SYMPOSIUM A
Amorphous and Nanocrystalline Silicon Science and Technology–2005
March 28 - April 1, 2005

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* Invited paper
Hydrogenated amorphous silicon (a-Si:H), nanocrystalline (nc-Si), and polycrystalline silicon (poly-Si) are the thin-film semiconductors used for large-area electronics. They are applied in backplanes for active-matrix liquid-crystal displays (AM-LCDs), in optical scanner and radiation imaging arrays, and in thin-film solar cells.

The tutorial describes silicon film growth and properties, device physics, and applications. State-of-the-art, low-temperature processing will be presented and related to recent work with flexible substrates of organic polymers, steel, and glass. Attention will be given to the connection between material properties and device performance. Existing and emerging applications will be described and discussed.

Instructors:
Sigurd Wagner, Princeton University
José Pedro Conde, Instituto Superior Técnico, Lisbon

SESSION A1: Pioneers in the Use of Photons to Study Films
Chair: Reinhard Carl
Tuesday Morning, March 29, 2005
Room 2002 (Moscone West)

8:30 AM *A1.1
The Electronic Structure of a-Si:H as Measured by Photoelectron Spectroscopy.
Lothar Ley, Institut für Technische Physik II, Universität Erlangen-Nürnberg, Erlangen, Germany.

Photoelectron spectroscopy (PES) is the most direct way to gain information about the density of occupied electronic states in condensed matter. As such it complements in an ideal way optical data and has helped to unravel some of the idiosyncrasies of the electronic structure of amorphous materials. Here I shall present seminal results obtained in the 80ies and 90ties on amorphous hydrogenated silicon (a-Si:H) and related amorphous materials. The topics covered include the identification of Si-H and Si-F bonding states deep in the valence band and the accompanying recession of the valence band edge which explains the opening of the fundamental gap with increasing hydrogen or fluoride content. Taking advantage of the surface sensitivity of PES some important results concerning the near surface enrichment in hydrogen on freshly prepared a-Si:H are presented which have helped to understand the growth of a-Si:H. The bulk of the talk, however, will cover information obtained from yield spectroscopy which is a variant of PES that has the advantage to complement up to seven orders of magnitude in the density of states. As such it brings valence and conduction band tails and the gap of a-Si:H. Thereby it was demonstrated that occupied D- defect states are always created below the Fermi level E_F and unoccupied D+ above E_F so as to minimize the electronic energy of the network. This was the birth of the defect pool model that has played a central role in the defect dynamics of a-Si:H ever since. By evaluating yield spectra as a function of boron doping it has been demonstrated that the valence band tail slope is unaffected by boron doping. That is in contrast to the weak bond - dangling bond conversion model and requires a reconsideration of this model for the case of heavy doping.

9:00 AM *A1.2

Photothermal deflection spectroscopy (PDS) has provided invaluable information about non-crystalline films, amorphous silicon in particular. Because of the potentially wide applicability of PDS to most thin films including those comprised of novel and exotic materials, it is useful to review the role of photothermal spectroscopy in understanding amorphous silicon along with the wide variety of experiments that have been performed using PDS. PDS has proven to be complementary to such measurements as electron spin resonance, luminescence, deep level transient spectroscopy, reflection and transmission, and photodiode current. In conjunction with these and other experimental methods, PDS has provided information about both the identity, energy, and density of charged defects in hydrogenated amorphous silicon. In addition PDS has been used to measure surface optical properties, film quality, radiative recombination, mu-tau products, thermal properties, and PDS microscopy when applied to amorphous silicon. Present and future prospects for PDS will also be discussed.

9:30 AM *A1.3
 Urbach Edge, Disorder, and Absorption on-set in a-Si:H. George Cody, Aerospace and Mechanical Engineering, Visiting Professor, Rutgers University-Piscataway, Princeton, New Jersey.

The optical properties of amorphous silicon are better known and understood, than any other amorphous semiconductor. Starting in the mid-70's, worldwide interest focused on amorphous silicon as the active component of a variety of thin film optical devices.Optimization of the optical properties, building the independent band model of Jan Tauc, was the first step toward optimization of the performance of thin film solar cells, and the information derived from the optical properties could be related to the electrical properties of the thin film material as well. The device interest in amorphous silicon gave experimentalists access to thin films of unprecedented uniformity, purity and homogeneity, and the precision of these early experiments led to the discovery of the Urbach edge in amorphous silicon[1], and to new fundamental optical models for the absorption edge of amorphous semiconductors by Hass and Ehrenreich[2], Grein and John[3], and more recently by Fortman[4]. The comparison between amorphous semiconductors and their crystalline counterparts highlights the remarkable successes of the theory, as well as its limitations. A recent analysis of extensive experimental data on the Urbach edge of amorphous silicon by Orapunt and O'Leary[5], concludes that not only does amorphous silicon have an Urbach edge which depends on disorder, but it also has an Urbach focus at 2 eV, plus or minus 0.06 eV, which does not! The discovery that crystalline silicon has an Urbach edge[3,6] suggests a variety of experiments to understand the similarities and differences between the Urbach edge of direct, and indirect, crystalline semiconductors, and their amorphous counterparts. In this talk we review the concept of a "standard model" for the absorption edge of amorphous silicon. We describe the physics of the model, summarize its experimental status, and discuss current limitations and opportunities. 1 G. D. Cody, in Hydrogenated Amorphous Silicon, Volume 21B: Optical Properties, J. I. Pankove, Ed., Academic Press, Orlando, 1984, pp. 11-82. 2 K. C. Hass, H. Ehrenreich, Annals of Physics, 40, (1967), 362. 3 C. H. Grein, S. John, Physical Review B, 39, (1989) 1140. 4 C. M. Fortman, Physical Review Letters, 81, (1998) 3683-6. 5 F. Orapunt, S. K. O'Leary, Applied Physics Letters, 84, (2004) 523-525. 6 G. D. Cody, Journal of Non-Crystalline Solids, 141, (1992) 3-15.

SESSION A2: Growth I: Large Grains and Epitaxy
Chair: Paul Schopp
Tuesday Morning, March 29, 2005
Room 2002 (Moscone West)

10:30 AM *A2.1
Large Grained Polycrystalline Films for Photovoltaic Devices.
Christine Faber Richardson and Harry A. Atwater; Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California.

We have investigated the low-temperature epitaxial growth of thin silicon films by hot-wire chemical vapor deposition on large-grained polycrystalline template layers formed by selective nucleation and solid phase epitaxy (SNSPE). Using reflection high energy electron diffraction (RHEED), X-ray diffraction (XRD), Raman Spectroscopy, and transmission electron microscopy (TEM), we have found the ideal conditions for epitaxial growth on templates. Epitaxial films were grown to over 500nm thickness with E-1 and substrate temperature of 400 C. Previously we have investigated epitaxial thickness as a function of temperature. Now we see the effect of hydrogen dilution on the critical epitaxial thickness and texture of the film. At each temperature there is an optimal dilution to reach the thickest epitaxial film. We have studied several deposition parameters and offer a slice in phase space of those results by varying pressure, H dilution, and substrate temperature. We have also characterized the structure of these films by AFM to look at the surface texture and light trapping advantage: FTIR to look at the H grain boundary and film incorporation; Raman to look at the crystalline fraction and photodecay and passivate the film surfaces. Although nickel is a known lifetime killer even in small concentrations, the lifetimes of films on SNSPE templates are comparable to the lifetimes of films on Si(100). Under
LII conditions, the minority carrier lifetimes for films on Si(100) range from 5.7 to 7.5 μs and the minority carrier lifetimes for films on SNSPE templates range from 5.0 to 6.0 μs. Films grown by HWCDV have been used in the fabrication of 1.5 μm-thick thin-film transistors with channel mobilities of 4.7 cm²/Vs on glass substrates. Using the Einstein relation, we can determine that, if the mobility in single-crystalline Si is comparable, the minority carrier diffusion coefficient would be 0.1175 cm²/s. From this value and the minority carrier lifetime of ~97 μs measured by RCPCD in a 1.5 μm thick film on Si(100), we obtain a value for the minority carrier diffusion length of approximately 1 μm, which is comparable to the thickness of the active layers for thin-film photovoltaics (1 to 30 μm). The minority carrier lifetimes of films on SNSPE templates are comparable, making it possible that the growth of epitaxial films by HWCDV on large-area substrates could be a viable strategy for the fabrication of thin-film photovoltaics. Preliminary device results will be discussed.

Low temperature polycrystalline Si TFTs have opened a way for the next generation of displays, due to higher mobility of charge carriers, relative to amorphous Si (a-Si) TFTs. The applications of polycrystalline silicon 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 in TFT characteristics, with emphasis on crystallization, gate dielectrics, and ion-doping. Especially, ion-doping is performed to provide the source/drain, channel-doing, and lightly-doped drains, followed by ion-activation. The activation is generally obtained by furnace-annexing, excimer laser annealing, rapid temperature processing, etc. A new approach to ion-activation has been studied using rapid thermal annealing combined with alternating magnetic fields. In combination with rapid temperature annealing, the activation processing is investigated in terms of preheating temperature, rapid thermal annealing, alternating magnetic field, operating temperature, and activation energy. Comparative approach has been made on i) furnace activation, ii) excimer laser annealing, and iii) Field-Enhanced RTA. The microstructural features were investigated from micro-Raman spectroscopy which incorporates both amorphous and polycrystalline assemblies. The ramifications of a new approach will be discussed in conjunction with active-matrix TFT for OLED.

We find that low-temperature silicon epitaxy on (100) silicon wafers by hot-wire chemical vapor deposition is dramatically improved when a tantalum filament is used in place of a tungsten filament to decompose the pure silane gas precursor. With a 12 nm/min growth rate, we obtain the thickest epitaxial layers with a Ta filament current of 1.5 A and 1.7 A substrate temperature of 370°C. At 500 nm of epitaxial growth, less than 1% of the film surface is hydrogenated amorphous silicon (a-Si:H). Transmission electron microscopy shows that at a thickness of 200 nm, these films are still entirely amorphous, and that micrometer-size regions remain amorphous to at least 1 micron in thickness. Epitaxial thickness increases with increasing substrate temperature, pressure and flow-rate dependences are also studied. Real-time spectroscopic ellipsometry is used for routine monitoring of epitaxial growth and subsequent breakdown into a-Si:H cones, and selected films have been studied with transmission electron microscopy. We will discuss our data in relationship to the hydrogen supersaturation [J. Thües et al., APL 77 (2000), and limited random mobility [D. J. Eshaghi et al., Phys. Rev. Lett. 65, 1277 (1990) and H. Jorke et al., Phys. Rev. B 40, 2005 (1989)] models for epitaxial breakdown.
Defect-free Ge heteroepitaxial films grown on Si substrates find many applications including III-V solar cells [1], photodetectors in 1.3-1.5 μm wavelength range [2], and high-mobility electron devices [3]. The growth of thick (~ few μm) pseudomorphic heteroepitaxial films on Si substrates beyond critical thickness, however, is difficult due to thermal and lattice expansion mismatches. In our earlier work on Ge/SiGe growth on patterned Si substrates, we have demonstrated substantial reduction in defect density as pattern sizes are reduced from μm to nm-scales [4]. Here, we report on extension of this work to 100 % Ge epilayer growth on nanostructured Si surfaces. Silicon nanostructured surfaces were prepared through a combination of interferometric lithography and standard semiconductor processing methods. The geometry of Ge layers was examined by SEM, TEM, and HRXRD measurements. The defect density was evaluated through etch pit measurements [4]. Preliminary evaluation shows three orders of magnitude defect density reduction to (less than 10^6/cm^2) in comparison with growth on un-patterned substrates. Details of characterization and photoresponse in 1.3-1.6 μm wavelength range will be presented at the conference. REFERENCES 1. S. A. Ringel, J. A. Carlin, C. A. Andre, D. M. Wilt, E. B. Clark, F. Jenkins, D. Scheinman, C. W. Leitz, A. A. Allerman, and E. A. Fitzgerald, Prog. Photovoltics 10, 417 (2002). 2. G. Masini, L. Colace and G. Assanto, Appl. Phys. Lett., 83, 3159 (2003). 3. J. A. Carlin, S. A. Ringel, E. A. Fitzgerald, M. Bulsara, and B. M. Keyes, Appl. Phys. Lett., 76, 1884 (2000). 4. A. Vanunu, A. K. Datye and S. H. Zaidi, Mat. Res. Soc. Symp. Proc. Vol. 809, 2004, Materials Research Society.

SESSION A3: The Roles of Hydrogen Chair: Paul Stradins Tuesday Afternoon, March 29, 2005 Room 2002 (Moscone West)

1:30 PM A3.1 First-Principles Analysis of Growth Precursor Diffusion on Surfaces of Plasma-Deposited Silicon Thin Films. Tamas Bakos, Mayur S. Valipa, and Dimitrios Maroudas; Chemical Engineering, University of Massachusetts, Amherst, Massachusetts.

Hydrogenated amorphous silicon (a-Si:H) thin films are commonly deposited using SiH₄-containing discharges under conditions where the SiH₃ radical is the dominant deposition precursor. The deposition of hydrogen-enriched a-Si:H-films on Si (100) surfaces is determined by the surface smoothness or roughness and, thus, influences the optical and electronic properties of a-Si:H films used in photovoltaic and optoelectronic devices. In this work, we analyze various diffusion pathways of the SiH₃ radical on the hydrogen-terminated crystalline Si(100)-(2×1) surface using first-principles density functional theory (DFT) calculations and compare the deposited hydrogen diffusion with a previous activation-barrier calculation. Hydrogen diffusion for this system is mediated largely by surface hydrogen recombinations, which are not well understood and the corresponding activation barrier for hydrogen diffusion is still not known. In this presentation, we focus on the role of atomic-scale mechanisms underlying SiH₃ radical migration on a-Si:H surfaces as derived through a detailed fundamental analysis based on atomistic simulation. Using molecular-dynamics (MD) simulations of impingement of SiH₃ radicals on growth surfaces of smooth a-Si:H films, we studied the diffusion of the SiH₃ radical over the temperature range 475 K ≤ T ≤ 800 K. By monitoring structural changes in hydrogen bonding configurations, we gain insights into the role of hydrogen diffusion on a-Si:H surfaces. The mobility of the SiH₃ radical was determined through the evolution of the mean squared displacement of the radicals center of mass, as monitored from the MD trajectory. The average activation barrier for radical diffusion on the a-Si:H surface was found to be 0.16 eV; this low barrier for diffusion is due to the weak adsorption of the radical onto the a-Si:H surface and its migration predominantly through overcoordination defects. In addition, we have carried out analysis of SiH₃ surface migration pathways based on density functional theory (DFT) calculations using crystalline Si surfaces as representative models of atomic bonding at film growth surfaces. The DFT analysis revealed that the SiH₃ surface migration barrier was reduced when the radical was weakly bonded to surface Si atoms that were overcoordinated. Interestingly, our MD simulations indicate that the diffusing SiH₃ radical incorporates into the SiH film only when it transfers an H atom and forms an Si-H bond. The SiH₃ radical on the Si surface can either be adsorbed or diffuse into the bulk a-Si:H film. This H-transfer process is thermally activated and has important implications for the valley filling mechanisms responsible for rapid surface smoothing mechanisms. A more accurate H-transfer process does not require the presence of dangling bonds in surface valleys, but leads to preferential Si incorporation in such valleys of the surface morphology.

2:00 PM A3.3 Experimental Evidence for Extended Hydrogen Diffusion in Amorphous Silicon during Light-soaking. Kail Fatiha,1,2, Fellah Sami2, Houdajjad Aoum3 and Roca i Cabarrocas Pere1; 1Laboratoire de Physique des Interfaces et des Couches Minces, Ecole Polytechnique, 91128 Palaiseau, France, 2Laboratoire d’Analyse des Solides, Surfaces et Interfaces, Unité de Thermique et Analyse Physique, Université de Reims, 51687 Reims Cedex 2, France.

We have studied hydrogen diffusion induced by light-soaking in p-type amorphous and intrinsic polyamorphic silicon films deposited on glass substrates. The glass substrates were separated from the vacuum side by a secondary vacuum obtained by a turbo molecular pump, the film being on the vacuum side. The effects white, blue, green and red light illumination were studied. Mass spectrometry measurements allow to detect hydrogen emissions from hydrogenated amorphous silicon thin films when they are exposed to the light from the glass side. This indicates a long range hydrogen motion through the whole film, which ends with a release of hydrogen into the vacuum system. The change in the film structure induced by the diffusion of hydrogen at low temperature during light soaking are characterized by spectroscopic ellipsometry and hydrogen exodiffusion measurements. In particular, a comparison of the hydrogen exodiffusion spectra of as-deposited and light-soaked samples shows that hydrogen content is reduced by 50 % in p-type amorphous silicon and by 30 % in polyamorphic silicon, with changes in hydrogen bonding configurations. These results unambiguously demonstrate the long range motion of hydrogen during light-soaking.


Silicon nitride (SiNₓ:H) layers were deposited using a high deposition rate Hot-Wire CVD technique (up to 3 nm/s) and their application as passivating antireflection coating on multicrystalline silicon solar cells was investigated. An important aspect is the dependence of the hydrogen release and diffusion during a short annealing treatment at temperatures well above the deposition temperature. Such annealing treatments (firing) are used during contact formation of growth crystallization regime.

11:45 AM A2.6 Ge Growth on Nanostructured Silicon Surfaces. Ganesh Vananu, Abhay K. Datye and Saleem H. Zaidi; 1Chemical and Nuclear, University of New Mexico, Albuquerque, New Mexico; 2Gratings, Inc, Albuquerque, New Mexico.

Under conditions of low SiH₄ dissociation during the plasma-assisted deposition of hydrogenated amorphous silicon (a-Si:H) thin films, the dominant deposition precursor is the SiH₃ radical. The remarkable smoothness of device-quality a-Si:H films grown under these conditions has been used to conclude that the SiH₃ radical is very mobile and can passivate dangling bonds in surface valleys during diffusion after depositing onto the film. However, the fundamental mechanisms underlying SiH₃ radical migration on a-Si:H film surfaces are not well understood and the corresponding activation barrier for the radical’s surface diffusion is still not known. In this presentation, we focus on atomic-scale mechanisms of SiH₃ diffusion on a-Si:H surfaces as derived through a detailed fundamental analysis based on atomistic simulation. Using molecular-dynamics (MD) simulations of impingement of SiH₃ radicals on growth surfaces of smooth a-Si:H films, we studied the diffusion of the SiH₃ radical over the temperature (T) range 475 K ≤ T ≤ 800 K. By monitoring structural characteristics, such as the atomic coordination of the SiH₃ radical and of the surface Si atoms to which the radical is bonded during diffusion, we elucidated the active mechanism of hydrogen diffusion on a-Si:H surfaces. The mobility of the SiH₃ radical was determined through the evolution of the mean squared displacement of the radicals center of mass, as monitored from the MD trajectory. The average activation barrier for radical diffusion on the a-Si:H surface was found to be 0.16 eV; this low barrier for diffusion is due to the weak adsorption of the radical onto the a-Si:H surface and its migration predominantly through overcoordination defects. In addition, we have carried out analysis of SiH₃ surface migration pathways based on density functional theory (DFT) calculations using crystalline Si surfaces as representative models of atomic bonding at film growth surfaces. The DFT analysis revealed that the SiH₃ surface migration barrier was reduced when the radical was weakly bonded to surface Si atoms that were overcoordinated. Interestingly, our MD simulations indicate that the diffusing SiH₃ radical incorporates into the SiH film only when it transfers an H atom and forms an Si-H bond; the transferred H atom can then either be adsorbed or diffuse into the bulk a-Si:H film. This H-transfer process is thermally activated and has important implications for the valley filling mechanisms responsible for rapid surface smoothing mechanisms. A more accurate H-transfer process does not require the presence of dangling bonds in surface valleys, but leads to preferential Si incorporation in such valleys of the surface morphology.
Hydrogen Bonding in Amorphous and Polycrystalline SiGe Alloys: Norbert H. Nickel*, Iuliana Sieber*, S. Itoh, S. Fischler, B. Alfarah, O. Khatib, J. K. T. Nielsen, M. Weizmann, R. J. Nicholas, U. Wiesner, A. Ross. 1Department of Materials Science and Engineering, University of Texas at Austin, Austin, Texas; 2Department of Physics, University of Texas at Austin, Austin, Texas.

