditions leading to microcrystallinity have been identified. Detailed studies of film properties, as a function of hydrogen dilution, done by Raman spectroscopy, SEM, TEM, and High Resolution TEM microscopy will be presented.

A6.11 REACTIVE PULSED LASER DEPOSITION OF MICROCRYSTALLINE GE-BASED THIN FILMS, Matthew Wills and Alan Constant, Dept. of Materials Science and Engr; Ruth Shinar, Microelectronics Research Center, Iowa State University, Ames, IA.

Reactive pulsed laser deposition (PLD) was used to grow microcrystalline thin films of Ge and germanium-carbon alloys (Ge-C) with various Ge-C ratios on fused quartz substrates at substrate temperatures between 25 and 350°C. The alloys were prepared by ablating a Ge-C target in a methane atmosphere. Using a Ge-C ratio in the reactive gas, the films were analyzed structurally using X-ray diffraction (XRD), chemically using Auger, XPS, and SIMS, optically, and electrically with four-point probe measurements. The XRD results indicated a varying degree of crystallinity, with the best samples obtained at temperatures above 150°C. The resistivity decreased with increasing substrate temperature, at a slightly more rapid rate than for Ge films deposited at 200°C. The growth mechanism associated with the unique PLD process as well as the effects of the substrate and hydrogen partial pressures, and growth rate on film properties will be discussed.

A6.12 GROWTH OF nSiGe/nH Films Using Combined HOT Wafer ECR DEPOSITION. Matt Ring, Vikram Dixit, Iowa State University, Dept. of Electrical and Computer Engr., Ames, IA.

We report on a novel growth technique for growing high quality nSiGe/nH heterostructures in a hot wafer system to decompose silane and germane while simultaneously subjecting the growing films to ion bombardment from an ECR plasma. Careful diagnostic experiments show that over 90% of the growth of the film can be attributed to the hot wafer, with only about 10% of growth being contributed by radicals generated by the plasma. However, the influence of ions on film growth is found to be profound. Both He and H ions were used in the experiment, and it was discovered that ion bombardment from a hot wafer temperature of 500°C can decrease the growth rate of Ge films deposited at 200°C by about 25%. The enhancement of the growth rate at a hot wafer temperature of 500°C can be attributed to a reduction in the sticking coefficient of the Ge atoms on the substrate. The growth rate of Ge films deposited at 200°C is about 0.5 Å/s at a hot wafer temperature of 500°C.

A6.13 NANOVAPOR FORMATION DURING GROWTH OF AMORPHOUS SI AND Ge. J.A. Florez and P. Kotula, Sandia National Laboratories, Albuquerque, NM; D.J. Srolovitz, Princeton University, Princeton Materials Institute, and Dept. of Mechanical and Aerospace Engineering, Princeton, NJ.

We investigated the formation of nanovoids in amorphous Si and Ge thin films using cross-section transmission electron microscopy and in situ stress measurement during deposition. Nanovoid formation is observed to occur during ultrahigh vacuum evaporative deposition of amorphous Si and Ge films. Relatively small increases in incident deposition temperature strongly suppress void formation in Si. In amorphous Ge films, however, nanovoid formation is largely suppressed even at room temperature. We used a marker layer technique, combined with annular dark field microscopy (Z contrast), to show that nanovoids in silicon are related to the development of high-aspect ratio surface roughness during deposition. Nanovoids are found to align in tracks perpendicular to the growth direction and the onset of void formation produces tensile stresses in the amorphous material. Our model accounts for the observations strongly suggest that nanovoids are produced via elastic bridging of cusps in the surface. The cusps themselves arise due to nanoscale surface roughning associated with limited adatom mobility. We will present a simple model to describe the mechanisms of void formation, and we will discuss the possibility of using marker-layer measurements of roughening to estimate the activation energy for 700 nm thick silicon. This work was supported in part by the Division of Materials Science and Engineering, Office of Science, U.S. Department of Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

A6.14 HOT-WIRE CHEMICAL VAPOR DEPOSITION FOR EPITAXIAL SILICON GROWTH ON LARGE-SCALE POLYCRYSTALLINE SILICON TEMPLETTES, M.S. Misson, C.M. Chen, and H.A. Atwater, Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA.

We investigate the low temperature (<600°C) epitaxial growth of thin silicon films by hot-wire chemical vapor deposition (HWCD) on Si (100) and polycrystalline silicon template layers formed by selective nucleation and solid phase epitaxy (SNPE). SNPE layers were formed by the use of nickel nanoparticles as nucleation sites for the solid-phase crystallization of phosphorus-doped amorphous silicon on SO_2 display grain sizes on the order of 100 μm and have been successfully used as seed layers for epitaxy on silicon substrates at 600°C [1]. HWCD has recently been shown to be a promising method for fast, low-temperature epitaxy [3]. We have grown 300 nm epitaxial films at 300°C on Si (100) substrates at an H_2/SiH_4 ratio of 20:1. The films are epitaxial and highly textured and display a periodic array of stacking faults. We will discuss the substrate temperature and hydrogen dilution conditions for epitaxial growth on Si (100), as well as the microstructural properties and photorelective decay lifetimes of undoped layers grown on SNPE templates and the suitability of these films for thin-film photovoltaic applications.


A6.15 ELECTRICAL AND OPTICAL PROPERTIES OF HYDROGENATED AMORPHOUS AND MICROCRYSTALLINE SILICON FILMS DEPOSITED BY THE SADDLE-FIELD GLOW DISCHARGE METHOD. M. Yeghiyants, T. Allen, K. Leong, I. Milostyn, D. Yeghiyants, S. Zlotynski, University of Toronto, Dept of Electrical and Computer Engineering, Toronto, ON, CANADA; T. Allen, University of Tennessee at Chattanooga, Dept. of Physics, Geology, and Astronomy, Chattanooga, TN.

Hydrogenated amorphous [a-Si:H] and microcrystalline [μc-Si:H] silicon films have been obtained using the D.C. sputter field glow discharge deposition method [1,2]. The structural nature of the films was verified by Raman spectroscopy [3], FTIR spectroscopy and TEM. The main deposition parameters influencing the onset of microcrystallinity were: (i) the substrate holder bias (30 < V_s < 100 V), (ii) the gas pressure (P ~ 200 mTorr), and (iii) the substrate holder bias (V_s < 100 V). The opto-electronic characteristics of both a-Si:H and μc-Si:H were investigated using UV/VIS spectroscopy and photoconductivity measurements. The presence of phosphorus-doping of a-Si:H and μc-Si:H films was also investigated. The electrical properties of aSi:H films were investigated in the range 7.5-8.5 V, while μc-Si:H films exhibited gaps in the range 2.8-2.4 V. Dark conductivity measurements of undoped films indicate that both a-Si:H and μc-Si:H films are highly resistive (ρ > 10^12-10^14 Ω-cm). Dark conductivity measurements of dopant films suggest that a-Si:H and μc-Si:H films are highly resistive (ρ > 10^12-10^14 Ω-cm). The possible use of both types of material for devices (solar cells) is discussed. References: 1. Kosteki, T. Allen, M. Yeghiyants, MRS Bull. 20 (1995) p. 89; 2. Zlotynski, S. Gasparsi, F. Kosteki, K. Leong, I. Milostyn, D. Yeghiyants, S. Zlotynski, MRS Bull. (2003).
CONTEMPORARY AMORPHOUS SILICON: S. Dine1, G. Grangély2, E. A. Schiff1, 1Syracuse University, Dept of Physics, Syracuse, NY; 2BP Solar, Inc., Traverse, VQ.

Hole drift mobilities are very low in amorphous silicon, and until about 1995 it appeared that these low values were fundamentally limited by the amorphous carbon film. Hence drift mobility in a-Si:H/micro-poly-Si thin films is limited mainly by the high growth rate of 5 nm/s by hot-wire CVD, materials fabrication technology has been progressively improved significantly. However, fabrication of solar cells or TFT by hot-wire CVD appears to be tricky, particularly controlling interface properties and high growth rate taking advantage of the two techniques. Proper control of process parameters, we expect to create the environment near the substrate, high density atomic hydrogen, low ion energy, simultaneously high flux of Si atoms and Si-related radicals, which should, in principle, favor nucleation and fast growth of a-Si:H films having low defect density. Based on this idea, we have modified our plasma CVD reactors to a combined plasma and hot-wire CVD system, where the array of tungsten filament, mounted on an innovatively designed filament holder placed on the ground electrode. The specialty of the filament holder and the reactor geometry and the critical issues to sustain the plasma will be discussed. We have fabricated micro-Si thin films under PECCVD conditions by decomposing silane diluted with hydrogen, the dark conductivity and the photoluminescence under monochromatic light (λ > 670 nm) of the best films are 7.7×10−10 S/cm and 3.0×10−7 S/cm, respectively. We can also fabricate a-Si:H films prepared by combined plasma and hot-wire CVD to synthesize a-Si:H films. A comparison of structural and electronic properties of the a-Si:H films prepared by PECCVD and combined plasma and hot-wire CVD will be presented. The results on the defect density studies on two types of a-Si:H films, analyzed by photoconductive spectroscopy, particularly in the amorphous-to-microcrystalline transition region, will be reported. The process parameters of a-Si:H films prepared by combined plasma and hot-wire CVD will be discussed. 1. A.R. Modly, A. Lloret, J. Perrin, J. Huc, J.L. Mconi, J.Y. Pursey and G. Roeh. MRS Symp. Proc. 377 (1995) p. 119.

A6.16

COMBINED PLASMA AND HOT-WIRE CVD: INNOVATION IN PLASMA PROCESSING OF µc-Si:H THIN FILMS. A.R. Modly, Department of Physics, Syracuse University, NY.

In spite of the fact that PECCVD µc-Si:H thin-film solar cells emerged as the dominant technology for the fabrication of µc-Si:H-based tandem solar cells, however, slow growth rate of intrinsic layer and relatively low efficiency of a-Si:H/µc-Si:H tandem solar cells, limit the potential of commercialization of this type of technology. Since the 1990s we have synthesized the microstructure of µc-poly-Si thin films with high growth rate (> 5 nm/s) by hot-wire CVD, materials fabrication technology. This has been progressively improved significantly. However, fabrication of solar cells or TFT by hot-wire CVD appears to be tricky, particularly controlling interface properties and high growth rate taking advantage of both the techniques. Proper control of process parameters, we expect to create the environment near the substrate, high density atomic hydrogen, low ion energy, simultaneously high flux of Si atoms and Si-related radicals, which should, in principle, favor nucleation and fast growth of µc-Si:H films having low defect density. Based on this idea, we have modified our plasma CVD reactors to a combined plasma and hot-wire CVD system, where an array of tungsten filament, mounted on an innovatively designed filament holder placed on the ground electrode. The specialty of the filament holder and the reactor geometry and the critical issues to sustain the plasma will be discussed. We have fabricated µc-Si thin films under PECCVD conditions by decomposing silane diluted with hydrogen, the dark conductivity and the photoluminescence under monochromatic light (λ > 670 nm) of the best films are 7.7×10−10 S/cm and 3.0×10−7 S/cm, respectively. We can also fabricate µc-Si:H films prepared by combined plasma and hot-wire CVD to synthesize µc-Si:H films. A comparison of structural and electronic properties of the µc-Si:H films prepared by PECCVD and combined plasma and hot-wire CVD will be presented. The results on the defect density studies on two types of µc-Si:H films, analyzed by photoconductive spectroscopy, particularly in the amorphous-to-microcrystalline transition region, will be reported. The process parameters of µc-Si:H films prepared by combined plasma and hot-wire CVD will be discussed.
A7.4 CORRELATION OF MATERIAL PROPERTIES AND OPEN-CIRCUIT VOLTAGE OF n-Si:H AND n-SiGe ALLOY SOLAR CELLS. Baocai Yan, Jeffrey Yang, Guanghui Yue, and Subhendu Guha, United Solar Systems Corp., Troy, MI.

To understand the properties of amorphous silicon solar cells, a study investigated the effects of boron doping on the performance of the cells. The open-circuit voltage (V_{oc}) and fill factor (FF) were studied as functions of boron concentration, and the results showed that the V_{oc} increases with increasing boron concentration, while the FF decreases. This suggests that the boron doping affects the photovoltaic performance of the cells.

A7.5 SIMULATIONS OF BUFFER LAYERS IN n-Si:H THIN-FILM SOLAR CELLS DEPOSITED WITH AN EXPANDING THERMAL PLASMA. A.M. H. Petr"o, M. Zemen", R.A.C.M. M van Swaaij and M.C.M. van de Sanden. "Delft University of Technology, DIMEST, De R., THE NETHERLANDS; "Eindhoven University of Technology, Department of Applied Physics, Eindhoven, THE NETHERLANDS.

In this study, the authors performed simulations of the performance of n-Si:H thin-film solar cells deposited with an expanding thermal plasma. The simulation results showed that the use of a doped buffer layer can improve the efficiency of the solar cells. The authors also investigated the effect of the buffer layer thickness on the performance of the solar cells, and found that a buffer layer thickness of around 10 nm is optimum for the best performance.

A7.6 MICROCRYSTALLINE [Si,Ge] H SOLAR CELLS. Jinjun Zhu, Vikram Dalal, Iowa State University, Dept. of Electrical and Computer Engineering, Ames, IA.

In this study, the authors investigated the performance of microcrystalline [Si,Ge] H solar cells prepared using ECR plasma growth conditions. The cells were doped with germanium and silicon using a two-step process. The results showed that the microcrystalline [Si,Ge] H solar cells have a high efficiency of around 14%, which is comparable to that of silicon solar cells.


In this study, the authors investigated the causes and variation of leakage currents in amorphous silicon PN-J ohodes, using a combination of experimental and theoretical approaches. The results showed that the leakage currents are primarily due to the presence of defects in the amorphous silicon layers, and that the leakage currents can be reduced by improving the quality of the material.

A7.8 HIGH WIRE CVD MICROCRYSTALLINE SILICON SOLAR CELL PERFORMANCE VERSUS W FILM TEMPERATURE AND FILM LIFETIME. E. Iwaseki, Y. Xu, B.P. Nelson, P. Stradley, and A.H. Mahan, National Renewable Energy Laboratory, Golden, CO.

The authors investigated the performance of high wire CVD microcrystalline silicon solar cells deposited using a high wire temperature technique. The results showed that the solar cell performance improves with increasing wire temperature, and that the film lifetime increases with decreasing wire temperature. The authors also investigated the effect of wire temperature on the defect density of the microcrystalline silicon film, and found that the defect density decreases with increasing wire temperature.


In this study, the authors investigated the recovery of light-induced changes in amorphous silicon solar cells. The results showed that the recovery of the changes is enhanced by increasing the temperature and by increasing the light intensity. The authors also investigated the effect of exposure to light on the performance of the cells, and found that the performance can be significantly improved by light exposure.
from sodium vapor lamps. We have also looked for changes in the performance of cells prepared with deliberate inclusion of impurities like carbon, boron, and nitrogen, as well as cells prepared under conditions known to induce light induced degradation in excess of that observed for standard cells prepared under optimized conditions.

We find that tandem cells that degrade about 11% after light soaking do not exhibit any recovery in 20 days but recover about 1.6% of their loss after 12 months and about 35% after 12 months at open circuit.

A-Si single junction cells that degrade about 20% after light soaking recover about 7% of the loss in 1 month and about 17%/+1 year.

However, when the single junction cells are made under normal conditions of gas flow and temperature, they degrade 30 to 60% and the recovery increases to as much as 25 to 35% after 1 year. Similarly, adding 2.1% C to the degradation increases the recovery to 40% and its recovery at room temperature to 22 to 35% after 2 years.

We are in the process of looking at the kinetics of the recovery process, and how it is influenced by temperature and illumination using both optimized and non-optimized devices. Since even optimized devices exhibit some recovery, there is room for further optimization of the process conditions to reduce light induced degradation.

A7.10 TOWARDS UNDERSTANDING THE DEGRADATION WITHOUT LIGHT SOAKING IN HOT-WIRE A-Si THIN FILM AND SOLAR CELLS. Q. Wang, National Center for Photovoltaics, National Renewable Energy Laboratory, Golden, CO; Keda Wang and Dauing Han, Dept of Phys & Astronomy, Univ of North Carolina at Chapel Hill, Chapel Hill, NC.

The degradation without light soaking has been observed in both thin films and solar cells fabricated using the hot-wire CVD technique. For solar cells, a 9.8% initial efficiency became 9.2% after a few weeks of being stored at room temperature. The degradation mainly comes from the fill factor (FF) and can be as much as 4-6%. From the intrinsic layers, we also find that the properties of the films change without light soaking; for example, activation energy (Ea) of conductivity decreases from an initial 0.9±0.1 eV to 0.85±0.9 eV after being stored in the dark for a few weeks. We suggest that the degradation of both materials and solar cells may share the same origin. It comes from the intrinsic layer upward shift of the Fermi-energy position. In the other words, the temperature may be more directly related to the intrinsic layer deposition. To explore whether the source of the slow degradation is the structural relaxation or the gas absorption from the air, we are studying the gas absorption effect of hot-wire films with and without gas-re sistive top layer and results will be reported.

A7.11 MATERIAL ASPECTS OF REACTIVELY MF-SPUTTERED ZINC OXIDE FOR TCO APPLICATION IN SILICON THIN FILM SOLAR CELLS. Jürgen Hülses, Oliver Kluth, Joachim Müller, Hildegarde Sickmann, Chitra Agarwalz, Bernd Bech, Institut für Photovoltaik, Forschungszentrum Jülich, Jülich, GERMANY.

Hans-Peter Beck, Institut für Schicht- und Grenzflächenforschung, Forschungszentrum Jülich, Jülich, GERMANY; Matthias Wettig, I. Physikalisches Institut, RWTH Aachen, Aachen, GERMANY.

Silicon thin film solar cells in the p-on (superstrate) structure require a transparent conductive oxide (TCO) film, which has to combine low series resistance, high transparency and an adequate surface texture. Magneto sputtered and textured-etched ZnO:Al films fulfill these requirements. However, for industrial applications high rate sputtering techniques are required and the results obtained on small areas have to be transferred to these techniques. This paper addresses the material properties of medium-frequency (m.f.) sputtered ZnO:Al films which were deposited in an in-line sputtering system using dual magnetron cathodes with a length of 750 mm. The ratio between oxygen and argon gas flow during the reactive sputtering process from metallic Zn-Al targets was controlled by plasma emission monitoring. The films were deposited in dynamic mode (static gaps of the magnetrons) with static deposition rates of ~200 mm/min. The electrical film properties were investigated by four point probe and hall measurements. XRD was used to determine the film structure. All films prepared for this study showed low resistivities (~10^-2 /Ω•cm) and excellent transparency. After etching in diluted hydrochloric acid SEM and AFM measurements revealed different surface textures depending on the sputtering process parameters and, in case of static deposition, on the substrate position of the film relative to the two dual cathodes. Three characteristic positions could be distinguished: The position between the two cathodes, the position directly opposite to the center of one of the cathodes and the position directly opposite to the center of each target. A-Si:H p-i-n solar cells prepared on texture etched ZnO coated glass substrates at these different positions showed variations in the sheet resistance and surface texture obtained after etching. The experimentally observed revealed the influence of the magnetron configuration on film growth and resulting surface texture obtained after etching.

AS7.2 STUDY ON ATOMIC STRUCTURE OF CACO3 AND PECVD AMORPHOUS SILICON FILMS BY USING REVERSE MONTE CARLO SIMULATION. Norikazu Tabuchi, Hideki Maemura, JAIST, School of Material Science, Ishiwara, JAPAN; Tadayoshi Kawanishi, Jun Morimoto, NIKE, Dept of Materials Science and Engineering, Kanagawa, JAPAN.

Structure of amorphous-silicon (a-Si) films are studied by conventional and small-angle X-ray diffraction techniques, and successive simulation by reverse Monte-Carlo method based on such experimental data. As initial stage, by based on uniform film model, atomic location in the a-Si film is calculated from structural factors derived from X-ray diffraction data. The Si-Si bond angle distribution and the Si-Si bond length distribution are evaluated and these structural parameters are compared for CacO3 (often called Hot-Wire-CVD) a-Si, PECVD a-Si and vacuum evaporated a-Si. And additionally, to obtain further realistic structural model, non-uniform micro-structure of a-Si observed in small angle X-ray diffraction is considered in initial trial structural function and the above model is modified and improved. This method has potential to clear the unique properties of CacO3-CVD a-Si, which is stable for the stress from light soak or electric current. From these studies, it has found that; 1) Si-Si bond length distribution and Si-Si-Si bond angle distribution of a-Si are likely to spread as hydrogen (H) contents in the films increases. 2) The ratio of the short range order of a-Si structure decreases as the dilution ratio by H2 to SiH4 increases, and 3) 60 degree and 90 degree Si-Si-Si bond angles are observed. They might originate from three oriented ranges and four oriented ranges of the a-Si film. CacO3-CVD a-Si, H content inside film is a few atomic %. The structural order of a-Si is hardly changing depended on H content. These results reveal the unique structure of CacO3-CVD a-Si films.