While amorphous silicon-germanium alloys are already successfully being used in triple-junction solar cells, polycrystalline SiGe alloys, among other applications, could be a good substitute for the Si absorber layer. The enhanced absorption of SiGe compared to Si makes it a very promising material. A major drawback of poly-SiGe alloys are localized states in the bandgap. However, they can be efficiently passivated with hydrogen. To optimize the defect passivation information on hydrogen bonding is important. The SiGe specimens investigated in this work were fabricated by the following steps. Initially, amorphous silicon-germanium films (a-Si1-xGex:H) were deposited by glow-discharge decomposition of a mixture of disilane, germane, and hydrogen to a thickness of 100 to 255 nm. The Ge content of the resulting samples was determined from elastic recoil detection analysis (ERDA) measurements and varied between 19 and 84%. A second series of poly-SiGe films were fabricated using an excimer laser. Because of the large hydrogen content of the a-SiGe:H films a step-by-step crystallization process was used to avoid ablation of the layers. The amorphous and polycrystalline SiGe films were characterized using Raman spectroscopy and hydrogen effusion measurements. The Raman spectra of the hydrogen related local vibrational modes show modes at 2000, 2100, and 1880 cm⁻¹ that are attributed to isolated Si-H, clustered (Si-H)₂, and Ge-H, respectively. With increasing Ge content in the alloys the intensity of the silicon related local vibrational modes decreases while the Ge-H related modes dominate the spectrum. Laser crystallization leads to a pronounced decrease in total H concentration. However, in completely crystallized poly-SiGe:H related local vibrational modes were no longer detectable. Therefore, information on H bonding could only be obtained from hydrogen effusion measurements. The H effusion spectra allowed to obtain the hydrogen density of states distribution [1]. Amorphous SiGe with a Ge content of about 15% revealed two peaks in the H DOS located at 0.8 and 1.4 eV below the H transport level. With increasing Ge concentration the peak at 1.4 eV decreases until it disappears at a Ge content of about 50%. Finally, a-Si0.5Ge0.5 reveals only one peak that is located 1 eV below the H DOS. Laser crystallization alters the H DOS completely. Firstly, H becomes more strongly bound by about 0.3 eV. In addition, the distribution of H binding energies increases independent of the Ge content. Laser crystallization causes a significant amount of H atoms to form complexes with binding energies larger than 2.5 eV. [1] N. H. Nickel and K. Bredehl, Appl. Phys. Lett. 82, 3029 (2003).
agglomeration, which can annihilate the desired quantum dot behavior. The use of nonthermal plasmas discussed in this presentation and the use of these two synthesis approaches: Plasma synthesis offers the efficiency of direct gas-to-particle conversion common to most gas phase approaches. At the same time is strongly reduces or completely eliminates agglomeration. We show that SE allows time of particles in the plasma region is small ( < 5 msec) and an aerosol of very small particles is produced. Transmission Electron Microscopy shows that crystalline particles smaller than 0.5 nm are obtained. Particularly collected on Si substrate of a native oxide layer they show bright photoluminescence in the red-orange region. Photoluminescence data, excitation scans, and absorption data are presented. Mass spectroscopic measurements show that silane is almost completely converted to particles in our discharger. The estimated production rate of luminescent silicon nanocrystals is a few tens of milligrams per hour. The presented reactor can easily be scaled-up by operating multiple discharge reactors in parallel. The comparatively large yield combined with the fact that very small particles are produced in a single step gas phase process without the need for any post-processing makes this system particularly attractive for the large scale production of silicon quantum dots. This work is supported in part by NSF under MRSEC grant DMR-0212302 and by InnovaLight, Inc.

4:00 PM A4.4
Electrodeposition of Nanoscale Germanium and Silicon in Ionic Liquids. Frank Endres, Technical University of Clausthal, Clausthal-Zellerfeld, Germany.

Ionic liquids are a new class of solvents with extraordinary physical properties. They are mostly based on organic cations and inorganic or organic anions and by definition their melting points are below 100 Celsius. These liquids have often negligible vapor pressure, high thermal stability (up to 350 Celsius), high ionic conductivity and wide electrochemical windows of up to 7 Volt. The latter property is very important for the electrodeposition of reactive elements such as Ge, Si, Al, Li and many others. We could show by the help of in situ Scanning Tunneling Microscope that the initial processes of germanium and silicon electrodeposition can be probed on the nanometer scale. For example, before the bulk phase of germanium forms on Au(111), an underpotential deposition sets in, and ultrathin layers between 100 and 300 pm with clearly metallic behavior grow [1-3]. With subsequent reduction nanocrystals start growing that show a metal to semiconductor transition in the thickness regime between 1 and 2 nm. With these liquids it is also possible to electrodeposit silicon, and we could show by in situ tunneling spectroscopy that a 100 nm thick silicon film has a band gap of 1.0 ± 0.1 eV, proving that intrinsic semiconducting silicon was electrodeposited in the amorphous state. Such ionic liquids are also well suited to the electrodeposition of nanocrystalline metals and alloys with grain sizes down to 10 nm [5]. [1] F. Endres, S. Zein El Abedin, Phys. Chem. Chem. Phys., 4 (2002) 1840 [2] F. Endres, S. Zein El Abedin, Phys. Chem. Chem. Phys., 4 (2002) 1949 [3] F. Endres, S. Zein El Abedin, Phys. Chem. Chem. Phys., 4 (2002) 1840 [5] S. Zein El Abedin, N. Borisienko, F. Endres, Electrochemistry Communications, 6 (2004) 510 [6] F. Endres, M. Bukowski, R. Hempelmann, H. Natter, Angew. Chem., Int. Ed., 42 (2003) 3428

4:15 PM A4.5
Wiring and Introduction of Single Silicon Nanocrystals into Multi-wall Carbon Nanotubes. Vladimir Syrcek1, François Le Normand2, Ovidiu Eren3, Cuong Phan-Huu1, Dominique Begia1, Benois Louis1, Jean-Claude Muller1 and Marc J. Ledoux1;
1LMSP/C-ECIL, 2040 Strasbourg, France; 2IPCMS, UMR 7504 CNRS, 23 rue du Looec, F67087 Strasbourg, France; 3CNRS-PHASE, 23 rue du Looec, F67087 Strasbourg, France.

In principle, since bulk silicon is an indirect bandgap semiconductor, it could not be used for optoelectronic applications. However, it has been demonstrated that efficient photoluminescence (PL) can be observed from silicon in the form of quantum dots (wires), i.e., silicon nanocrystals with sizes less than 5 nm. At small size, quantum confinement together with surface state effects start to take place resulting in opening of the bandgap and considerable increase of radiative recombination probability. The most common techniques used for the SE synthesis are silicon ion implantation and silicon dioxide (SiO2) thin film, annealing of SiO2/amorphous silicon layers

and chemical vapor deposition. Very often, the problem here is the difficulty in achieving Si-nc concentrations high enough to obtain efficient light emission properties with large area devices. We have developed an alternative technique for the ex-situ preparation of Si-nc by pulverization of porous silicon layers followed by their implementation into liquid spin on glass (SOG) SiO2 as basic host matrices where we expect to overcome such problems. We have indeed verified that Si-nc, embedded in SOG, maintains its superior luminescence, transport properties and optical gain. As it is well known, since the first successful synthesis of carbon nanotubes (CNTs), these materials are of interest both to theoreticians and experimentalists as a unique 1D nano-material. One of the most promising applications is the filling of these CNTs by nanoparticles as a nano-reservoir for the stabilization of these nanotubes. As has shown our preliminary results, a solution of free floating colloidally prepared Si-nc can be introduced within carbon nanotubes CNTs. The approach for the preparation of Si-nc ex-situ, in principle, offers unique possibilities. For instance we are able to continuously fill the CNT with Si-nc even after the CNTs are embedded in silicon dioxide matrix. In addition, the surface chemistry can be used to effectively alter the properties of the Si-nc including PL brightness, PL maxima position, surface tension and electronic lifetime. In the proposed contribution we will present this innovative low-cost procedure to wire and introduce Si-nc (2-5 nm) embedded in liquid by capillary forces, into CNTs with different inner diameters in the range 5-50 nm. The Si-nc were produced by electrodechemical etching in colloidal suspensions. We will show that we are able to obtain well-separated and wired single Si-nc with conducting multiwall CNTs crucial for real-world applications. One more advantage is these devices can be used as light sensors, microchips and solar cells. The performance and reliability of many of these devices are influenced by their heat transport characteristics. In this work, we use three-dimensional molecular dynamics simulations and fluctuation dissipation relationships to study the effect of grain size on thermal conductivity of nanocrystalline silicon at room temperature. We found that thermal conductivity decreased linearly with decreasing grain size. Interestingly, the thermal conductivity of model amorphous silicon corresponds to an effective grain size of ~1nm, i.e., the length equivalent to the length of two Si-Si bonds. To obtain a more detailed understanding of thermal transport process we performed lattice dynamics calculations on our model structures and compared localization and polarization of vibrations characterizing amorphous and nanocrystalline model silicon structures.

4:45 PM A4.7
Multi-Scale Growth Study of Vacuum Evaporated a-Si Nanostructured Thin Films. Anam Ansar1, Kate Kaninska2, Motofumi Suzuki3, Ludwik Martiń4 and Kevin Robbins2; 1Rogroupement Quebecois pour les Materiaux de Pointe (RQMP) and Department of Engineering Physics, Ecole Polytechnique de Montreal, Montreal, Quebec, Canada; 2Department of Physics, Queen’s University, Kingston, Ontario, Canada; 3Department of Engineering Physics and Mechanics, Graduate School of Engineering, Kyoto University, Kyoto, Japan.

Nanostructured silicon is an important electronic material with varied applications as light sensors, microchips and solar cells. The performance and reliability of many of these devices are influenced by their heat transport characteristics. In this work, we use three-dimensional molecular dynamics simulations and fluctuation dissipation relationships to study the effect of grain size on thermal conductivity of nanocrystalline silicon at room temperature. We found that the thermal conductivity decreased linearly with decreasing grain size. Interestingly, the thermal conductivity of model amorphous silicon corresponds to an effective grain size of ~1nm, i.e., the length equivalent to the length of two Si-Si bonds. To obtain a more detailed understanding of thermal transport process we performed lattice dynamics calculations on our model structures and compared localization and polarization of vibrations characterizing amorphous and nanocrystalline model silicon structures.

Porous materials with a structure controlled on the nanometer-scale are important in a wide variety of applications, including photonics, electronics and biomaterials. Glancing Angle Deposition (GLAD) allows the fabrication of films with nano-engineered morphology whose properties can be tailored. GLAD is based on thin film deposition by evaporation onto a substrate that is tilted at a high angle, (a > 75°), relative to the vapour flux. This geometry leads to an effect called atomic shadowing, which occurs when the vapour flux is prevented from reaching the substrate by previously deposited material. This results in the development of a porous structure forming a 2D array of isolated nanocolumns of material. Atomic shadowing is scale-invariant and therefore results in the formation of fractal nanostructures, which broaden with height according to a power-law relation. We have investigated the growth of GLAD nanostructures using a combination of in situ spectroscopic ellipsometry (SE) and ex situ atomic force microscopy (AFM) in the sub-nanometer to 10 nm regime, and by in situ SE, ex situ variable angle SE (VASE) and Field-emission Scanning Electron Microscopy (FESEM), in the 10 nm to 0.5 μm regime. We show that SE allows determination of film thickness, optical properties, bifringence, and
AFM analysis shows that disk-like (~200 Å) pc-Si:H. For thicker films (10 to 500 nm), we have investigated backplanes for flat panel displays (FPDs). However, we have obtained fully high-quality films, which makes it difficult to use ELA for large-size displays. As an alternative method for silicon crystallization, deposition, which is related to the crystal structure of silicon and nickel silicide.

**A5.4 Effects of Post Annealing and Material Stability on Undoped and n⁺ nc-Si:H Films Deposited at 75 °C Using 13.56 MHz PECVD.** Czang-Ilo Lee, Andrei Sazonov and Arvind Nathan; ECE, University of Waterloo, Waterloo, Ontario, Canada.

Undoped nc-Si:H is a low-cost active layer alternative to polycrystalline silicon (poly-Si) for active matrix thin film transistor (TFT) backplanes for flat panel displays (FPDs). However, this material is highly sensitive to oxygen adsorbed from the ambient, which can undermine the long-term device reliability. In this paper, the effects of post-deposition annealing and material stability of undoped and n⁺ nc-Si:H films have been investigated. The films were deposited at a very low temperature (75 °C) by standard 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) and subsequently annealed at temperatures exceeding the deposition temperature (120–300 °C). Electronic, structural, and chemical composition properties were studied using measurements of electrical conductivity, Raman spectroscopy, X-ray diffraction (XRD), atomic force microscopy (AFM), Fourier transform infrared (FTIR) spectroscopy, and secondary ion mass spectroscopy (SIMS). The as-grown nc-Si:H films showed a high crystallinity of 83%, an oxygen concentration of 2 × 10¹⁸ at/cm³, and a dark conductivity of 10⁻⁶ S/cm and 1 S/cm in case of undoped and n⁺ nc-Si:H films, respectively. The dark conductivity in all films demonstrated high stability against prolonged ambient atmosphere exposure, which can be attributed to low oxygen concentration and stable hydrogen passivated grain boundaries. On the other hand, in n⁺ nc-Si:H films, the dark conductivity increases by more than one order of magnitude after annealing in ambient atmosphere, followed by a decrease below the as-grown value. Depending on the annealing temperature, the dark conductivity can drop as low as 10⁻ⁱ⁰ S/cm. In n⁺ nc-Si:H films, the decrease in the dark conductivity was lower. However, in undoped nc-Si:H films capped by amorphous silicon nitride (a-SiNₓ), this was not observed. In all films, no significant change in the film microstructure before and after annealing was detected. However, a small decrease in the hydrogen content accompanied by an increase in the oxygen content was observed in uncapped nc-Si:H films. It was therefore concluded that the dark conductivity is affected by oxygen desorption from the ambient atmosphere. Detailed experimental results will be presented along with modeling results based on hydrogen effusion-assisted oxygen absorption.

**A5.5 Study of Steady State Photoconductivity in Highly Crystallized Doped and Undoped Microcrystalline Si Films.** Sajad Raaz1,2, Sathyendra Kumar1,2, P. Rocca i Cabrero3, R. Vanderhagen1 and B. Drevillon3; 1Physics, Indian Institute of Technology, Kanpur, Kanpur, Uttar Pradesh, India; 2Sanlent Centre for Display Technologies, Indian Institute of Technology Kanpur, Kanpur-208016, Uttar Pradesh, India; 3Laboratoire de Physique des Interfaces et des Couches Minces (UMR 7647 du CNRS), Ecole Polytechnique, 91128 Palaiseau Cedex, France.

Hydrogenated microcrystalline silicon (µc-Si:H) is a promising material for large area photonic devices such as solar cells, sensors and thin film transistors (TFT's) that based panel displays. Recently, this material has drawn more attention compared with hydrogenated amorphous silicon due to higher conductivity, large carrier mobility and better stability against light induced changes. However, plasma-deposited µc-Si:H is inherently a heterogeneous material consisting of micro and nano size crystallites, amorphous tissues and voids. Understanding carrier transport in such a system is undoubtedly a challenging task. Though there are several reports on the electronic transport in doped µc-Si:H, little attention is paid to the carrier transport in undoped µc-Si:H. We have obtained fully crystallized dense undoped µc-Si:H films on glass substrates by standard rf glow discharge plasma CVD technique using a mixture of SiF₄, Ar and H₂ at low substrate temperatures (~200 °C). Structural properties of the films were well characterized by in-situ spectroscopic ellipsometry, Raman scattering, X-ray diffraction and atomic force microscopy.

**SESSION A5: Poster Session: Characterization—Nano, Micro, Poly-crystalline Films**

**Tuesday Evening, March 29, 2005**

Salons 8-15 (Marriott)

**A5.1 Instabilities and Temperature Dependence of Photoelectronic Properties of Microcrystalline Si Films.** Christian Breunig; Instiut fur Physik, Carl von Ossietzky Universitat Oldenburg, Oldenburg, Germany.

We critically assess the determination of the photoelectronic properties of microcrystalline silicon in terms of majority-carrier mobility-lifetime products from steady-state photocconductivity and minority-carrier mobility-lifetime products from the steady-state photocurrent decay measurements. We show how large metastable changes in the dark conductivity upon moderate heat treatment in vacuum to remove adsorbrates translate into change in the measured values characterising the photoelectronic properties if excess-carrier measurements in air and after heat treatment are considered. We note that these effects are not related to metastable defect creation and annealing. After establishing a standard heat-treatment procedure prior to photocurrent measurements, we determined the temperature and photon flux dependence of the major and minority-carrier mobility-lifetime products in microcrystalline silicon with different degree of crystalline volume fraction. Numerical modelling provides further insight and supports the suggestion of a rather symmetric density-of-states distribution on valence and conduction band tails in microcrystalline silicon.

**A5.2 Abstract Withdrawn**

**A5.3 Microstructural Analysis of Nickel-Mediated Crystallized Poly Silicon Films Using AFM, EBSD and XTEM.** Sanjeev Soni, Myung-Kyu Park, Nari Ahn, Ilsang Choi, Jinwook Seo and Jaeha Lee; 1Materials Analysis Team, Corporate R&D Center, Samsung SDS Co, Yongin, Gyeonggi-do, South Korea; 2Tech. Development Corporate R&D Center, Samsung SDS Co, Yong In, Gyeonggi-do, South Korea.

Active matrix organic light emitting diode (AMOLED) displays fabricated by using low temperature polycrystalline silicon (poly-Si) thin film transistors (TFT's) revealed the possibility of realizing low cost, high-quality images with low power consumption. For the crystallization of amorphous silicon (a-Si) in AMOLED fabrication, excimer laser annealing (ELA) method has been widely used because of its reliability without causing any damage to low-cost glass substrates. However, the ELA process that utilizes a line beam laser, plays a role as a barrier for diffusion of metal catalyst for the electronic transport in doped tissues and voids. Understanding carrier transport in such a system is undoubtedly a challenging task. Though there are several reports on the electronic transport in doped µc-Si:H, little attention is paid to the carrier transport in undoped µc-Si:H. We have obtained fully crystallized dense undoped µc-Si:H films on glass substrates by standard rf glow discharge plasma CVD technique using a mixture of SiF₄, Ar and H₂ at low substrate temperatures (~200 °C). Structural properties of the films were well characterized by in-situ spectroscopic ellipsometry, Raman scattering, X-ray diffraction and atomic force microscopy.

**Tuesday Evening, March 29, 2005**

Salons 8-15 (Marriott)
microscopy techniques. This article will basically cover results on the dark and steady state photoconductivity measurements carried out on samples of different thicknesses and their crystallinity. In our photoconductivity measurements on the same sample we used He-Ne red Laser of 15mW output (yields a maximum photo-generation rate of $P = 10^{-4} \text{ cm}^{-2} \text{s}^{-1}$). Intensity is varied from $10^4 \text{W cm}^{-2}$ to $10^6 \text{W cm}^{-2}$ by using neutral density filters. The samples were placed in He cryostat operating in the temperature range of 15 $\text{K}$ to 325 $\text{K}$. The dependence of photoconductivity ($\sigma_{\text{ph}}$) on the temperature and the intensity of light were measured in a temperature range 15 $\text{K}$ to 325 $\text{K}$. Temperature dependence of photoconductivity data is fitted to standard power law $\sigma_{\text{ph}} \propto T^\gamma$, where the exponent $\gamma = (T/T_0 + T_0)$ contains the information on recombination mechanism in the semiconducting material. The variation in $\gamma$ is found to be $0.5 < \gamma < 0.9$ for thin samples, and $0.15 < \gamma < 1$ in a crystalline sample. Mechanisms of carrier transport and recombination governing these temperature and intensity dependences will be discussed in the paper. In order to evaluate the properties like free carrier concentration and mobility in undoped Si, Hall effect measurements were also performed in the temperature range 300-450 $\text{K}$.

A5.6 Transport and Meyer-Neldel Rule in Microcrystalline Silicon Films. Steve Reynolds, Vladimir Smirnov, Friedhelm Finger, Charles Main and Reinhard Carusi; EPICentre, University of Aberaty Dundee, Dundee, United Kingdom; IFV, Forschungszentrum Juelich, Juelich, Germany. Dep. of Mech. and Physics, University of Dundee, Dundee, United Kingdom.

The Meyer-Nelder Rule (MNR) has been observed in microcrystalline silicon (mc-Si) thin films, where it can be altered by doping, by varying the degree of crystallinity [1]. Although it has been shown that exposure to atmosphere may cause both reversible and irreversible changes in conductivity over a wide range [2], a systematic study of the effect of the MNR has to be carried out. In the present work, changes in dark conductivity, activation energy and conductivity prefactor measured on individual samples due to aging are reported. The data are found to follow the MNR smoothly, and to correlate well with results from a series of samples of varying crystallinity. Our primary motivation for this study is to discover more about reversible and irreversible ageing processes, and how they may affect interpretation of transport measurements [3] and long-term stability of devices such as thin film solar cells [4]. 


The secondary ion mass spectrometer combined with a time of flight analyzer is well known as a powerful technique for surface analysis and for ultra shallow depth profiles. Unfortunately, the main advantage of the SIMS technique is often shadowed by a major problem: the quantification of the results is not straightforward and sometimes nearly impossible. This inconvenience is caused by a well known phenomenon, the matrix effect, which means that the intensity of the signals depends strongly on the nature of the studied sample and on the primary ions. Using Cs+ ions for sputtering offers a semi-quantitative solution to depth profiling. Specifically, the use of these alkali ions strongly increases the negative ion yields, decreases the positive ones and allows the formation of MCs+ and MCs2+ clusters. The study of these clusters has shown their low sensitivity to matrix effect and their applicability to quantitative profiles [1,2]. Recently, Niethuis and Grehl [3] developed a new approach consisting of co-sputtering Xe and Cs in order to control the Cs surface concentration, thus allowing the optimization of elemental and cluster ion yields. In a previous work, we applied that technique on different well-defined samples (e.g. Si and SiO2) and we monitored positively ions as a function of the sputtering beam Cs concentration [4]. First, we observed the decrease of the elemental ions due to the work function lowering, as is predicted by the tunneling model. We then studied the behavior of the MCs+ and the MCs2+ clusters. The MCs+ yields exhibit a maximum at a given Cs/Xe beam concentration ratio, depending on the studied element M but also on his chemical environment (e.g. Si and SiO2) and on the energy of the Cs beam. Those maximums are consequences of the competition between the varying surface Cs coverage (direct concentration effect) and the decreasing ionization probability due to that varying Cs. However, at low Cs surface concentration, the Cs ionization probability is close to 1 and the Cs+ signal saturates the detector. In this work, we combined the Cs/Xe co-sputtering with a very low current analysis method called burst alignment in order to measure Cs surface concentration in our photoconductivity measurements on the same sample we used He-Ne red Laser of 15mW output (yields a maximum photo-generation rate of $P = 10^{-4} \text{ cm}^{-2} \text{s}^{-1}$). Intensity is varied from $10^4 \text{W cm}^{-2}$ to $10^6 \text{W cm}^{-2}$ by using neutral density filters. The samples were placed in He cryostat operating in the temperature range of 15 $\text{K}$ to 325 $\text{K}$. The dependence of photoconductivity ($\sigma_{\text{ph}}$) on the temperature and the intensity of light were measured in a temperature range 15 $\text{K}$ to 325 $\text{K}$. Temperature dependence of photoconductivity data is fitted to standard power law $\sigma_{\text{ph}} \propto T^\gamma$, where the exponent $\gamma = (T/T_0 + T_0)$ contains the information on recombination mechanism in the semiconducting material. The variation in $\gamma$ is found to be $0.5 < \gamma < 0.9$ for thin samples, and $0.15 < \gamma < 1$ in a crystalline sample. Mechanisms of carrier transport and recombination governing these temperature and intensity dependences will be discussed in the paper. In order to evaluate the properties like free carrier concentration and mobility in undoped Si, Hall effect measurements were also performed in the temperature range 300-450 $\text{K}$.
stress to microstructures during AIC of PECVD a-Si. A number of AOT and AOB films with equal thickness of Al and a-Si from 20 to 200 nm were prepared by depositing the Al layer on top of a-Si at low temperature (500 degree) and process cost is very low. However, MILC poly-Si is contaminated by nickel silicide. Therefore, it caused high leakage current and low carrier mobility. To obtain low silicon contamination and defects, poly-Si with unidirectional orientation is necessary. So, we studied the effects of crystal filter on MILC orientation. Also we observed change of MILC microstructure between normal MILC and CF-MILC. A 500–A-thick amorphous Si thin film was deposited by low pressure chemical vapor deposition (LPCVD) on Si wafer. After the amorphous Si deposition, the samples were patterned by photolithography method and then a-Si layer was etched by conventional plasma etching with SF6. When amorphous Si layer was deposited on a-crystall filter wafer that used amorphous Si deposition at 550 °C, samples were crystallized in vacuum. The orientations of poly-Si grains which was passed crystal filter and not passed crystal filter were observed by electron back scattering diffraction (EBSD: JSM 6500F). And we used normal scanning electron microscope (SEM) to observe microstructure. We could observe that the width of crystal filter was the narrower, the MILC orientation was oriented with (111) direction. Since the selected unidirectional silicide (1st silicide) which was passout through crystal filter would make 2nd silicide to crystallize amorphous silicon region with same 1st silicide direction. Using CF–MILC, we were able to get unidirectional poly-Si.

A6.4 Laser Crystalization of Compensated Hydrogenated Amorphous Silicon Thin Films. Rosari Sohle, Norbert H. Nicolzi, and Karsten von Maydell; 1 Fysika, Fakultas MIPA, Universitas Indonesia, Depok, Indonesia; 2 Hahn-Meitner-Institut, Berlin, Germany; 3 Hahn-Meitner-Institut, Berlin, Germany.

Compensated hydrogenated amorphous silicon films were crystallized using a step-by-step laser deuteration and crystalization procedure. The influence of laser crystalization on structural change, hydrogen bonding and hydrogen diffusion is investigated employing Raman spectroscopy and hydrogen effusion measurements. The starting material was grown on quartz substrates by low pressure plasma chemical vapor deposition. The hydrogen bonding was measured by Raman spectroscopy and hydrogen effusion measurements. The AOT films decreases slightly with no kinks. From correlation of stress measurements indicated that the compressive stress of AOT films decreases dramatically with a kink before both Al and a-Si exchange their position. However, the in situ stress measurements indicated that the compressive stress of AOT films increases with a kink before both Al and a-Si exchange their position. The in situ stress measurements indicated that the compressive stress of AOT films increases with a kink before both Al and a-Si exchange their position. The in situ stress measurements indicated that the compressive stress of AOT films increases with a kink before both Al and a-Si exchange their position. The in situ stress measurements indicated that the compressive stress of AOT films increases with a kink before both Al and a-Si exchange their position. The in situ stress measurements indicated that the compressive stress of AOT films increases with a kink before both Al and a-Si exchange their position. The in situ stress measurements indicated that the compressive stress of AOT films increases with a kink before both Al and a-Si exchange their position.
to 600 degrees. The electrical and optical properties of the Ge thin films were evaluated by the Hall effect measurement and the optical absorption coefficient measurement. In the case of the Ar gas sputtering, the gas mobility of Ge thin film increased with rising substrate temperature, and reached 40 cm²/Vs at 600 degrees. This mobility is an unexpected high value nevertheless the poly crystalline thin film contains many defects due to low mobility. The optical absorption coefficients of Ge thin films increased to 10³ cm⁻¹ at 1500 nm corresponding to the energy gap, which is much higher than that of the single crystal Ge. On the other hand, the absorption constant of single crystal Ge increases up to 10⁶ cm⁻¹ at 1100 nm. This result suggests that the Ar-H₂ mixture gas sputtering is able to reduce the defect density and improve the electrical properties. It is suggested that the poly crystalline Ge thin films prepared by the RF sputtering method are hopeful to realize a new PV-cell for TPV system.

A6.6
TCAD Modeling of Metal Induced Lateral Crystallization of Amorphous Silicon. Aleskys M. Agapov¹, Valeri V. Kalinin¹, Alejandro M. Myasnikov¹ and Vincent M. C. Foon²; ¹Institute of Semiconductors Physics, Novosibirsk, Russian Federation; ²Hong Kong University of Science and Technology, Hong Kong, Hong Kong.

In our previous publication (A.M.Myasnikov et al., MRS proc., v.715, 2002, A22.11, and v.762, 2003, A17.2) mechanism of nickel diffusion and spreading resistance probe (SRP) measurements for quality control of metal induced lateral crystallization (MILC) of amorphous silicon (a-Si) were studied. Now we present TCAD modeling and explanation of experimental results, which were obtained. A layer of 300 nm thick a-Si was deposited on silicon substrate with thickness around 400 nm. Silicon film was ion-implanted at a dose of 10¹⁵/cm² and an energy 40 keV with B⁺, BF₂⁺, P⁺, As⁺ ions. 5 nm thickness nickel island seeds were used with different pattern. Temperature and time of recrystallization varied from 550°C to 1100°C and from 10 seconds to 20 hours. The sizes of MILC regions were in the range from some microns to 200 μm. Then MILC regions were measured by spreading resistance profiler 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 nickel/MILC regions. We have found, that SRP method can be used 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 of the samples having MILC regions differ greatly in conduction, 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 poly-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. ISE TCAD models were implemented for carrier mobility in a-Si and recrystallized layers implanted by boron, phosphorus and arsenic. By using these models the spreading resistance of MILC regions was compared with experimental results. Nickel penetration and distribution in silicon layers were calculated also and the correlation between Nickel penetration and the motion of recrystallization front was found.

A6.7
Electron Field Emission from SiC/Si Heterostructures Formed by Carbon Implantation Into Silicon and Etching of the Top silicon Layer. Yunmei Xing, Yanqi Yu and Jiali Wang; Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai, China.

High-intensity electron field emissions were obtained from SiC/Si heterostructures prepared by carbon implantation into silicon at 700°C and subsequently etching of the top silicon layer. Carbon implantation was carried out at 160 keV with a dose of 3.0×10¹⁷cm⁻². Densely distributed sharp tips were easily observed at the interface of the SiC/Si heterostructure for all samples. The lowest turn-on field of 2.6 V/micron was attributed to the highest implantation dose in this work. Post-implantation annealing at 1250°C in Ar for 5h was used to improve the crystallinity of the carbon implanted SiC layer, while electron field emission from SiC/Si heterostructures got little enhancement. It suggests that 3C-SiC precipitates embedded in silicon substrate interface which have formed during high temperature carbon implantation. Post-annealing put little effect on these 3C-SiC precipitates.

A6.8
Electron Field Emission from Laser Crystallized HWCVD and PECVD Thin Silicon Films. M. Z. Shaikh, Kevin O'Neill, Saydullah Peresheev and Mervyn J. Rose; Electronic Engineering and Physics Division, University of Dundee, Dundee, United Kingdom.

This paper reports on Laser crystallisation of thin silicon films by excimer laser and Nd:YAG laser intermoderate, to produce an electron source for use in a perspective cold cathode field emission device. This results in a new phase of conducting crystallites in an insulating medium, tested through the performance of field emission measurement. We analysed changes in the morphology, electronic and optical properties of the Ge thin films, two growth methods namely PECVD and HWCVD, were studied. The absorption coefficients in microcrystalline silicon by using Atomic Force Microscopy (AFM). This shows how the varying intensities of the laser affect the films. It was found that the laser energy required for crystallization is highly dependent on the supporting material. Also interaction of these metals with the silicon film during the laser annealing process was studied. Increase in surface roughness was seen after laser annealing.

A6.9
GaAs Growth on Micro and Nano Patterned Ge/ Si1-XGexX Surfaces. Ganesh Vanamani¹, Abhaya K. Datey¹, Ralph Dawson² and Saleem H. Zaidi¹; ¹Chemical and Nuclear, University of New Mexico, Albuquerque, New Mexico; ²Center for High Technology Materials, University of New Mexico, Albuquerque, New Mexico.


SESSION A7: Poster Session: Metastability Tuesday Evening, March 29, 2005

Salons 8-15 (Marriott)

A7.3
Low-Intensity Dependence of the Staebler-Wronski Effect in a-Si:H with Various Densities of Defects. Minoru Kumasda¹, Ryohei Sakai¹, Akiharu Morimoto¹ and Tatsuo Shimizu²; ¹Div. Electrical Engineering and Computer Science, Grad. School of Natural Sci. and Tech., Kanazawa Univ., Kanazawa, Japan; ²NTT
The mechanism of the Stebler-Wronski effect in a-Si:H has not yet been clear, despite many efforts for a long time. According to Stutzmann, the density of photocreated dangling bond (DB) obeys the following relation with \( r = 2 \) in device quality a-Si:H, \( N_t(1) = N_s(t) = 0 \) and DB densities for illumination time \( t \) and before illumination, respectively. \( A \) is a constant, and \( G \) is the light intensity. However, the experimental studies to check the light-intensity dependence are less than the theoretical estimations previously reported. Recently, it was reported that the value of \( r \) becomes smaller with increasing the N content in a-Si:N:H alloy films [1]. A similar trend has been found in a-Si:H with increased DB density. Samples in which the neutral DB density had been increased to 2.6 x 10^{13} cm^{-3} (without surface contribution) by annealing at 400°C for 1 h exhibited a smaller value of \( r = 0.90 \) compared to the as-deposited samples. Furthermore, samples which had been illuminated with a light intensity of 1 W/cm² for 1 h and having the neutral DB density of 5.3 x 10^{13} cm^{-3} without surface contribution also showed a small value of \( r = 0.90 \). We tried to explain the observed results by using rate equations for the densities of DB and floating bonds (FB) based on the FB-mediated photocreation of DB[2]. When the densities of DB and FB before illumination increase, the light-intensity dependence of the DB density for a moderate value of the illumination time becomes weaker, qualitatively consistent with the observed results. The FB density first increases, having a maximum and then decreases, and then increases gradually toward the saturated value. After the FB density passes the minimum, the light-intensity dependence of the DB density approaches one with \( r = 2 \). The model of Stutzmann cannot explain the present results, and the mediation such as FB is needed for the photocreation of DB. It is possible that the H-mediated model of Branz can also explain the results.


A.7.2 Electronic Properties of Improved Amorphous Silicon–Germanium Alloys Deposited by a Low Temperature Hot Wire Chemical Vapor Deposition Process. Shawik Datta1, David Cohen1, Don L. Williamson1, Yueqin Xu2 and Hury Mahan3

1Physics, University of Oregon, Eugene, Oregon; 2Physics, School of Mines, Golden, Colorado; 3National Renewable Energy Laboratory, Golden, Colorado.

We have established superior electronic properties for a series of seven a-Si,Ge:H alloys with Ge fractions ranging from 20 to 80 at. %, including those produced by low temperature hot wire chemical vapor deposition (LPCVD) allows the obtention of high quality a-Si:H materials grown in a standard plasma deposition system. We report plasma electronic diagnostics, optical and electrical measurements, TEM image analysis and infra-red absorption spectroscopy of a/Si:H films deposited in a conventional plasma deposition process to determine the spectra of defect related optical transitions. Previous studies of the oxidation of a-Si:H films with Ge fractions ranging from 0 to 80 at. % have been carried out using rate equations for the densities of DB and floating bonds (FB) based on the FB-mediated photocreation of DB previously reported. Recently, it was reported that the value of \( r \) becomes smaller with increasing the N content in a-Si:N:H alloy films [1]. A similar trend has been found in a-Si:H with increased DB density. Samples in which the neutral DB density had been increased to 2.6 x 10^{13} cm^{-3} (without surface contribution) by annealing at 400°C for 1 h exhibited a smaller value of \( r = 0.90 \) compared to the as-deposited samples. Furthermore, samples which had been illuminated with a light intensity of 1 W/cm² for 1 h and having the neutral DB density of 5.3 x 10^{13} cm^{-3} without surface contribution also showed a small value of \( r = 0.90 \). We tried to explain the observed results by using rate equations for the densities of DB and floating bonds (FB) based on the FB-mediated photocreation of DB[2]. When the densities of DB and FB before illumination increase, the light-intensity dependence of the DB density for a moderate value of the illumination time becomes weaker, qualitatively consistent with the observed results. The FB density first increases, having a maximum and then decreases, and then increases gradually toward the saturated value. After the FB density passes the minimum, the light-intensity dependence of the DB density approaches one with \( r = 2 \). The model of Stutzmann cannot explain the present results, and the mediation such as FB is needed for the photocreation of DB. It is possible that the H-mediated model of Branz can also explain the results.


A.8.3 Study of the Oxidation of Polycrystalline SiGe: Formation of Ge Nanocrystals and their Related Luminescence. Carmelo Fernandez1, Manuel Avella1, Juan Carlos Delgado2, C. Barry Pflug3, A. Perlman4; 1Physics, School of Mines, Golden, Colorado; 2National Renewable Energy Laboratory, Golden, Colorado; 3Instituto Tecnologico e Nuclear, Sacaven1, Portugal; 4Instituto Tecnologico e Nuclear, Sacaven1, Portugal.

The oxidation of polycrystalline SiGe layers deposited by low pressure chemical vapor deposition (LP-CVD) allows the obtention of nanocrystalline Ge. The luminescence emission of the layers evolves with the oxidation time. In particular intense violet luminescence (3.1 eV) related to the Ge nanocrystals is observed. The properties of this emission can be controlled by the adequate selection of the oxidation parameters (time, temperature and atmosphere). Dry and wet oxidation were used to obtain the nanoparticles, showing differences that concern the evolution of the luminescence emission, the composition of the Ge layer during the oxidation and the composition of the grown oxides. The characterization study was carried out by cathodoluminescence, Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy and Rutherford backscattering (RBS). SiGe layers (Ge fraction, 0.3) with thicknesses of 35 and 15 nm, where used in each oxidation atmosphere in order to discern the emission of the grown oxide from the emission of the nanoparticles. The correlation between the violet luminescence, the Raman spectra and the FTIR data allows to obtain the oxidation time allows to establish that the violet luminescence is related to recombination at Ge related oxygen deficient centers located at the interface of the Ge nanocrystals with the oxide matrix. These recombination centers are formed by incorporated oxygen ions that are contained within the outer shell of the Ge nanocrystals formed by the oxidation of the continuous Ge layer segregated from the oxidized SiGe layer. The violet luminescence is not related to quantum confinement inside the
Ge nanocrystals, since the peak wavelength does not shift with the nanocrystal size. However, it reaches its maximum efficiency when the maximum surface area between nanocrystals and the oxide matrix is formed. On the other hand, once the Ge is fully oxidized the violet luminescence is fully quenched and two bands in the near infrared spectral range appear. The differences between the two oxidation mechanisms and the effects in terms of the composition of the oxide layers and the evolution of the poly SiGe layer, the formation of nanocrystals and the luminescence emission.

A8.4 Thermal and Laser Annealing of Si Nanocrystals, Implanted with B and P Ions. Gregory A. Kachurin1, S. G. Cherkova1, V. A. Volodin1, D. V. Marin1, V. G. Kesler2, A. K. Gutkovsky2, D. I. Tetelbaum3 and H. Becker3; 1Institute of Semiconductor Physics, Novosibirsk, Russia; 2Institute of Physics, Novosibirsky State University, Novosibirsk, Russia; 3Nizhniy Novgorod, Russian Federation; 4Laser Zentrum Hannover, Hannover, Germany.

Because of the great importance of Si for microelectronics, continuous downsizing of the devices and the ability of quantum-size Si nanocrystals to emit strong visible light, the interest in the development of techniques to create and modify Si nanocrystals has increased considerably. Ion implantation is the most commonly used method for the modification of the silicon device features. Here we report on the effect of 1013-1015 cm-2 B and P ions implantation and of subsequent annealing on the light-emitting Si nanocrystals (Si-ncs), formed preliminarily in the thermally grown SiO2 layers. The post-implantation heat treatments were performed by the 30 min furnace annealing in an inert ambient within the temperatures of 800-1100°C, in the presence of excimer laser pulses. Photoluminescence (PL), Raman spectroscopy, high-resolution electron microscopy, X-Ray Photoelectron Spectroscopy (XPS), and optical absorption were used for characterizations. The low fluence implantations have shown even individual displacements in Si-ncs quench their PL. Restoration of PL from partly damaged Si-ncs proceeds at annealing less than 1000°C. However the fully amorphized nanoinclusions need 1000-1100°C anneals to be re-crystallized, that is much more than the crystallization temperature of bulk Si. High-temperature annealing increases the Si-ncs size and the materials of capping shell of NC. To find out the effect of the nc-Si QDs. The direct recombination was observed by examining the QDs. The direct recombination was observed by examining the relation of the nc-Si QD size and the refractive index of the silicon nitride film. The PL peak energy and the refractive index of the films, which were grown by plasma-enhanced chemical vapor deposition. The composition of silicon nitride matrix was confirmed by XPS and FT-IR measurement. This result is positive evidence of direct recombination in nc-Si QDs.

A8.5 Experimental Evidence of Direct Recombination in Nanocrystalline Silicon Quantum Dots. Taeyoung Kim1, Nae-Man Park1, Kyung-Hyun Kim1, Kwan Sik Cho1, Gun Yong Sung1 and Anish G. Joshi1; 1Physics, Rutgers University, Piscataway Division, Electronics and Telecommunications Research Institute, Daejeon, South Korea; 2Nan Science & Technology, Univ. of Seoul, Seoul, South Korea.

Recently, a great deal of research effort was focused on the low-dimensional structures of indirect-gap materials such as silicon. Although the bulk crystalline silicon exhibit very weak luminescence due to the indirect bandgap in their electronic structures, silicon nanocrystals having a quantum confinement effect (QCE) have provided an efficient luminescence at room temperature due to the enhancement of electron-hole radiative recombination rate. Because the mechanism of the efficient photoluminescence (PL) from nanocrystalline silicon (nc-Si) is controversial and not well understood; it is important to clarify theoretically and experimentally the intrinsic optical properties in these quantum-confined structures. Many theoretical results have been shown to predict that in the sizes of nc-Si quantum dots (QDs), the band-gap energy is blueshifted into the short range of visible light and the type of the band-gap transforms from indirect to direct. Nevertheless, the experimental result has not been reported clearly about direct recombination in the nc-Si QDs having the QCE so far. In this work, we report on the experimental evidence for the QCE in zero-dimensional Si-ncs and the direct recombination in nc-Si QDs. The direct recombination was observed by examining the relation of the nc-Si QD size and the refractive index of the silicon nitride film. The PL peak energy and the refractive index of the films, which were grown by plasma-enhanced chemical vapor deposition. The composition of silicon nitride matrix was confirmed by XPS and FT-IR measurement. This result is positive evidence of direct recombination in nc-Si QDs.


One-dimensional silicon nanostructures have been successfully made by using the proximity and accumulation effects of electron-beam (e-beam) lithography. Wire structures are fabricated in a thin poly silicon layer on a silicon substrate with a 400 nm buried SiO2. Measurements of the current-voltage characteristics at various temperatures from 4 K up to 300 K show significant nonlinearities and single-electron effect behavior. The blockade size is significantly affected by thermal effects, oscillations of the blockade, and the conductivity dependence on the gate potential.

A8.7 Charging Effect of a Ne-Si in a SiO2 Layer with Respect to the Post-Sharpening Steps Using Scanning Probe Microscopy. S. H. Jin1, Y. Kang2, J. M. Son3, E. K. Lee4, J. M. Kim5, M. K. Choi6, Eunhye Lee7, Kyoyool Lee8, J. H. Lee8 and C. J. Kang9; 1Physics, Myongji University, Yongin, Gyeonggi, South Korea; 2Devices Lab, Samsung Advanced Institute of Technology, Yongin, Gyeonggi, South Korea; 3Department of Electrical Engineering, Myongji University, Yongin, Gyeonggi, South Korea; 4Materials Lab, Samsung Advanced Institute of Technology, Yongin, Gyeonggi, South Korea.

Scanning probe microscopy (SPM) with a conducting tip has been used to characterize the electrical properties of silicon nanocrystals (NCs). The NC samples were measured by aerosol techniques and followed by a sharpening oxidation for improving the uniformity of size distribution and isolation. Through the direct injection and removal of charge from the conducting tip, electrical properties were monitored and analyzed with respect to the shape, size and the materials of capping shell of NC. To find out the interface states formed after a sharpening oxidation, we also measured C/DV-V dependence of a NC with different capping shells and the results were compared with those of 100µm × 100µm MOS capacitor. Temperature dependence of charging and discharging of each NC were also measured and analyzed.

A8.8 Formation of Antimony 1D-Nanostructures on Si(5 5 12). Surface, S. M. Shivaprasad1, Mahesh Kumar1, Amish G. Joshi1 and Vinod Kumar Palwal1; 1Surface Physics & Nanostructures Group, National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi, New Delhi, India; 2Department of Physics, Panjab College (University of Delhi), Lodhi Road, New Delhi, New Delhi, India.