AS7.3 LOCALIZED STATES IN MICROCRYSTALLINE SILICON PHOTOVOLTAIC STRUCTURES STUDIED BY POST-TRANSIT TIMING-OF-FLIGHT SPECTROSCOPY. Vsevolod Aksenov, Steve Reynolds, Charlie Main, Univ of Aberystwyth, Daniel Sch of Computing and Advanced Technologies, Dundee, UNITED KINGDOM; Friedhelm Finger, Reinhard Carus, Forschungszentrum Jülich, IPV, Jülich, GERMANY.

Much interest continues to be shown in the optimization of microcrystalline silicon for use as the absorber layer in solar cells. Factors such as RF power and silane concentration are known to have a strong influence on cell efficiency, and optimum performance has been correlated with preparation conditions close to the transition to the amorphous growth regime. In a previous study of epitaxial microcrystalline silicon films using transient photocurrent (TPC) [1], we showed that transitional films appear to have a higher defect density and a broader conduction band tail than optimized amorphous silicon films, and also that the shallow position of the Fermi level in highly crystalline material gives rise to behavior similar in character to that observed in n-type amorphous silicon. We have extended our work to include a study of pin solar cells using post-transit timing-of-flight spectroscopy. This method has the advantage of being applicable to device structures, and is thus potentially more useful, but is unable to probe to such shallow energies as TPC. Higher dark currents and steeper decays are also encountered. However, despite these limitations, we have obtained data that suggest a flat density of defect states exists between 0.3 and 0.7 eV over a range of silane dilutions, in contrast to the TPC results. It is suggested that these differences in behaviour may arise from the anisotropic nature of the films. [1] S Reynolds, V Aksenov, C Main, R Carus and F Finger, MRS Res. Soc. Symp. Proc. 715, A21.2 (2002).
SESSION A9: GROWTH I: MECHANISMS

Wednesday, April 22, 2003
Sakura 5/6 [Merrick]

8:30 AM  A9.1
COMBINATORIAL APPROACH TO THIN-FILM SILICON MATERIALS AND DEVICES. Qi Wang, Leandro R. Telesca*. Helio Mostinho, Rob To, John Perkins, Daeyeon Han*, and Howard M. Branz, National Renewable Energy Laboratory, Golden, CO.

We apply the powerful combinatorial approach to thin-film Si materials and devices research. We fitted our hot-wire chemical vapor deposition chamber with XYZ substrate translation, milled shutters, and shadow masks to implement many combinatorial methods. For example, we have explored, in detail, the transition region of thin Si changes from amorphous to microcrystalline silicon. This transition is sensitive to deposition parameters such as hydrogen-to-silane dilution, chamber pressure, and substrate temperature. A material library on just a few substrates led to a three-dimensional map of the transition as it occurs in our deposition system. This map guides our scientific studies, and enabled us to use several different transition materials in our optimized solar cell research. We also grow thickness-gradient wedge samples spanning the amorphous-to-microcrystalline Si transition. These samples map the temporal change of thin silicon phase on a single spatial dimension. With these wafers, the structural, optical, and electrical properties can easily be studied through the continuous phase transition. We have examined the nature of the phase change with Raman spectroscopy, atomic force microscopy, x-ray absorption fine structure, x-ray absorption near-edge spectroscopy, variable angle spectroscopic ellipsometry, ultra-violet reflectivity and other techniques. Combinatorial techniques also accelerate device research. In solar cells, for example, it has significantly accelerated the optimization process of p-, i-, n- and buffer layers through wide exploration of the complex space of growth parameters in only a few deposition runs. It has also been useful to correlate the materials properties of single layers in a device to their performance in the device. Not only has the combinatorial approach greatly increased the rate of materials and device experimentation in our laboratory, it has also been a powerful tool leading to a better understanding of structure-property relationships in thin film Si.

9:00 AM  A9.2
SiH4 DIFFUSION AND GROWTH PROCESSES OF n-Si:H. P. Vignonier, P.W. Penceok, J. Robertson, Engineering Dept., Cambridge University, Cambridge, UNITED KINGDOM.

We have studied a variety of microscopic surface processes on the hydrogen-terminated Si surface using total energy potential calculations, in order to understand and the growth mechanism of n-Si:H. Surface diffusion is known to be able to fill voids and give rise to the observed smooth surface. The question is whether surface diffusion is the weakly bound Si-H (silyl) radical, or other species. We showed previously that the silyl radical can bind weakly to the fully hydrogen-terminated Si surface. Here, we find that the silyl can diffuse very fast on nearest neighbor Si-H surface groups than between second-neighbor surface Si-H groups, i.e., across a (110)-H-like surface than over a (111)-H-like surface. Diffusion allows the silyl to create a surface dangling bond (DB) by abstracting Si-H, and a second silyl to then add to the DB to give a bound SiH3 group. In the standard picture, this bound SiH3 does not need to diffuse, it is the first stage of film growth. In this picture, a metastable adsorbed species does the diffusing. An alternative picture is that the H abstraction is a radical reaction, occurring whenever an incident H or silyl hits the surface, without any diffusion, to create the DB. The second silyl then comes along and adds to the DB to give the bound SiH3 group, and it is this species which could diffuse. In this picture, a fully bound DB would need to diffuse. We show that this is less likely. Thus, the calculations support the conventional model of growth. Finally, the effects of different hydrogen surface terminations are shown to be deleterious to surface diffusion, showing why low temperature deposition without H dilution gives poor material.

9:15 AM  A9.3

Although the efforts on constructing a growth model for n-Si:H have been fruitful and have contributed greatly to the understanding of the n-Si:H deposition process, there are several issues in the growth mechanism of n-Si:H that are still not completely unraveled. The interaction of SiH3 radicals with the Si surface under different surface conditions (as determined by the substrate temperature) is one particular unresolved issue for which there is still insufficient experimental data. Therefore we have carried out dedicated experiments under SiH3 dominated film growth conditions and in the absence of ion bombardment in the expanding thermal plasma. The SiH3 surface reactivity has been determined from time-resolved cavity ring-down spectroscopy experiments for substrate temperature in the range of 50° - 450°C. This has revealed a temperature dependent surface reactivity for SiH3 of 0.30 to 0.33. The fact that also the Si growth rate is temperature independent has direct consequences for possible recombination and/or desorption reactions of the SiH3 radicals at the surface. A temperature independent surface reactivity for SiH3 is furthermore striking because the chemical state of the n-Si:H surface during growth changes drastically. From the combination of in situ attenuated total reflection infrared spectroscopy and argon ion-induced desorption of surface hydrogen, it has been found that the dominant silicon hydrides on the n-Si:H surface change from SiH3 to SiH2 to SiH for increasing substrate temperature. The implications of these observations for the n-Si:H growth mechanism will be addressed and the growth model will be refined using simulations and theoretical calculations reported in the literature.

9:30 AM  A9.4
MODELING RADICAL-SURFACE INTERACTIONS AND H-INDUCED CRYSTALLIZATION IN PLASMA-DEPOSITION OF SILICON THIN FILMS. Sureshprasad Sharan, Sanit Agarwall, Enay S. Ayyub, and Dimitrios Maitlis, Department of Chemical Engineering, University of California, Santa Barbara, CA.

Hydrogenated amorphous silicon (a-Si:H) and nanocrystalline silicon (nc-Si:H) thin films grown by plasma deposition from SiH4/H2 discharges are widely used in photovoltaic and flat-panel display technologies. Understanding the nanoscale physical-chemical surface processes during film deposition is crucial for controlling the film structure and electronic properties. Toward this end, we have developed an atomistic-scale computational analysis of the plasma-surface interactions in a-Si:H deposition. This approach combines classical molecular dynamics (MD), molecular statics, and Monte Carlo simulations with quantum mechanical density-functional-theory calculations of surface reaction energetics. Growth of n-Si:H on initially H-terminated crystalline Si (001) substrate surfaces is modeled by MD simulations of repeated impingement of SiH3, SiH2 and SiH radicals, separately, as precursors. In this presentation, surface chemical reactions during film growth will be discussed, as well as the evolution of the film's structure, surface morphology and roughness, surface reactivity, and surface composition. The role of Si-Si bond straining in mediating SiH3 precursor surface diffusion in the valley-filling mechanism leading to smooth film surfaces will be emphasized. The fundamental mechanism of H-induced crystallization of a-SiH also is analyzed through MD simulations of repeated H atom impingement on a-Si:H films. Detailed structural analysis of the exposed n-Si:H film revealed the formation of nanocrystalline regions embedded within the amorphous Si matrix. The MD simulations showed that H atoms diffuse into the a-Si:H film and insert into strained Si-Si bonds to form inclined straining and bonds-centered H (Si-Si-H) configurations. The existence of this distorted H (D) in a-Si:H was also observed in the (111) plane H2 plasma was experimentally verified through in situ infrared spectroscopy. The insertion of H into strained Si-Si bonds results in structural relaxation and rearrangement of the Si matrix, thus leading to crystallization.

9:45 AM  A9.5
EFFECTS OF EXCITATION FREQUENCY AND H2 DILUTION ON CLUSTER GENERATION IN SHANE HIGH FREQUENCY DISCHARGES. Masaharu Shizume, Atsushi Hiroaki, Takamura Ogata, Kusumori Kogu, Yukio Watanabe, Kyushu Univ. Dept of Electronics, Fukuoka, JAPAN.

Previously we have shown that the microstructure parameter of n-Si:H films decreases below 0.003 with decreasing the cluster amount in SiH4/H2 discharges by using the cluster suppressed plasma CVD method [1]. In order to clarify the conditions under which a low amount of clusters incorporated in n-Si:H films, effects of
11:15 AM A10.3
THE ROLE OF SURFACE DIFFUSION AND ITS RELATION TO THE HYDROGEN INCORPORATION DURING HYDROGENATED AMORPHOUS SILICON GROWTH. Arno Smets, Erwin Kesales and Richard van de Sanden, Department of Applied Physics, Eindhoven University of Technology, Eindhoven, THE NETHERLANDS.

In this contribution a systematic study of the role of surface diffusion and its relation to hydrogen incorporation during hydrogenated amorphous silicon (a-Si:H) growth from a SiH$_2$ dominant plasma beam is presented. It will be demonstrated that the growth rate and substrate temperature dependence of the surface roughness evolution and of the hydrogen, vacancy and void incorporation into the a-Si:H network during growth are signatures of surface diffusion processes occurring during growth. In situ single wavelength ellipsometry (SWE) and ex situ atomic force (AFM) measurements have been used to study the roughness evolution, whereas ex situ infrared (IR) absorption measurements on a-Si:H films have been used to study the hydrogen, vacancy, and void incorporation. Void incorporation with hydrogen bonded at void surfaces are a result of a limited active surface diffusion process, whereas the m- and α-vacancies (m-, α-vacancy silicon incorporation, i.e. the incorporation of a compact cluster of monohydrides, happens at a site where cross-linking between two Si-H bonds has not occurred. The cross-linking step is activated with 0.21 ± 0.02 eV in agreement with previous studies [1]. SWE and IR absorption measurements provide independent verification that the limited activated surface diffusion step has an activation energy within the range of 0.8 to 1.1 eV. This rules out the possibility that the diffusion waves observed in the p-type material is responsible for the surface roughening. Possible surface diffusing candidates responsible for the surface roughening will be discussed. [1] W.M.M. Kessels, A.H.M. Smets, D.C. Munn, E.S. Aydil, D.C. Schram and M.C.M von de Sanden, Thin Solid Films 388, 151 (2001).

11:30 AM A10.4

A great deal of work has gone into understanding the relationship between silicon thin film growth and its effect on light induced degradation. Hydrogen diffusion of silane has been observed to reduce light induced degradation. Increasing the growth temperature is widely viewed as a means of improving light induced stability. This is especially true under conditions required for increasing growth rates that exacerbate the generation of higher silane related radicals. Increasing the temperature has been suggested to reduce the extreme fluctuations that generate the higher silanes. We have recently shown that the cathode potential in DC discharges of silane is sensitive to the density of negatively charged ions. Real time monitoring of the cathode potential has also been used to detect gradual changes in silane to hydrogen ratio in the plasma that discernably influences the stability of the cathode material. Here, we have compared the cathode voltage trends during the deposition of the layers of n-type silicon single junction cells. As the growth rate is increased from 1 to 10 Å/s, the cathode potential is observed to become unstable. In this case, the increase in temperature is increased from 200 to 250°C, the cathode potential for the lower growth rate plasmas remain almost the same while a large increase is observed for the higher growth rate plasmas and the fluctuations disappear. This is consistent with increased temperature reducing the higher silane generation and in turn, particle formation. [3] However, when we modified the heater assembly to obtain a more uniform temperature distribution over the electrode area of our small (30cm x 30cm) reactors, fluctuation in cathode potential did not occur at 200°C, and increasing the temperature to 250°C did not cause any change in the cathode potential for the higher growth rate plasmas. Concurrently, the light induced degradation of a-Si:H single junction devices improved from ~25% to ~20%.

11:45 AM A10.5
HYDROGENATION OF SILICON SURFACES: CRYSTALLINE VERSUS AMORPHOUS. Andreas Lehner, Florian Kohl, Martin S. Brandt, Martin Stutzmann, Walter Schottky Institut, Technische
Hydroxylation is a common starting process for the functionalization of silicon surfaces. Residual oxide layers on silicon have a negative influence on the degree of hydroxylation achievable. The crystalline silicon surfaces, oxidation can be minimized by proper treatment, but never completely avoided. On the other hand, formation of a natural oxide on the surface of hydrogenated amorphous silicon is much slower, therefore providing a better surface for a complete hydroxylation. In the present study, we have investigated in a systematic way the kinetics of natural oxide formation on hydrogenated amorphous silicon and crystalline silicon surfaces and the influence of this oxide layer on subsequent hydroxylation by octodecane. The structural and chemical properties of the different surfaces have been studied by AFM and X-ray Photoelectron Spectroscopy. In addition, changes in the surface recombination velocity have been monitored by photodiodes with strongly absorbed light and by surface photovoltage. Optimized conditions for the hydroxylation of crystalline and amorphous silicon with a minimum density of structural and electronic defects will be discussed.

SESSION A11: THEORY OF AMORPHOUS MATERIALS
Wednesday Afternoon, April 23, 2003
Salon 5/6 (Marriott)

1:30 PM A11.1
NUMERICAL STUDIES OF THE DYNAMICS OF AMORPHOUS SILICON: STRUCTURE, NUCLEATION AND ENERGY LANDSCAPE. Normand Maussane, Université de Montréal, Dept de Physique and GCM, Montreal, Quebec, CANADA.

Using various simulation techniques, such as molecular dynamics, the activation-relaxation technique and bond-switching algorithms, we are slowly developing a consistent picture of the dynamical properties of amorphous silicon. For example, results of an extensive search for the activated events surrounding a single minimum, in a well-relaxed model represented by a modified Stillinger-Weber potential, confirm that barrier height at the transition point, for activated mechanisms, is determined primarily by the binding energy of a single bond and not the details of the mechanism. We will discuss these results in detail as well as recent simulations of nucleation in liquid and amorphous silicon. This work was performed in collaboration with Francis Vukoviet, Philippe Benmouss. It is funded in part by NSERC (Canada) and FCAR (Quebec). NM is a Cottrell Scholar of the Research Corporation.

2:00 PM A11.2
DETECTING MEDIUM RANGE ORDER IN AMORPHOUS SILICON FILMS WITH THEORETICAL MODELING AND FLUCTUATION TRANSMISSION ELECTRON MICROSCOPY. S.V. Kessar, S.M. Nikolashvili, Paul Voyles, J.R. Abeles.

The fluctuation transmission electron microscopy (FEM) technique [1] yields information about the three- and four-body atomic correlations functions of amorphous silicon (a-Si) or a-Si:H via the statistical variance of the dark field image intensity V as a function of the scattering vector k and real-space resolution Q. To date all a-Si and a-Ge samples for which the FEM signal has been measured have shown peaks in V(k) which cannot be explained by the continuous random network (CRN) model. The paracrystalline (PC) model [2], consisting of 1-3 nm crystalline Si (c-Si) grains embedded in a CRN matrix, explains these features quantitatively. We have constructed many different realizations of the PC model using a modified Barkema-Maussane bond-switching algorithm, which yields physically realistic network statistics. We have varied (i) the number of c-Si grains present, (ii) the volume fraction of the grains, and (iii) their size distribution. We have calculated the expected FEM signatures using a modification of the image generation code by Kirkland [3]. The close match between these simulations and experimentally obtained FEM data provides strong support for the PC model. Our simulations show that a fluctuation map, consisting of FEM data as a function of both k and Q, can be used to distinguish the contributions of effects (i)-(iii) in the nano-scale structure. [1] J.M. Gibson et al., Ultramicroscopy 88, 189 (2000). [2] S.M. Nikolashvili et al., Phys. Rev. B 63, 155207 (2001). [3] M.M. Tracy et al., J. Non-Crys. Sol. 231, 99 (1998). [4] E.J. Kirkland (unpublished).

2:15 PM A11.3
MEASURING MEDIUM RANGE ORDER IN AMORPHOUS MATERIALS. P. Kehlisch, R.K. Dash, Material Science and Engineering Department, Rensselaer Polytechnic Institute, Troy, NY; P. Voyles, Bell Laboratories, Murray Hill, NJ; M. Gibson, Advanced Photon Source, Argonne National Laboratory, Argonne, IL. M.M. Tracy, NEC, Princeton, NJ.

We have examined simulated transition electron microscopy (TEM) images of model atomic structures of paracrystalline amorphous silicon. The variance of the simulated image intensity from these models shows quantitatively achievable FEM of crystalline silicon surfaces, oxidation can be minimized by proper treatment, but never completely avoided. On the other hand, formation of a natural oxide on the surface of hydrogenated amorphous silicon is much slower, therefore providing a better surface for a complete hydroxylation. In the present study, we have investigated in a systematic way the kinetics of natural oxide formation on hydrogenated amorphous silicon and crystalline silicon surfaces and the influence of this oxide layer on subsequent hydroxylation by octodecane. The structural and chemical properties of the different surfaces have been studied by AFM and X-ray Photoelectron Spectroscopy. In addition, changes in the surface recombination velocity have been monitored by photodiodes with strongly absorbed light and by surface photovoltage. Optimized conditions for the hydroxylation of crystalline and amorphous silicon with a minimum density of structural and electronic defects will be discussed.

SESSION A12: MELTSTABILITY
Wednesday Afternoon, April 23, 2003
Salon 5/6 (Marriott)

3:30 PM A12.1
NEW PHYSICS IN NEW RATE EQUATIONS FOR THE CREATION AND ANNEALING OF LIGHT INDUCED DEFECTS IN a-Si:H INCLUDING GE ALLOYS. P.A. Sheehy, Dept. of Physics, Washington University, St. Louis, MO; J.D. Cohen, Dept. of Physics, University of Oregon, Eugene, OR.

Although hundreds of experimental studies and dozens of ball and stick type models have been published on the effect of light induced defects in a-Si:H, there is no consensus on what actually causes the generation and/or annealing of such defects. It is not even clear how hydrogen participates, if at all. Motivated by recent experiments with unannealed results on the generation and annealing of light induced defects on Si and Ge sites in a-Si:H with small amounts of Ge, we have considered the consequences of a number of equations describing the effects. This work explores a detailed or macroscopic analysis but instead focuses on classes of theories and important questions independent of any detailed mechanism. Thus we investigate questions
concerning the interaction or interference between potential dangling bond sites on Si and Ge atoms and the competition for a limited facility in forming hydrogen (part of hydrogen bonding) and other defects. In this analysis it is imperative to at least try to come with the observed "stretching out" of time scales observed in all annealing experiments. This is, the annealing data described by a simple rate equation can only be fit by greatly stretched exponential which implies a very broad (and certainly unphysical) distribution of rates. We show that the same classes of rate equations need a far narrower distribution of rates than other classes in order to fit the data.

3:45 PM A12.2
KINETIC EFFECTS OF LIGHT-INDUCED EFFECTS ON THE HETEROGENEOUS SILICON SOLAR CELLS. Guoshun Yue, Jeffrey Yang, Baoguo Yan, Kenneth Lord and Subhendu Guha, United Solar Systems Corp., Troy, MI.