Oblate, high index Si surfaces like, {5 5 12} are being probed for forming 1D nanostructures in the form of nanowires or chains. The surface topography of Si(5 5 12) presents a single-domain planar reconstruction that is composed of row like structures having nanoscale widths providing a unique template for the growth of 1D nanostructures. In this paper we are reporting the adsorption-desorption studies of Sb onto (2x1) reconstructed surface of Si(5 5 12). Earlier, we have reported [1,2] the adsorption of Sb on low index surfaces (001 and 111), and thus studying its interaction on high index like {5 5 12} surface is interesting. The experiments were performed UHV with in-situ growth and probed by using AES, LEED and EELS studies. The AES uptake curve taken at RT shows the presence of multiple features that may arise due to the presence of row-like surface topography of (5 5 12). Initially, the Sb adsorption takes place in the form of simultaneous multilayers up to 4ML that gives rise to an island type of growth for coverages upto 20ML. During RT growth, LEED studies at submonolayer coverages show that Sb adatoms preferentially occupy the secondary and tertiary rows, which have higher dangling bond density as compared to primary rows that are devoid of any dangling bonds. The LEED pattern of clean Si(5 5 12) surface shows alternate sharp lines and spot patterns characteristic of the (2x1) reconstruction. In LEED photographs this can be seen as the disappearance of regular LEED spots within the main lines leaving some equal spaced intense spots for submonolayer coverages. It is also observed that for Sb coverages above 1ML, the remaining strong LEED spots along the lines also
1Electrical Engineering and Computer Sciences, University of California, Berkeley, Berkeley, California; 2Electrical Engineering, University of Arkansas, Fayetteville, Arkansas.

We report on a procedure for the synthesis of fluorescent silicon nanowires using aluminum thin film as a catalyst. The formation mechanism of the nanowires is based on the diffusion of silicon in the aluminum thin film. The silicon stops at the film grain boundaries. The growing Si crystals accumulate at the film grain boundaries, which gives rise to an array of Si nanowires perpendicular to the substrate. Characterization of the nanowires has been done using scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS). These nanowires are unique in the sense that the nanowires grown in a horizontal fashion instead of the more common vertical direction. Most of the nanowires have a diameter of about 50-60 nm and a length of over 10 gm.

A8.10 Synthesis of Fluorescent Si Nanomaterial Films from Silicate Water Glass Solutions. Munir H. Nayfeh1,2 and Laila Abdassam1.
1Physics, University of Illinois, Urbana, Illinois; 2Research Division, NanoSi Technologies, Champaign, Illinois.

We report on a procedure for the synthesis of fluorescent silicon nanomaterials from silicates or water glass solutions. When a positively biased platinum substrate is immersed in a solution of sodium metasilicon salts (Na2SiO3) in H2/H2O, a current is drawn and a thin coating is formed on the substrate. Fluorescence spectroscopy and microscopy, Fourier transform infrared spectroscopy (FTIR), and material analysis using x-ray photo spectroscopy (XPS) and Auger electron spectroscopy (AES) show that the film consists of silicon-coated platinum. The films are characterized by 2.85 nm diameters and 3.0 nm diameter nanostructures. The films are useful in large-area electronic and optoelectronic applications.

A8.11 Hot-mesh Chemical Vapor Deposition for 3C-SiC Growth on Si and SiO2. Kanji Yasui, Jynphee Eto, Yasuara Narita, Masakazu Takata and Tadashi Akahane; Electrical, Electronic and Information, Nagasaki University of Technology, Nagasaki, Japan.

SiC is a wide bandgap semiconductor expected in the field of electronic devices for high frequency, high power and high temperature applications. Among many polypeptide, cubic SiC (3C-SiC) is stable phase at low temperatures and can be grown on Si substrates. Therefore, the epitaxial growth of 3C-SiC on Si substrates has been extensively investigated. In the conventional chemical vapor deposition (CVD), however, SiC growth at high temperatures (>1000 deg C) inevitably results in the growth of voids at SiC/Si interfaces. It is important for the fabrication of high quality SiC/Si system to lower the growth temperature. In addition to the SiC growth on Si substrates, fabrication of the SiC on insulator (SOI) structure has been extensively investigated for the MEMS applications. In our previous studies, 3C-SiC epitaxial films were grown at 900 deg C by triode plasma CVD using organosilicon compounds such as monomethylsilane (MMS) and dimethylsilane (DMS) as source gases, while those were not grown at the low temperature by low pressure (LP) CVD using the same source gases [1]. From the experiments by triode plasma CVD, H radicals generated in the RF plasma was considered to induce desorption of H atoms and excessive methyl-groups from source molecules on the growing film surface. In the plasma CVD process, however, incident of the charged particles such as ions and electrons may degrade the crystal structure during the SiC growth. By catalytic reaction on hot-tungsten (W) wire, the SiC growth can be effectively decomposed and high density of hydrogen radicals can be generated [2]. In this study, the growth of 3C-SiC on Si(100) and SiO2 substrates was investigated by hot-mesh (HM) CVD, which utilizes a hot W wire of a mesh structure as a catalyst. From the X-ray diffraction spectra SIC films grown by HM CVD using MMS, it was found that 3C-SiC films were epitaxially grown at above 750 deg C, while those grown by LP CVD were amorphous. From the experimental results of SiC growth on SiO2 layer, poly-crystalline SiC films were grown at the substrate temperature above 900 deg C, while <100> oriented SiC films were grown at the substrate temperature of 750 deg C at 900 deg C. Above 900 deg C, H atoms can be thermally desorbed from Si-H and C-H bonds present at the growing film surface. On the other hand, H atoms of C-H bonds cannot be thermally desorbed at 750 deg C. Therefore, the growth of <100> oriented SiC films at 750 deg C is considered to be the result of a reaction between H radicals and precursors on the growing film surface.

A9.2 Spectral Sensitivity and Color Selectivity in Multilayer Stacked Devices. Paula Louro1, Fernandes Miguel1, Alessandro Fantoni1, Guilherme Lavareda2, Carlos Nunes de Carvalho2, Yuriy Vygranenko1 and Manuela Vieira1; 1DEETC, ISTL, Lisbon, Portugal; 2CFM, UTL, Lisbon, Portugal.

Color detection in two terminal silicon based devices is based on the spatially separated absorption of different wavelengths. The discrimination between the different absorption regions becomes complex when three color information is required. In this work an attempt of full color discrimination is presented. The sensitive devices are multilayer stacked structures ([p(SiC:H)/(Si:H)n(SiC:H)/p(SiC:H)/(Si:H)n(SiC:H)]) sandwiched between two transparent electric contacts. The thickness and the absorption coefficient of the front p-n cell is optimized for blue detection and red transmittance and the thickness of the back one adjusted to achieve full absorption in the green and high transmittance in the blue spectral ranges. Color discrimination is achieved through the modulation of one, two or both cell depletion regions by an applied external voltage.
Photocurrent and spectral response under different steady state optical bias (AL=650 nm; 550 nm; 450 nm; 0-400 STC =20) and applied voltage for full color discrimination and to evaluate the sensor responsivity to different light wavelengths, the photocurrent generated by a modulated red light (AS=650nm) is measured under different optical bias. In these measurements, the e-H back absorber element is illuminated through the back diode with red modulated light and the optical bias applied through the front diode side. Result shows that the conversion efficiency to a red modulated light under blue optical bias is maximized when the front diode is 800-a-Si:H/AI photodetector is unipolar and minimized in the red range if the absorber layer of the back diode is around 1 μm thick. In those devices the green photons absorption mainly occurs across the front diode, the n-p defects interface and at the front back diode. Under red illumination the a-Si:H back absorber acts as a load due to the light penetration depth 5μm and the red photons and the collection is almost independent and determined by the dark characteristics of the front diode. In the green spectral range as the reverse bias increases due to the increase of the potential drop across the back diode the collection increases linearly. The effect of the applied voltage on the color selectivity and spectral sensitivity is discussed and compared by a physical model that takes into account the experimental data and the results obtained through a detailed numerical simulation based on the ASCA simulator.

**A9.3 Application of SC-Simul for Numerical Modeling of the Opto-Electronic Properties of a-Si:H/c-Si Heterojunction Diodes, Budapest Bruggemann, Maximilian Horsch, Saloo Tardon and Gottfried H. Bauer; Institut fur Physik, Carl von Ossietzky Universitat Oldenburg, Oldenburg, Germany.**

We present the numerical-modelling programme SC-Simul which is available free of charge. In addition to stationary device modelling, time-dependent experiments can also be treated for which the progress in the time-dependent current, carrier and other distributions within the devices can be inspected. Typical devices that can be modelled are a-Si:H pin diodes and a-Si:H/c-Si heterojunction diodes. The presentation focuses on the latter devices and shows simulation results on current-voltage characteristics, photocurrent, photoluminescence, and electroluminescence, for which the influence of interface defects is shown to be strong. We detail the role of an intrinsic a-Si:H buffer layer between the doped a-Si:H layer and c-Si wafer and how its influence on device behavior is also determined by the density of interface defects. Based on these simulation results we shall also comment on the conflicting experimental results in the literature on the benefits of such a buffer layer.

**A9.4 Two-Dimensional a-Si:H/a-Si:H n-i-p Sensor Array with ITO/a-SiN, Antireflection Coating, Yuriy Vygranenko, Jeff Chang and Arokia Nathan; Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.**

This paper presents a two-dimensional a-Si:H/a-Si:H n-i-p photodiode array with switching diode readout, developed specifically for fluorescence lifetime imaging microscopy. This device structure and fabrication processing has enabled enhancement of the external quantum efficiency of the encapsulated device up to 80%, reduction of the photodiode leakage down to 10 pA/cm² at -1 V reverse bias, and increase of the rectification current ratio of the switching diodes up to 109. The critical fabrication issues associated with deposition of device-quality materials, tailoring of defects at the i-p interface, device patterning with dry etching, junction passivation, and contact formation, will be discussed, both sensing and switching diodes were characterized. While the observed dark current in the photodiodes at low reverse bias voltages is primarily due to carrier emission from deep states in the a-Si:H bulk, the leakage in the small switching diodes stems from pinched-off defects along junction sidewalls. Optical losses in the photodiodes with ITO/a-SiN, H antireflection coating were evaluated by numerical modeling, and the calculated transmission spectra correlated well with the experimental data. Measurements of the charge transfer time and output linearity demonstrate the efficiency of the single-switching diode readout configuration. The response of the array to optical excitation was also investigated. The observed long-term retardation in the signal rise and decay at illumination levels less than 10^6 photons/ cm²·s can be associated with charge trapping in the undoped layer.

**A9.5 Amorphous Silicon Based p/in Structure for Color Sensor, Shihan Zhang, Leandre Raniero, Elvira Fortunato, Isabel Ferreira, Hugo Aguiar and Rodrigo Martins; Material Science, Faculty of Science and Technology, New University of Lisbon and CEMOP-UNINOVA, Caparica, Portugal.**

The optical band gap of hydrogenated amorphous silicon can be modified by adding controlled amounts of carbon or germanium during the deposition. The amorphous silicon based photodetectors can be obtained with sensitivities ranging from the ultraviolet to the infrared. In the last years, bias controlled two- and three-color detectors on stacked a-Si:H/a-Si:H heterojunctions have been extensively investigated. This work deals with the study of the devices and the composition on the colour selection of the collection spectrum of glass/ZnO:Ga/a-Si:H/a-Si:H x-oxyl/ch/a-Si:H/a-Si:H/Al single chamber plasma enhanced chemical vapour deposition (PECVD) system. The cross contamination were minimized by a rotation cover substrate holder system. The devices can detect the blue illumination at full reverse bias and the red photons in the red range and the green photons in the red range if the absorber layer of the back diode is around 1 μm thick. In those devices the green photons absorption mainly occurs across the front diode, the n-p defects interface and at the front back diode. Under red illumination the a-Si:H back absorber acts as a load due to the light penetration depth 5μm and the red photons and the collection is almost independent and determined by the dark characteristics of the front diode. In the green spectral range as the reverse bias increases due to the increase of the potential drop across the back diode the collection increases linearly. The effect of the applied voltage on the color selectivity and spectral sensitivity is discussed and supported by a physical model that takes into account the experimental data and the results obtained through a detailed numerical simulation based on the ASCA simulator.

**A9.6 Hydrogen Content in Silicon Nitride Films Deposited by PECVD and used as Support Layer and Absorber Layer for Uncooled Microlithometers, Roberto Carlos Ambrozio, Alfonso Torres, Andrei Kosarev, Mauro Landia and Adrián Izmeryoñ; Electronics, INAGE, Puebla, Mexico.**

We have studied silicon nitride films SiNx deposited by Low frequency (LF) PECVD technique at the substrate temperature Ts=350°C using silicon antireflection films deposited by PECVD including hydrogen bonding and content, nitrogen content, refraction index and etch rate are reported and analyzed. The results show similar physical properties to those in the films obtained at Te=700°C by LPCVD. The comparative investigation of bonding structure by FTIR analysis was achieved, and the quality of hydrogen bonding based on FTIR analysis are presented. It was observed that low hydrogen content in the films correlated with low etch rate in 10% buffered HF solution, therefore those films present a material with a good selectivity for etching in respect to others (PSG, Al etc). It makes promising to employ the films in surface micromachining for fabrication of device structures, e.g. microlithometers. Additionally, the N-1 band at 830-840 cm-1 was analyzed due to the absorption presented in the hydrogen. This film can be used as absorber layers in uncooled microlithometers.

**A9.7 Fabrication and Characteristics of FeSi2-Si Based Infrared Light Emission and Detection Devices, C. F. Chow1,2, S. P. Wong1,2, Y. Gao1,2, N. Ke3, Q. Li3, W. Y. Cheung1,2, M. A. Lourenço4 and K. P. Hon4; 1Electronic Engineering, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; 2Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; 3Materials Science and Technology Research Centre, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; 4School of Electronics Engineering, Computing and Mathematics, University of Surrey, Guildford, Surrey, United Kingdom.**

Silicon-based optoelectronics has been a topic of increasing research interest in the past decade and there has been significant progress towards a working Si-based light emitting device despite the indirect bandgap nature of Si. For example, electroluminescence (EL) at room temperature was recently reported from Si metal-oxide-semiconductor (MOS) structures [1] and room-temperature emission from beta-FeSi2 LED was also successfully demonstrated [2]. In this work, MOS structures were fabricated on Si with oxide layer grown by well-controlled rapid thermal oxidation (RTO). The FeSi2 nanocrystals were formed inside the MOS active region by iron implantation using a metal vapor vacuum arc ion source at various conditions. EL properties from these FeSi2-Si MOS structures after varying the thermal treatment from 80 to 300K. Our preliminary results showed that clear EL signals were obtained even at room temperature for some of the devices prepared at appropriate processing conditions. Details on the fabrication and thermal treatments of these devices and the dependence of the EL properties on the processing parameters will be presented and discussed. Metal-semiconductor-metal (MSM) photodetector device structures based on the implanted FeSi2-Si system have also been fabricated and their performance as Si-based IR detectors will be reported. This work is partially supported by the Research Grants Council of Hong Kong SAR (ref. no. CUHK 4231/03E), and C.N. Yang Optical Science Fund (1) M.-J. Chen et al., J. Appl. Phys. 83 (2003) 4652 [2] M.A. Lourenço et al., Nucl. Instr. Meth. H206 (2003) 436.
A9.9 Effect of Post-Oxidation of Silicon Nanocrystals as a Floating Gate of Nonvolatile Memory: Jung Min Kim1, Min Ki Choi, Y. Khang2, E. K. Lee3, Eun Hye Lee3, Kyo Yeol Lee4, Joo Hyun Lee5, C. J. Kang6, 1Electrical Engineering, Myongji University, Yongin, Gyeonggi-Do, South Korea; 2Polystyrene, PMMA, di-chloro di-methyl Silane (DDMS) and Sylgard etc. have been tried. We find that polystyrene and PMMA arrest the photo-induced degradation of PS up to the maximum duration tested (300hrs). However, PS samples coated with DDSMS and Sylgard continue to degrade upon LS. FTIR shows appearance of new bonding configurations at the PS/polymer interface. These may be responsible for the improved stability of PS after polymer coating, by making stronger bonds. The changes at the interface after LS in the DDSMS and Sylgard coated PS, which show degradation, will be compared with those found in the PMMA and polystyrene coated samples and the factors responsible for the stability of PL will be examined. It is interesting to note that although Polystyrene coated PS is stable, a coating of SiO2 does not remove the SWE, although it makes it somewhat smaller. This and other differences between the degradation of a-Si:H and PS layers will be discussed.

In this work, electrical properties of Si nanocrystals(NCs) were analyzed with respect to the post-oxidation; shell formation of NCs. The Si nanocrystal samples produced by pyrolysis and laser ablation methods were followed by sharpening oxidation steps. In this step Si NCs are capped with a thin oxide or nitride layer of 1~2nm for isolation and the size control. It also affects the interface states of NCs, resulting in the change of electrical properties. To find out this effect, conversion measurements were done on a MOS capacitor structure. And the results were analyzed for the size, density, shell materials and shell thickness of NCs. We also present localized property of a Si nanocrystal observed by scanning probe microscopy (SPM).

SESSION A10: Growth II: Microcrystalline Films
Chair: Michio Kondo
Wednesday Morning, March 30, 2005
Room 2002 (Moscone West)

8.30 AM A10.1 Room Temperature Deposition of Nanocrystalline Si Thin Films. Rushikesh Chaudhakshar Mani and Eray S. Aydil; Chemical Engineering, University of California Santa Barbara, Santa Barbara, California.

Hydrogenated nanocrystalline silicon (nc-Si:H) has tremendous potential for various applications in solar cells, thin film transistors (TFTs) for flat panel displays, single-electrode transistors and memory devices, and Si-based light emitting diode (LED) devices. At low temperature (100 °C) deposition of nc-Si:H thin films is desirable for manufacturing devices on flexible and inexpensive substrates (e.g. plastic). Plasma enhanced chemical vapor deposition (PECVD) presents an affordable synthesis method for large area deposition of nc-Si:H thin films. We demonstrate the deposition of thin films containing nanocrystals of silicon using an inductively coupled plasma source and SiH4 diluted in H2 at room temperature on silicon and GaAs substrates. In situ surface and diagnostic techniques, such as attenuated total internal reflection - Fourier transform infrared spectroscopy (ATR-FTIR) and spectroscopic ellipsometry (SE), were used to probe the surface and bulk silicon hydrides species (SiHx) and to determine the thickness of the growing film, respectively. The change in the substrate temperature was carefully monitored using the infrared radiation transmission through the ATR crystal in our ATR-FTIR setup. The possibility that nanocrystal formation is due to plasma heating. The deposited films were characterized using ex-situ techniques such as Raman spectroscopy, grazing angle X-ray diffraction (XRD) and transmission electron microscopy. The deposited films show a nanocrystalline fraction in the grain sizes of 3~10 nm in the as-deposited films and 1 to 100 nm in the high temperature. The in situ ATR-FTIR and SE data are consistent with H-induced ordering of amorphous silicon layers which leads to the nucleation of nanocrystals within the film.


Nanocrystalline Ge:H is a potentially important material for solar cells and image sensors. In this talk, we describe the growth and properties of nanocrystalline Ge:H films and devices. The films and devices were grown using a remote ECR plasma discharge. The precursor gases were germane, diluted 10% in hydrogen, and hydrogen. The ratio of hydrogen to germane was systematically varied to study the influence of hydrogen etching. The deposition pressures were low, in the range of 5 mTorr. The deposition temperatures were varied between 150 °C and 300 °C. The films were measured for their carrier concentration and mobility, using Hall effect measurements as a function of temperature. The films were measured for their structure using x-ray diffraction and Raman spectroscopy. From x-ray diffraction, it was found that the grains had <220> orientation and the grain sizes achieved were usually large, ranging from 100 to as high as 85 nm. All the films showed a sharp Raman peak at 300 cm-1, characteristic of crystalline Ge. It was discovered that as hydrogen etching increased, the grain sizes decreased. Similarly, increasing power decreased the grain size for a given hydrogen dilution and deposition temperature. At very low growth temperatures, the grain size decreased. All the films were n type as grown. The doping varied between 1E16 and 1E17/cm3. Dopings could be changed by adding ppn levels of Band P during growth. The mobilities were observed to be 8 cm2/V-sec. Proof of concept p-i-n junction solar cell devices were made on single crystals. The devices showed quantum efficiency extending out to 1300 nm. By adding Si to Ge, the open-circuit voltage could be systematically increased.

9:00 AM A10.3 Influence of Pressure and Plasma Potential on High Growth Rate Microcrystalline Silicon Grown by VHF PECVD. Aad Gortijn, Jeroen Franske, Janatanda Kumar Rathi and Rudi E. I. Schropp; Duy Institute, SID-Physics of Devices, Utrecht University, Utrecht, Netherlands.

Microcrystalline Silicon (µc-Si) based single junction solar cells are deposited by VHF PECVD using a microwaves heated hot chuck at high pressures in depletion conditions. At a deposition rate of 1.3 nm/s, a stabilized conversion efficiency of 6.9% is obtained for a single junction solar cell with a µc-Si i-layer of 1 µm thick with a thin Ag back contact. The i-layer is made near the transition from amorphous to crystalline. In order to control the material properties in the growth direction, the hydrogen dilution of silane in the gas phase is graded following different profiles with a parabolic shape. It is observed that the performance of solar cells improves under light soaking conditions at 50 °C (in 400 hrs, the FF improved from 0.67 to 0.70 and the diode quality factor from 1.81 to 1.72), which we attribute to post deposition equilibration of a fast deposited transition material. Upon increasing the deposition temperature, the mobilities were observed to be 8 cm2/V-sec. A high efficiency of 7.1% (initial) with a ZnO/Ag back reflector. The performance is generally lower at higher rates due to poorer i-layer quality (higher defect density) due to smaller relaxation times for growth processes, resulting in a higher energy ion bombardment at higher plasma power. High process pressures can be used to reduce the ion energy by decreasing the mean free path. The product of the maximum pressure and the electron free path at which the process is performed, limits the range of this method. As an alternative method to limit the ion energy, we control the DC self bias voltage using an external power source. In this way the quality of the µc-Si layers and the performance of the solar cells can be further improved.

9:15 AM A10.4 Seed-Layers for the Preparation of Hydrogenated Microcrystalline Silicon with Defined Structural Properties on Glass. Christoph Ross, Yaohua Mai, Reinhard Carus and
The substrate dependence of the growth of microcrystalline silicon (μc-Si:H) generally limits the possibilities of characterization of device-grade material. For example, a deposition process leading to highly efficient cells in a layer-by-layer deposition on glass with different properties on glass, which is a common substrate for material characterization. This limitation could be overcome if one substitutes the thin- or "seed-layer" on which a microstructure similar to that of "seed-layer" coated glass, and p-type μc-Si:H. The hydrogen dilution of the silane source gas is varied in order to cover the full range from highly crystalline to amorphous growth. For "seed-layers" we use thin μc-Si:H prepared with high hydrogen dilution in a separate PECVD step. Results from Raman spectroscopy, electrical conductivity measurements, and photothermal deflection spectroscopy (PDS) are presented. While the contribution of the "seed-layer" to optical absorption and Raman mode excitation can be neglected, the conductivity is corrected for the "seed-layer" contribution. High hydrogen dilution leads to highly crystalline material for all substrates, where no significant differences in microstructure are detected. On the other hand, major differences occur for a wide range of lower hydrogen dilution including optimum conditions for solar cell preparation as well as the microcrystalline-to-amorphous transition regime. Hot-wire-CVD of "seed-layers" [1] for achieving a crystalline content higher than of layers on bare glass and close to layers on p-type μc-Si:H. (2) For creating a homogeneous structure throughout the layer, and (3) shifting the position of the microcrystalline-amorphous transition towards lower hydrogen dilution. Moreover, the "seed-layer" is effective for reducing stress as can be seen from film adhesion on flat substrates. Finally, as a consequence of improved homogeneity, artifacts in the PDS spectra, which occur for moderately crystalline material on bare glass, are strongly reduced. Absorption data which are gained in this way are in good agreement with structural data obtained by Raman spectroscopy. It is concluded that "seed-layers" of the present type significantly improve material characterization for device-grade μc-Si:H films. [1] O. Vetter, M. Hiilsbeck, J. Wolff, R. Carius, F. Finger, Thin Solid Films 427, 48 (2003).

9:30 AM A10.5

We measure times for complete solid phase crystallization (SPC) of a-Si:H thin films that vary eight orders of magnitude from a few days to a few minutes as a function of deposition conditions. The activation energy is approximately 1.6 eV and depends little on film thickness or deposition rate. Hydrogenated amorphous silicon (α-Si:H) films, 1-7 μm thick, were deposited by high deposition rate (100-1000 Å/s) hot-wire chemical vapor deposition (HWCVD). We annealed these a-Si:H films over a wide temperature range (0.5 to 1300 °C) using temperatures of such radicals are responsible for the bond-breaking. We have developed a deposition method to reduce Si-H2 concentration in the i layer using a triode-plasma chemical vapor deposition method, where a plasma was separated from the film deposition region and hydrogen dilution leads to higher Si-H2 bond density in the i layer. We have employed the i layer deposited by a triode system to p-i-n type a-Si:H solar cells. The p-i-n type solar cells were fabricated on a textured SnO2/glass substrate (ASAHI VU type). By applying triode system, Si-H2 concentration decreased to about one third (1.7% for conventional parallel-plate-electrode to 0.6% for a triode configuration), and correspondingly the degradation ratio decreased from 10% to 5% by optimization in the triode plasma system. Further improvement has been developed using a proper hydrogen dilution for the i layer and an antireflection layer between TCO and the p layer. As a result, we have achieved the stabilized efficiency of 8.1% with degradation ratio of 8% in n-type a-Si:H solar cells has been reported [2]. In this study, we have employed the i layer deposited by a triode system to p-i-n type a-Si:H solar cells. The p-i-n type solar cells were fabricated.
double p-layer structure. The solar cell has a structure of glass/SiO$_2$/undiluted p-a-SiC:H/p-diluted p-a-SiC:H/p-type a-Si:H/AI. The intrinsic p-Si:H (p-i-p-Si:H) multilayers were prepared by alternate H$_2$ dilution under continuous ultraviolet (UV) light irradiation using the photo-CVD system. From the Fourier transform infrared (FTIR) and photoluminescence (PL) measurements, unique characteristics of the p-Si:H multilayer absorber, which is different from those of conventional undiluted amorphous silicon (a-Si:H) absorbers. In particular, the p-Si:H multilayer absorber exhibits a superior light-soaked metastability when compared to conventional p-Si:H absorbers. In order to improve the p-Si:H multilayer solar cell performance, we adopted an a-Si:H double p-layer structure. A lightly boron-doped (1000 ppm) H$_2$-diluted p-type a-SiC:H (p-a-SiC:H) buffer layer with a high conductivity, and well-defined film structure, and slow deposition rate improves the open-circuit voltage ($V_{oc}$), short-circuit current density ($J_{sc}$), and fill factor (FF) of the solar cells by the Tauc-Lorentz silicon photodiode. This simple, non-invasive technique, allowed us to front from powder generated in the plasma using a 419nm Ar-laser and a high efficiency single junction solar cells incorporating high deposition rate correlation between the causes of powder formation and cell changing the deposition temperature and/or adding germane to the gas mixture. We found that while the initial performance is similar, the highly conductive buffer layer effectively increases the built-in potential at the p/i interface, diminishing electron back diffusion to the window layer. Thus, we have achieved a high initial efficiency of 10.4 % without using a double back reflector such as ZnO/Ag and also achieved a highly stabilized efficiency of 9.0 % after about 10 h (100mW/cm$^2$, AM 1.5) light irradiation.

SESSION A11.3
Correlation between Powder in the Plasma and Stability of High Rate Deposited a-Si:H.
Guozhen Yue, Gautam Ganguly, Baojie Yan, Jeffery Yang and Subhendu Guha; United Solar Ovonic Corp., Troy, Michigan.

Improvement of the stability of hydrogenated amorphous silicon (a-Si:H) alloys deposited at high rates is perhaps the most important task for cost reduction of solar cells based on this material. On one hand, correlations between higher silane density (from mass spectroscopy), the deposition rate of silicon dimers, the flow rate, and the stability of devices have been investigated [1]. On the other hand, it has been shown that solar cell intrinsic layers incorporating clusters produced in the plasma are more stable than standard a-Si:H [2]. Here we report our efforts to ascertain which of these observations is valid in a reactor used to fabricate high efficiency single junction solar cells incorporating high deposition rate (8-10Aper s) intrinsic layers using modified very high frequency (MVHF) plasmas. We have monitored the light scattered at 90° from powder generated in the plasma using a 419nm Ar-laser and a silicon photodiode. This simple, non-invasive technique, allowed us to use the same reactor used to make the solar cells. We first studied the change in the light scattered signal as a function of the total gas flow keeping the hydrogen to silane ratio (R) constant. We verified that, as has been reported previously [4], a maximum in the scattered light intensity is observed with increasing flow rate. We then compared the initial performance and the light induced degradation of two sets of single junction cells of similar intrinsic layer thickness as a function of the flow rate. We found that while the initial performance is similar, the stable efficiency was the lowest and the relative degradation the highest at a flow rate where the powder scattered light intensity was maximum. It is reasonable to conclude that there is indeed a correlation between the causes of powder formation and cell degradation as suggested in reference 1 and this is in contradiction with the results of reference 2. We have investigated the effects of changing the deposition temperature and/or adding germane to the gas mixture. These experiments reveal surprising behavior of the powder density with both variables. The behavior can be understood qualitatively by considering the rates of formation (reactions between radicals) and removal (gas flow, temperature gradient) of the powder particulates. We expect to use this formulation to devise the optimum deposition conditions and reactor design for minimizing the effects of powder, and for improving the stability of devices. [1] R. Roca i Cabarrocas et. al., Proc. 2nd World Conf. on PVSEC, Vienna, 1998, p-929 [2] P. Roca i Cabarrocas, MRS Symp. Proc.507 (1998) p-855 [3] J. Yang et. al., MRS Symp. Proc 664 (2001) p-A11.3.1 [4] Y. Matsunaka et. al., Jpn. J. Appl. Phys. 38 (1999) p-4556

SESSION A12: Photonic Devices: Experiment and Theory

Chair: Richard Weisfield
Wednesday Afternoon, March 30, 2005
Room 2002 (Moscone West)

1:30 PM *A12.1 Photonic Band Gap Materials: Engineering the Fundamental Properties of Light. Sajeev John, Physics, University of Toronto, Toronto, Ontario, Canada.

Photonic Band Gap (PBG) materials are artificial, periodic, dielectrics that enable engineering of the most fundamental properties of electromagnetic waves. These properties include the laws of reflection, diffraction, and spontaneous emission of light. Unlike traditional semiconductors that rely on the propagation of electrons through an atomic lattice, PBG materials execute their novel functions through selective trapping or “localization of light” using engineered defects within the dielectric lattice. This is of great practical importance for all-optical communications and information processing. Three-dimensional (3D) PBG materials offer a unique opportunity for simultaneously (i) synthesizing micron-scale 3D optical circuits that do not suffer from diffraction losses and (ii) engineering the electromagnetic vacuum density of states in this 3D optical micro-chip. This combined capability opens a new frontier in integrated optics as well as the basic science of radiation-matter interactions. We review recent approaches to micro-fabrication of photonic crystals with a large 3D PBG centered near 1.5 microns. These include direct laser-writing techniques and holographic lithography. We review the concept of a hybrid 2D-3D PBG hetero-structure in which a 2D photonic crystal micro-chip layer is suitably lattice matched and embedded within a 3D PBG material. This microchip layer contains optical wave-guides and optical cavities - that enable frequency selective control of spontaneous emission of light from atoms. Unlike traditional wave-guides that confine light in a high refractive index medium using total internal reflection, these air-wave-guides operate using the principle of light localization for confinement of light along a low refractive index path. We demonstrate a nearly universal approach to ultra-thin, three-dimensional, integrated optics in general 3D PBG architectures. These 3D optical circuit paths are constructed using broadband, loss-less, chip-to-chip interconnects between 2D micro-chip layers,
intercalated within the 3D PBG host material. Unlike electronic micro-circuitry, each air-wave-guide path can simultaneously conduct hundreds of wavelengths of light through the 3D micro-channel. In addition to exhibiting diffraction-less flow of light through micro-scale bends, this optical micro-channel allows the engineering of very large and abrupt changes in the local electromagnetic density of states as a function of frequency. This leads to unprecedented frequency selective control of spontaneous emission, modification of the blackbody radiation spectrum, and some fundamentally new optical functions unattainable in conventional photonicics.


For standard visible and near-infrared light detectors, the detection is generally described using photon energies and numbers. For radio frequency waves picked up using an antenna and diode, i.e., a radio receiver, classical electromagnetics is fully adequate to describe the detection. But neither approach works when an antenna and diode are used to detect higher energy radiation in what is generally thought of as the domain of photons. We describe the operation and design of a detector comprising a micro-antenna and an ultra-high-speed metal-insulator tunneling diode. When the photon energy is on the order of or larger than the scale of the diode nonlinearity, we describe the detection using a semiclassical approach. The detector can pick up radiation from gigahertz to infrared (carrier) frequencies, and detect signals at up to terahertz/sec sensitivities. By incorporating a double-insulator quantum well we provide a high-performance detector for efficient detection. This crystal radio for photons is a practical, integratable thin-film detector for a wide range of applications from broadband communications, through terahertz imaging, to ultra-high-speed infrared detection.

2:30 PM A12.3 New Light Trapping in Thin Film Solar Cells Using Textured Photonic Crystals. Lirong Zeng, Yasha Yi, Ching-Yin Hong, Xiaomin Duan and Lionel C. Kimerling; Materials Science and Engineering, MIT, Cambridge, Massachusetts.

Thin film solar cells are leading candidates for next generation photovoltaic applications due to lower materials costs and simpler device manufacturing technology. However, one crucial problem for thin film solar cells is the short optical path length, which prevents the sufficient absorption of light. In order to improve cell efficiency, it is important to enhance the optical path length, that is, to trap light in the cell. We have successfully developed a new light-trapping scheme applicable to all thin film solar cells by using novel photonic structure on the backside reflector. Our back reflector design combines reflection grating of substrates with distributed Bragg reflector (DBR). It makes incident light strongly bent and reflected almost parallel to the substrate of the absorber layer; hence the optical path length can be enhanced by a factor of one thousand, more than two orders of magnitude longer than that obtained by conventional light-trapping schemes. Furthermore, it provides extremely high reflectivity with large optical bandgap over several hundred nanometers in the solar spectrum range. The reflectivity of our Si/SiNx DBR reaches 99.6%, while that of our Si/SiO2 DBR is as high as 99.98%, which is significantly higher than that of the best Al reflector (R<99%). Therefore, almost all the incident light with an energy higher than the bandgap of the absorption layer material can be completely absorbed and converted to electron-hole; in turn the quantum efficiency of the solar cells will be enormously enhanced by our new light trapping scheme.

SESSION A13: Metastability Chair: Iana Riewe

Wednesday Afternoon, March 30, 2005 Room 2002 (Moscone West)

3:15 PM A13.1 Effect of Fermi Level Position in Intrinsic a-Si:H on Evolution of Defect States under Light Exposure. Miro Zeman1; Vojtech Nadazy1,2; Rudolf Durny3 and Wim Metselaar; 1Delft University of Technology, Delft, Netherlands; 2Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia; 3Slovak University of Technology, Bratislava, Slovakia.

Inherent to hydrogenated amorphous silicon (a-Si:H) are the reversible changes in electronic properties of a-Si:H under light exposure, known today as the Staebler-Wronski effect. It is generally accepted that light soaking leads to the creation of additional dangling-bond defects, which deteriorate the performance of a-Si:H devices such as solar cells. However, dangling bonds alone are not sufficient to explain changes in solar cell characteristics under light exposure. Recently, the presence of defects other than dangling bonds has been proposed [1-3] that are expected to play a role in the degradation of a-Si:H cells. We present experimental results from charge deep-level transient spectroscopy showing the evolution of the programmed defect-states distributions in intrinsic a-Si:H due to light soaking. This evolution is expected to take place at the p/i and n/i interfaces of the cells. By applying a positive (negative) bias voltage to a metal/insulator/a-Si:H (MIS) structure we are able to move the Fermi level to the valence (conduction) band edge in the n-i or p-i layer. By annealing the MIS structure at the freeze-in temperature of a-Si:H, while keeping this structure under bias voltage, a new programmed energy distribution of defect states is obtained. The programmed defect-states distribution at the negative (positive) voltage in the intrinsic a-Si:H layer represents the p-type (n-type) distribution as expected close to the p/i (n/i) interface in the intrinsic layer of the solar cell. We observe that the distributions of these programmed defect states and their following evolution due to light exposure are quite different in comparison to the intrinsic distribution [3]. The defect-state distribution of the intrinsic layer in the bulk of the solar cell is characterized by similar contributions from the positively charged defect states above midgap, Dv, neutral states, Dz, and negatively charged states below midgap, De. In the programmed p-type (n-type) defect-states distribution there is an excess of the Dv (De) states and a small contribution of the De (Dv) states. Light exposure modifies both the p- and n-type distributions, resulting in similar broad distributions of states located at and below midgap, while the states above midgap slightly decrease. This evolution is connected with the one of the intrinsic defect states distributions. But neither approach works when an antenna and diode are used to detect higher energy radiation in what is generally thought of as the domain of photons. We describe the operation and design of a detector comprising a micro-antenna and an ultra-high-speed metal-insulator tunneling diode. When the photon energy is on the order of or larger than the scale of the diode nonlinearity, we describe the detection using a semiclassical approach. The detector can pick up radiation from gigahertz to infrared (carrier) frequencies, and detect signals at up to terahertz/sec sensitivities. By incorporating a double-insulator quantum well we provide a high-performance detector for efficient detection. This crystal radio for photons is a practical, integratable thin-film detector for a wide range of applications from broadband communications, through terahertz imaging, to ultra-high-speed infrared detection.

3:30 PM A13.2 The Creation and Relaxation Kinetics of Light Induced Defects in a-Si:H Located at Different Energies in the Gap. Matthew Louis Albert1; Jingdong Deng1; Xinwei Niu1; Joshua M. Pearce2; Robert W. Collins3 and Christopher R. Wronski; 1Electrical Engineering, The Pennsylvania State University, University Park, Pennsylvania; 2Physics Department, Clarion University of Pennsylvania, Clarion, Pennsylvania; 3Physics Department, University of Toledo, Toledo, Ohio.

Until recently there has been no direct evidence reported for the “fast” and “slow” light induced states in a-Si:H films such as found in the two step experiments carried out on solar cells. An investigation of the nature of those states was carried out in a described study, and the optical path length can be enhanced by tens of thousands of times, more than two orders of magnitude longer than that obtained by conventional light-trapping schemes. Furthermore, it provides extremely high reflectivity with large optical bandgap over several hundred nanometers in the solar spectrum range. The reflectivity of our Si/SiNx DBR reaches 99.6%, while that of our Si/SiO2 DBR is as high as 99.98%, which is significantly higher than that of the best Al reflector (R<99%). Therefore, almost all the incident light with an energy higher than the bandgap of the absorption layer material can be completely absorbed and converted to electron-hole; in turn the quantum efficiency of the solar cells will be enormously enhanced by our new light trapping scheme.
Silicon Determined by Transient Capacitance Techniques. Stefan Cotoa, Nazir F. Kherani and Stefan Zukotynski; Electrical & Computer Engineering, University of Toronto, Toronto, Ontario, Canada.

The increase in the defect density under illumination, the Streeblov-Stavely effect, in hydrogenated amorphous silicon (a-Si:H) has been the subject of study for many years. Tritiated amorphous silicon (a-Si:H:T) is prepared by incorporating tritium, a radioactive isotope of hydrogen, into the a-Si:H network. The transmutation of tritium into helium leads to the creation of well-defined defects. In this region, which is consistent with the decay of the intermediate state, hydrogen and helium go into the lattice. Tritiated amorphous silicon samples have been studied using ESR and CPM. These measurements show defect creation of density that cannot be explained by the process alone [1-3]. Tritiated amorphous silicon films were deposited using the sinter-field deposition system. Tritium atomic concentration in the films was between 0.5% and 1.5%, determined by thermal emanation method. The doublet line shape of the doublet line bound by palladium onto the a-Si:H:T films which had been deposited on n-type crystalline silicon substrates. The junction capacitance of the Schottky devices after annealing showed an increase with time, suggesting an increase in total number of defect states in the gap. Isothermal Capacitance Transient Spectroscopy [4] was used to determine the density of states positioned near the conduction band in the gap. Measurements carried after annealing revealed a peak in the density of states at about 0.6 eV from the conduction band, commonly attributed to positively charged dangling bonds (D^+); the integrated density of states decreased with time. Both time evolutions could be fitted to exponential curves, reaching saturation after about 300 hours. This defect dynamics can be explained by the production of D^+ dangling bonds and their conversion to neutral defects D^0. This study sheds new light on the mechanisms involved in defect formation and on the Streebov-Stavely effect. T. Kostek, N. Kherani, P. Stradins, F. Gaspari, W.T. Shmayda, L. S. Sidhu, and S. Zukotynski, IEE Proc.- Circuits Devices Syst. 150, 274 (2003) [2] J. Whitaker, J. Viner, S. Zukotynski, N. Kherani, E. Johnson, P. C. Taylor, F. Stradins, Mat. Res. Soc. Symp. Proc. A 24.4 (Spring 2004) [3] S. Piana, S. Costea, T. Kostek, N. P. Kherani, S. Zukotynski and W. T. Shmayda, Mat. Res. Soc. Proc.: I.8.10 (Fall 2004) [4] Y. Chen, F. S. Wang, J. W. Tsai, H. C. Cheng, Jpn. J. Appl. Phys. 37, 2739 (1994)

4:00 PM A13.4 Image and Color Sensitive Detector Based on Double p-i-n a-SiC:H Photodiodes. Manuel Carvalho Vieira1, Miguel Fernandes1, Paula Loureiro1, Alessandre Fontao1, Yuji Vygrenako1, Guilherme Lavaredo2 and Carlos Nunes Carvalho2; 1DEETC, ISEL, Lisbon, Portugal; 2CFM, UTL, Lisbon, Portugal.

A large area optically addressed image and color sensitive detector is presented. The sensor structure is a two terminal multilayered structure based on two stacked sensing/switching p-i-n a-Si:H:H diodes and two transparent conductive contacts. The imaging is performed in a white-light imaging process: the illumination converts the optical image into a localized packet of charges and the optical read which performs the charge to current conversion by detecting the photodiode current amplified by a high beam scanner. In this sensor the charge packets are optically injected either into the p-i-n front sensing photodiode or at the switching one depending on the wavelength of the absorbed radiation. Its confinement inside the illuminated regions promotes a low optical field profile across the p-i-n back switching diode that can be readout through a light scanner without the need of the usual pixel architecture. This approach simplifies the interconnections as only two terminals are necessary. By tailoring of the sensor configuration (layers thickness, absorption coefficient of the absorber layers and junction sequences) and the readout parameters (applied bias and scanner wavelength) this work evaluates the possibility of using this double diode structure in a high-performance opto-electronic imaging and color detection device. The various design parameters and the optical readout process tradeoffs are discussed. The influence on the transfer functions of different a-SiC:H sensing absorbers optimized for red transmittance and blue reflection were also analyzed. Results show that with a thin (~200 nm) a-Si:H sensing and a thick (>500 nm) a-Si:H switching absorber are used, the device behaves itself as a filter giving information about the wavelength and the position where the optical image is absorbed. By sampling 4 optically separated region on the two bias voltages it is possible to extract separately the RGB integrated information with a good rejection ratio. A readout of 1000 lines per second is achieved allowing continuous and fast image sensing, and color recognition. A transient SPICE model of the complete device will be presented and supported by a 2D numerical simulation.