We have recently observed a significant light-induced increase in the open-circuit voltage ($V_{oc}$) of mixed-phase hydrogenated silicon solar cells. We proposed that this increase is associated with a light-induced structural change. In addition, light soaking under reverse bias and forward current injection experiments suggest that the $V_{oc}$ increase has the same origin as the Stehleber-Wronski effect (SWE). In n-Si:H cells, SWE typically results in a decrease in $V_{oc}$. Mixed-phase solar cells, however, structural change and SWE would affect $V_{oc}$ in opposite directions. In this paper, we investigate the kinetics of the light-induced effect on mixed-phase solar cells. The values of $V_{oc}$ and fill factor (FF) for the cells with different initial $V_{oc}$ were frequently recorded during annealing. For the cells with a low $V_{oc}$, which is below 0.8 V, the increase in $V_{oc}$ was slow and did not saturate for the experimental time of up to 16 hours. For the cells with medium initial $V_{oc}$ (0.8 - 0.95 V), the $V_{oc}$ increased rapidly and then saturated. Cells with high initial $V_{oc}$ (0.95 - 1 V) showed an increase in $V_{oc}$ in the beginning, followed by a $V_{oc}$ decrease. All the light-soaked cells exhibited a decrease in FF. The observed behavior of $V_{oc}$ is consistent with our mixed-phase model. The SWE appears to be more pronounced in the cells with high $V_{oc}$ and low crystal volume fraction than those with low $V_{oc}$ and relatively high crystal volume fraction. Based on our analysis, we believe that the reduction of crystal volume fraction or grain size may not be the only mechanism for the observed $V_{oc}$ increase. Mesostructured and microcrystalline quality, such as increased defects near the grain boundary, can also result in the $V_{oc}$ increase.

4:00 PM A12.3
MOO MODULATIONS IN n-Si:H FILMS UPON LIGHT INDUCED DEGRADATION. Lakshminarayana Nittala, Yeonwoong Jung, John R. Abeleson, Department of Materials Science & Engineering, University of Illinois, Urbana, IL.

In disordered materials, structural information at the nanoscale (24 nm) can be observed using Fluorescence Electron Microscopy (FEM), which is sensitive to the 3 and 4-body atomic correlation functions. The FEM technique involves calculating the statistical variance in dark field image intensities as a function of the scattering vector and the microscope resolution. Previous FEM studies have shown the presence of considerable medium range order (MRO) in n-amorphous silicon (a-Si:H) thin film devices which do not follow the predictions of a conventional random network model. The increased MRO is ascribed to the presence of ~2 nm sized crystalline grains which are hexagonally arranged and therefore invisible to diffraction measurements; to distinguish this special situation, they are called nanoparacrystals. Previous FEM studies on n-Si:H have examined very thin (~20 nm) vacuum-deposited samples. We have shown that the MRO modulations in these films are small (but definitely non-zero) when the films are subjected to light soaking and thermal annealing treatments [1].

However, changes in MRO may be thickness dependent: surface and interface recombination of carrier pairs suppress the Stehleber-Wronski Effect (SWE), and the presence of a surface oxide retards the effects of thermal and electrical annealing of ~0.2 µm thick films so that these effects are and better representative of the absorber layer in solar cells. In this study, we perform FEM on the central portion of device quality n-Si:H films which are first subjected to light soaking and/or annealing treatments, then chemically thinned from both sides to the ~20 nm thickness required for FEM analysis. The observed changes in MRO are correlated with the SWE and explained in terms of changes in the paracrystalline structure. [1] P.M. Voyles and J.R. Abeleson, "Medium Range Order in Amorphous Silicon Measured by Fluorescence Electron Microscopy," accepted by Solar Energy Materials (2012).

4:15 PM A12.4
TEMPERATURE DEPENDENCE OF A HYDROGEN DOUBLET SITE IN LIGHT-SOAKED n-Si:H FROM 1H NMR, T. S. A. Allen, P.C. Taylor, University of Utah, Dept. of Physics, Salt Lake City, UT; G. Ganguly, and D.E. Carlson, BP Solar, Tucson, VA.

From 1H NMR at 7 K on n-grown, light-soaked, and annealed samples of n-Si:H an additional doublet signal appears only after light soaking. This doublet indicates a locally spaced pair (approximately 2.3 Å separation) of hydrogen atoms that are not seen from other hydrogen atoms. The concentration of these doublets is between 10⁻¹⁲ and 10⁻¹⁴ cm⁻³ and is generally consistent with ESR measurements of the defect density after light soaking [1]. We report the temperature dependence of this doublet from 7 K to about 10 K and find that it appears in a manner that is consistent with local motion of the hydrogen atoms. Details of the local motion will be discussed. I. T. So, P.C. Taylor, G. Ganguly, and D.E. Carlson, Phys. Rev. Lett. 89, 015502 (2002).

3:40 PM A12.5
EVIDENCE FOR A TRAP-INDUCED INSTABILITY IN n-Si:H. Vikram Dahi, Puneet Sharma, and Aniz Ahmed, Iowa State University, Dept. of Electrical and Computer Eng., Ames, IA.

We have studied the early time degradation kinetics and CPM spectra of n-Si:H films. We find that at the earliest times (≤100 s), the kinetics follow a time and intensity dependence that can be explained assuming a mono-molecular carrier capture event. The intensity dependence is such that the time required to achieve a given dicing bond density is inversely proportional to the intensity, as predicted from mono-molecular kinetic equations. We also find, by measuring the entire alpha vs. energy spectrum during both early (1 min. 10 min) and longer term (>10 hours) degradation, that there is a decrease in gap state density in the energy region around 1.3 eV below the conduction band; and an increase in the gap state density in the region around 1.0 eV. The decrease at ~1.3 eV, the mono-molecular kinetics of this early stage of degradation, and the intensity dependence of degradation, all fit the charged trap to dangling bond conversion model proposed by David Adler in 1984. We have also studied the isothermal annealing behavior of this second kind of defect, and it appears that the normal dangling bond defect, when the inverse of photo-conductivity is plotted vs. the normal ~1.0 eV dangling bond defect, a hysteresis is observed during both degradation and annealing, as would be the case if there were two distinct types of defects present in the material. To make sure that surface effects were not involved, we also made samples with passivated surfaces, using a graded gap (Si,C) layers to drive both electrons and holes away from the surface. The results were essentially the same for both surface passivated and unpassivated samples. Based on the spectroscopic and kinetic evidence, we propose that the so-called fast states in n-Si:H may be Adler-type charged defects. The importance of this new type of defect on stability of solar cells will be discussed in the paper.

4:45 PM A12.6
EVOLUTION OF CHARGED GAP STATES IN n-Si:H UNDER LIGHT EXPOSURE. M. Zemskov, V. Nadvirny, R.A. C.M. van Swaaij, J.W. Mecher, Delft University of Technology, DIME, Del6, THE NETHERLANDS, R. Dormy, Slovak University of Technology, Bratislava, SLOVAKIA.

Inherent to hydrogenated amorphous silicon (a-Si:H) are the reversible changes in electronic properties of n-Si:H under light exposure, known today as the Stehleber-Wronski effect (SWE). It is generally accepted that light soaking leads to additional dangling-bond defects. We present experimental results from deep-level transient spectroscopy (DLTS) that reveal a surprising behavior of the bandgap states in n-Si:H during light soaking. The DLTS experiments show that prior to the creation of deep states around mid gap, there is an initial decrease of the density of gap states located above midgap, this observation indicates that in the early stage of light soaking, annihilation of some type of defects takes place. We propose microscopic atomic configurations that introduce charged states in the band gap of n-Si:H. The positively charged states above midgap, normally assigned to positively charged dangling bonds, are related to a charged complex formed by a Si dangling bond and a hydrogen molecule. The observation of this complex in the early stage of light exposure supplies mobile hydrogen. The origin of the negatively charged states below midgap is attributed to floating bonds and not to negatively charged dangling bonds. Having identified the origin of the temporal dependence of this doublet from 7 K to 300 K above about 10 K the signal disappears in a manner that is consistent with local motion of the hydrogen atoms. Details of the local motion will be discussed. I. T. So, P.C. Taylor, G. Ganguly, and D.E. Carlson, Phys. Rev. Lett. 89, 015502 (2002).

SESSION A13: GROWTH III: HWCVD and nc-Si:H
Thursday, April 24, 2008
8:30 AM A13.1
PERSISTENT STATES OF HOT WIRE CHEMICAL VAPOR
DEPOSITION TECHNOLOGY. Raul E. Schroop, Utrecht University, Delft Institute, SID - Physics of Devices, Utrecht, THE NETHERLANDS.

In this review, the latest achievements in Hot Wire CVD technology will be presented and illustrated by the performance of silicon thin film devices. In recent years, important progress has been made: (1) It has been shown that there are no fundamental limitations in HCWCD with respect to substrate area. Using a periodic configuration of multiple short wires, good uniformity (±5%) has been achieved by Aoyama et al. at a rate of 96 cm² x 40 cm. (2) High quality microcrystalline Si can be produced. Solar cells in the n-i-p configuration are currently better than those made by PECVD. At Ithiel, the efficiency of such cells is 0.9%, and Utrecht has recently made a silicon film on glass by HCWCD multilayered triple junction solar cells. (3) HCWCD offers the potential of ultrahigh deposition rates. At NREL, a-Si:H has been deposited at rates in excess of 12 mm/s, and at Utrecht University μc-Si:H rates are in excess of 1 mm/s. (4) New and improved demonstrations of microcrystalline thin film transistors (TFTs) with mobilities in excess of 1 cm²/Vs with an 18 μm channel have been shown to be stable and μc-Si:H TFTs have been made (at Sony) with mobilities in excess of 40 cm²/Vs. (5) The efficient production of atomic H in HCWCD is beneficial in passivation processes, for instance in HIT cells; but it can also be applied in etching processes. (6) Alloys of Si with various functions can be made, such as SiN, for antireflection and passivation coatings. Remarkably, all of these results have been achieved without detailed knowledge about the primary reactions at the filament, the gas phase reactions, and the reactions with the growing film. The choice of filament material and its operation temperature have a large influence on the production of crystalline structures and thus on the quality of the resulting film. HCWCD is basically an ion-free deposition technique, which is an advantage for many kinds of thin films. Polymer deposition and nanotube formation are other areas in which HCWCD has proven its feasibility.

9:00 AM A13.2
PROPERTIES OF HIGH QUALITY β-TYPE MIFORM CRISTALLINE-SI PREPARED BY CAT-CVD Hidetsu Matsunuma, Koushi Katsuno, Masaya Itoh and Atsushi Misuda, JAIST, Tsukuba, Ibaraki, JAPAN.

Cat-CVD (Catalytic Chemical Vapor Deposition), often called Hot-Wire CVD, is a new method to prepare device quality a-Si, microcrystalline (μc-Si) and poly-Si films. Particularly, a-Si and μc-Si were already used as n-layers in p-i-n solar cells and the cell efficiency of about 10% was achieved in spite of much higher deposition rates than PECVD. Thus, it is valuable to know the properties of β-type μc-Si films as a transparent window layer for improving the efficiency of full Cds-Cu2O solar cells. Here, the properties of μc-Si films, which are obtained by using large diameter silane gas, are extensively studied along with the properties of boron doped p-type films. So far, it is found that: (1) by H-dilution of silane, films of a thickness of only 20 nm or less of μc-Si on both glass and ITO of Asahi-KK without an Si incubation layer; (2) by making μc-Si transparent, it is much more improved than that of a-Si, particularly at the region of short wave length light, for instance, the absorption coefficient is decreased by one order of magnitude, the wave length of light passing through and height of enough as window layers, and by boron doping, the conductivity as large as 0.3 cm²/Vs can be obtained keeping transparent properties. The results demonstrate the feasibility of Cat-CVD μc-Si as a new window material for solar cells.

9:15 AM A13.3
HIGH RATE DEPOSITION OF MICROCRYSTALLINE SILICON THIN FILMS FOR P-I-N SOLAR CELLS. Takeshi Matsuoka, Michio Kondo, Akita Meishin, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, JAPAN.

High rate deposition technique of intrinsic microcrystalline silicon (μc-Si:H) thin films is essentially required for cell fabrication in view of future industrial mass production. We have demonstrated that high pressure and high deposition rate (HPDR) conditions in plasma-enhanced chemical vapor deposition (PECVD) process are effective to provide high quality μc-Si:H films at high deposition rates in excess of 20 Å/s [1]. We have also found that HCWCD plasma can suppress ion-bombardment and μc-Si:H film growth even when higher discharge power is used in the higher μc-Si:H deposition rate regime. Here we present the results on μc-Si:H p-i-n solar cells grown at 20 Å/s by 100 W PECVD using HPDR technique. In such high rate regime, we found that the deposition pressure plays a dominant role in determining short circuit current (Jsc) of solar cells. With an increase in deposition pressure from 3 to 6 Torr, Jsc increases by 50% due to a large improvement in long wavelength response, while deposition rate is almost unchanged. From the relationship between Jsc and crystallization of the layers, we estimate the formation of μc-Si:H toward the larger crystallites with (220) preferential orientation. Further improvement in Jsc is achieved at a deposition pressure of 7 Torr by applying a higher discharge power. As a result, we have obtained an efficiency of μc-Si:H solar cell (Jsc=223 mA/cm², Voc=0.52 V, FF=0.7) with a 2 μm thick i-layer grown at 20 Å/s. The above results offer the advantages of the use of HPDR technique for the fabrication of high efficiency solar cells at high deposition rates [1]. M. Kondo et al. J. Non-Cryst. Solids, 84, 262-269 (2000).

9:30 AM A13.4
INVESTIGATION ON THE REAL-TIME MONITORING OF THE CRYSTALLINITY OF HYDRONGENATED MICROCRYSTALLINE SILICON FILMS. Christof Ross, Friedhelm Finger, Reinhard Carus, Institut für Photovoltaik (IPV), Research Centre, Juelich, GERMANY.

Transitions between microcrystalline and amorphous silicon as a function of growth parameters have attracted a lot of interest during the last 30 years (1). For microcrystalline Si, a growth transition from amorphous to crystalline structure is obtained. Transition results in best material properties for devices such as solar cells (2). However, the growth in this regime very critically depends on the substrate. Therefore, a real-time control of the crystallinity is desired. We present a method for monitoring the evolution of crystallinity during the growth by using in situ spectroscopic ellipsometry. The crystallinity is gained from the analysis of the shape of ellipsometric spectra by using only a few spectral points in the near UV. For the present system these results in a sampling rate of up to 6 scans per minute. Hence, if the film grows with a rate of 0.1-0.2 μm/s the crystallinity can be measured at intervals of 1-2 nm, which is an order of magnitude smaller than the probe depth. Results are shown for (i) microcrystalline Si on silicon and for (ii) microcrystalline silicon absorber layers grown on p-type silicon. It turns out that evolutions of crystallinity can be monitored successfully. The crystallinity of selected films is in good agreement with the crystalline volume fraction measured by Raman spectroscopy. Further improvements of the system are discussed. The method turns out to be well suited for a process control. - Reference: [1] A. S. Ferrotto, R. J. Koval, C. E. Snaidero, and E. M. Yoshina, Appl. Phys. Lett. 84 (2002) 2666. (2) O. Vetterl, F. Finger, R. Carus, P. Huglo, L. Houwen, O. Kluh, A. Lambertz, A. Meumm, B. Reh, G. Wagner, Solar Energy Materials and Solar Cells 62 (2000) 97.

9:45 AM A13.5
TOWARDS MICROCRYSTALLINE SILICON N-LP SOLAR CELLS WITH 10% CONVERSION EFFICIENCY. Luc Feinleib, Xavier Nigulier, Jocelle Guilet, Corinne Droz, Julien Thaler, Evelyne Vallat, Avind Shah, Institute of Microtechnology (IMT), University of Neuchatel, SWITZERLAND.

High-performance microcrystalline and amorphous silicon solar cells are the key elements for a successful combination to form the “micromorph” tandem cell. Here, the authors report on the successful realization of an amorphous silicon tandem cell by the VHF PE-CVD deposition process; the cell has a conversion efficiency exceeding 9% (Voc=520 mV, Ff=78%, Jsc=24.2 mA/cm²) and was deposited at a rate of 2.6 Å/sec. This milestone was achieved by a successful combination of three elements: (i) fine-tuning of the silicon concentration (SC) in the silicon + hydrogen source gas used for deposition of the intrinsic i layer; (ii) incorporation of an optimised back-reflecting substrate into the cell; (iii) the methodical development of p- and n-type-deposited absorber layers for a-si control of the critical i-layer deposition, OES is shown to be a useful process-control tool. On the other hand, a complete posterior microstructure characterization of this cell will be discussed i.e. based on Raman and TEM data. Above cell performance could be obtained by a substantial increase in Voc while maintaining reasonable Jsc values. Earlier, systematic investigations had revealed a trade-off between those two values in function of SC used for i-layer deposition. The authors now show that a variation in SC as used for deposition of i-layers in a-Si solar cells does not influence current generation in the long-wavelength region (above 900 nm), provided suitable light-diffusing back-reflectors are employed. In this wavelength range, a saturated conversion efficiency is obtained, independently of the SC used. The fabrication of a micromorph stacked cell integrating such μc-Si:H bottom cell is under way.

SESSION A14: GROWTH IV: HWCD AND μC-Si:H
Thursday Morning, April 24, 2003
Salon 5/6 (Marriott)

10:30 AM A14.1
ROLE OF HF FOR MICROCRYSTALLINE SILICON NUCLEATION. Hiroyuki Fujimura, Michio Kondo and Akita Meishin, AIST, Ibaraki, JAPAN.

02
Nucleation of microcrystalline Si (μc-Si:H) from the hydrogenated amorphous Si (a-Si:H) phase has been studied by applying real-time spectroscopic ellipsometry (SE) and high-resolution transmission electron microscopy (HREM). It has been found that the high intrinsic stress in the a-Si:H phase is essential for μc-Si:H nucleation. In plasma-enhanced chemical vapor deposition using high hydrogen dilution, μc-Si:H nucleation was observed at a much lower intrinsic stress inside a-Si:H exceeding 750 MPa, regardless of deposition temperature [1]. As the result of alternating μc-Si:H deposition and H2-plasma treatment, we confirmed that the high compressive stress in μc-Si:H strongly inhibits the formation of the SiH2 (n=1-2) complex that has been proposed to be a precursor for μc-Si:H nucleation. The results presented here show a large substrate effect. In the μc-Si:H growth process, the μc-Si:H growth on a ZnO substrate at high hydrogen dilution, a porous interface layer has been formed due to the high intrinsic stress in the μc-Si:H layer. The atomic-scale processes that govern this structural transition are analyzed through molecular dynamics (MD) simulations of repeated H atom impingement on computationally generated a-Si:H films. We showed recently that H-induced crystallization was mediated by insertion of H atoms into strained Si-Si bonds through the formation of intermediate bridging and bond-centered (BC) configurations as the H atom diffused through the a-Si:H film. This presentation focuses on the analysis of the mechanism and energetics of these H insertion pathways. Prior to insertion, diffusing H atoms are observed to insert into strained Si atoms, forming a bridging configuration. If the H atom bonds both to the Si atoms that are bonded. After H insertion, a-Si:H film is further strained or broken, or it may relax restoring the Si-Si bond to the equilibrium length, as previously described, and reappears in a bond-centered configuration. On the other hand, when a diffusing H atom occupies the bond-centered (BC) location between two Si atoms that are not originally bonded, a Si-Si bond forms after the H atom diffuses away. The energetics of H insertion into strained Si-Si bonds, its correlation with bond strain, and its implications in the structural relaxation of the amorphous phase are discussed.

11:45 AM A14.5
OPTICAL FUNCTIONS OF TRANSPARENT CONDUCTORS AND THEIR IMPACT ON COLLECTION IN AMORPHOUS SILICON SOLAR CELLS. S. Louie, R.W. Collins, Materials Research Institute, Center for Thin Film Devices and Department of Physics, Pennsylvania State University, University Park, PA; G. Ganguly, BP Solar, Tianou, VA; Joong Hwan Kim and Kyoung Su Lim, Korea Advanced Institute of Science and Technology, Daejeon, KOREA

We have established procedures for determining the optical functions of textured transparent oxide (TCO) films that are used as contact layers in amorphous silicon-based thin film solar cells. These procedures combine [i] multichannel Mueller matrix spectroscopy using a dual rotating-compensator spectroscopic ellipsometer in reflection from the top surface of the TCO film, which provides spectra in the index of refraction n versus photon energy E, and [ii] multichannel transmission spectroscopy through a double-thick TCO sandwich connected with index-matching fluid, which provides spectra in the extinction coefficient k versus E. These techniques have been designed to extract accurate n(E), k(E) spectra with essentially full reflection of the scattered light that arises due to microscopically roughness. The required spectra for doped SnO2 samples have been obtained using a Kramers-Kronig consistent expression that combines three components: [i] Drude characteristic for intrinsic absorption, [ii] a Tauc-Lorentz characteristic for interband absorption, and [iii] a Sellmeier characteristic for additional dispersion. These three components represent "electronic oscillators" with resonant frequencies [i] \( \omega_m \), [ii] \( \omega_n \) in the near-ultraviolet, accessible to the spectroscopists, and [iii] \( \omega_p \) well above the accessible range. A procedure that takes data from the ellipsometric and transmission spectroscopies iteratively has been most successful in this analysis. Among the primary optical losses in a-Si:H solar cells include absorption by the TCO film as controlled by k(E) and reflection from the TCO/air interface as controlled by n(E). In this paper, we characterize such optical losses in detail through modeling the solar cell optical quantum efficiency and demonstrate the extent to

as small as 3.2 nm being resolved, are obtained using high resolution transmission electron microscopy (HRTEM). Electron energy loss spectroscopy has been acquired in the transmission electron microscope. The optical absorption spectra, measured using the constant photocurrent technique, indicate that the Urbach slope and mid-gap defect density are lower in the a-Si:H films than in conventional a-Si:H films, which has resulted in a lower midgap defect density, the magnitude of the decrease in the dark conductivity following light exposure is comparable in the a-Si:H films that are seen in more defective a-Si:H. The dependence of the a-Si:H film properties on the plasma discharge condition has been studied by using the plasma discharge control parameters as="amorphous silicon solar cell materials. Eli Sutter and Don Williamson, Colorado School of Mines, Department of Physics, Golden, CO.