4:15 PM A13.5 Observation of a Hydrogen Doublet Site in High Defect Density As-Grown a-Si:H by 1H NMR. David Charles Bobela1, 2.

Tining Su1, Craig Taylor1 and Gautam Ganguly2; 1Physics, University of Utah, Salt Lake City, Utah; 2United Solar Ovonic Corp., Troy, Michigan.

2H NMR studies of a-Si:H with ~10^17 cm^-3 defects grown by PECVD with a rate of 3 Å/s, show the existence of a hydrogen doublet for both as-grown and light-soaked samples. The doublets' breadth of ~10kHz corresponds to a pair of hydrogen atoms separated by 2.2 Å. In a previous study by Su et al. [1], a similar doublet (for high quality samples) appears upon light soaking, in densities consistent with densities of optically induced hydrogen bonds. Su et al. also report the apparent narrowing of this feature for temperatures approaching 20 K. We observe the doublet, in a sample where no intended light-soaking has occurred, over the range of 5 - 20 K. The as-grown sample exhibits a similar doublet line shape as the light-soaked at 8 K. As-grown T3 experiments for temperatures within said temperature range show that the doublet component relaxes on the same time scale as hydrogen bonded to silicon component (width ~2kHz). Moreover, the doublet line shapes display no narrowing. These results suggest that the doublet is due to SiH2 for these samples. 1. T. Su, P.C. Taylor, G. Ganguly, and D.E. Carlson, Phys. Rev. Lett. 89, 015502 (2002).

4:30 PM A13.6 Light-soaking Effects on the Open-circuit Voltage of a-Si:H Solar Cells. Jianjun Liang1, Eric A. Schiff1, Subhendu Guha2, Baojie Yan2 and Jeffrey Yang2; 1Physics, Syracuse University, Syracuse, New York; 2United Solar Ovonic Corp., Troy, Michigan.

The open-circuit voltage $V_{oc}$ of amorphous silicon (a-Si:H) solar cells measured under intense (solar) illumination generally declines only a few percent under light-soaking. This behavior is remarkable in the context of the much larger relative changes in the photocurrent and the deep-level density measured in amorphous thin films during light-soaking. Since $V_{oc}$ is also a probe of bulk recombination in amorphous a-Si:H films (it measures a quasi-Fermi level splitting), it should be consistent with the other measurements, and indeed modeling studies have suggested that even fairly sizable deep levels densities need not strongly affect recombination in these samples. In this paper we explore possible reasons for the apparent coincidence that the growth of the deep level density saturates just as it begins to marginally affect $V_{oc}$. We present first measurements of the kinetics of the decay of the open-circuit voltage at 295 K. In several samples the long-time decay $\Delta V_{oc}$ (between 1 and 200 hours) follows the form $V_{oc} = (K t / e)^{\beta}$, with $\beta$ = 1.2 and $K$ = 1000 lines per second is achieved allowing continuous and fast image sensing, and color recognition. A transient SPICE model of the complete device will be presented and supported by a 2D numerical simulation.
significant differences in the DLCP profiles for the nc-Si:H layers deposited under constant hydrogen dilution with those deposited using hot-wire chemical vapor deposition (HWCVD). For the former, the DLCP decreases in the direction of film growth, exceeding 10^{16} cm^{-3} as one approaches the top surface of the film. This variation is attributed to an increase in crystalline size as the film growth progresses. In contrast, when hydrogen profiling is employed to maintain a smaller crystallite size, the samples exhibited DLCP profiles indicating a maximum value below 10^{16} cm^{-3} within the middle of the film before decreasing again toward the front surface. Second, the TPC measurements reveal spectra that appear quite amorphous-like at lower temperatures but more similar to a-Si:H at higher temperatures. We believe that this variation in appearance indicates the mixed-phase nature of the nc-Si:H material studied. Specifically, the photopacitance spectra for these samples appear more amorphous-like at lower temperatures than the minority carrier collection is poorer at lower temperatures, but more amorphous-like at higher temperatures when the minority carrier collection is higher in the nanocrystalline component of these nc-Si:H samples. This then suppresses the TPC signal from this component compared to the a-Si:H component. In contrast, because the transient photocurrent signal is only enhanced by the additional minority carrier collection, these spectra appear amorphous-like at all temperatures. Finally, we have investigated light-induced degradation in these devices after light-soaking for 100 hours with red filtered (610nm) ELH light at 100mW/cm^2. Such light-soaking is found to cause a dramatic decrease in hole collection, similar to that caused by reducing the measurement temperature of the samples. We believe that this is likely related to the light-induced degradation in performance in these nc-Si:H solar cells. However, the light exposure does not appear to cause the decreased defect density (dangling bonds). Possible mechanisms for the observed light-induced degradation in these nc-Si:H films will be discussed.

SESSION A14: In-situ Optical Characterization of Films 1

Chair: Rob Collins
Thursday Morning, March 31, 2005
Room 2002 (Moscone West)

8:30 AM *A14.1


Hirayuki Fujiwara and Michio Kondo, National Institute of Advanced Industrial Science and Technology, Tsukuba-shi, Ibaraki, Japan.

We have performed real-time process control and characterization of hydrogenated amorphous silicon (a-Si:H) growth on crystalline silicon (c-Si) in a-Si:H/c-Si heterojunction solar cells. By applying real-time spectroscopic ellipsometry (SE) [1], thickness control of a-Si:H layers with a precision better than ±1% has been demonstrated during a-Si:H p-i-layer growth on the n-type c-Si substrate by conventional plasma-enhanced chemical vapor deposition. Due to thin layer thicknesses of less than 5 nm, as-prepared for a-Si:H/c-Si heterojunction solar cells, precise real-time thickness control is of significant importance especially for mass production. A heterojunction solar cell fabricated by our process shows a relatively high conversion efficiency of 14.5% (V_oc =574 mV, J_{sc} =391 mA/cm^2, and FF=0.756). In this solar cell, ITO (70 nm) and Al were used for top and rear electrodes, respectively. For the a-Si:H growth, real-time SE revealed (i) island growth of the a-Si:H i-layer on the substrate, (ii) rapid surface roughening during the a-Si:H p-layer growth on the i-layer, and (iii) reduction of H content after the p-layer growth. In order to characterize interface structures, we have further applied real-time infrared attenuated total reflection spectroscopy (ATR). From these results and the formation of a porous interface layer with a large SiH_2 hydrogen content of 30 at.% at the a-Si:H(i-layer)/c-Si interface, although a-Si:H i-layers have been reported to provide excellent surface passivation on c-Si surface [2]. Furthermore, at the a-Si:H p/i interface, the presence of a transition layer with a thickness of 2 nm was indicated. The above results show that the growth processes of the a-Si:H p-i-layers are far more complicated than expected. Based on the SE and ATR results, we discuss the growth processes and structures of a-Si:H in a-Si:H/c-Si heterojunction solar cells. [1] H. Fujiwara, M. Kondo, and A. Matsuda, Physical Review B 63 (2001) 115306. [2] M. Taguchi et al., Prog. Photovolt: Res. Appl. A (2000) 503.

9:00 AM *A14.2

Real-Time Spectroscopic Ellipsometry as an in-situ Probe of the Growth Dynamics of Amorphous and Epitaxial Crystal Silicon for Photovoltaic Applications.


In-situ real-time spectroscopic ellipsometry (RTSE) is gaining widespread acceptance as a powerful tool for the investigation of the deposition and growth dynamics of myriad types of thin films. R.W. Collins and co-workers have established a broad foundation for these studies with their work using in-situ RTSE to create phase diagrams for amorphous silicon (a-Si) and nano-crystalline silicon (nc-Si) deposited using plasma enhanced chemical vapor deposition (PECVD). Their work takes advantage of the sensitivity of spectroscopic ellipsometry to surface roughness and optical properties, and how these parameters relate to transitions in the growth phase of the material, to provide a microstructural description of the growth. In this work, we report on our work using in-situ RTSE to study the dynamics of hot-wire chemical vapor deposition (HWCVD) of a-Si and epitaxial crystal silicon (epi-Si) for photovoltaic applications. We utilize RTSE as both an in-situ diagnostic and post-growth analysis tool for HWCVD grown a-Si/crystalline silicon heterojunction (SHJ) solar cells grown by HWCVD. RTSE enables precise thickness control of the 3 to 10 nm thick layers used in these devices, as well as monitoring crystallinity and surface roughness in real time. We have found that by monitoring the pseudo-dielectric function in real time during growth we gain immediate feedback on the breakdown of epi-Si growth. Post-deposition analysis of the RTSE data provides quantitative information on the percent of nc-Si and a-Si versus film thickness. The RTSE analysis has been confirmed by cross sectional TEM. Based on the rapid feedback provided by RTSE we have surpassed the previous HWCVD record of 200 nm of epi-Si growth, now achieving maximum thicknesses of 500 nm of epi-Si. TEM analysis has shown that micron-sized areas of these films achieve 1000 nm of epi-Si thickness.
SESSION A15: Transport and Recombination - Novel Devices

New Insights into the Recombination Mechanism of Amorphous Silicon. Klaus Lips and Christoph Boehne; Silizium-Photovoltaik, Hahn-Meitner-Institut, Berlin, Germany.

Since the discovery of photoluminescence (PL) in amorphous silicon (a-Si:H) in 1974 many experiments have been carried out to identify the underlying recombination mechanisms. With the number of experiments conducted also the number of models for the explanation of the observations increased. In a-Si:H, a complex interaction of photogenerated excess charge carriers with a high density of localised states in the forbidden gap exists. This results in a wide distribution of distances between photogenerated electron-hole pairs (e-h) and defect states. Two extreme processes are distinguished, one as an excitonic capture process at the recombination site and the other as an excitonic capture process at the recombination site with subsequent radiative emission. The localisation length of the photogenerated excess charge carriers with a high density of localised states (defect states and dangling bonds) as well as extraction are proposed to exist but no conclusive evidence has been presented that prove either of these mechanisms. In this presentation, we will revisit this 30-year-old problem using a recently developed and very powerful technique, namely pulsed optically detected magnetic resonance (pODMR). Different from standard continuous wave ODMR, the trapped e-h pairs are excited coherently by very short and intense microwave pulses thereby altering the spin configuration of the recombining e-h pairs on time scales faster than the shortest decoherence time. This then will result in an oscillation of the recombination probability. It is this coherent manipulation of the charge carrier ensemble that enables to extract valuable information about the recombination mechanism such as distance distributions between e-h pairs or recombination rates. The collective spin motion is observed as Rabi oscillations in the PL allowing to identify the different recombination processes by their characteristic decay times as well as through their characteristic Rabi frequency. In a-Si:H we observe three different Rabi frequencies at 10 K which we identify from their q values to originate from three distinctively different recombination mechanisms, namely (i) non-radiative tunneling of band-tail electrons to neutral dangling bonds (db); (ii) radiative tunneling between dipolar coupled distant e-h pairs trapped at band-tail states which are separated by more than 9 Å; (iii) e-h pairs in close proximity forming a strongly exchange coupled state. We attribute the 9 Å limit below which no dipolar coupled pairs are detected as the localization length of the exchange coupled e-h pairs. A direct capture process at dangling bonds as observed in microcrystalline silicon at the c-Si/SiO₂ interface is not observed in a-Si:H at T = 10 K.

Multiple-Trapping Model with Meyer-Neldel Effect and Field-Dependent Effects: Time-Of-Flight Simulations for a-Si:H. Jesse Maseen¹, Arthur Yelon¹, Louis-Andre Hamel² and Wen Chao Chen²; ¹Department of Engineering Physics, Ecole Polytechnique de Montreal, Montreal, Quebec, Canada; ²Department of Physics, University of Montreal, Montreal, Quebec, Canada.

In the past, various processes have been introduced into the standard multiple trapping model (MTM) to account for energy-reducing empirical data concerning time-of-flight (TOF) experiments for a-Si:H. Chen et al. [1] incorporated the Meyer-Neldel Effect (MNE) into the MTM model, producing good results in the low field regime and a field assisted detrapping model, the dopant jump model (DJM) [2], giving reasonable results in the high field domain. We have now included both MNE and DJM together in the MTM model, assuming exponential band tails of localized states, in the hope of improving agreement with high field experiments without degradation agreement at low field. Monte Carlo simulations show that this combined model (MNE-DJM) improves agreement between theory and experiment. Particular attention was paid to general mobility measurements, μ(T,F), and to α₁(T,F) and α₂(T,F), the dispersion parameters before and after and the transit time τ. These results were tested for temperatures ranging from 50K to 350K and for electric fields varying from 50k V/cm to 350k V/cm. We observe that the values of α₁(T,F) and α₂(T,F) improve for all temperatures and the LK model describes measurements of μ(T,F) well for the range of fields mentioned above. The electron distribution function in the localized states, (E), gives us insight into the behaviour of carriers in deep traps, which mainly concerns multi-phonon interactions and its effects on transport dynamics. Although this model provides satisfactory results for carrier transport in amorphous silicon, the scarcity of high field experimental data prevents us from more rigorously testing the present model. [1] W.C. Chen, L.A. Hamel and A.Yelon, J. Non-Cryst. Solids 260, 226 (1997). [2] W.C. Chen, L.A. Hamel and A.Yelon, J. Non-Cryst. Solids 268, 225 (1999).

Computer Modeling of Non-Equilibrium Multiple-Trapping and Hopping Transport in Amorphous Semiconductors. Charles Main¹, Joe Marshall², Steve Reynolds² and Mervyn Rose²; ¹Division of Electronic Engineering and Physics, University of Dundee, Dundee, United Kingdom; ²University of Wales Swansea, Swansea, United Kingdom.

In this paper we demonstrate a simple computational procedure for the simulation of non-equilibrium transport in a disordered amorphous semiconductor in which both multiple-trapping and hopping processes are occurring simultaneously. The simulation is based on earlier work on hopping transport, which employed a Monte-Carlo method. Using the same model of carriers, we now employ a stochastic matrix approach to speed computation, and include also multi-trapping transitions between localised and extended states. We use the simulation to study the relative contributions of extended state conduction (with multi-trapping) and hopping conduction (via localised states) to transient photocurrents, for various distributions of localised gap states, and as a function of temperature. The implications of our findings for the interpretation of transient photocurrents are examined.
High current density diodes have potential applications in a variety of devices, including thin-film electronic devices. This can be achieved using Modified Triode Plasma Chemical Vapor Deposition (MTPCVD). We have developed an analytical model that describes the transition to higher doping levels, allowing us to determine the optimal value for the load resistance coupled to the sensor. The model is validated by experimental results, which show a good agreement with the theoretical predictions. This allows us to understand the experimental work, simulate the sensor response based on the electrical model, and assess the sensitivity and selectivity of the sensor. The analytical model shows promise for developing thin-film technology for solar cells and other applications.


Microcrystalline, nanocrystalline and amorphous silicon thin films are receiving great attention in developing a large-area silicon technology on flexible plastic substrates including optoelectronic devices, thin film transistors and solar cells. Previous studies on the plasma-enhanced chemical vapor deposition (PECVD) of thin films using SiH4-H2 plasmas put in evidence that the surface temperature and the hydrogen dilution are crucial parameters for the control of film nano- and microstructure. Specifically, for microcrystalline silicon hydrogen dilution 90% and temperature exceeding 180°C are required to obtain dense and ordered microcrystalline films with a crystalline fraction >70%. Furthermore, the existence of an impurity sublayer limited the possibility of depositing very thin <500 nm fully microcrystalline microcrystalline films on plastics. In this contribution, PECVD from He diluted SiF4 and SiH4 is demonstrated to be a variable ratio deposition of full microcrystalline (h > 70%) thin films at low temperature <100°C on plastic substrates and without high H2 dilution. Peculiarities of the films are the absence of any amorphous incubation layer at the early growth stage and the control of the crystalline transition by gas phase composition. The influence of the ratio Si-rich on the film microstructure and properties is presented. A comparative analysis of the "amorphous" thin film structure and properties is presented. A comparative analysis of the "amorphous" thin film structure and properties is presented. A comparative analysis of the "amorphous" thin film structure and properties is presented. A comparative analysis of the "amorphous" thin film structure and properties is presented.

Development of Deposition Phase Diagrams for Thin Film Si_{1-x}Ge_{x}:H by Plasma Enhanced Chemical Vapor Deposition (PECVD) is studied with the motivation to develop deposition phase diagrams for optimization of these materials in photovoltaic applications. The Si_{1-x}Ge_{x}:H films were deposited on native oxide/substrates using rf PECVD and were measured in real time using a rotating-compensator multidimensional ellipsometer. Conditions similar to those used for optimum pure a-Si:H were adopted first, including low substrate temperature (T<200°C), low rf power (0.08 mW/cm²), and low total pressure (<1 Torr). The flow ratio G = [GeH4]/[SiH4]+[GeH4] was fixed at G = 0.1 to 0.5, leading to a 20°C gap of F_e ~ 1.3 eV. Two significant differences are observed between the phase diagrams of pure Si:H and Si_{1-x}Ge_{x}:H. First, the n+(a-μc) transition for the series of alloys is shifted to much larger R compared to pure Si:H. Thus, the presence of Ge in the growth process strongly suppresses the H-induced nucleation of microcrystals from the amorphous phase. Second, the n−→(a+μc) transition is more abrupt with the thin layer thickness of 200 Å for the alloys, even as the n−→(a+μc) transition for thick films is approached and crossed. In conclusion, for Si:H, the n−→(a+μc) transition exhibits a smooth, exceeding the thin layer thickness of 4000 Å, and is a common feature among these studies.
The growth process of a-Si:H by HWCVD is studied by analyzing the surface roughness evolution during film growth. This analysis, which is the first extensive investigation of the temperature dependence of the surface roughness evolution, is based on the work of Collins and co-workers [1] and gives information on aspects such as initial film growth, surface roughening and smoothing, and surface diffusion mechanisms. Purely amorphous films have therefore been deposited from undiluted silane and at low deposition rates (88 nm/min) while monitoring the growth by real-time spectroscopic ellipsometry for substrate temperatures between 70 and 450 °C. The thickness of the surface roughness is deduced from a two-layer optical model and analyzed as a function of the film thickness similar to the analysis performed by Collins et al. [1]. The initial roughness is approximately identical for all substrate temperatures indicating a similar nucleation behavior at different temperatures. After nucleation and depending on substrate temperature the surface smoothness during growth for temperatures above 150 °C. The position of the amorphous-to-amorphous roughening transition is observed within the film thickness range of 10–15 nm with the optimum at ~15 nm at ~250 °C. Analysis of the post-initial growth phase by RTSE and ex-situ AFM demonstrates a self-affine growth in good agreement with previous results by, e.g., Smets et al. [2]. In general, our results at 250 °C are in excellent agreement with previous work by, e.g., Collins et al. [1] on RF-PECVD deposited a-Si:H. Our temperature dependent studies, however reveal some new insights in the growth mechanism of a-Si:H. First of all the smoothing rate after nucleation is rather slow and temperature independent. An analysis in the framework of a stochastic growth equation suggests that the usual mono-radical surface diffusion picture of surface smoothing needs to be replaced by a bi-radical picture in which growth only occurs on an active site. This bi-radical picture contains the possibility that both precursor as well as the active site are mobile. Furthermore, the analysis of the stochastic growth equation also suggests a novel interpretation of the post-initial growth phase in which the observed growth exponent beta monotonically decreases from about 0.18 to 0.05. We conjecture that a conserved non-linear term rules the surface smoothing, resulting in a power-law exospheric scaling behavior in the high temperature limit. [1] R.W. Collins, A.S. Ferlauto, G.M. Ferreira, C. Chen, J. Koh, R.J. Koval, Y. Lee, J.M. Pearce, C.R. Wronski, Sol. Energy Mater. Sol. Cells 78 (2003) 143. [2] H.A.M. Smets, W.M.M. Kessels, M.C.M. van de Sanden, Appl. Phys. Lett. 82, 865 (2003).

8:45 PM A16.4 Low-to-Medium Energy Ion Bombardment Effects on Interlayer Formation During Thin Film Growth in Plasma-CVD Environment. Ayam Amassian, Patrick Desjardins and Ludvik Martina; Regroupement Quebecois sur les Materials de Pointe (RQMP) and Department of Engineering Physics, Ecole Polytechnique de Montreal, Montreal, Quebec, Canada.

Plasma-enhanced chemical vapor deposition (PECVD) is recognized as a highly versatile and flexible deposition technology. Significant research efforts have been directed towards plasma chemical vapor deposition (CVD) for the fabrication of high-quality thin films with well defined properties, but many questions remain unanswered, including thin film growth dynamics and interface formation under the influence of plasma irradiation. We demonstrate the capability of in situ real-time spectroscopic ellipsometry (RTSE) to detect and precisely quantify the modifications of c-Si in O₂ plasma with ion energy ranging from ~0.05 to 0.7 keV. Dynamic Monte-Carlo (DMC) simulations have allowed us to show that these modifications, which include primarily amorphization and oxidation, result from ion implantation and defect generation. Simulations also show evidence of surface swelling and sputtering due to plasma-surface interactions, which occur simultaneously with the initial nucleation and immediately after the completion of the film growth. In the case of thin film deposition by PECVD, ion bombardment is also responsible for ion-mixing of substrate and film atoms, which results in interface formation. We show excellent agreement between DMC predictions and RTSE characterization. This study has given insight into the PECVD deposition process and the role of ion bombardment in the synthesis of porous and dense SiO₂ for optical coatings by dual-frequency microwave/radiofrequency plasmas.
The low oxygen concentration and high crystalline volume fraction of PECVD SiO$_2$ quality undoped nanocrystalline silicon, deposited only on the source and drain area. Each source and drain was connected by a Mo electrode in order to apply the same electrical field strength for each pattern. After crystallization of amorphous silicon in the channel region, 100-nm-thick SiO$_2$ and 300-nm-thick Mo films were sequentially formed on the channel as a gate oxide and gate metal, respectively. Finally, poly-Si TFTs were fabricated in the 2-inch array module, using only the thermal process at the peak process temperature of 500°C. The electrical characteristics of poly-Si TFTs were measured by HP 4140B equipment. The electric fields applied through common electrodes connected to source and drain area led to the directional crystallization of amorphous silicon from negative electrode side to positive electrode side at 500°C. This directional crystal growth enabled us to remove the metal impurity incorporation, which is the main cause for increased off-state drain leakage current, out of the channel. In this process, the applied field induced directional growth of needle-like elongated grains and accelerated the crystal growth rate. As a result, we can increase the carrier mobility because these elongated grains reduce the chances of carrier scattering at the poly-Si grain boundary. Field effect carrier mobility of FALC-processed poly-Si TFTs were estimated to be 200cm$^2$/Vs at a drain voltage of 0.1V, and off-state drain leakage current at the gate voltage of -10V was approximately on the order of 10$^{-12}$ A.