There is a constant drive for improving a-Si:H and a-SiGe:H materials as intrinsic layers for use in solar cells with recent interest focused on depositing good quality materials at high deposition rate. Cell performance degradation typically occurs in a-Si:H and a-SiGe:H materials, which may depend critically on the microstructure and the presence of the hydrogen content in microwaves, high-quality region, reduced density area, and Ge composition fluctuations in the alloy films. Although such features have been observed from small-angle X-ray and neutron scattering studies, more direct and detailed information about the microstructure and linking of particular structures to the deposition conditions could lead to improvements in stability and performance of solar cells. Here we use cross-sectional transmission electron microscopy (XTEM) to investigate the microstructure of a-Si:H and a-SiGe:H films prepared by both plasma-enhanced and hot-wire chemical vapor deposition. The XTEM studies show the presence of spherical-like and highly elongated microwaves in device quality a-SiGe:H, as well as in hot-wire a-Si:H grown at high deposition rates. The direct XTEM imaging allows us to follow the evolution of the structural inhomogeneity with increasing the thickness of the films. Investigation of the microstructural properties of a-Si:H prepared near the edge of microcrystallinity which show a lot of promise regarding improved stability will be presented as well.
which microscropic roughness at the TCO/layer interface can serve as an “anti-reflection layer” for enhanced collection.

SESSION A15: GROWTH V: LOW TEMPERATURE AND HIGH RATE
Thursday Afternoon, April 24, 2003
Sala n 5/6 (Marrriott)

1:30 PM *A15.1
VERY HIGH INTEGRITY THIN FILM DEPOSITIONS AT VERY LOW TEMPERATURES
Takahiro Ohmi, Akimoto Tomoe, Hiroaki Tanaka, and Maneki Hiyama, New Industry Creation Hatchery Center, Tohoku University, Sendai, JAPAN.

It is usual understanding that the film quality is improved by increasing the substrate temperatures and decreasing the film growth rate for the ultra clean process environment free from various contaminants. On the other hand, recent progresses of semiconductor industry and the LCD display industry essentially require the very high speed film growth at very low temperatures with keeping the very high quality of thin films. In order to establish this very essential requirement, following four new technologies must be completely implemented to the process equipment such as Radical Reaction Based Processings instead of Current Molecule Reaction Based Processings, Ultra Clean Process Environments Free From Various Contaminants Where Process Gas Flow Rate, Contamination and Composition Must Be Completely Controlled, and Scheduled Value, Respectively. Ultra Clean Wafer Surface Free From Various Contaminants Such As Particles, Metals, Organic Molecules, Moisture and Neutral Oxide With Keeping Atomic Order Surface Plasma and Hydrogenation Particularly for Base Silicon Film, and Completely Regulated Ion Bombardment onto the Wafer Surface to Promote Very High Integrity Thin Film Growth by Activating the Wafer Surface Where the Bombardment Ion Energy and Angular Distribution Are Less Than the Critical Value Giving rise To Surface Damages and Greater Than The Critical Value Giving Rise To Sufficient Surface Activation to Promote Very High Integrity Thin Film Growth. Respectively. Thus, very high integrity single crystal Si, SiO2 and Si3N4 film have been obtained at 300-400°C.

2:00 PM A15.2
REACTION CONTROL IN AMORPHOUS SILICON FILM DEPOSITION BY HYDROGEN CHLORIDE. Akhiro Takano, Takohito Wada, Shoji Fujikake, Takashi Yoshida, Tokio Ohta, Fuji Electric Corporate Research and Development, Ltd., Yokosuka, JAPAN; Eiji S. Aoyagi, Department of Chemical Engineering, University of California, Santa Barbara, CA.

HCl was added to SiH4 containing plasma to grow Si:H(Cl) films aiming at an alternative dangling bond terminator. Bulk and surface infrared spectra, film thickness and optical band gap were in situ examined by multiple total internal reflection Fourier transform infrared spectroscopy and spectroscopic ellipsometry. SiHCl4 was also used as a compensating Cl source for Si:H(Cl) film deposition experiments. In the conventional SiH4/Cl2/He system, the deposition rate increases significantly as already reported. The increase in the deposition rate introduces a monotonous decrease in refractive index and optical band gap widening. Although the deposition rate is typically limited to below 10 nm/sec in order to avoid the optical band gap widening for an application to solar cells. In these Si:H(Cl) films, Cl is not a major dangling bond terminator. In contrast, the introduction of HCl, which does not affect the deposition rate significantly, changes top surface compositions of growing films drastically from higher silicon hydride to chlorinated lower hydride. The surface reaction control eliminates unfavorable higher hydride bonding structures and reduces optical band gap widening, in the deposited film. The Si:H(Cl) films deposited from the mixture of SiH4 and HCl do not show significant optical band gap widening in spite of containing over 10 nm Cl atoms, a concentration that is comparable to that of hydrogen. A strong correlation between Cl and H for surface bonding sites is reflected on the Cl concentration increasing at the expense of decreasing H concentration with the increase in HCl partial pressure in the gas phase. The new α-Si:H(Cl) material from the HCl/He system, in which Cl acts as a major dangling bond terminator together with H without optical band gap widening, is expected to be a promising material for amorphous solar cells.

2:15 PM A15.3
MATERIAL STRUCTURE OF MICROCRYSTALLINE SILICON DEPOSITED WITH AN EXPANDING THERMAL PLASMA.
E. van de Sanden, M. Zisman, R. Veenstra*, D. Williamson**, M. C. de Graaf, J. A. C. M. van de Sanden*, Delft University of Technology, DMEI-ECTM, Delft; THE NETHERLANDS; *Colorado School of Mines, Department of Physics, Golden, CO; **Eindhoven University of Technology, Department of Applied Physics, Eindhoven, THE NETHERLANDS.

In solar cell technology much research effort is directed towards the high-rate deposition of microcrystalline silicon, because the optical band gap of this material is ideally suited for the intrinsic layer of the bottom cell in a tandem solar cell in combination with a hydrogenated amorphous silicon (α-Si:H) top cell. Furthermore, the change transport properties and the stability against light soaking are better than that of α-Si:H. With expanding thermal plasma chemical vapour deposition (ETP CVD) high deposition rates have been achieved for the deposition of α-Si:H (around 0.7 nm/s successfully applied in solar cells). Here we apply this technique for the deposition of microcrystalline silicon films with varying crystalline fraction at rates of about 1 nm/s. We used several techniques to characterise the material, in particular the material structure. The crystalline fractions are measured from Raman spectroscopy as well as from X-ray diffraction (XRD) and shift in the peak due to the Scherrer formula. Small angle X-ray scattering (SAXS) and flat on homogeneity measurements indicate void volume fraction of 30% and 50%. However, void volume fractions of about 30% are obtained when the Braggman effective medium approach is applied for the X-ray refractive index. This contribution is not yet understood. When the samples are tilted the SAXS signal is lower than for the untitled case, indicating elongated object parallel to the growth direction in the films. These objects can also be seen in high-resolution transmission electron microscopy (HRTEM) images of the samples, which elongated structures in the growth direction are visible.

SESSION A16: CRYSTALLIZATION
Thursday Afternoon, April 24, 2003
Sala n 5/6 (Marrriott)

3:00 PM *A16.1
HIGH QUALITY POLY-SI BY SILICIDE MEDIATED CRYSTALLIZATION OF AN AMORPHOUS SILICON. Jin Jung, Department of Physics and TFT-LCD National Lab, Kyung Hee Univ, Dong-dae-mo-ku, Seoul, KOREA.

A super-grain polycrystalline silicon can be obtained by the metal induced crystallization of amorphous silicon. The optimization of the metal density used for the metal induced crystallization and the crystallization procedure are key factors for the growth of large-grain polycrystalline silicon on glass. We carried out the various approaches to the high quality polycrystalline Si by silicide-mediated crystallization (SMC) of amorphous silicon. The metal density, heating methods, electric field, amorphous silicon precursor have been varied in the present work The crystalline properties were studied through TEM, SEM, EDSD and AFM. We found that the orientation of grains are different even in one sample, however, the most of grains have only one orientation in one grain. The crystallization mechanism of SMC and the approach to improve the quality of the poly-Si will be discussed on the basis of our experimental results. The performances of thin-film transistors using SMC poly-Si will be discussed in relation with the crystalline properties. The flick-effect mobility of higher than 250 cm²/Vs has been obtained with the SMC poly-Si in glass.

3:30 PM A16.2
STRESS EFFECTS ON NANOCRYSTAL FORMATION BY NICKEL-INDUCED CRYSTALLIZATION OF AMORPHOUS SILICON. Youcheng Liu, Michael D. Deal, Mahmooda Saltman, and James D. Fannon, Center for Integrated Systems, Stanford University, CA; Department of Chemical Engineering, University of Southern California, CA.

Metall-induced crystallination (MIC) of amorphous Si is gaining increasing interest because of its potential use for low-temperature fabrication of integrated circuits. In this work, the MIC technique was used to make Si nanocrystals on a Si substrate. A novel stress effect on the crystallization were studied. Amorphous Si films were deposited onto the Si substrate with thermal oxides on top by low-pressure chemical vapor deposition (LPCVD) and then patterned into nanoscale pillars by electron beam lithography and reactive ion etching. A conformal low-temperature oxide (LTO) layer was deposited on the pillars, followed by an anisotropically etch back to form a spacer, leaving only the top surface of the pillars exposed to the 5 nm Si etching deposition afterwards. An HF dip for different times was used to partially remove the LTO spacers on the pillars, leading to different LTO thicknesses on different samples. These samples were then annealed to crystallize the amorphous Si pillars, forming Si nanocrystals. Transmission electron microscopy (TEM) characterization revealed a clear dependence of the crystallization rate on the pillar size as well as the LTO thickness. The crystallization rate was lower for pillars with thicker LTO spacers. This trend is consistent with the LTO thickness was lower for pillars with narrower width. A model based on the stress in the pillars is proposed to explain this dependence. This model suggests some methods to control the MIC process and achieve high quality Si nanocrystals.
3:45 PM A16.3
FIELD-EFFECT GERMANY-INDUCED CRYSTALLIZATION OF AMORPHOUS SILICON ON GLASS. Jabir Derakhshesh, Shams Mohajernejad, Negin Golshani, Ali Khaki-Firooz, University of Tehran, Ist of Electrical and Computer Engineering, Tehran, IRAN; Michael Robertson, University of Auckland, Wolfville, NS, CANADA.

A low temperature metal-free field-induced Ge crystallization on glass is reported. E-beam deposition of 1000 Å Si followed by 100 Å Ge layers gives the same active film at a substrate temperature of 400°C on 1200 μm thick ordinary glasses. A 100 Å SiO₂ layer is used for the passivation of Ge film. Lm-apart contact pads are used to apply external voltages of 10-100 V. Si/Ge bi-layer through the oxide layer during post treatment at temperatures from 350 to 450°C. While samples treated without an external voltage are not crystalline, those annealed in the presence of applied voltage become crystalline as confirmed using SEM, XRD and TEM analysis. Conductivity measurements from 100-10⁵ S cm⁻¹ from the negatively charged electrode with a rate of 60 μA/cm² at 450°C, extending up to 1.5 mm. Also a low rate of 4 μA/cm² is observed for the growth from the positive electrode. The value of applied voltage plays a crucial role in crystalline quality of Si films. Samples annealed with 10V; show a sheet resistance of 10⁴ Ω/sq whereas those treated with 100V; show a value 10 times higher, indicating a lower conductivity and inferior carrier mobility.

Polycrystal films vary between 0.1 and 0.2 μm, as exhibited by SEM. It also shows that grains are distributed in a wavy fashion extending outward from the cathode side. Samples treated with 100V during annealing show sharp and well-defined rings in TEM analysis, but in those annealed with 100V the rings are blurry. For the former samples, crystallization has been further confirmed using XRD analysis, where Si< 2θ ≥ 60° is clearly discernible. We speculate that a combination of lateral growth in the Ge film as distributed seed for crystallization and external external field is responsible for such a fast and metal-free growth. Also attempts are being made to fabricate Si-TFTs using an inverted-staggered structure.

4:00 PM A16.4
PREDICTION OF THE INTERFACE RESPONSE FUNCTIONS FOR AMORPHOUS AND CRYSTALLINE S AND Ge AND THE IMPLICATIONS REGARDING EXPLOSIVE CRYSTALIZATION. Eric Albertson, Chair, School of Biomedical Engineering, Cornell University, Ithaca, NY.

Interface response functions for amorphous and crystalline forms of Si and Ge were studied for several empirical atomic-scale models and compared to results from continuum modeling as well as experiments. The empirical potential models of interest include the Stillinger-Weber (SW), Environment-Dependent Intermolecular Potential (EDIP), and the Modified Embedded Atom Method (MEAM) models for Si and the SW for Ge. All of these models were found to produce unacceptable representations of the interface response functions of both solid phases due either to their poor prediction of the amorphous melting point or a significant error in the prediction of the maximum solidification velocity. Given that the best of these models was the SW potential, which produces a very accurate interface response function (IRF) for crystalline silicon, this potential was modified to critically improve the prediction of the melting of the amorphous phase crystal. Increasing the three-body SW term by about 15% produced a significant improvement in the melting line for a-Si and a-Ge with little impairment of the prediction of the crystalline melting points. The implications of these results to explain the kinetics of explosive crystallization processes are discussed. However, these simulations also expose the inadequacy of an IRF representation of the amorphous phase in the light of significant evidence for homogeneous melting in the bulk amorphous material as well as heterogeneous melting at the amorphous/liquid interface. A new two-mode model for amorphous group IV melting is proposed which helps explain recent new experimental data on the explosive crystallization of a-Ge. [A. Chojnicka and M.O. Thompson, PhD thesis, Cornell University, 2001].

4:15 PM A16.5
ADVANCED LATERAL CRYSTAL GROWTH OF a-Si THIN FILMS BY DOUBLE-PULSED IRRADIATION OF ALL-SOLID-LASERS. Yoshio Kado, Koji Seike, and Kazunari Yamanouchi, Research and Development Center, Sumitomo Industries Ltd., Higashimatsuyama, Japan; Ken-ichi Hayashi, Japan Advanced Optical Materials, Matsuyama, Japan, Ibaragi, Japan; Cheng-Guo Jin, ACT Center, TIC Corporation, Tokyo, Japan.

A compact annealing machine with all-solid-state green lasers has been developed, which has the advantage of wide adjustment of solidification rate through the delay time control of long pulses (pulse width 100ns). And advanced lateral crystal growth (ALCG) process has been not be done by double-pulsed solid-state laser annealing (DLA). The laser beam has a line shape 0.1mm wide and 17mm long, and the beam profile on the short axis is quasi-gaussian (FWHM 0.1mm). Scanning the line beam along the short axis at the 85% overlapping ratio, the lateral crystal growth area of pitch 1mm steps to the long side is extended to the 80% overlapping ratio. The advanced lateral growth mechanism is easily explained with a crystal growth model of an a-Si thin film 50nm thick. The first irradiation, each seed of width 1mm and length 4mm generates near the middle the energy density gradient of the Gaussian beam parallel to the long axis. (2) At the second irradiation of scanning length 14mm, each seed melts and grows laterally to 8mm outward. (3) At the third irradiation of scanning length 3X14mm, each of regrowth area regrows to the same way to the lateral is formed elongated areas from each seed bump each other. The ALCG process is shown on the sectional view of the crystal growth layer. The ALCG process is shown the sectional view of the crystal growth layer. The ALCG process is shown the sectional view of the crystal growth layer.
A17.1
CHARACTERIZATION OF ULTRATHIN AMORPHOUS SILICON AND CORRELATION WITH CRYSTALLINE EVOLUTION AFTER THERMAL ANNEALING
Jin-Wei Park, C.A. Richter, N.V. Nguyen, John E. Bonevich, and Eric M. Vogel, National Institute of Standards and Technology, Semiconductor Electronics Division, Gaithersburg, MD; Jin Yong Kim, National Institute of Standards and Technology, Ceramics Division, Gaithersburg, MD.

Ultrathin amorphous silicon (especially less than 10 nm thick) has tremendous potential for use in single electron memory devices, optoelectronic devices, and tunneling nanodevices. In this ultrathin regime, physical metrology issues such as thickness, morphology, structural density, and interfaces become important factors for the control of zero-dimensional or one-dimensional confined structures. We will present results of precise physical characterization of ultrathin amorphous silicon and discuss how crystalline evolution is affected by these physical properties during thermal annealing. Ultrathin amorphous silicon layers were deposited by low pressure chemical vapor deposition at 550°C. The thickness of these layers is controlled between 2 nm and 20 nm. The thickness of amorphous silicon was measured by both vacuum ultraviolet photoemission spectroscopy (VUV-SE) and cross section transmission electron microscopy (TEM). Atomic force microscopy (AFM) and TEM were used to characterize the microstructural changes. RBS surface roughness of the samples prepared by AFM, is shown to be independent of film thickness. The bandgap energy measured by VUV-SE appears to increase with decreasing film thickness in the studied thickness range. Simultaneous oxidation and annealing techniques were used to crystallize the ultrathin amorphous silicon. We experimentally observe that the crystalline evolution depends upon the thickness and microstructure of the initial amorphous silicon layer. Above 10 nm thickness of amorphous silicon, only polycrystalline silicon is observed to evolve. We will also show the various crystalline characteristics that evolve for films below that thickness.

A17.2
STUDY BY SPREADING RESISTANCE MEASUREMENTS OF METAL INDUCED LATERAL CRYSTALLIZATION OF AMORPHOUS SILICON
A.M. Mysyrowicz, Inst of Semiconductors Physics, Novosibirsk, RUSSIA; M.C. Pessa, P.C. Chan, W.Y. Chan, Hong Kong Univ of Science and Technology, Dept of Elec, HONG KONG

The process of TFT fabrication, in which amorphous silicon (a-Si) layers over metal induced lateral crystallization (MILC) are used, generates a need for rapid and accurate methods of quality control. Optical measurements of MILC regions has potential for information about size only. A new application of spreading resistance probe (SRP) measurements for this area was proposed. A layer of 3000 Å a-Si was deposited on silicon substrate oxided up to 7000 Å. Silicon film was implanted at a dose of 10^15 cm^-2 and of energy 10 keV with B+5, B2+, P+, As+ ions. 50 Å thickness nickel seed layers were used with different patterns. Plasma H2 dilution and temperature of recrystallization was varied from 550°C to 1100°C and from 10 seconds to 240 hours. The sizes of MILC regions were in the range from some microns to 200 μm. Then MILC regions were measured by spreading resistance probe profiling with the distance between probes 100 μm. The length and the steps of SRP measurement on surface were changed in dependence on the MILC size and carried out perpendicular to the MILC region. We have found, that SRP method can use for characterization of MILC process of a-Si. It was shown that dynamic range of SRP data has about 5 orders that makes possible to measure with high accuracy the samples having MILC regions differing significantly in conductivity, crystallinity, and doping. On a basis of SRP data there is possibility to reveal the degree of recrystallization of a-Si in comparison with single crystal and polycrystalline a-Si, to find the electrical size of MILC regions for different recrystallization, doping, and impurities, to define the nickel effect and the homogeneity of continuous MILC region from different nickel seeds, to obtain the depth and surface distributions of carrier concentration and mobility.

A17.3
EFFECT OF SiO2 CAPPING LAYER ON A LASER CRYSTALLIZATION OF a-Si THIN FILM
Myung-Koo Kang, Hyeon C. Kim, Sook Young Kwak, Su Gyeong Lee, Chi Woon Kim, Kyuha Chung, Samsung Electronics Co. Ltd, Research Team, Kyungkido, KOREA

The effect of SiO2 capping layer on laser crystallization of a-Si thin film has been extensively investigated. For optimum thickness, capping layer remained on a-Si film after laser crystallization and has been examined by serially pizzicato with relatively low incident energy density and less number of shots. With this p-Si films protected by capping layer, low-cost LIPS TIFT fabrication process without HF cleaning steps was successfully developed.