For the application of high resolution liquid crystal display (LCD), array of polycrystalline silicon thin film transistors (poly-Si TFTs) were fabricated on a corning 1737 glass substrate using Ni induced field aided lateral crystallization (FALC) process. In this experiment, Ni, which is the metal for field crystallization of amorphous silicon, was deposited only on the source and drain area. Each source and drain was connected by a Mo electrode in order to apply the same electrical field strength for each pattern. After crystallization of amorphous silicon in the channel region, 100-nm-thick SiO$_2$ and 300-nm-thick Mo films were sequentially formed on the channel as a gate oxide and gate metal, respectively. Finally, poly-Si TFTs were fabricated in the 2-inch array module, using only the thermal process at the peak process temperature of 500°C. The electrical characteristics of poly-Si TFTs were measured by HP 4140B equipment. The electric fields applied through common electrodes connected to source and drain area led to the directional crystallization of amorphous silicon from negative electrode side to positive electrode side at 500°C. This directional crystal growth enabled us to remove the metal impurity incorporation, which is the main cause for increased off-state drain leakage current, out of the channel. In this process, the applied field induced directional growth of needle-like elongated grains and accelerated the crystal growth rate. As a result, we can increase the carrier mobility because these elongated grains reduce the chances of carrier scattering at the poly-Si grain boundary. Field effect carrier mobility of FALC-processed poly-Si TFTs were estimated to be 200cm$^2$/Vs at a drain voltage of 0.1V, and off-state drain leakage current at the gate voltage of -10V was approximately on the order of 10$^{-12}$ A.

The gate-voltage range that can be used depends critically on the performance of AMFPIs used for radiography, fluoroscopy and mammography. In this presentation, detailed results of the investigation of the effects of X-ray irradiation of polycrystalline silicon thin film transistors are presented. These initial results are encouraging and suggest that the effects of radiation are not severe.

For the application of high resolution liquid crystal display (LCD), array of polycrystalline silicon thin film transistors (poly-Si TFTs) were fabricated on a corning 1737 glass substrate using Ni induced field aided lateral crystallization (FALC) process. In this experiment, Ni, which is the metal for field crystallization of amorphous silicon, was deposited only on the source and drain area. Each source and drain was connected by a Mo electrode in order to apply the same electrical field strength for each pattern. After crystallization of amorphous silicon in the channel region, 100-nm-thick SiO$_2$ and 300-nm-thick Mo films were sequentially formed on the channel as a gate oxide and gate metal, respectively. Finally, poly-Si TFTs were fabricated in the 2-inch array module, using only the thermal process at the peak process temperature of 500°C. The electrical characteristics of poly-Si TFTs were measured by HP 4140B equipment. The electric fields applied through common electrodes connected to source and drain area led to the directional crystallization of amorphous silicon from negative electrode side to positive electrode side at 500°C. This directional crystal growth enabled us to remove the metal impurity incorporation, which is the main cause for increased off-state drain leakage current, out of the channel. In this process, the applied field induced directional growth of needle-like elongated grains and accelerated the crystal growth rate. As a result, we can increase the carrier mobility because these elongated grains reduce the chances of carrier scattering at the poly-Si grain boundary. Field effect carrier mobility of FALC-processed poly-Si TFTs were estimated to be 200cm$^2$/Vs at a drain voltage of 0.1V, and off-state drain leakage current at the gate voltage of -10V was approximately on the order of 10$^{-12}$ A.

The substrate is glass. The source and drain contacts are made of Al deposited using 34
Poly crystalline Silicon Thin-Film Transistors, Doochul Choi, Muyeong-Seob So, Byoungdeog Choi, Inbok Song and Hyokyoung Chung; Corporate Research and Development Center, Samsung SDI, Kyonguks, South Korea.

We investigated effects of boron-doped channel on electrical characteristics for low-temperature poly crystalline silicon (LTPS) thin film transistor (TFT). We fabricated both intrinsic- and doped-channel n-TFTs and characterized the device performance in view of short channel effect and threshold voltage control that are important aspects of application of a polycrystalline system on panel (SOP). For the application of TFTs in SOP, there is a great interest in scaling down of device dimensions to meet the needs of switching speed and low power consumption. As the channel length of the device is scaled down, the drain voltage can lower the barrier height of the channel near the source. Through the investigation of the drain induced barrier lowering (DIBL) effect, the short channel effect was characterized with varying channel length for the intrinsic- and doped-channel n-TFTs. The doped-channel n-TFT begins to appear at shorter gate channel length of about 3 μm or so, compared to intrinsic-channel TFT having 6 μm or so. We have confirmed the effectiveness of channel doping to control the threshold voltage. We were able to positively shift the threshold voltage for n-TFT without degrading sub-threshold slope and make sure the switching off at the gate voltage of 0 V. We also found the reduced standard deviation of threshold voltages among the TFTs over the wide range of gate channel doping.

SESSION A18: Poster Session: Characterization - a-Si:H and alloys B

Thursday Evening, March 31, 2005 5:00 PM - 7:00 PM
Salons 8-15 (Marriott)

A18.1 Stark Splitting in Photoluminescence Spectra of Er in a-Si:H
Minoru Kuno,
Mitsui Takahashi, Akikuro Morinoto and Tatsuo Shimizu; 1 Division of Electrical Engineering and Computer Science, Graduate School of Natural Science and Technology, Kanazawa University, Kanazawa, Japan; 2NTT Microsystem Integration Labs., Atsugi, Japan.

The wavelength 1.54 μm of the optical transition of Er ions coincides with a minimum loss of silica optical fibers and many works have been done aiming applications to optical devices. Because the optical transition between states for f orbitals is inhibited by symmetry, we need a lower symmetry around the Er ions to obtain mixing of orbitals with different symmetries. a-Si:H films are useful as a host material since the disorder of the amorphous network makes Er ions have the orbitals with different symmetries and the flexibility of amorphous network makes possible a higher amount of Er ions incorporated in the host. Understanding the excitation mechanism for Er ions is important to get a strong emission. The incorporation scheme of Er ions is essential for discussing the excitation mechanism, and should be reflected in the photoluminescence (PL) spectra. We tried to decompose the PL spectra at different temperatures and pursue the change by annealing. Er-doped a-Si:H films were prepared by magnetron sputtering in an atmosphere of Ar and H2 mixture. The thickness of the film was around 80 nm. The content of Er was estimated to be 0.8 at %. The shape of the Er PL spectra were decomposed into several lines on the photon energy abscissa. At first, the 1K spectrum was reproduced by adding four Gaussian lines with increasing linewidths. Because at this low temperature only the lowest energy level of 11/2 contributes to the radiative transition, the energy levels in 11/2 which are split by the Stark effect are determined to be located at 5.3 meV, 19.4meV and 36.4 meV relative to the lowest energy level of 11/2. These three energy levels are roughly different from those for Er in amorphous silicon. This implies the nearest neighbor of Er are oxygen ions which have been introduced unintentionally in the sample during preparation. Next the spectra observed at the temperature were decomposed to give the Stark splitting between the second lowest level of 11/2 and the lowest level of 11/2; although the number of component lines and ambiguities increased. Annealing makes the PL intensity increase up to 400℃ and decrease rapidly at 500℃. The peak positions of the component lines of temperature were decomposed to give the Stark separation.


Polycrystalline Silicon (pm-Si:H) thin films have emerged as an alternative to conventional a-Si:H due to their better transport properties and improved stability. These improvements are attributed to the presence of nano-crystalline inclusions in the amorphous matrix which grows under controlled conditions by PECVD. Possible changes in the density of gap states due to the presence of crystallites is of central importance in understanding steady state and dynamic characteristics of devices using these materials. We have studied n-TFT and pm-Si:H grown at different conditions by PECVD. Possible changes in the density of gap states due to the presence of crystallites is of central importance in understanding steady state and dynamic characteristics of devices using these materials. We have studied n-TFT and pm-Si:H grown at different conditions by PECVD. 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literature, these values are used. The model succeeds in simulating published results over a wide range of experimental conditions. This model is the projection of the experimental results of mercury concentration enhancement initialises growth of photoactive impurity centres. The highest photoresponsivity was of 3x10^-3 Ohm-1m-1 for films with yttrium content of 12 weight %. The reflective and absorptive spectrum shows that the maximum absorbance of the spectrum range is less than 0.5 microns and the band gap is of 1.75 eV for the composition with highest photoresponsivity. This work presents the new results of atomic force microscope (AFM) and optical investigations (infra-red and ellipsometry) of amorphous silicon alloy with yttrium (a-Si-Y). The amorphous a-Si-Y films were deposited on silicon substrates by electron-beam sputtering of special alloy compositions in vacuum without hydrogen inlet. The reason of hydrogen exclusion is fact that in time hydrogen leaves the film that leads to instability first of all of electric characteristics in time. To fulfil the broken bands yttrium was introduced to technological procedure. In this work we choose yttrium concentration in films required for sputtering special alloys from 6-25% before from previous results the samples with yttrium more than 25% had microcrystalline structure. Also in this paper we left deposition time from 5 to 25 min. From new results of AFM it is obtained that films have amorphous structure with some rare microcrystalline inclinations. For the first time in paper we present the result of ellipsometric analyses. Spectroscopic ellipsometry measurements were performed using a classical angle spectroscopic ellipsometer with a Xe-lamp source, single chamber monochromator, continuously rotating analyser and auto-rettarder. The ellipsometric angles and were determined in the spectral range from 0.8 eV to 5 eV at 6deg, 7deg and 7deg angle of incidence.

SESSION A19: Poster Session: Growth-Microcrystalline and Nanocrystalline Films
Thursday Evening, March 31, 2005, 8:00 PM
Salon 8-15 (Marriott)

A19.1 Fabrication of Nano-Crystalline Porous Silicon on Si Substrates by a Plasma Enhanced Hydrogenation Technique. Yaser Abdell,1,2, Puya Hashemi1, Fatemeh Dehghan Nayeri1, Ashkan Belnam1, Shamseddin Mohajerzadeh1, Javad Kouchakzadeh1,2, M. D. Robertson1,2 and E. Arzi1,2; ECE Department, Thin Film Lab, University of Tehran, Tehran, Iran; 1Department of Physics, Tehran University, Tehran, Iran; 2Department of Physics, Acadia University, Wolfville, Nova Scotia, Canada.
A novel method for fabrication of nano-crystalline silicon films is introduced by using plasma hydrogenation and annealing steps. Using this technique, formation of nano-size grains is achieved by means of hydrogenation of already-deposited silicon layers without a need to ion implantation or wet chemical processes. N-type <100> silicon wafers are used as the substrate. After proper cleaning, a 0.1µm-thick SiO2 layer is grown by thermal oxidation followed by deposition of a 1000Å silicon layer using sputter-evaporation. The Si deposition was performed at temperature of 25ºC and base pressure of 2x10^-9 Torr. The as-grown samples are amorphous and they are placed in a DC-PECVD reactor for hydrogenation. Several hydrogenation steps were done in base pressure of Torr with power density of 4.5 and 6.5 W/cm2 and temperatures ranging from 300ºC to 450ºC. Each step of hydrogenation has the duration of 15 and 30 mins. This step is followed by an in-situ annealing at a temperature 70ºC higher. By successive hydrogenation-annealing steps nano-crystalline porous structures are obtained. It is believed that in the process of hydrogenation, hydrogen radicals replace the dangling bonds of Si atoms in the amorphous structure and by deactivating the previously hydrogenated bonds they impart energy to silicon atoms, enhancing the chance for nucleation and growth of nano-crystalline sites. The samples are characterized by SEM, TEM and photoemission/PL analyses. The porosity of these structures is confirmed by SEM and small separated spherical grains sizes smaller than 50nm are observed. As indicated by SEM, for a constant plasma power, the samples hydrogenated at higher temperatures have smaller and more isolated grains whereas samples prepared at lower temperatures have a denser distribution of grain sizes between 3 and 10nm. The electron diffraction pattern also shows concentric rings corresponding to various crystal orientations. The porous Si is also characterized by the PL analysis. The wavelength of the incident light was 254nm. The peak of the PL spectrum decrease between 600nm for different conditions in experiments which is in the visible light spectrum. The analyses also show that by decreasing the grain size the peak shifts toward smaller wavelengths with a lower peak intensity.
A10.2
CO2 Laser Annealing Synthesis of Silicon Nanocrystals Buried in Si-rich SiO2: Chun-Jung Lin1, Yu-Lun Chueh2, Li-Jen Chou2 and Gong-Ra Lin1; 1Department of Photonics & Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan; 2Department of Materials Science and Engineering, National Tsing Hua University, Hsinchu, Taiwan.

The localized synthesis of 3.8 nm-thick nc-Si nanocrystals (nc-Si) in Si-rich SiO2 (SRSO) by CO2 laser annealing at the power density of below ablation-threshold (5.8 x 103 W/cm2) is demonstrated. The 280 nm-thick Si film is prepared by PECVD under a SiH4-to-N2O flow rate ratio of 1:20, since the SiO2 exhibits a high absorption coefficient of about 0.102 cm-1 at wavelength of 10.6 µm, a direct-writing CO2 laser annealing system with focusing spot size of 62 µm2 is used to locally anneal the SRSO and precipitate the nc-Si. A thermophysical model reveals the surface temperature of SRSO ranging from 130°C to 1340°C achieved by varying laser power densities from 1.5 x 104 to 6.0 x 104 W/cm2. The CO2 laser-ablation-threshold power density is about 5.8 x 103 W/cm2, corresponding to the optimized annealing temperature 1285°C. The CO2 laser annealing is capable of the precise control on power density and spot size, which benefits the in-situ and localized annealing temperature of the as-deposited nc-Si film, and can avoid the thermal damage of the other electronic devices nearby the annealing site. The nc-Si dependent photoluminescence (PL) was observed at 806 nm or longer, whereas the ablation damaged SRSO film exhibits a significant blue PL at 413 nm. In the PL, the PL intensity is increased with increasing laser fluence due to the solid phase structural transitions as well as the peak shift, which is interpreted as due to the solid phase structural transitions as well as the peak shift, which is interpreted as due to the solid phase structural transitions as well as the peak shift. The blue-shift of PL is mainly attributed to the formation of E' defects prior to the precipitation of nc-Si. At the power density of 6.0 x 104 W/cm2, a significant PL at 806 nm with spectral linewidth of 106 nm is observed. The reflective index of the SRSO films is found to be 1.57 at 633 nm, which is mainly attributed to the increase in density of nc-Si embedded in SRSO. The structure of the CO2 laser annealed SRSO with buried nc-Si is similar to that treated by conventional furnace annealing process. The highest power of the CO2 laser as well as the peak surface temperature on SRSO sample is located in the beam spot center since the beam profile of the CO2 laser is circularly Gaussian distributed. The PL wavelengths at outer area of the laser-treated spot are 600-620 nm since a lower surface temperature only induces a weaker nc-Si precipitating process. The PL at 806 nm is observed in the area of the illuminated laser spot. High resolution transmission electron microscopy (HRTEM) analysis reveals that the average size of 3-8 nm nc-Si embedded in SRSO film is about 6 nm, which correlates well with the theoretical prediction of a corresponding PL at 806 nm. The TEM estimated square density of the nc-Si in SRSO film under the laser power density of 6.0 x 104 W/cm2 is about 1.24 x 1012 cm-2.

A10.3

Microcrystalline silicon (µ-Si) thin films are being actively investigated for TFT and solar cell applications. For large area that panel display applications, the µ-Si thin films offer the possibility of fabricating TFTs with performance intermediate to those of a-Si and poly-Si. However, the most highly advanced µ-Si thin film technology is deposited in the form of the post-deposition crystallization process which allows the deposition of high quality microcrystalline Si thin films by high-density PECVD techniques; which is gaining interest in area of thin film processing because of high tensile electron concentration, low plasma potential, and independent control of plasma energy and density. The µ-Si thin films are fabricated on glass substrates using a combination of H2 and SiH4 precursors at a temperature of 350 °C. The effects of the applied rf power and H2/SiH4 ratio on crystallinity and microstructure of the µ-Si thin films were investigated. The microstructure of the deposited films was examined by x-ray diffraction, Raman spectroscopy, and TEM techniques. The effects of the film thickness on the microstructure were analyzed in the range of 35-600 nm. The microcrystalline phase was identified by XRD patterns and the crystallite sizes were calculated from the FWHM of the XRD peaks corresponding to various planes. The microcrystalline volume fraction in the as-deposited films was evaluated using the Raman spectra. The surface and cross-sectional morphological of the films were observed by SEM. The typical deposition rate of the µ-Si thin films was greater than 350 Å/min in the H2/SiH4 ratio range of 20-100. For a 1500 Å-thick film deposited at H2/SiH4 ratio of 20, the typical microcrystalline volume fraction and the average crystallite size corresponding to <111> orientation were 75% and 160 Å, respectively. The microcrystalline phase formation was further verified by TEM analysis. The observed crystallinity and high performance µ-Si thin films show the potential of the high-density PECVD technique for the low temperature processing of high quality films with superior control of bulk and interfacial characteristics.

A10.4
Crystallization Study on Initial Growth Region of µ-Si Films with Different Preferential Orientations: Yasushi Schajima, Toshiyuki Sugano, Toshie Sugano, Toshiki Okamoto; Department of Systems Innovation, Osaka University, Toyonaka, Osaka, Japan.

Microcrystalline silicon (µ-Si) thin films prepared by PECVD have been widely utilized for thin film p-n solar cells. In general, the growth of µ-Si is elucidated by vapor phase growth [1]. In our previous study, however, solid phase structural changes during vapor phase growth were attributed to solid phase structural transitions [2]. The microcrystallinity of the (200) oriented µ-Si being suitable for the photovoltaic layer was discussed in conjunction with that of the randomly oriented µ-Si. The crystalline volume fractions of the both samples were 50-60%. In this case, a highly oriented µ-Si, the degree of the (220) preferential orientation as well as the grain size in the initial 0.5 µm thick region were increased after the 2.5 µm thick deposition compared to those of the 0.5 µm thick deposited film, which is interpreted as due to the solid phase structural transitions as we have reported [2,3]. Meanwhile, in the initial 0.5 µm thick region of random orientation µ-Si, no pronounced difference was monitored between the 2.5 µm thick and 0.5 µm thick deposited film. In addition, the microcrystallinity was improved with increasing deposition thickness as generally observed. These structural features found in the random orientation µ-Si could be elucidated by the vapor phase model [1]. Therefore, the crystallization growth of µ-Si would play a crucial role for the appearance of the solid phase structural transitions. [1] A. Matsuda, et al., JNCS 338-340 (2001). [2] T. Toyama, et al., JAP 42 (2000) L1347. [3] T. Sugano et al., to be presented at 51th IEEE PVSC (2005).

A10.5
Rapid Thermal Annealing Crystallization of a-Si:H Films Deposited by HWCVD: B. To, T. Kaydanova1, J. Pejnovic2, D. Topin1, J. Alleman1, T. Kaydanova1, E. Iwanickov2, P. Stradins1, Q. Wang1, D. Readey2, B. To1, Archie H. Mahan1, H. Branz1 and D. S. Ginley1; 1NREL, Golden, Colorado; 2Colorado School of Mines, Golden, Colorado.

The post-deposition crystallization of as-deposited a-Si:H films has the potential to enable scaleable and economic fabrication of polycrystalline Si for solar cells and high performance thin film transistors. Although many different methods are being considered to achieve this goal, rapid thermal annealing (RTA) is particularly promising because it is fast, economical and industrially applicable. Here, we report on application of RTA to thick (1-2 micron) a-Si:H films deposited on glass by HWCVD. A key aspect of the rapid thermal annealing process is the affect of the initial hydrogen content. RTA experiments were done on both low (1 at.%) and high (8 at.%) hydrogen content a-Si:H films. Optical reflectivity, XRD, SEM and AFM were used to characterize the crystallinity and morphology of the annealed films. Initial experiments were single step (temperature) RTAs of high-H a-Si:H films at temperatures ranging from 650 to 900°C with the at-temperature hold time ranging from 720 to about 6 seconds. The ramp to 900°C was done to the solid phase of 20-60%. For high-H films annealed at 900°C, the crystallite size estimated from XRD increases from ~300 to 420 angstroms as the hold time is increased from 6 to about 60 seconds. In addition, using the intensity of the e(-111) XRD peak as a complete crystallization can be obtained in 6 seconds at 900°C and 3.5 minutes at 700°C. Further analysis of crystallized high-H films by cross sectional SEM and optical micrographs shows, in some cases, bubble like features which may be formed by extremely rapid hydrogen loss. Preliminary results show
that for the RTA of low-H films, for 6 second 900°C anneals, the crystallite size is ~ 400 angstroms compared to 300 angstroms for the high-H counterparts. Importantly, we will compare the crystallite size using the single step (temperature) annealing process might improve the crystallite size and reduce the bubble-defect formation. For the high-H films, the first lower-temperature step is intended to evolve hydrogen without causing crystallization. We will compare the crystallite size using the single step and two step process versus the amount of hydrogen evolved during the first anneal. Results will also be reported using a two step process for the low-H films, with the first anneal designed to explore the effect on crystallinity that can be introduced before the second anneal takes place. In addition to using a-Si:H films deposited on glass, we will report on selected experiments done with a-Si:H deposited on c-Si to facilitate quantitative tracking of the hydrogen evolution.