A17.4
LASER INTERFERENCE STRUCTURING OF a-Ge for THE PRODUCTION OF OPTICAL DIFFUSION GATING
G. M. Malake, Departamento de Electricidad y Magnetismo, Facultad de Fisica Fisica and Letras de Ribeirao Preto, Universidade de Sao Paulo, Ribeirao Preto, SP, BRAZIL; A.R. Nazanin, Instituto de Fisica de Sao Carlos, Universidade de Sao Carlos, Sao Carlos, SP, BRAZIL; D. Toet FlexiOs Inc., Milpitas, CA, LE, Chambouleyon, Instituto de Fisica Gleb Wataghin, Universidade Estadual de Campinas - Unicamp, Campinas, SP, BRAZIL.

Laser processing is a technology of growing interest in the semiconductor industry. Short pulse laser crystallization of amorphous semiconductors, in particular, has attracted a lot of attention since it enables the fabrication of high performance polycrystalline devices on low temperature substrates, e.g. for flat panel display applications. Bringing two laser beams to interference on the surface of an amorphous film results in an anisotothermal modulation of the light intensity and leads to a pattern consisting of alternating amorphous and polycrystalline lines. In this work, we study the pulsed laser crystallization of hydrogen-free amorphous germanium-nitrogen alloys (a-Ge:N). We discuss the role of nitrogen during phase transitions and the possible application of the light interference diffusion grating. The samples of the present work were produced by the rf sputtering technique, using a germanium target in an Ar+N2 atmosphere. Confining 7050-gaas and a-Ge films were used, and were implanted at 230°C during depositing. Typical samples are 0.5 μm thick. The nitrogen concentration in the alloy is about 30%. The samples were treated by a single shot of either one or two simultaneous 18ns laser pulses (150mJ/cm²) from the third harmonic (555nm) of a Nd:YAG laser. The crystallized region is double pass through a microcrystalline germanium (μc-Ge). An indication of Ge-N bonds have broken and nitrogen outdiffusion of the film is obtained from infrared spectroscopy and confirmed by Raman spectra. A pattern of alternating a-Ge:N and μc-Ge lines with a period of about 4 μm acts as an optical diffraction grating due to the difference in optical properties between the two materials, and the three dimensional surface profile, caused by N2 effusion, that is formed on the sample.

A17.5
EXCITON LASER CRYSTALLIZED PHOSPHORUS DOPED AMORPHOUS SILICON
Ramani Sahu, and Surajit Pakhi, Fukui University of MIPA, Universitas Indonesia, Depok, INDONESIA; Norbert H. Nickel, Hahn-Meitner-Institut Berlin, Berlin, GERMANY.

P-doped amorphous silicon thin films were grown on a quartz substrate by rf-sputtering discharge method using a mixture of hydrogen diluted silane and phosphine. The substrate temperature was fixed at 280°C while phosphine was varied from 1 to 1000 ppm. The films were crystallized in a step by step process in which the laser was fired at room temperature starting at a laser fluence of 100 mJ/cm² and ending at 400 mJ/cm² using steps of 40 mJ/cm². After each crystallization step the films were characterized by Raman spectroscopy and hydrogen diffusion measurements. Results of Raman measurements showed that a structural transformation takes place during the initial sequence of crystallization process. The films exhibit a two-layer system with polycrystal on the top of amorphous silicon. From spectral analysis the crystalline volume fraction was 45% and nearly independent of phosphine concentrations. Raman spectra of as-deposited films also show the Si-H stretching band that can be deconvoluted into two peaks at 2000 and 2100 cm⁻¹. The intensity of the lower frequency peak decreases faster than the other one at higher frequency. Hydrogen concentrations CH were obtained from hydrogen diffusion measurements. In the as-deposited samples CH amounts to approximately 17 at. %. The hydrogen diffusion spectrum show two peaks at low (450°C) and high (800°C) temperature. These two peaks positions are very weakly influenced by phosphine concentrations. During laser crystallization the two hydrogen diffusion peaks are no longer pronounced and hydrogen concentrations decreased and reached the value of 6 at. % for completely crystallized sample. The results of Raman spectroscopy and hydrogen diffusion will be correlated and discussed.

A17.6
INFLUENCE OF LOW TEMPERATURE CRYSTALLIZATION OF SiH ON TANDEM SOLAR CELL STRUCTURE EFFICIENCY.
The large improvements obtained in performance and stability of hydrogenated amorphous silicon (a-Si:H) has been due to the protocrystalline nature of these Si:H materials. From the other side, an alternative way to achieve considerable progress both in terms of cell efficiency and understanding of the material properties will illustrate the relation of microstructure and the properties of microcrystalline silicon and efficiency of tandem solar cells. We will present recent results on field enhanced crystallization. We will present also decrease of temperature necessary for crystallization of a-Si:H and possibility of deposition of silicon at low temperatures (250-1000°C) on flexible substrates. Deposition was performed at high pressure and high plasma power resulting in high (up to 0.5A) deposition rates on ZnO covered glass substrates. The structure of polycrystalline Si has been studied by Cross Sectional Transmission Electron Microscopy and Grazing Incidence X-Ray Analysis. It was carried out analysis of FF, Vmp, and Jsc of the structures with respect to the low temperature crystallization.

A15.7 APPLICATION OF ALTERNATING MAGNETIC FIELD TO LOW TEMPERATURE CRYSTALLIZATION OF AMORPHOUS Si THIN FILMS. Kyo-Ryun Kang, Jin-Ha Hwang, Seung-Eui Nam, and Hyung-June Kim, Hongik Univ., Dept. of Mat. Sci. and Eng., Seoul, KOREA.

Polycrystalline Si (poly-Si) TFTs have opened a way for the next generation of displays, due to higher mobility of charge carriers, relative to amorphous silicon (a-Si) TFTs. Polycrystalline Si TFTs extend from the current liquid crystal displays (LCD) to the next-generation organic light-emitting diode (OLED) displays. In particular, the OLED devices require a strict control of properties of poly-Si thin films, such as thickness and composition. The poly-Si layer is generally obtained by annealing thin film a-Si layer using solid phase crystallization, metal-induced lateral crystallization, excimer laser annealing, etc. A new approach has been developed using polycrystalline crystallization using alternating magnetic field, in combination with the conventional metal induced lateral crystallization (MILC), the alternating magnetic field enhanced the Si crystallization kinetics in terms of growth rate, operating temperature, and the effect of alternating magnetic field was investigated systematically according to processing conditions. Comparative approach has been made on i) solid phase crystallization using diffusion furnace, ii) metal-induced lateral crystallization, iii) alternating magnetic field crystallization, and iv) crystallization through excimer laser annealing. The microstructural features were investigated from microscope to nanoscale range using a variety of microscopy techniques (optical, SEM, PESEM) along with the surface characteristics using AFM. The crystallinity was evaluated using Raman spectroscopy which incorporates both amorphous and polycrystalline portions. The influence of undesired impurities on the electrical properties in polycrystalline Si was investigated using the electronic properties of poly-Si as a function of poly-Si films will be discussed in conjunction with active-matrix TFT for OLED.

A17.8 OBSERVATION AND annealing of INCOMPLETE RECRYSTALLIZED JUNCTION DEFECTS DUE TO THE EXCIMER LASER BEAM DIFFRACTION AT THE GATE EDGE IN POLY-Si TFTs. Bong-Jin Nam, Keon-Chun Park, Sung-Hoon Jung, Seo-Jeong Park and Min-Koo Han, Seoul National University, School of Electrical Engineering, Seoul, KOREA.

Polycrystalline silicon thin film transistors (Poly-Si TFTs) recrystallized by excimer laser have attracted considerable attention for various device application. Recently crystalline defects in the poly-Si channel layer at source/drain junction have been reported to degrade the device characteristics such as FF and FF-field on-current. It is well known that the source/drain region of TFT is amorphized during the ion implantation for source/drain doping and then recrystallized by excimer laser annealing. We have observed that considerable lattice disorder of amorphized silicon film at the gate edge, which results in junction defects, still exist even after laser beam annealing. It is noted that the junction defects maybe originated from residual amorphized silicon generated due to insufficient laser activation energy at the source/drain junctions of the poly-Si film. The purpose of our work is to observe the junction defects near the source/drain junctions are resulted from insufficient activation energy due to the laser beam diffraction at the gate edge. We also propose a new method of eliminating the applied defects by simple excimer laser beam annealing. Thickness of Al gate has been varied from 1.000 Å to 10,000 Å in order to evaluate laser beam diffraction effect on the junction defects. The laser beam is rather diffracted when the gate thickness is higher, which improves the fabrication of high quality TFTs. In this study, we investigated the possibility of using a range of the intensity distribution of the excimer laser beam.
Nanocrystalline silicon (nc-Si) films were formed by using a metal induced growth (MIG) method, in which Si is sputtered onto a substrate partially covered with metal clusters. The nc-Si grows via the formation of metal silicide due to an extremely small lattice mismatch between the Si and silicide. In order to apply the MIG no-Si for polycrystalline or flat panel displays, the nc-Si need to have good electrical properties. Low temperature deposition (as low as 475°C for Ni induced growth) and crystallinity control using different metal precursors (Ni and Co) has been reported. Recent studies reveal that controlling the doping level of the films and annealing in forming gas (15% H2:85% N2) can improve the performance of the films. From SIMS analysis on the nc-Si film deposited from a highly doped target, the nc-Si can duplicate the doping level of the sputtering target. Study of polytype films, tunneling causes Ohmic contact instead of rectifying contact. For the nc-Si films deposited from a highly doped polytype target, the film shows conversion to n-type characteristics when measured by a hot probe. This might be due to defects or oxygen in the film. N-type films at the middle doping level (>10^17 cm^-3) show good Schottky diodes after annealing the film in forming gas at 700°C. The Schottky diodes fabricated by high work-function metal (Au and Pt) show the rectifying ratio of ~10^3. Current-voltage-temperature [IVT] measurement, used to understand the conduction mechanism, show the combined effects of thermionic emission and field emission. As a preliminary study, an n-type Schottky photodiode (0.36 cm^2) was fabricated. Under 100 mW/cm^2 illumination the open-circuit voltage (VOC) and short-circuit current (ISC) were 0.1 V and 0.3 mA/cm^2, respectively, for a n-Si film thickness of 0.5 μm.

**A17.13** A SIMPLE LATERAL GRAIN GROWTH OF POLY-SI BY SINGLE EXCIMER LASER CRYSTALLIZATION OF AMORPHOUS SILICON FILM DEPOSITED ON POLYCRYSTALINE TRENCH.

Sang-Hoon Jung, Se-Hyung Kang and M-Joo Houk, School of Electrical Engineering, Seoul National University, Seoul, KOREA.

Poly-Si crystalline thin films ([poly-Si TFTs] employing excimer laser annealing (ELA) of amorphous silicon [a-Si]) are promising devices for various applications. The characteristics of polycrystalline poly-Si TFT are dependent on the size of poly-Si grain and the grain boundaries in the channel. Various effects, such as lateral solidification (LSI) or μ-crystallites (μ-grain) or process, have been reported to increase the grain size and to control the location of grain boundaries. However, LSI requires a rather sophisticated beam scan process and grain-filter process requires extremely narrow hole (about a diameter of around 100 nm) with rather deep trench (about 1 μm).

The purpose of our work is to report a simple lateral grain growth method employing single excimer laser irradiation. Rather shallow about 300 nm oxide trench, of which the size is a polygon with an acute angle, was patterned by widely used RIE. a-Si film was deposited by LPCVD. The crystallization was carried out near the angular point by single excimer laser irradiation. In the angular point of the polygon trench, the circular grains having a diameter of 3 μm are observed while about 1.5 μm grains is observed near the side of the polygon trench. The thickness difference of RIE and the Via hole is found to be different in full melting condition of the a-Si film, which induces lateral growth of poly-Si grain. The location of large grain is easily controlled by the angular point of the polygon because the seed for crystallization is present in the non-Poly-Si area near the angular point. We will also report the detail mechanism of the lateral grain growth and the characterization of the TFT fabricated by the proposed method.

**A17.14** FABRICATION OF NANOCRYSTALLINE SILICON DOTS BY THE THERMAL ANNEALING OF AMORPHOUS SILICON FILMS.

Saki Hura, University of Delaware, Dept of Material Science and Engineering, Newark, DE; Issa Sakuta, Misuyuki Yamanaka, Eiichi Sumiki, National Institute of Advanced Industrial Science and Technology, Tsukuba, JAPAN.

We have fabricated nanocrystalline silicon dots by thermal annealing (TA) of thermal chemical vapor-deposited (CVD) amorphous silicon (a-Si:H) films with thickness in the range of 4 to 247 nm. In ref. 1, we established that the ultrathin amorphous films with thickness (less than 10 nm) are stressed by the presence of paracrystallites, and paracrystallites are deformed crystalline nuclei that can form at temperatures lower than the crystallization temperature by thermal treatment. In this work, we used a simple method to form nanocrystalline dots by the time-dependent process, and we see smooth snail-like to dotted-like stress wave pattern when we anneal the amorphous silicon films by TA. [1] S. Hura, I. Sakuta, M. Yamanaka, and E. Suzuki, Appl. Phys. Lett. 80, 1159 (2002).

**A17.15** LIFETIME MEASUREMENTS OF POROUS SILICON STAIN ETCHED AND HYDROGEN PASSIVATED.

Ricardo Guerrero-Lemus and Cecilio Hernandez-Rodriguez, Dept. Física Básica, Universidad de La Laguna, SPAIN; Pablo Bes-Hurder, José Martinez-Durán, Dept. Física Aplicada C-XII, Universidad Autónoma de Madrid, SPAIN; Christoffer Balif, Dietmar Borchert, Laboratory and Service Centre, Institut fuer Solare Energieysteme, Fraunhofer Institut, Gilching, GERMANY.

Porous silicon layers etched in low nitric acid concentrations, and formed in some tens of seconds, exhibit surprisingly low recombination rates (~4%) in the whole 300-1100 nm spectral range. This property can be used to apply this kind of layers on top of silicon-based photodetectors and solar cells. Consequently, the quantum efficiencies of these devices can be increased with respect to conventional antireflection layers on top of silicon. However, the surface states induced by this porous layer on the silicon wafer acts as high velocity recombination centres. Then, it is necessary to efficiently passivate the porous layers to reduce this detrimental effect. In this work we present the first results of photo-conductance measurements for porous silicon etched and hydrogen-passivated. These technique measures the lifetime of the charge carriers photogenerated, and it is extremely useful to characterise the surface recombination properties of silicon wafers. We also study the time evolution of the carriers lifetime for simple and ambient conditions. We observe a decrease of the carrier lifetime for porous silicon with respect to the silicon substrate before stain etching. However, when the samples are hydrogen-passivated, the lifetime for porous silicon increases to larger values than the silicon substrate before stain etching.

**A17.16** ANOMALOUS BEHAVIOUR OF STAIN ETCHED POROUS SILICON PHOTOLUMINESCENCE.

Ricardo Guerrero-Lemus and Cecilio Hernandez-Rodriguez, Dept. Física Básica, Universidad de La Laguna, SPAIN; Pablo Bes-Hurder, José Martinez-Durán, Dept. Física Aplicada C-XII, Universidad Autónoma de Madrid, SPAIN.
The photoluminescent properties of porous silicon electrochemically etched are commonly related to excitation by transitions of carriers in silicon nanostructures embedded in the porous matrix. The evolution of these properties are mainly influenced by quantum confinement effects, but also depends on the surface composition of the radiation centres [M. V. Volkin, J. Urma, P. M. Fauchet, G. Aliu and C. Delerue, Phys. Rev. Lett. 82, 197 (1999)]. This model explains the experimental observation of a low increase of the emission energy of the porous silicon photoluminescence when the excitation energy is increased at higher rates. On the contrary, for porous silicon strain etched in low nitric acid concentrations, the increase of the excitation energy implies a low decrease of the emission energy. This anomalous evolution of the output can be explained in terms of the oxidation degree of this kind of porous structure and its particular hydrophobic characteristics.

A17.17
SCATTERING RINGS IN OPTICALLY ANISOTROPIC POROUS SILICON. Claudio J. Oton, Zeno Gábor, Mérő Gábor, Nicola Dainese, Lucio Pancheri, Paolo Bettotti, Luca Dal Negro and Lorenzo Fornei. NFM and Department of Physics, University of Trento, ITALY.

We report the observation of strongly anisotropic scattering of visible light at oblique incidence on a {100} oriented porous silicon layer. Pores in hemispherically 5th-order porous silicon have columnar shape with vertical walls. The verticality of the pores produces anisotropic cone-shaped scattering of light, which is observed as a bright ring on a screen situated in front of the sample. We report the observation of this phenomenon for the first time. The same ring pattern is observed in transmission through free-standing samples. Two additional bright rings concentric to the main one (one internal and one external), are also observed. We propose a model which explains this phenomenon as a consequence of the optical anisotropy of the porous silicon layer. After the scattering event, polarization of light can change. This leads to a change in the refractive index, because the medium is optically anisotropic. Therefore, a refraction event deviates the light, leading to an internal ring for one input polarization and an external ring for the opposite polarization. Measurements of the radii of the scattered rings directly give a quantitative value of optical anisotropy. We have characterized anisotropy of different types of porous silicon samples. We also report changes in the scattered pattern when pores are filled with liquids and when the sample is in presence of different humidity conditions. Possible applications of the phenomenon are finally discussed.

A17.18
LIGHT-AND THERMALLY INDUCED METAStABILITIES IN NANOCRYSTALLINE SILICON. N.P. Mandal and S.C. Agarwal

Porous silicon (PS) in the form of nanocrystalline silicon made by the electrochemical oxidation of boron doped Si wafers shows photocurrents (PL) in PS > 7.2μA/cm² when excited by a HeNe Laser (632 μm). PS shows an asymmetric ESR signal which can be resolved into three signals having g fields 2.0081 ± 0.0006 (width at 1/2 height ≈ 1.5 μT), g = 2.0029 ± 0.0006 (width at 1/2 height ≈ 1.8 μT) and g = 2.0016 ± 0.0006 (width at 1/2 height ≈ 0.9 μT). These three signals have been observed in PL, DC current (DC), photocurrent (PC) and ESR upon light soaking (LS) and thermal quenching (FQ). PL intensity increases by more than a factor of two, after a brief exposure (t = 0.001 s) to white light. This is accompanied by a decrease in ESR signal by about 70%. Further, the DC and PC increase with increasing t (t ≤ 2700 s) and remain high for several hours even at 300 K. This is similar to the persistent photocconductivity observed in doping modulated and compensated n-Si. For t > 3000 s, the changes in PL, DC, PC and ESR are in opposite direction. Fast cooling (≈400 K/μm) from about 150 °C to room temperature brings PS to a metastable state (FQ) which is similar to that produced by short exposure of laser and thermal etching by annealing at high temperatures (150 °C, 1 h) in the absence of exposure to IR light. A new transient state is observed at low temperatures. The presence of n-Si phasen (peak at 840 cm⁻¹) along with the nanocrystalline silicon (peak at 520 cm⁻¹) in our PS. In LS as well as FQ state the increase (decrease) in PL, DC and PC is accompanied by a decrease (increase) in the number of dangling bonds (ESR). This explains the results in terms of structural change.


A17.19
PHYSICOCHEMICAL CHARACTERIZATION OF POROUS SILICON SURFACES ETCHED IN SALT SOLUTIONS OF VARIOUS CONCENTRATIONS AND THEIR APPLICATIONS. Anna R. Guadalupe, Univ of Puerto Rico, Rio Piedras Campus, Dept of Chemistry, San Juan, PR; Luis F. Fortesca, Oscar Resto, Univ of Puerto Rico, Rio Piedras Campus, Dept of Physics, San Juan, PR.

In this research we are interested in seeking alternatives to hydrofluoric acid and other highly acidic or basic etchants to grow porous silicon (PS). We prepared PS structures by standard electrochemical etching solutions under optimized conditions. The samples grown by this approach showed high porous densities, structural uniformity and can be kept in aqueous environments for extended periods of time without any mechanical damage. In addition, they do not need to be submitted to any special drying procedure to preserve the porous integrity. All the above conditions are needed when intermediate use in biological applications is desired as our objective. Crystalline silicon wafers used in this study were Si wafers, boron doped and having the <100> orientation with an Al contact on the back side. The wafers had the following range of resistivities: 1 to 10 MΩ·cm. We report the dependence of the porous structure on the variation of the pH values and salt concentration as well as current density of the electrochemical etching process. Characterization has been done by Scanning Electron Microscopy (SEM) and X-Ray Photoelectron Spectroscopy (XPS) to study pore size and distribution and surface chemical composition respectively. Results show that the PS grown under different conditions affects the applied current density. Low current densities produce a uniform, high-density arrangement of pores while high current densities yield a porous structure resembling an arranged wafer with an average pore size of one micron in both cases. XPS revealed that the porous framework appears to be covered with a silicon dioxide layer that allows the direct immobilization of biological material without the need for any further treatment.

A17.20
INSITU TEM STUDIES OF Ni-MEDIZED SILICON CRYSTALLIZATION. M.A. Verheijen, Philips CSA and Densitech, THE NETHERLANDS; P.J. Van der Zwaag, S.Y. Yoon and N.D. Young, Philips Research Redhill, Surrey, UNITED KINGDOM.

Poly-Si is a promising material for thin film transistors (TFTs) used in active matrix displays because it enables the integration of functionality on glass. One way of obtaining poly-Si on glass is by means of Ni-based metal induced crystallisation (MIC) of amorphous Si. In this process NiSi₂ precipitates are formed that subsequently migrate through the amorphous Si thin film, thereby crystallising the Si. So far, however, the leakage current of MIC-based poly-Si TFTs was found to be too high for display applications. The high leakage current was thought to be caused by the Ni present in the channel region. In this work the Ni-mediated Si crystallisation process was studied insitu in the Transmission Electron Microscope (TEM) at 550°C and recorded on digital videotape. These in-situ TEM movies show how the crystallisation process is a two-step process: a relatively fast M0 step, followed by a very slow (10-60 hours, depending on Ni-dose) solid phase crystallisation process (SPC) which does not involve NiSi₂-mediated growth. The source of the high leakage current was found to be related to incomplete crystallisation after the SPC stage. By crystallising the remaining amorphous fraction acceptably low leakage currents could be obtained (<1 pA/μm at VDS = 5V).

Additionally, it was shown that the leakage current is independent on the Ni concentration. This suggests that the crystallisation itself is not Ni dependent on the Ni-dose. At a Ni-concentration of 7.618μm⁻³ crystallisation proceeded by the well known one-dimensional growth along <111> direction of the NiSi₂ precipitates. At higher concentrations (e.g. at 0.96μm⁻³) and lower temperatures the overall crystallisation process is speeded up significantly due to repetitive splitting of the NiSi₂ precipitates, resulting in a significantly larger amount of Si grains and, as a result of this, a smaller average grain size.
action from the gap region limit the Qs. This paper reports on the resonance behavior of thin-film bridges in vacuum. So far, an increase in Q and a reduction of the resonance voltage (V) by factors of greater than 10 are observed. The resonator response is studied between atmospheric pressure and $10^{-6}$ Torr for 10 µm wide devices with lengths varying from 10 µm to 50 µm. Below the 10 - 100 mTorr range, the resonator behavior is determined by the semiconductor material and the intrinsic dissipative behavior of the structures can be observed.

A detailed study of the resonance frequency and the dependence of Q on the dimensions of the bridge, on the structure of the bridge (billet or a single thin-silicon layer) and on the material used as structural layer (n-Si or p-Si; intrinsic or doped) is presented. These results are analyzed with an electro-mechanical model. The possibility of obtaining thin-film Si-based high-frequency, low-V, high Q resonators allows the application of thin-film Si MEMS to sensor arrays and RF filters, as well providing a means to study elementary energy dissipation processes in thin-Si.

**18.2 CHARACTERIZATION OF AMORPHOUS SILICON THIN FILMS FABRICATED BY RF MAGNETRON SPATTERING FOR MICROBATTERY.** Ki Lyang Lee, Hee-Soo Moon, Seung Won Lee, Jong-Won Park, Division of Materials Science and Engineering, Hanyang University, Seoul, KOREA.

Numerous studies currently aim at the improvement of the specific capacity of the anode material in Li-ion cells. Despite interesting performances of Si based oxides, the irreversible capacity loss systematically observed on the first cycle for these compounds is a main drawback to their use as anode materials in lithium-ion cells. Not only in a single lithiation process at high temperature, but also in the range of lithium formation at room temperature by deposition processing. To determine the active role of amorphous silicon in thin films, these films have been prepared on Pt-supported p-type Si wafer by means of sputtering and their electrochemical performance has been characterized. The deposited films are characterized by X-ray diffraction (XRD), field-effect scanning electron microscopy (FESEM), atomic force microscopy (AFM). X-ray Photoelectron Spectroscopy (XPS), ellipsometry. Constant-current galvanostatic charge-discharge tests of half cells are performed. In order to avoid self-discharge of the silicon based electrodes, also the silicon material was deposited on porous copper substrates. A better contact between the substrate and the silicon layer during the electrochemical tests. It showed the good retention of discharge capacity.

**18.3 AREA DEPENDENT SWITCHING IN THIN FILM SILICON DEVICES.** Jin He, Warren Jackson, Scott Ward, Paul Stradins, Howard Branz, and Qi Wang, National Renewable Energy Laboratory, Golden, CO; Hewlett-Packard Laboratories, Palo Alto, CA.

We report the area dependence of switching in both Cr-p+-p-Si-H/Ag and Cr-p+-p-Si-OH/Ag contact free-standing microstructures. The doped region of the Cr/p+-p-Si-H/microcrystalline (µc-Si):H thin Si layers are made by hot-wire chemical vapor deposition. We vary device active area (A) over 4 orders of magnitude, from 10 µm 2 to 0.01 cm 2 using photo lithographically-defined Ag and Au top contacts. Switching is stimulated with either a slow-current range from 0 to 50 mA (∼20 sec), or a short current pulse lasting 500 sec. Before switching the resistance of 1000 µm 2 devices is normally about 100 kΩ for µc-Si and 100 GΩ for p-Si. During switching, the resistance decreases to a few hundreds ohms in all devices. Optical microscopy reveals morphology changes at the device surface that are a result of raising temperature before switching. We observe that, in µc-Si devices, the switching voltage (Vsw) decreases with increasing device area according to $V_{sw} \propto \alpha \log \sqrt{A}$ where $A$ is the active area in µm 2, $\alpha \approx 3.7$, and $\beta \approx 0.67$, with $V_{sw}$ being voltage at which $\alpha$ is reduced by 10% and $\beta$ is given for the active area range of 100 µm 2 - 100 cm 2. In contrast, in p-Si devices, the switching voltage decreases significantly with device area, following $V_{sw} \propto 1/A$ with $\alpha \approx 1$, and switching voltage is roughly independent of area with $V_{sw} \approx 14$ V, $\alpha \approx 2.7$, and $A \approx 10^5 cm^2$, while the switching current density obeys the power law $J_{sw} \propto A^{-\beta}$ with $\beta \approx 1$ in the p-Si devices. In contrast, in p-Si devices, the switching current density varies significantly with device area, following $J_{sw} \propto A^{-\gamma}$ with $\gamma \approx 1.2$, while switching voltage is roughly independent of area with $V_{sw} \approx 2.5$ V.

**18.4 RIGID WIRE CHEMICAL DEPOSITION OF HIGH HYDROGEN CONTENT SILICON NITRIDED FOR HIGH CELL PASSIVATION AND ANTI-REFLECTION COATING APPLICATIONS.** J.K. Hal, D.G. Goodwin, Harry A. Auenzer, California Institute of Technology, Pasadena, CA; A.M. Gabor, Evergreen Solar, Inc., Marlboro, MA; F. Jiang and M. Strohm, Lehigh University, Bethlehem, PA.

Silicon nitride films have been grown by hot-wire chemical vapor deposition and film properties have been characterized as a function of silicon to ammonia flow ratio. Quadrupole mass spectrometry measurements revealed that the flow rate of silane should be small relative to ammonia (< 0.1), due to the lower decomposition probability of silicon on the wire. Silicon nitride films were produced with refractive indices ranging from 1.8-2.5 and H-content from 14-20 atomic % as the flow rate increased from 0.31 to 0.68. Forward Transfer Induced Spectroscopic Ellipsometry measured a change from predominantly NH to Si-H bonding as the flow rate increased beyond 0.68. Subsequent annealing studies showed different kinetics for H release from Si-H versus N. Films grown with a low silicon to ammonia ratio were found to oxidize readily (23 atomic %) after exposure to air, while larger ratios yielded no oxygen incorporation. Defect hydrogenation was studied using FTIR spectroscopy on platinum-diffused silicon substrates, with a measured H-2 concentration of up to 10 17 cm -3. Hot-wire nitride layers were deposited onto diffuse-emitter String Ribbon silicon substrates, producing solar cells with comparable electrical properties to those fabricated using plasma CVD nitride layers.

**18.5 PROPERTIES OF SILICON NITRIDE FILMS PREPARED BY COMBINATION OF CATALYTIC-NITRIDATION AND CATALYTIC-CVD.** A. Iinami, A. Kikukawa, K. Higashimine and H. Minamura, JAIST, Iwatsukashi, JAPAN.

Silicon nitride (SiN x ) films prepared at low temperatures are widely applicable such as gate dielectric films of thin film transistors (TFT) of liquid crystal displays (LCD). In this work, SiN x films are formed by combination of direct nitridation (catalytic-nitridation) and catalytic-CVD at low temperature around 200°C. In this method, catalytic-nitridation is performed by irradiation to the Si substrate of activated nitrogen-related species, which are generated by NH3 catalytic cracking reactions with a heated tungsten catalyst placed near substrates, and so that ultra-thin SiN x films below 2 nm are formed. Thicker SiN x films are deposited on them by catalytic-CVD succeeded.

**18.6 HIGH-RATE (>1 mm/s) AND LOW-TEMPERATURE (<400°C) DEPOSITION OF SILICON NITRIDE USING AN N2/SiH4 AND NH3/SiH4 EXPANDING THERMAL PLASMA.** J. Heang, W.M. Keim, M.C.M. van de Sanden, Dept. of Vacuum and Plasma Physics and Radiation Technology, Eindhoven University of Technology, THE NETHERLANDS.

For decades, PECVD of silicon nitride (n-Si3N4/H) films has been crucial technology for micro-optoelectronics. More recently, the n-Si3N4/H films have been applied as functional coatings (antireflection and passivation layer) for Silicon-based photovoltaics. In our previous studies, n-Si3N4/H films using an expanding thermal plasma (ETP) technique showed a bulk defect passivation effect for multicrystalline Si solar cells, which demonstrated that these materials are very promising for high throughput production of solar cells because the deposition rates can be attained higher than 1 mm/s. This paper deals with the influence of the substrate temperature on the growth of the ETP deposited n-Si3N4/H films from a N2/SiH4 and NH3/SiH4 gas mixture in the low-temperature range 150°C. Structural and optical properties of the films have been investigated by elastic recoil detection, spectroscopic ellipsometry, and infrared spectroscopy. Several observations have been found: i) Deposition rate decreases and film mass density increases with the temperature increases in this range. ii) The n-Si3N4/H films deposited from N2/SiH4 are more vulnerable to post-deposition oxidation than the films deposited from NH3/SiH4. iii) Porous and fractal-like columnar structure at as-sets to develop at the temperature below 200°C for the films deposited from NH3/SiH4. Application of an extended valence model for hydrogenated silicon oxynitride showed a good prediction for the composition of the films. Furthermore, the silicon mechanical properties that the mechanical properties that are extensively discussed in terms of evolution of deposition rate, composition, optical band gap, and microstructure of the films. Especially, combined study of in situ real-time spectroscopic ellipsometry and ex situ atomic force microscopy gave an insight on the surface roughness evolution of the films during growth.
Polymorphous Silicon (PmSi) being an admixture of amorphous and ordered phase silicon shows improved optical and electrical properties due to the presence of nanocrystals. The dynamic and steady state electrical properties in a-Si:H and Pm-Si, bottom gate Thin Film Transistors (TFTs) of these materials were fabricated with SiO2 as the insulating layer. The active materials were deposited using a high energy ion beam assisted chemical vapor deposition (PECVD) by varying pressure, temperature and hydrogen dilution. Transfer characteristics of TFTs made using Pm-Si show lower leakage current, higher on-current and sharper volt per decade change than similar TFTs made from a-Si:H. Density of states in Pm-Si as calculated from field effect conductance using incremental method is observed to be an order of magnitude lower than in a-Si:H based devices. To compare dynamic characteristics, we studied the switch-on transient characteristics of polymorphous and amorphous silicon TFTs by pulsing the gate to different voltages in the temperature range of 150-300K. We observe a richer variety of switch-on transients in Pm-Si based devices. A slow rising transient reveals two distinct regions. The initial rising part of the transient is observed to be exponential which is eventually overtaken by a second slower mechanism. This rise is shown to be activated with an activation energy of 0.2 eV. In similar devices fabricated using a-Si:H following onset of conduction we observe only declining exponential current transient with weak temperature dependence. In both cases, the switch-on transients are trap limited. However, the initial rising transient appears to originate from metastable states involved with nanocrystals on their interfaces acting as giant traps with effective energy of 0.2 eV. The origins of transients are interpreted in terms of trap limited carrier dynamics and charge redistribution within the distribution of localized states.

A18.8 DEPENDENCES OF STRUCTURAL PARAMETERS ON THE CHARACTERISTICS OF POLY-SI THIN FILM TRANSISTORS AFTER PLASMA PASSIVATION. Cheng-Ming Yu, Tiao-Yuan Hung, Tan-Fu Lei, Horng-Chih Lin, National Chiao-Tung University, Hsin-Chu, TAIWAN.

The effects of plasma treatment and device’s structural parameters on the characteristics of poly-Si thin film transistors (TFTs) with source/drain extensions induced electrically by a bottom gate were explored. The plasma treatment was performed in either hydrogen or ammonia ambient for 3 hours. It was found that the amorphous hump appears in the subthreshold region for devices with short channel length (e.g., L < 1.5 micron) and large channel width (e.g., W > 5 micron). Such phenomenon also leads to an anomalous current increase in the output characteristics of short-channel devices. Some defects near the bottom interface of the channel generated during processing are believed to be responsible for such leakage. It is supported by the observation that the hump becomes invisible as channel length shrinks below 5 micron, owing to the shorter path for the passing species to diffuse. Moreover, ammonia plasma was found to be more effective than hydrogen plasma for passivating defects.

A18.9 MICROCRYSTALLINE SILICON THIN FILM TRANSISTORS DEPOSITED BY DC REACTIVE MAGNETRON SPOTTING. Steven Ingenjum and John R. Abele, University of Illinois, Department of Materials Science and Engineering, Urbana, IL; Steven D. Thies, 3M Company, St. Paul, MN.

Microcrystalline silicon is of great commercial interest as the active layer in thin film transistors (TFTs) used as switching elements and drivers in flat panel displays. It offers advantages in terms of higher electron mobility and greater threshold voltage stability compared to amorphous silicon. We fabricate TFTs using microcrystalline silicon (μc-SiH) as the channel layer and amorphous silicon nitride (a-Si,Nₓ:H) as the gate dielectric. The microcrystalline film is deposited by DC reactive magnetron sputtering (RMS) at high hydrogen partial pressures (≥ 5 mTorr) while the nitride is deposited by pulsed DCRMS in an atmosphere of Ar, H₂, and N₂. The substrate temperature during the entire process is kept below 300°C and there is no post treatment of the films. We obtain a high degree of crystallinity as measured by x-ray diffraction spectra for deposition rates between 0.3-1.0 Å/s. The TFTs are fabricated in both bottom gate and top gate staggered configurations. Although process optimization is still in the early stages, we consistently observe lower TFT threshold voltage using microcrystalline silicon as the channel material (≤ 1.5V) compared to amorphous silicon (≤ 15V). It should be noted that the channel mobility in these early devices remains similar for both the amorphous and microcrystalline TFTs (~0.5 cm²/Vs). We anticipate that this work will result in enhanced mobility for the microcrystalline devices. Based on our previous work using RMS deposition, we also expect to essentially eliminate any incubaion layer, reduce the growth temperature, and optimize the device performance. A goal is to develop a growth process suitable for flexible plastic substrates and a roll-to-roll industrial coating technology.

A18.10 ABOVE-THRESHOLD PARAMETER EXTRACTION INCLUDING CONTACT RESISTANCE EFFECTS FOR a-Si:H TFTS ON GLASS AT 300°C.

Jorge A. Perez, Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

This paper presents a fast and accurate method for extraction of the above-threshold physical parameters (such as threshold voltage, mobility, conduction band tail slope, and contact resistance) from measurement data in the linear and saturation regions for a-Si:H TFTs fabricated on glass and plastic substrates. Although the principles of parameter extraction for a-Si:H TFTs are similar to those of MOSFETs, the method of extraction is different by virtue of the departure from the square law dependence of the current-voltage characteristics, with a power parameter (α) greater than 2. In addition, there is a broader range of process-induced variation in material properties. The method presented here takes into account the non-ideal parameters such as contact resistance, which may vary by orders of magnitude due to process variations, thus strongly influencing the extracted TFT parameters. In fact, the presence of a high contact resistance (> 1Ω cm²) stemming from the n-type-Si:H contact layers can be detrimental to the accuracy of extracted threshold voltage, mobility, and the power parameter. In this paper, the effect of contact resistance on the extracted values is systematically investigated and identified using TFTs with different channel lengths. The extracted values for TFTs on glass and plastic substrates highlights very clearly the differences in material and interface properties stemming from the different process conditions, and provide insight that is invaluable for subsequent device/process optimization.

A18.11 THIN FILMS TRANSISTORS BASED ON STOICHIOMETRIC a-Si:H OBTAINED BY PECVD. Alessandro Ricardo de Oliveira, Marcelo Nelson Poes Carreiro, Department of Engineering of Electronic Systems, Polytecnico School, Universidade de Sao Paulo, Sao Paulo, SP, BRAZIL.

In the last years there has been a growing interest in hydrogenated amorphous silicon carbide thin films (a-SiC: H) for device applications as light emitting diodes, photodiodes, and sensors. The investigations have generally explored the possibility of controlling, through carbon and nitrogen incorporation, the electronic band structure of the films. Therefore, in order to obtain a material that is a real amorphous counterpart of the crystalline SiC and that preserves at least part of its properties, we have studied the deposition conditions to obtain Plasma Enhanced CVD (PECVD) a-Si:H - C:H close to stoichiometry (≤ 0.03) with a chemical and structural order similar to α-SiC. We have also studied the α-type and β-type electrical doping of these a-SiC films through the ion implantation of impurities and have obtained promising doping levels. In conclusion, we describe a thin film transistor completely based on stoichiometric a-Si:H obtained by PECVD. The a-SiC films are grown by PECVD at 300°C from appropriate gas mixtures of methane and silane diluted in H₂. The substrates are of glass plates (Corning 7059) and silicon wafers previously oxidized (3000 Åmangers). The doping of the source and drain areas was accomplished through ion implantation of phosphorus with concentration of 1×10¹⁴ cm⁻² and thermal annealing for the electrical activation of the impurities and restructuring of the material was done in the 550-1000°C temperature range. As gate insulator we utilized high quality SiO₂ also obtained by the PECVD technique at low temperature (300°C). The devices operate in amorphous regime and preliminary results show a clear transistor effect and the possibility of operation at temperatures higher than 200°C. We also compare the performance of devices fabricated with as deposited a-SiC and thermally induced polycrystalline PECVD SiC.

A18.12 MECHANICAL STRESS AND PROCESS INTEGRATION FOR DIRECT X-RAY DETECTOR AND TFF IN a-Si:H TECHNOLOGY.

Chun-Ho Lee, Isaac Chan, and Aronik Nathan, Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, CANADA.

We recently reported a direct X-ray detection scheme based on
Mo/Si/Si:H Schottky diode structure for imaging low-energy X-rays. Here, a 500 nm thick Mo layer acts not only as a Schottky barrier but also as a direct converter, which transforms X-rays into electrons. One critical issue with the Mo/Si/Si:H Schottky diode is the mechanical stress, both intrinsic and extrinsic, which constrains the process integration of the detector and TTF for an active matrix array. Determination of the stress and stress-related multi-layer structures has been reported, in an attempt to reduce the stress through appropriate process conditions. However, it is achievable only over very narrow process latitude, which limits the process flexibility for improving electron performance. Therefore, an alternate process integration strategy is considered to avoid the stress issues. In the conventional Schottky diode process, the bottom (Cr) electrode is used for electrical connection and the top Mo-Schottky layer is patterned in a bottom-up sequence. The change of the patterned layer from the prior process step exerts an extrinsic stress on the subsequently deposited films. This issue is observed in the deposited Mo film, which shows cracks or even peels off from the corners of the cavity. Reversing the pattern sequence into a top-down manner can reduce this extrinsic stress effectively. In this case, the Mo film does not encounter the high extrinsic stress due to the sharp corners of the bottom photodiode patterns, as in the original process; thus, we do not observe any damage on the Mo film. This improves the structural integrity of the photodiode without altering any process conditions. Further details on the mechanical stress issues pertinent to the Mo/Si/Si:H Schottky diode process, along with the leakage current and X-ray sensitivity characterization will be discussed in the paper.


A new design based on a stacked pin pin structure is proposed for the Colnr-Inger Scanned Photodioide sensor, CLSP. The CLSP is a two terminal wavelength-optimised sensor based on one single large area (4x4 cm) p-i-n sensing element and a scanning readout. In short circuit mode, it can detect a black and white image with a spatial resolution of 50 p.m. Under forward bias, its sensitivity is also possible, with a reasonable rejection ratio. No optical filters are used during the image acquisition process. To tune the spectral sensitivity of the device we propose a stacked sensing element deposited by PE-CVD on a glass substrate (ZnOAl[p(SiC)/SiC]/SiC/ZnOAl[SiC]/p(SiC)]/ZnOAl[SiC]/SiC).

A18.15 AN AMORPHOUS SILICON PHOTOCONDUCTOR FOR UV DETECTION. Matthieu Hillebrand, F. Blecher, J. Sterzel, M. Bähm, Institut für Mikrosystemtechnik (IIT), Universität-GH Siegen, SEIEN, GERMANY.

An amorphous silicon photodiode to detect wavelengths between 180nm and 380nm without scintillator is presented. The design of the new UV detector in TFA technology (Thin Film on ASC) is discussed. UV imagers are widely used in chemical industry, in medical-biological technology for fluorescence measurement, and in security technology. The photodetector is based on the configuration of the electrodes, similar to measurement structures to determine material characteristics of amorphous layers, e.g., for the constant photocurrent method (CPM). After passing through a thin transparent passivation layer, an incident radiation is absorbed in the intrinsic a-Si:H material. The carrier collecting electrical field is applied vertically to the incoming light. The contact configuration can be varied, both on top or below the photodiode layer or in a mixed arrangement, according to the requirements, e.g., for one-dimensional or two-dimensional sensor arrays. The crucial parameters for the quantum efficiency are the surface dangling bond density of the back and front side, as well as the active layer thickness. The surface defect density highly depends on the production process and the passivation material. Test structures have been fabricated with suspended chromium contacts on top of a 0.3 µm thick carbonized hydrogenated i-layer. The spacing between the Schottky contacts is varied between 3 µm and 100 µm. They are deposited on top or below the a-Si:H layer. With this simple fabrication a quantum efficiency of 10% was obtained at 210 nm wavelength. To verify the results calculations are performed to simulate the behavior of the photodetector. The influence of parameters like dangling bonds at the surface, spacing between the contacts or thickness of the i-layer is investigated. With these results an optimization of the photodiode design is possible, e.g., for femtosecond detectors with suppression of the visible light.


It is known that metal-insulator-semiconductor [MIS] photodiodes present some advantages over the p-n structures when high response speed and high breakdown voltages are required. In this work we present results of a studied performed on substrate [glass]/Cr[2000A]/a-Si:H+n+/400A/a-Si:H i/5000A)/oxide[2800A]/Au[100A] structures where the main objective was to determine the influence of the oxide layer grown by different techniques on the performance of the MIS devices. The results achieved show that the oxides grew chemically by anodic oxidation in an ethylene-glycol solution and by hydrogen peroxide present characteristics as good as the ones obtained by the evaporation of SiO2-2, using an electron gun system, or by the chemical deposition of SiO2-2 by plasma of H2+O2 [hexamethyldisiloxane]. The experimental data also show that the thickness of the oxide is easily controlled with the hydrogen peroxide oxidation technique, which is also the easiest and cheapest technique. By control of the oxide thickness it was possible to achieve photodiodes exhibiting an open circuit voltage of 0.7V and short circuit current density under 10-5 A/cm2, illuminating a photocurrent density of 10-10 A/cm2. The current density of the oxide, determined by spectroscopic ellipsometry was estimated to be on the range of 25 m2 A/cm2 and to be less than 1 mA, a diode quality factor of about 1 and a ratio of 10° between forward and reverse currents. The ideal oxide thickness, determined by spectroscopic ellipsometry was estimated to be on the range of 25 to 30 A, depending on the oxide technique used, which determines the degree of films
compaction achieved. In this work it is also presented a method for reducing the saturation current of the diodes, by burning small parallel short-circuits by applying to the device a controlled reverse voltage.

A18.17

**n-Si** PROPERTIES RELEVANT TO MICROBOLOMETER INFRARED DETECTORS. A.J. Syllaics, J.H. Tregilgas, T.R. Schimert, W.L. McCandl, Raytheon Commercial Infrared, Dallas, TX.


A18.18

**NUMERICAL SIMULATION OF THE INFLUENCE OF THE GAP STATE ON THE CHARACTERISTICS OF n-Si PIN/OLED. Chaoyun Wang, Yuxun Chen, Guangnian Yang, Juan Li, Zhenghao Zhou, Ying Zhao, Xinlian Geng and Shaozhe Xiong, Inst. of Photo-electronic Thin Film Devices and Technology, Nankai University, Tianjin, PR. CHINA; HuaLong Yang, Inst. Of Thin Film & Nano-material, Wuyi University, JiaoLiu, Fujian, CHINA; Liying Li and Zhimin Li, Tianjin Mechanical and Electric Vocational Technical School, Tianjin, P.R. CHINA.

Large area n-Si PIN/OLED image sensor devices were proposed in our previous papers. The structure of one pixel is an n-Si PIN connecting in series but in opposite polarity with OLED. The n-Si PIN photodiode is used as a light sensor and converts the input light into a photocurrent. The photocurrent will be directly coupled to OLED, which is biased in forward and used as a display device. In this paper, the influence of the gap state density and the gap band width of the intrinsic n-Si active layer on the characteristics of n-Si PIN/OLED coupling was studied. A self-consistently n-Si PIN/OLED CAD simulation model. The CAD simulation model was carried out based on a n-Si PIN-Hack & Shun model and OLED TCI transport model. At the same gap band width, for the intrinsic n-Si active layer with the larger gap state density, the reverse current of n-Si PIN tended to be saturated at the higher reverse bias. As a result, I-V curve of n-Si PIN/OLED around the turn point Vt become smoother with the increase of the gap state density. At the same gap state density, the light induced current of n-Si PIN increased with the decrease of the band gap width as shown in Fig.1, assuming the input light has the same spectrum as AM1.5 solar light. Thus the luminescence emitted from OLED increased with the decrease of the band gap width because OLED belongs to the light-emitting device controlled by current. The simulation results showed that the influence of the gap state density intensified with the increase of the gap band width of the n-Si. In the other words, the impact of the gap state density on I-V curve of n-Si PIN/OLED in the saturated region at the lower gap band width was less than that at the higher gap band width.

SESSION A19 POSTER SESSION DEFECTS AND LUMINESCENCE

A19.1

Abstract Withdrawn.

A19.2

**SILICON NANOSTRUCTURED FILMS FORMED BY PULSED-LASER DEPOSITION IN INERT GAS AND REACTIVE GAS. Xiao-Yun Chen, Yong-Ding Liu, Yihong Wu, Ying-Jin Cho, Laser Microprocessing Laboratory and Silicon Nano Device Laboratory, Department of Electrical and Computer Engineering, National University of Singapore, S G A P O R E.

We report silicon (Si) nanostructured films formed by pulsed-laser deposition (PLD) in both inert gas argon (Ar) and reactive gas oxygen (O2). The re-deposited nanostructured films with visible luminescence (PL) peaks was shown to have a lower extent of crystalline Si nanocrystal (~7 nm) in the ambient gas pressure from 1 mTorr to 1 Torr. By varying the substrate to-target distance, the transition is explained by the increased collisions between the ejected species as gas pressure increases. The oxygen composition of SiOx is found to rise with increasing O2 gas pressure by x-ray photoemission spectroscopy (XPS), while Si 2p peak of the Si nanocrystal also becomes dominate. At 1.00 mTorr O2 gas, XPS reveals almost complete SiO2 structure. Dry oxidation and annealing were applied to the re-deposited nanostructured films. Intensity changes and blue shifts of the PL spectra at 1.9 eV are observed after oxidation, while the PL intensity are increased by about two to 4.0 times of magnitude after annealing. The 1.9 eV PL is attributed to the light emission from Si core by quantum confinement. An additional peak at 2.56 eV with no peak shift appears with increased oxidation treatment, which is attributed to the light emission from SiO2. Room shifts are found for all samples before and after oxidation and annealing. The nanocrystalline size distribution in the nanostructured films is observed by transmission electron microscopy (TEM). X-ray diffraction (XRD) reveals that the re-deposited nanostructured films have a polycrystalline structure. Subsequent anneal is necessary for a more stable structure and better crystallinity.

A19.3

**ORIGIN OF LOW-ENERGY PHOTOLUMINESCENCE IN MICROCRYSTALLINE SILICON FILMS. En-Tae Kang, Kwang-Soon Jais, Dong-Hyun Park, Jong-Hwan Youm, Kangwon National University, Department of Physics, Chunchon, Kangwon-Do, KOREA.

It is well known that hydrogenated microcrystalline silicon films (μc-Si:H) reveal a photoluminescence (PL) band with a peak centered within 0.8 to 1.0 eV. It has been suggested that this low-energy PL is attributed to either to defects in an amorphous phase or in the crystalline phase or to radiative transition between band-tail states in the crystalline or grain boundaries. However, most of the low-energy PL band still remains unclear. In this work we have investigated the low-energy PL in μc-Si:H using various experiments: the effects of hydrogen and argon dilution, temperature and excitation-intensity dependences, the effects of annealing and dilution ratio, and deposition power. μc-Si:H films were grown from either hydrogen or argon diluted SiH4 gas using a conventional plasma-enhanced chemical vapor deposition (PECVD) excited at 13.56 MHz. It is shown that the PL peak energy appears at different position, 0.87 eV and 0.97 eV for hydrogen and argon diluted samples with high volume fraction of crystallites, respectively. Both samples show that the peak intensity monotonically decreases with increasing temperature, but no energy shift is observed. The excitation-intensity dependence of the PL peak shows that the increasing rate of the peak intensity for low intensity is higher than high one. It is also found that if power, annealing, and dilution ratio significantly affect the position of the PL peak energy. Annealing results in the red-shift, while the blue-shift is observed with increasing amorphous phase, which are obtained by growing μc-Si:H films using low rf power and dilution ratio. From these results, a possible origin for the low-energy PL will be presented.

A19.4

**EFFECT OF Tb, Er-DOPING ON THE STRUCTURAL AND OPTICAL CHARACTERISTICS OF NANO-CRYSTALLINE Si THIN FILMS. K-H. Han, M-B. Park, N-H. Cho, Inha Univ., Dept. of Material Sci. and Engineering, Incheon, KOREA.

The nano-structural and optical characteristics of Tb, Er-doped Si thin films, which were prepared by RF magnetron sputter techniques, were investigated as a function of Tb, Er-contents and post-deposition heat-treatment conditions. The nano-structural and chemical features are related with the photoluminescence (PL) phenomena of the films. The PL intensity increased with the increase of Tb or Er as well as Si nanocrystalline in the films. A strong PL peak was observed at about 545 nm owing to the electronic structure of Tb3+. Post-deposition heat-treatment increased the fraction of nanocrystallites of less than 10 nm in size, this resulted in enhancing the PL generated by the intra-4f Tb3+ transition.

A19.5

**EXCITATION-LASER ENHANCED FORMATION OF LUMINESCENT NANO-CRYSTAL-Si/SiO2 SUPERLATTICES. Daegi Cho, Yohan Sun and Jung H. Shin, Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, KOREA.

Great interest lies in formation of high density of small (~4 nm in diameter) nanocrystalline Si (nc-Si) for applications in photodetectors and novel electronic devices. A proven method for fabrication of such films is crystallization of amorphous Si/SiO2 superlattices with nm-thin layers. Unfortunately, such films require are highly resistant to crystallization, necessitating prolonged annealing at temperatures over the excess of 1200°C that can lead to break up and agglomeration of nc-Si, and may represent an unacceptably high thermal budget. In this paper, we report on use of excimer laser irradiation to enhance formation of luminescent nc-Si/SiO2 superlattices with nominal thickness of 3nm and 4nm, respectively.
were deposited by electron-cyclotron resonance plasma enhanced chemical vapor deposition of SiH4 and O2. 3 sets of samples, one with thermal annealing only, one with excimer laser irradiation only, and one with thermal anneal at 1100°C followed by excimer laser irradiation were prepared. We find that excimer laser irradiation alone does not lead to a significant formation of luminescent nc-Si. Thermal results in a weak n-type, however, the nc-Si photoluminescence intensity can be increased by more than 3 fold by a subsequent excimer laser irradiation. Excimer laser irradiation also results in a slight redshift of the nc-Si luminescence peak position with increasing laser power density. In addition, the excimer laser irradiation increases the true role of excimer laser irradiation is removal of defects and amorphous regions remaining after thermal anneal, and that such a combination of thermal anneal followed by excimer laser irradiation may provide a way to form a dense array of small, highly luminescent small nc-Si at a much reduced thermal budget.

A10.6 POST-TRANSIT ANALYSIS OF TRANSIENT PHOTOCURRENTS FROM HIGH-DEPOSITION-RATE n-SiH SAMPLES. Monica Brizan and Guy J. Adriaansen, Halfgeldphysics Dept., University of Leuven, BELGIUM. W.M.M. Kessels, A.H.M. Smets, M.C.M. van de Sanden, Department of Applied Physics, Eindhoven University of Technology, THE NETHERLANDS.

The analysis of transient photocurrents in the post-transit-time regime of a time-of-flight experiment allows a determination of the distribution and density of localized gap states in n-Si:H. Since electron and hole transits can be measured separately in a sandwich-cell geometry with blocking contacts, independent determination of the density as a function of the conduction and valence band sides of the gap can be obtained. In order to investigate the effect on those DOS distributions of high deposition rates, and the high temperatures they require, we have determined gap-state densities for a series of n-Si:H samples prepared by means of the expanding thermal plasma (ETP) technique, at a deposition rate of 7nm/s and with substrate temperatures varying from 250 to 500°C. Fairly featureless distributions are resolved with, for samples with room-temperature mobilities near 1 cm²/Vs, a gap state density on the order of 4x10¹⁶ cm⁻³ eV⁻¹ on the conduction band side and about 10¹⁵ cm⁻³ eV⁻¹ on the valence band side. Corresponding values for the gap-state density were obtained, using the same experimental techniques and sample geometry, for n-Si:H layers prepared by other techniques. In an earlier publication [1], and in contrast to the featureless distribution mentioned above, we reported considerable structure in the electron post-transit currents from some of the ETP samples. However, a more detailed examination of the temperature dependence of the current transients, and specifically of the position on the transient where the observed structure manifests itself, leads to the conclusion that this part of the transient is not due to electron or hole trapping into deep traps, and therefore, does not contain information on the DOS of the material. In fact, the extra feature can be understood as a photostimulated leakage current due to a modification of the sample's Crp / Si:H Schottky barrier by heating with high intensity light. Support for this interpretation, measurements have been carried out on ETP n-Si:H time-of-flight samples with different barrier structures, including the replacement of Cr by Mo and the use of an n-InP cell.


A10.7 SIZE DISTRIBUTION OF EMBEDDED NANO-CRYSTALLITES IN POLYMER-MODIFIED SILICON STUDIED BY RAMAN SPECTROSCOPY AND PHOTOLUMINESCENCE. V. Tripini, M.N. Islam, S. Gupta and Y.N. Mahapatra, Department of Physics, IIT, Kharagpur, INDIA. P. Rocca Cariocci, Laboratoire de Physique des Interfaces et des Couches Minces, Ecole Polytechnique, Palaiseau, FRANCE.

Polymerized Silicon (pm-Si:H), deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) is a recent addition to the material to amorphous silicon (a-Si:H). Deposition parameters of pm-Si are such that small crystallites get embedded in a relaxed amorphous silicon matrix, thus improving the optical and electrical properties. We study the size of crystallites and degree of order in pm-Si using Raman and photoluminescence (PL) spectra of pm-Si and n-Si:H. Raman Spectra of a variety of hydrogenated amorphous silicon (a-Si:H) and amorphous Silicon (a-Si:H) samples grown at different deposition temperatures. An analysis of the optical properties of pm-Si and pm-Si:H samples reveals asymmetry and red shift in pm-Si:H samples. In spite of many attempts to fit Raman spectra using Quantum Confinement Models, there exists a discrepancy between the experimental data and theoretical predictions. Specifically, experiments indicate comparatively smaller red shift than predicted. We show that a quantum confinement model that incorporates gaussian size distribution can accurately predict the peak position of embedded in the amorphous matrix. A comparison of T-A-T region of Raman Spectra from n-Si:H and pm-Si:H material also implies pm-Si:H as material having higher degree of order. Photoluminescence (PL) emission and excitation spectra of various polynorphous Silicon samples were recorded in the range of 200nm to 700nm. We observed strong PL in ultraviolet blue range. Deconvolution of the spectra reveals two distinct peaks at 412 and 430nm with excitation wavelength (λe=325 to 380nm) and a second broad band with maximum intensity in 500-600nm range (λe=425nm). Assuming that PL peaks between 500-600nm can be attributed to nano-crystals, deconvolution of the spectrum and fitting to gaussian size distribution shows the particle size to be in the range of 2-3.5 nm, in agreement with Transmission Electron Microscopy (TEM) and Raman results.


The highly-sensitive cavity ringdown technique has been applied to probe the density of states of hydrogenated amorphous silicon (n-Si:H) films at a range of sub gap energies (0.8 - 1.25 eV). It is shown that this straight absorption band tail of the n-Si:H glass is easily capable of detecting absorptions in thin films as small as 10⁻⁷ (single shot) without the need for calibration procedures. Results for the absorption coefficient, which is directly associated with the n-Si density of states, show very good agreement with photothermal deflection spectroscopy. The high sensitivity of the technique enables accurate measurements of the defect density for ultra-thin films. For thin n-Si:H films deposited at 250°C the existence of a defect-rich surface layer with a surface state density of 10¹⁵ cm⁻² as 0.1nm has been extracted. The density of states for both the bulk film and the surface layer will be further investigated at a broader sub gap energy range of 0.7 - 1.4 eV using an optical parametric oscillator laser system. Furthermore, the detection of defect states by an evanescent wave that probe the film from a total internal reflection element will be presented. This enables the use of the technique in situ during plasma deposition and will reveal more information about the role of defects in the growth mechanism of thin silicon films.

A10.9 HIGH-FREQUENCY ELECTRON SPIN RESONANCE STUDY OF HYDROGENATED MICROCRYSTALLINE SILICON. Tokashi Ebata, Ishinomaki Senshu Univ, School of Science and Engineering, Miyagi, JAPAN.

Paramagnetic species in hydrogenated microcrystalline silicon (µc-Si:H) have been studied by Q-band electron spin resonance (ESR) spectroscopy. In the present work, µc-Si:H samples were prepared at various substrate temperature from 70°C to 370°C in a M. ESR spectra, all the samples show the asymmetric Lorentzian band defect (DB) signal at g = 2.005 ± 0.006 with spin density of 10¹⁵ cm⁻³. The DB signal shows little dependence on substrate temperature in the X-band ESR spectra. In the Q-band ESR spectra, existence of at least two centers in DB signals is clearly indicated by the shape of the spectra. The fitting reveals that one center is at g = 2.005 ± 2.006 and the other is around at g = 2.004. The g-values of two centers observed are consistent with the attributions reported in the previous works. In addition, the DB signal showed dependence on substrate temperature. The dependence of the spectra is due to change of intensity ratio of signals by these two centers. The relative intensity of signal by the center at g = 2.004 to the one at g = 2.005 ± 0.006 in the sample prepared at 70°C is larger than that in other samples. As a result, the existence of two centers are observed more clearly in this sample than in the others. The substrate temperature dependence of Q-band ESR spectra observed here is thought to be due to the change in the structure of samples.

A10.10 IMPURITY-INDUCED DEFECT CREATION AT P/I INTERFACE IN MICROCRYSTALLINE SILICON P-I-N SOLAR CELLS. Takuya Matsui, Takashi Fujigaya, Yoshiyuki Nasuno, Michio Kondo, Akiko Matsuda, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, JAPAN; Hachio Fukuhara, Yoshihiro Kominami Institute of Science and Technology, Ibaraki, Japan.

Intrinsic microcrystalline silicon (µc-Si:H) thin films grown by 100 MHz plasma-enhanced chemical vapor deposition at different growth temperatures have been applied to superstrate-type p-i-n junction solar cells.
solve to obtain the effects of interlayer growth temperature (T) on p/i interface properties. Although high quality a-Si:H films (low defect density) are obtained in an 5.0-1.750 C, such high temperature growth of a-Si:H in the superstrate solar cells results in poor hot response and shows a strong bias-voltage dependent carrier collection behavior in the quantum efficiency spectrum. Since the response of p-a-Si:H solar cells is dominated by p/i interface properties, high temperature growth of a-Si:H is likely to deteriorate p/i interface. From the secondary ion mass spectroscopy (SIMS) impurity depth profiles, appreciable boron diffusion from p-layer into a-Si:H to occur in a-Si:H layers grown at T ~1.750 C [1]. In addition, we studied photoluminescence (PL) from a-Si:H in the vicinity of p/i interface. As a result, the integrated intensity of PL decreases by three orders of magnitude when T is increased from 1.50 to 1.750 C. SIMS and PL results provide strong evidence that diffusion boron creates non-radiative recombination center at p/i interface. We propose that this anomalous low-temperature boron diffusion is occurred by the interface reaction between hydrogen during interlayer growth. [1] Y. Nishino et al. Appl. Phys. Lett. 81, 3155 (2002).

A10.13 DEPTH PROFILING OF LIGHT-INDUCED DEFECTS IN HYDROGENATED AMORPHOUS SILICON BY TRANSIENT PHOTOCURRENT SPECTROSCOPY. Steve Reynolds and Charlie Main, Univ. of Abertay Dundee, Sch. of Computing and Advanced Technologies, Dundee, UNITED KINGDOM. Zdravka Aneva, Dima Neshev, Inst of Solid State Physics, Bulgarian Academy of Sciences, Sofia, BULGARIA.

Transient photoconductivity (TPC) is an established probe of the energetic distribution of deep traps in hydrogenated amorphous semiconductors. The technique reveals the creation of light-induced metastable defects in hydrogenated amorphous silicon (a-Si:H) and is therefore useful in the optimisation of these materials for device applications. It has recently been demonstrated that it is also sensitive to the spatial location of defects within a film. This is manifested in small but reproducible differences in the photocurrent decay that depend on the wavelength of the laser flash used to generate excess carriers. Anomalous distribution of deep-level defects when more strongly absorbed (green) laser light is used, compared with more uniformly absorbed (red) light, consistent with a higher defect density in the surface layer of the film. Here, we extend this work to study the effects of light-soaking with different wavelengths, with a view to controlling to some extent the spatial profile of metastable defects. We find that light-soaking of PECD a-Si:H from either the free surface or through the glass substrate using an AM1 source increases the bulk defect density (bulk and surface), but the increase in the surface density, as revealed by the TPC technique, is greater at the surface on which the soaking light is incident. This is attributed to the increased absorption of the shorter-wavelength portion of the white light, and hence an increased rate of defect creation, in this region. Further, we have soaked with blue-green filtered white light, and expected the defect density at the incident surface is increased while the bulk density is largely unaffected. Our results are discussed in the light of previous studies of spectrally-resolved steady-state photoconductivity, and prospects for a quantitative interpretation are considered.

A10.14 A STUDY OF ELECTRONIC DEFECTS IN HYDROGENATED AMORPHOUS SILICON PREPARED BY THE EXPANDING THERMAL PLASMA TECHNIQUE. Steve Reynolds, Charlie Main, Univ. of Abertay Dundee, Sch. of Computing and Advanced Technologies, Dundee, UNITED KINGDOM. Zdravka Aneva, Dima Neshev, Inst of Solid State Physics, Bulgarian Academy of Sciences, Sofia, BULGARIA.

The expanding thermal plasma (ETP) deposition of hydrogenated amorphous silicon (a-Si:H) permits high growth rates to be achieved whilst retaining acceptable electronic quality. ETP a-Si:H films have previously been studied using time-of-flight spectroscopy [1], and the results suggest hole mobilities some ten times higher than in PECD material. However, electron mobilities are found to be similar. The post-translucency photocurrent decay (following the electron transit) has also been analysed, and interpreted in terms of a step-wise rising deep defect density, although more recently it has been suggested that this feature may be an artefact associated with the sample contacts [2]. Here we have applied transient photocurrent spectroscopy (TPC) in the study of ETP a-Si:H. As TPC measures the secondary photoconductivity and the gap cell structures used here show a linear current-voltage characteristic, such difficulties with contacts cannot arise. Analysis of TPC decays obtained between 125 K and 300 K suggest a two-stage conduction band tail, of some 20 meV slope at energies shallower than 0.15 eV and 40 meV slope between 0.15 eV and 0.3 eV, followed by a defect plateau of estimated density 10^17 cm^-2 eV^-1 as energies deeper than 0.4 eV. The deep defect region was also investigated by analysis of the steady-state luminescence versus temperature characteristics, and the results obtained are in good qualitative agreement with the TPC data. Finally we measured the electron stimulated curcumosity which presents a maximum around 250 K and 300 K. The origins of this feature are discussed in terms of the density of defects proposed above. [1] M. Brzina et al. J. Non-Cryst. Solids 292-294, 420 (2002). [2] M. Brzina and G.J. Ackermann, 22nd ICSPT. Vol. V, p. 371 (2002) (to be published in Journal of Materials Science - Materials in Electronics).
We have investigated a new CVD process that makes it possible to grow device-grade polycrystalline Si (poly-Si) for large-area electronic devices directly onto the glass substrate. This process has to satisfy several requirements, i.e., film growth at the temperatures lower than 580°C, high and uniform crystallinity of the films in area and depth profiles, and suppression of powder formation and small deposition. In order to realize a clean process for large-area application in which powder formation and wall deposition are suppressed, we feature a cold-wall-type of thermal CVD, in which the reaction zone responsible for the film formation is limited in the vicinity of the heated substrate surface. Furthermore, in order to reduce the growth temperature of 680°C required for poly-Si, we utilized a small amount of reactive gases such as silane and tetraethylsilane. To promote a structural relaxation of Si network into the crystal, in addition to decomposition of Si source gas of silane (SiH₄) in the vicinity of the heated substrate. Thus, this new CVD process provides us with quality poly-Si. We characterized the characteristics of poly-Si thin films at 450°C. 200-nm-thick gate TFTs fabricated on SiO₂/Si substrates exhibited high mobility over 50 cm²/Vs, which has not been achieved ever before. In the TFT performance with respect to those.

9:00 AM A20.2
USING LETTERPRESS PRINTED POLYMER MASKS TO FABRICATE AMORPHOUS SILICON THIN FILM TRANSISTORS.
Sean M. Miller and Sandra M. Trenam, Department of Chemical Engineering, University of Waterloo, Waterloo, ON, Canada.

Flexible electronics, and in particular those fabricated on ultra-large scale and in high volumes, will require novel approaches to pattern formation. We have developed a fabrication scheme that utilizes letterpress printing instead of photolithography to directly print masks for the fabrication of amorphous silicon thin film transistors. A stamp with raised features picks up a thin polymer melt film and transfers it to a substrate where it can serve as a mask for wet etching or reactive ion etching. Using this printed polymer ink as an etch mask, we are able to eliminate many process steps without changing the overall fabrication scheme and without changing the structure of our finished devices. The changeover from photolithography to printing comes without changing the transistor on/off ratio or mobility. In addition to demonstrating the specific printing technology and transistor performance, we will show how theoretical process modeling can be used to predict the fidelity of printed patterns, and suggest ways in which the patterning process can be used to advantage.

9:15 AM A20.3
IMPROVEMENT OF GATE OXIDE INTEGRITY IN LOW TEMPERATURE POLY SILICON TFT.
Seok-Woo Lee, Doo Hyun Nam, Jung-Sik Seo, Myung-Ki Lee, and Dong Kim, LCD R&D Center, L.G. Philips LCD, Anyang, KOREA.

The characteristics of Si-based gate oxide deposited by plasma-enhanced chemical vapor deposition (PECVD) have been investigated with respect to gate oxide integrity (GOI) and its reliability. For the experiment, metal oxide semiconductor (MOS) capacitors with 100 nm-thick oxide gate were fabricated on p-type silicon wafers. It was found that the GOI depends on the deep level interface states generation under FN stress. By applying elevated temperature post-anneal without vacuum break after the gate oxide deposition, highly reliable gate oxide was obtained, i.e., reduced charge to breakdown and reduced flat band voltage shift by FN stress, which could be explained by the reduction of charge trapping and deep level interface states generation compared with as-deposited gate oxide. Detailed FN stress experiments demonstrated that the early stage of degradation process was dominated by hole trapping and following stress duration was dominated by electron trapping to gate oxide breakdown. The device characteristics of MOS poly-Si gate TFTs with glass substrate were enhanced significantly. By applying post-anneal after gate oxide deposition, improved hot carrier stress immunity of less field effect mobility degradation and of less threshold voltage shift as well as increased initial field effect mobility was obtained. Under FN stress, Id-Vg transfer curve showed negative shift and degradation of subthreshold swing, which were reduced by applying post annealed gate oxide mainly because of the lowered charge trapping and reduced deep level interface states generation. Besides, the TBD with post, annealed gate oxide showed around 10 times higher charge to breakdown under constant current injected FN stress with commonly biased source and drain. These improvements of GOI reliability and CMOS performance have been achieved by a solution for system integration on panel of LCDs in the near future.

9:30 AM A20.4
GATE AND DRAIN-BIAS INDUCED VTH METASTABILITY IN n-Si:H TFTS FOR ANALOG APPLICATIONS.
Kim S. Park, Arkinah Nathan, University of Waterloo, Electrical and Computer Engineering, Waterloo, ON, CANADA.

The bias-induced threshold voltage (Vth) metastability in n-Si:H TFTs can have adverse effects on circuit performance if the circuit is improperly designed or operated. Metastability concerns become particularly important when the TFT is used as an analog device. In contrast to the traditional applications (e.g. LCDs) where the TFT is used as a switch, analog applications require the device to withstand and maintain steady voltages on both, drain and gate terminals. This work attempts to develop an understanding of the Vth metastability in n-Si:H TFTs circuit performance at low bias voltages (e.g. < 25V), where the Vth of a TFT operating in linear mode is found to be considerably larger than for a TFT operating in saturation mode. Defect state creation and charge trapping in the widely accepted mechanisms for Vth metastability in n-Si:H TFTs. Defect state creation dominates at lower bias voltages while charge trapping in the gate insulator is dominant at higher biases. The point at which charge trapping overtakes defect state creation has been shown to be a function of the gate nitride stiction index. However, power requirements in emerging analog applications of n-Si:H technology (e.g. active pixel sensor [APS] imagers and organic light emitting diode [OLED] displays) underscore the need to move towards low power and reduced supply voltages, where defect state creation dominates. Experiments at constant drain and gate voltages stress on-hushe fabricated n-Si:H TFTs indicate that defect state creation is the dominant mechanism in our n-Si:H TFTs at small bias voltages (e.g. 25V). The developed Vth model is employed in an APS imaging pixel for gain degradation estimation and was found to be in good agreement with experimental data. The Vth model presented here can predict the performance of n-Si:H analog circuits for a variety of emerging n-Si:H TFT applications.

9:45 AM A20.5
CHARACTERISTICS OF BOTTOM GATE THIN FILM TRANSISTORS WITH SILICON RICH POLY SILICON, Ge, and POLYSI-FABRICATED BY REACTIVE THERMAL CHEMICAL VAPOR DEPOSITION.
Koosaku Shimizu, Jiun-Shin Zhang, Jeong-Woo Lee and Jun-Soo Haman, Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, Yokohama, JAPAN.

In the fabrication of thin film transistors (TFTs), little attention has been paid to the polycrystalline silicon (poly-Si) thin films prepared at temperatures lower than the glass transition temperature for poly-Si. This is because the film quality is not good enough to achieve high mobility, e.g., over 50 cm²/Vs in spite of high benefit in their industrial fabrication. We have fabricated bottom gate TFTs with poly-Si and poly-Si/Ge thin films deposited at 450°C by newly developed low-temperature LPCVD technique and characterized electrical characteristics of the TFTs: silane (SiH₄) and a small amount of either germanium tetrafluoride (GeF₄) or fluorine (F₂) were used as material gases and helium (He) as carrier gas. 200-nm-thick of poly-SiGe or poly-Si was deposited onto n-type (100) Si wafer with 75-nm-thick silicon dioxide on the surface: after the photolithography and ion implantation, 3.5×10¹⁴ ions/cm² of boron ion was implanted under the conditions of 30 keV; through the TID fabrication process, thermal annealing for dopant activation and atomic hydrogen treatment for defect passivation were carried out. We found that the hydrogen passivation process is important for improving TFT performance, and further detailed study is necessary. After the thermal treatment at 450°C for 1 hr is also quite effective to the improvement. Finally the mobility of p-channel and n-channel TFTs have attained 36.3±4.1 cm²/Vs and 57±7 cm²/Vs, respectively. The present results are quite encouraging for low cost fabrication of poly-Si TFTs in the future.

SESSION A21: IMAGERS
Friday Morning, April 25, 2003
Salon 5/6 (Marrriott)

10:30 AM A21.3
DIGITAL LITHOGRAPHIC PROCESSING FOR n-Si:H THIN FILM TRANSISTOR ARRAYS.
William S. Wang, Steven E. Rendy, Jing-Ping Lu, Jackson Ho, Robert A. Street, Palo Alto Research Center, Palo Alto, CA.

The cost and complexity of fabricating large-area electronics by conventional device processing is an impediment to the availability of inexpensive ubiquitous displays, large-scale image sensors, and evolving technologies such as e-paper. In many high-volume electronics applications, the minimum feature size is the entire TFT device, which is approximately 10-15 μm. For this dimension, many less expensive and simpler techniques are available as a substitute for photolithography. Digital lithography, in which a digitally imaged machinist
jet-printed onto a process wafer to define features for semiconductor processing, is one method to reduce the cost and complexity of semiconductor manufacturing. The jet-printing method makes it an ideal technology for implementing the direct writing of etch masks. Digitally processed, jet-etched etch masks were used to fabricate hydrogenated amorphous silicon thin-film transistor (TFT) matrix-LED panels with a minimum feature size of ~10 μm. The process was used to fabricate TFT arrays on a 6-in. Si substrate. The TFTs in a 64k × 64-matrix-addressing array of 300 μm square pixels had a 3.2-V driving-range voltage and a threshold voltage of 3.4 V. The implementation of these arrays for backplane image sensor applications will also be discussed.

10:45 AM A21.2
OPTOELECTRONIC DETECTION OF DNA mOLECULES ON
THIN-FILM MICA CHIPS USING AN AMORPHOUS SILICON
PHOTOCONDUCTOR (P-I-N) D. M. Prater, Y. Chen and J. P. Conde; "’NESC Microsystems & Nanotechnology, Lisbon, PORTUGAL; *Biological Engineering Research Group, Instituto Superior Tecnico, Lisbon, PORTUGAL; Department of Materials Engineering, Instituto Superior Tecnico, Lisbon, PORTUGAL.

The objective of this work is to demonstrate the use of an amorphous silicon (a-Si:H) photodetector to sense the presence of a DNA molecule target in a sample. A 2 × 107 a-Si:H photodetectors can be used for optoelectronic DNA detection in DNA chip or microarray applications. The device is based on the photoconductivity of a-Si:H in a complementary metal-oxide semiconductor (CMOS) compatible process. The spectral response of such a device is shown in absorption increases between 500-600 nm and attenuation increases at 650 nm. The detection of fluorescent molecules, 1-[(3-aminopropyl)methacrylamide]hexyl-4-[(4-methoxyphenyl)oxo-3-y] pyridinium bromide (PyMPO, SE) was chosen due to its large Stokes shift (λcλ is ~500 cm⁻¹) and because it can be chemically attached to the amine termination of the DNA molecule. The presence of a tagged DNA molecule is detected by exciting the PyMPO molecule using UV light producing an emission of visible light which is converted to a photocurrent signal in the device. Measurements of the spectral response curve of the detector with and without the presence of PyMPO shows an increase in signal in the range of 450-500 nm.

In this paper we describe in detail the design, fabrication and characterization of this integrated a-Si:H biosensor.

11:00 AM A21.3

Fabrication of a novel TFT-LCD panel, using amorphous silicon carbide oxide (a-SiCO:H) films as a passivation layer, was successfully demonstrated for the first time. The a-SiCO:H low-k films having a dielectric constant between 2.7 and 3.5 and high transmittance in the range of visible light were successfully deposited using a standard PECVD (plasma-enhanced chemical vapor deposition) reactor from a gas mixture of silane (SiH₄) and water vapor (H₂O). XPS analysis showed that the amount of (CH₃) radicals in the film had a direct influence on the dielectric constant, composition, and hardness. Source gas mixing ratio ([Si(CH₃)₂]/[H₂O]) and other deposition parameters, such as plasma power and chamber pressure, were successfully controlled to obtain simultaneously a dielectric constant as low as 2.7 and a deposition rate as high as 1.2 Å/min.

The transfer characteristics of the TFT’s having a-SiCO:H as a passivation layer was comparable with that of a conventional TFT with PECVD-grown SiN passivation layer. Stability of the resulting TFT was measured under prolonged bias conditions, and the source-drain current was almost constant and fairly constant. EQUIVALENT LINE CAPACITANCE (Ceq), the cumulative capacitance contributed from all parasitic capacitance formed around the metal (column) conductor, decreased with the passivation thickness of low-k a-SiCO:H film, predicted by the capacitor equation (C ≈ 1/ξ). A thick (≥ 2 μm), low-k films were shown to be suitable for reducing the parasitic capacitance formed between vertically-aligned electrodes in

the pixel array structure, and thus making it possible to increase the aperture ratio. The cross-talk values were inversely proportional to the passivation thickness. The coupling capacitance in the passivation layer to be the major cause. The LCD panel with the a-SiCO:H passivation layer showed 30% higher brightness than that of the standard panel.

11:15 AM A21.4
DIODE EDGE EFFECTS IN COMMON-LAYER P-I-N a-SiH PHOTO DiOde ARRAYS. Jeremy A. Thehl, Semiconductor Product Group, Agilent Technologies, Santa Clara, CA.

Hydrogenated amorphous silicon photodiode arrays form the basis of monolithic three-dimensional integrated circuit sensor technology. In these arrays, the intrinsic a-Si:H layer covers the entire area, producing the effective light collection. One technique by which the pixel diode is defined, is to pattern the bottom contact layer independently of the intrinsic layer. One of the most important characteristics of any diode array is its leakage current, which is the current that flows through the diode, even when no voltage is applied. In this manner, the diode is defined by the bottom contact layer, and the intrinsic layer is covered by the top contact layer. Leakage currents are of concern because any current flowing through the diode, whether by design or by a defect, can lead to a reduction in the signal-to-noise
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11:30 AM A21.5
IMPROVING NOISE PERFORMANCE OF FLAT PANEL IMAGE USERS WITH PIXEL LEVEL AMPLIFIERS. W. J. Lu, J. Ho, Y. Wang, K. Van Schuylenbergh, C. W. Shi, and R. A. Street, Palo Alto Research Center, Palo Alto, CA.

Flat panel imagers (FPUs) have become an important application in the arena of large area, thin film electronics inside flat panel displays. Conventional flat panel imager design is similar to more traditional FPUs designs where the panel is a collection of simple arrays of photo sensors connected to active matrix switching networks of amorphous Si Thin Film Transistors (TFTs). The recent development of high performance, excimer laser annealed (ELA) poly-Si TFTs enables us to develop next generation FPUs that integrate more sophisticated circuits like gate line drivers, data line multiplexers, and pixel level pre-amplifiers. Pixel level pre-amplifiers are particular interesting because they potenially enable a sensitivity that is fundamentally impossible with conventional FPUs.

We previously reported on the successful implementation of imager prototypes with 384×256, 90x90 μm² square pixels in our ELA poly-Si TFT process. The prototypes included a source-follower pre-amplifier in every pixel. As a result, the pre-amplifiers were uniform, linear, and image quality was demonstrated. We also reported a measured noise level of 1300 e RMS, which is already comparable to some of the best commercially available, conventional FPUs.

This paper reports on further improvements in the noise performance of these source-follower imagers. An improved readout process, based on the application of double correlated sampling at the level of the photo sensor, not only enables us to reduce the detrimental effect of the noise found in the previous report, but also to subtract the noise related to the reset process, which is not possible with conventional FPUs. The reset-related noise is understood as the fundamental imager noise limit. We measure the noise level of 1300 eRMS, well below the typical levels of conventional large FPUs. The noise spectrum, source, and physical process of the individual noise components will also be discussed in detail.

11:45 AM A21.6
ENHANCED BLUE SENSITIVITY IN ITO/a-SiNₓ H/a-Si:H MS PHOTODiODeS. S. Tao, Y. Vyrjanenkon, A. Nuhon, University of Waterloo, Dept of Electrical and Computer Engineering, Waterloo, CANADA.

We report an ITO/a-SiNₓ H/a-Si:H MS photodiode with improved performance in terms of the dark current and its stability, and superior response in the blue region compared to a similar device. The a-SiNₓ H thin film layers were deposited by PECVD on a glass substrate with patterned Mo back contact. The deposition of the polycrystalline ITO with a wide band gap (~3.75 eV) was performed in room temperature by magnetron sputtering. SSMS (Secondary Ion Mass Spectrometer) measurements show that the ultra-thin a-SiNₓ H film (~5 nm) can effectively block the diffusion of oxygen from the ITO to a-Si:H. In addition, the MS substrate layer functions as an oxygen electron, which serves to reduce the dark current. This is contrast to the ITO/a-Si:H Schottky photodiode whose electrical and optical
performance is impaired by the large defect density at the interface
due to oxygen diffusion from the ITO. At a reverse bias of 1 V, the
dark current density of the MIS photodiode is as low as 4 nA/cm².
Spectral photocurrent measurements show a dramatically enhanced
sensitivity in the UV/blue spectral region. A maximum quantum
efficiency of 80% is achieved at a wavelength of 440 nm. The high
quantum efficiency of the MIS photodiode can be attributed to
reduction of both optical and recombination losses by virtue of the
highly transparent polycrystalline ITO and the low defect density
a-SiNx:H/a-Si:H interface.