A19.6 Dependence of Microcrystalline Silicon Growth on Ion Flux at the Substrate Surface in a Saddle Field PECVD. Erik Johnson, Nazir P. Khan, Elektroteknisk & Kemiisk Engineering, University of Toronto, Toronto, Ontario, Canada.

The Saddle-Field Glorh Discharge PECVD system emulates RF-like excitation using a semi-transparent anode and a DC power supply. It has been used to deposit high quality amorphous and microcrystalline hydrogenated silicon thin films in the past. The growth of microcrystalline material is particularly sensitive to the conditions under which it is produced. Significant levels of microcrystallinity are only produced under conditions of lower pressure and electrical isolation of the substrate surface from the grounded substrate holder. We present a relationship between two-step substrate electrical potential and microcrystalline growth, as quantified by Raman scattering spectroscopy, at growth pressures near the minimum required for microcrystalline growth. A series of films were prepared in the Saddle-Field Glorh PECVD system at a constant hydrogen dilution level (10% silane in hydrogen) and at pressures between 150 mTorr and 300 mTorr. The substrate bias - which has little effect on the electrical conditions of the plasma by virtue of its remoteness - was varied between -150 V to 250 V for each pressure condition. Under no conditions was this voltage enough to sustain a plasma on its own. It was observed that at the higher growth pressures, applying an external, positive substrate bias promoted microcrystalline growth while biasing the substrate to the floating potentials did not. As well, the amount of microcrystallinity increased with increasing substrate bias. At lower pressures, very limited microcrystallinity was observed and no correlation with substrate bias was noted. The minimum substrate bias necessary to achieve microcrystalline growth decreases with increasing pressure. The ion and electron flux to the growth surface under these conditions was also studied. It was observed that the growth conditions that yield microcrystallinity also showed a net negative current to the surface, which increased exponentially with increasing substrate bias. For the non-microcrystalline growth at lower pressures, no such exponential behaviour in the current was observed. The correlation between microcrystallinity, substrate bias, and net substrate current indicates that electrical interaction between the remote plasma and the growth surface strongly influences microcrystalline fraction in the Saddle-Field PECVD.

A19.7 Pit Formation in Amorphous Si Thin Films after High Temperature Thermal Annealing. Tyler Roschuk 1,2, Jacek Konopka 1, Michael Flynn 1,2, Othman Zalloum 3,2, and Peter Masche 1,2; 1 Engineering Physics, McMaster University, Hamilton, Ontario, Canada; 2Centre for Electroplottic Materials and Devices, McMaster University, Hamilton, Ontario, Canada.

Thin amorphous silicon (a-Si) films have been deposited using electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR-PECVD). Post-deposition these films have been subjected to thermal annealing at temperatures up to 1200°C for times up to 1 hour. The films are ultra low temperature (below 200°C) and higher has been found to cause the formation of a polycrystalline layer within the film through transmission electron microscopy (TEM) images. In addition, scanning electron microscopy (SEM) and atomic force microscopy (AFM) have revealed that the crystallite sizes of these films become heavily pitted after high temperature annealing. These pits have been observed to show preferential orientation and structure. Further TEM imaging has been used to type the formation of this polycrystalline layer and its influence on the observed pit formation. The effects of substrate type and film thickness on pit formation has been analyzed by comparing samples deposited unto <100> and [111] oriented Si and oxidized Si substrates with film thicknesses up to 2500 Å. Changes in the film crystallinity have been examined through X-ray diffraction experiments and correlated with the results of TEM imaging. Additionally, the role of the substrate temperature during deposition and its influence on the observed pit formation in these films has been examined. The refractive indices and extinction coefficients of these films have been determined through the use of spectroscopic ellipsometry and correlated with the processing parameters and structural properties of the films. Finally, we introduced “ceramic filament holder” to eliminate metallic impurities to achieve perfect growth of a-Si:H films. In this work, we report on growth of a new form of poly-Si thin films on glass substrates at low temperature (~250°C) prepared with ceramics hot-wire CVD. For the first time, we introduced “ceramic filament holder” to minimize metallic impurities and a new concept of “confining thermal radiation from the filament” by specially designed the filament holder to reduce substrate and ambient temperatures by thermally energizing the reacting species. In this new hot-wire CVD equipment, we call it ceramics hot-wire CVD, we developed poly-Si thin films on glass substrate at low temperature (~250°C). We observed for the first time “pentagonal” and “hexagonal” rings throughout the surface morphology revealed by atomic force microscopy. Consistent with this unusual geometrical pattern on the AFM surface morphology, we observed six transverse optical (TO) modes at 465-500 cm⁻¹, 507 cm⁻¹, 515 cm⁻¹, 517 cm⁻¹, 520 cm⁻¹ and 522-523 cm⁻¹ respectively, in addition to, TO peak around 370 cm⁻¹. Other than these several TO Raman modes and the presence of “pentagonal” and “hexagonal” rings in the AFM micrograph, we do not have any idea what is the structural structure of these films, a “new form” of poly-Si films? X-ray diffraction also indicates new type of structure of these films. We will discuss the structure and chemical composition of these poly-Si films, combining the contributions from SEM, AFM, TO and secondary XRD and XRD measurements. The electronic properties of these poly-Si films also show surprise, consistent with structural properties. 1. A. R. Middya, J. Guillete, J. Perrin and J. E. Bercaw; Mat. Res. Soc. Symp. Proc. Vol. 400 (1996) p. 289; 2. J. K. Rath, F. D. Tichelaar, H. Meiling and R. E. I. Schropp, Mat. Res. Soc. Symp. Proc. Vol. 507 (1998) p. 879.

A19.8 Growth of "New Form" of Poly-Si Thin Films Synthesized by Ceramics Hot-Wire CVD. Abdul Rafik Middya 1, Jian-Jun Liang 2, and Kartik Ghosh 3; 1 Physics, Syracuse University, Syracuse, New York; 2 Physics, Syracuse University, Syracuse, New York; 3 Physics, Astronomy and Materials Science, Southwest Missouri State University, Springfield, Missouri.

Polycrystalline silicon (poly-Si) thin films synthesized by hot-wire chemical vapor deposition show promise for application of these materials in solar cells and thin film transistors. The special features of hot-wire CVD technology include high growth rate, textured surface and columnar growth, low process temperature (~450°C), relatively high mobility (~20 cm²/V s⁻¹), low carrier concentration (~ 10¹⁰ cm⁻³) characteristic of these films. The room temperature resistivity of these poly-Si films can be varied almost by orders of magnitude by in-situ gas phase doping for p-type films. The solar cells performance using these materials in pin structure show high short-circuit current (Jsc ~ 24 mA/cm²) for absorber layers with defect density ~ 10¹⁷ cm⁻³, whereas the state-of-the-art μc-Si solar cells produces nearly same amount of current (~ 26 mA/cm²) with Voc of ~ 0.6 V. Therefore, these μc-Si solar cells show light-induced degradation. Clearly, the potential of hot-wire CVD poly-Si thin films solar cells has not yet been achieved in reality. In this work, we report on growth of a new type of poly-Si thin films on glass substrate at low temperature (~250°C) prepared with ceramics hot-wire CVD. For the first time, we introduced "ceramic filament holder" to minimize metallic impurities and a new concept of "confining thermal radiation from the filament" by specially designed the filament holder to reduce substrate and ambient temperatures by thermally energizing the reacting species. In this new hot-wire CVD equipment, we call it ceramics hot-wire CVD, we developed poly-Si thin films on glass substrate at low temperature (~250°C). We observed for the first time "pentagonal" and "hexagonal" rings throughout the surface morphology revealed by atomic force microscopy. Consistent with this unusual geometrical pattern on the AFM surface morphology, we observed six transverse optical (TO) modes at 455-500 cm⁻¹, 507 cm⁻¹, 515 cm⁻¹, 517 cm⁻¹, 520 cm⁻¹ and 522-523 cm⁻¹ respectively, in addition to, TO peak around 370 cm⁻¹. Other than these several TO Raman modes and the presence of "pentagonal" and "hexagonal" rings in the AFM micrograph, we do not have any idea what is the structural structure of these films, a "new form" of poly-Si films? X-ray diffraction also indicates new type of structure of these films. We will discuss the structure and chemical composition of these poly-Si films, combining the contributions from SEM, AFM, TO and secondary XRD measurements. The electronic properties of these poly-Si films also show surprise, consistent with structural properties. 1. A. R. Middya, J. Guillete, J. Perrin and J. E. Bercaw; Mat. Res. Soc. Symp. Proc. Vol. 400 (1996) p. 289; 2. J. K. Rath, F. D. Tichelaar, H. Meiling and R. E. I. Schropp, Mat. Res. Soc. Symp. Proc. Vol. 507 (1998) p. 879.

A19.9 Nanocrystalline-Si Thin Film Deposited by Inductively Coupled Plasma Chemical Vapor Deposition (ICP-PECVD) at 150°C. Sang-Myun Han, Joong-Hyun Park, Hye-Jin Lee, Kwang-Sub Shin, and Min-Koo Han; Seoul National University, Seoul, South Korea.

Nanocrystalline silicon (nc-Si) thin film transistor (TFT) may be a promising device for various applications, including electronic displays due to rather simple process compared with poly-Si TFT and better performance compared with a-Si TFT. Conventional plasma enhanced chemical vapor deposition (PECVD) method has been widely researched to deposit nc-Si film. It is known that inductively coupled plasma (ICP) mode can generate high density plasma. ICP-PECVD may also provide a certain advantages such as high deposition rate and improved crystallinity over PECVD. The purpose of our work is to report nc-Si film deposition by ICP-PECVD under low temperature TFTs which can be applied to flexible displays. The flexible displays may have certain merits compared with the present rigid displays. For flexible displays, it is inevitable to limit the process temperature to avoid deformation of substrates like plastics. The Si films were deposited at ultra low temperature (below 200°C) and characterized. We deposited nc-Si film by ICP-PECVD at 150°C. ICP power was 400W. The process gas was SiH₄ diluted with He as well as H₂. The flow rate of H₂/H₂ was varied from 20:1 to 2:1 and...
that of SiH$_4$ was 8 sccm. The crystalline volume fractions evaluated from the Raman spectrum of the nc-Si film were above 70%. X-ray diffraction (XRD) patterns of the nc-Si films deposited by ICP-CVD with He dilution had a (220) orientation and the intensity of (311) peak increased as the He dilution ratio increased. In the case of H$_2$ dilution, (111) and (220) peaks as well as (311) peak were observed. The grain size of 40 – 50nm was observed by SEM and AFM in the film deposited in the condition of high dilution. Our experimental results show that nc-Si film deposited by ICP-CVD may be suitable for active layer of nc-Si TFTs.

A10.10 Abstract Withdrawn

A10.11 Effects of N$_2$O Fluence on The PECVD-Grown Si-rich SiO$_x$ with Buried Si Nanocrystals. Chia-Yang Chen$^1$, Chun-Jung Lin$^1$, Gong-Hu Lin$^1$, Hao-Chung Kuo$^1$, Yu-Lun Chen$^2$, Li-Jen Chou$^2$, Chi-Hsiung Chang$^3$ and Eric Wei-Guang Diao$^3$. $^1$Department of Photonics & Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan; $^2$Department of Materials Science and Engineering, National Taiwan University, Taipei, Taiwan; $^3$Department of Applied Chemistry and Center for Interdisciplinary Molecular Science, National Chiao Tung University, Hsinchu, Taiwan.

The growth of silicon-rich substoichiometric silicon oxide (SiO$_x$) with buried Si nanocrystals (nc-Si) by plasma enhanced chemical vapor deposition (PECVD) with optimized N$_2$O fluence is demonstrated. The SiO$_x$ with highest excess Si density can be obtained by detuning the fluence ratio of Si$_2$H$_6$ to N$_2$O. Photon induced luminescence analysis revealed a pseudo-solids result for samples with varying SiH$_4$ fluence. By changing N$_2$O fluence from 105 sccm to 130 sccm, strong PL at 550-870 nm has been observed in the post-annealed SiO$_x$ film with dense nanocrystalline Si (nc-Si) clusters. After annealing at 1100°C from 15 to 120 min, a 22 nm redshift in PL is detected. The maximum PL intensity is observed at 761 nm for the 30-min annealed SiO$_x$ film grown at 120-sccm N$_2$O-fluence. The wavelengths and associated linewidths of PL spectra for samples annealed at different durations are ranging from 735 nm to 761 nm and from 133 nm to 177 nm, respectively. Alternatively, a larger N$_2$O fluence and a longer annealing time also cause the PL blueshift by 65 nm and redshift by 20 nm, respectively. The blueshift is attributed to shrinkage in the size of nc-Si under the participation of dissolved oxygen atoms from N$_2$O. The density of precipitated nc-Si reaches its maximum after 30 min annealing. Longer annealing time results in the reduction on both the PL intensity and the size of nc-Si, since the outer surface of nc-Si becomes oxidized by the surrounding SiO$_x$ matrix. Besides, different annealing time is required to precipitate nc-Si in the Si-rich SiO$_x$ grown with different N$_2$O fluxes. The bright-field cross-section viewing TEM photograph for the annealed Si$_x$O$_{1-x}$ film is demonstrated to support the existence of nc-Si. The lattice distance between two (111)-oriented planes of 0.63 nm observed from a Si substrate is employed as a standard ruler to estimate plane-to-plane distance of nc-Si (about 0.19 nm). According to the X-ray diffraction (XRD) data, the (111) planes of Si with diameter ranging from 4.4 to 5.0 nm are determined as (220). The TRPL analysis indicates that the luminescent lifetime lengths from 20 ps to 52 ps as nc-Si size extends from 4.4 to 5.0 nm, which increases linearly with the size of nc-Si. As the ratio of n$_{nc}$ to n$_{nc}$(Si$<$1) increases, the density of nc-Si is decreased from 8.3 x 10$^7$ cm$^{-3}$ to 1.2 x 10$^7$ cm$^{-3}$.


In the recent years it has been demonstrated that the remote expanding thermal plasma (ETP) deposition tool, which has easily access to ultra-high hydrogenated deposition rates for amorphous silicon of up to 100 Å/s, preserves the material quality of a-Si:H material deposited by the ETP technique at high deposition rates. Therefore the incorporation into a pin solar cell where temperatures are limited by the p-layer remains a challenge. Employing an additional ion bombardment by means of an external RF bias under high growth rate conditions supplies additional energy to the growing film thereby improving the film properties without the necessity to increase the substrate temperature above 250 °C. In this work it is demonstrated that the external RF bias results in the creation of an additional growth flux, a reduction of the void incorporation, smoother surfaces, and an increase in the vacancy density. In general, in absence of external RF bias the majority hydrogen content is fixed for pure ETP a-Si:H growth. However, employing RF substrate bias provides us access to a larger variety of microstructures, i.e. the microstructure of the material can be tuned at constant hydrogen content. The relation of these results to typical ion bombardment enhanced surface processes such as surface diffusion, surface smoothing, Si sputtering and Si displacement is discussed. It is shown that only a moderate RF power is required to influence the opto-electronic performances of c-Si:H. This allows to considerably reduce the sub gap absorption related defects. Using this approach the solar-cell performance, utilizing ETP material at high deposition rate and low temperature, has improved.

A20.2 Thin Films of GeC$_{x}$ Deposited Using a Unique Hollow Cathode Sputtering Technique. Rodney Joseph Suckup$^1$, Natalie J. Jannd$^2$, Jason S. Schrader$^1$ and Vikram L. Dalal$^3$. $^1$Electrical Engineering, University of Nebraska, Lincoln, Nebraska; $^2$Electrical and Computer Engineering, Iowa State University, Ames, Iowa.

Experimental results on thin films of the new material Ge$_x$C$_{1-x}$, deposited by a unique dual plasma hollow cathode sputtering technique are presented here. The (Ge, C) system is extremely promising since the addition of C to Ge may reduce the lattice dimensionality of the materials compared to its pure silicon counterpart. The maximum PL intensity is observed at 761 nm for the films deposited onto both silicon and glass substrates. The initial films on the glass substrates had no or very little photo response and after a few depositions it was decided to deposit only on silicon. The films deposited onto glass were amorphous in nature, but the films deposited onto silicon were perfectly crystalline. This crystallinity has been characterized with Raman spectroscopy and X-ray diffraction (XRD). A typical Raman spectrum indicated that the pure Ge films were polycrystalline. However, the normal Ge$_x$C$_{1-x}$ films were not as perfectly crystalline. The indications are that the films are polycrystalline in nature and this has been verified by XRD. Typical samples have peaks at angles which indicate that the 111, 220, and 311 faces are most prominent. Auger depth profiling studies of the Ge$_x$C$_{1-x}$ films have also been made. The incorporation of C into the films is relatively uniform and is on the order of 7 to 8%, higher than any other method at this growth rate, 1.5 Å/s. Fourier Transform Infrared Spectroscopy (FTIR) yielded interesting results. The FTIR spectrum over the wave number range of interest was featureless except for a small absorption peak (1110 cm$^{-1}$) attributable to the SiO$_2$ at the interface between the Si substrate and the GeC film. This is a desirable result because it means that the hydrogen is not bonding to the substrate, even though a high density plasma rich in hydrogen is present in both nozzles, or in some cases, just the Ge nozzle. Prior films of a-Si:Ge:H had prominent peaks at 1880cm$^{-1}$ and this indicates a GeH bond. A probable cause of this lack of H bonding in these films is that the substrate temperature in this experiment is considerably higher during deposition than it was during the amorphous Ge deposition. One important factor in achieving useful GeC films for device applications is to get the C to bond interstitially in the Ge crystal. The most recent films shown a large peak in the FTIR spectra at 530cm$^{-1}$ which indicates such an interstitial Ge-C bond.

A20.3 Improved Optical Loss Characteristics of PECVD SiO$_x$N$_y$ Films Using Low Frequency Plasma. Sudipto Naskar$^1$, Christopher A. Bower$^1$, Brian R. Stoner$^2$ and Jeffrey T. Glass$^3$. $^1$MCNC-RDI, RTP, North Carolina; $^2$Duke University, Durham, North Carolina.

With the continued growth of photonics, silicon oxy-nitride (SiO$_x$N$_y$) is becoming a popular material for optoelectronic applications owing to its large tunable refractive index. However, with the increase in refractive index, these films tend to show poor optical transmission characteristics since the material tends to become hydrogen rich. In this research effort we have investigated the influence of growth conditions on the loss characteristics of PECVD SiO$_x$N$_y$ films. The films are grown at 350°C substrate temperature and 1 Torr pressure with silane (SiH$_4$) and nitrous oxide (N$_2$O) precursors gases. The precursor flow rate and power input to the system are varied as the two primary parameters. It is observed that films grown at 100 KHz
plasma frequency proved to be more transmissive than films grown at 13.56 MHz plasma frequency. Elastic recoil detection analysis showed that the hydrogen content is less in the low frequency films than the high frequency films which is believed to be the reason for the low loss behavior. In this presentation the influence of growth conditions on loss behavior will be discussed with special reference to the effect of hydrogen in the oxynitride film.


We study the role that the growth temperature plays in determining the amount of disorder present within silicon films deposited through ultra-high-vacuum molecular beam epitaxy. For the purposes of this study, we have deposited eleven silicon films on quartz substrates for a variety of different growth temperatures, ranging from 38°C to 572°C. Through measurements of the Raman spectrum and the optical absorption spectrum corresponding to each film, we have quantitatively determined how the disorder within the silicon films. We find that the amount of disorder increases as the growth temperature decreases, and that there is a particular dramatic decrease in the disorder as the growth temperature increases beyond 450°C. We suggest that this dramatic increase of disorder corresponds to a transition in the structural nature of the deposited silicon films, from disordered amorphous silicon to a more ordered form.

A20.5 Low Temperature Growth of Amorphous Silicon Films on Plastic Substrates by Catalytic CVD Technique. Wan-Sheung Hong1, SungHyun Lee2, Kyung Eun Lee3, Chul Lae Cho4, SeungGil Han5, Jongman Kim6, Jangyeon Kwon7 and Youngsoo Park8; 1Electronics Engineering, Sejong University, Seoul, South Korea; 2Samsung Advanced Institute of Technology, Yongin-city, Kyunggido, South Korea.

Low temperature polycrystalline silicon (LTPS) films are a key component of thin films transistors (TFTs) for driving active matrix organic light emitting displays (AM-OLEDS). Fabricating good quality LTPS films on plastic substrates has been a big challenge, since the overall process temperature is limited to the glass transition temperature of the plastic substrate. Also, a low content of atomic hydrogen is desired to prevent damage during crystallization. Therefore, a deposition technique that has a high deposition rate, a low hydrogen content and a low process temperature is required for preparing amorphous silicon precursor films on plastic substrates. In this study, amorphous silicon films for application as a precursor for laser-annealed polycrystalline silicon were deposited by a Catalytic (Hot Wire) CVD technique. The films were successfully deposited on polyethersulfone (PES) substrates held at room temperature. By adopting a custom-designed cooling system, the substrate temperature was suppressed to <120°C during the process. The chamber pressure and the gas flow rate were chosen as main process parameters, and the deposition rate and the atomic concentration of hydrogen in the films were analyzed. The gas flow rate showed different effects on the deposition rate in the high pressure regime and in the low pressure regime. The hydrogen content varied in rather a complicated way with pressure and flow rate. Also, there exists a certain region of process parameters, where both the deposition rate and the hydrogen content exhibit abrupt changes. A very high deposition rate (~100 Å/sec) was achieved, but the hydrogen content could be controlled effectively in the range of 0.1~5 at%. These films were suitable precursor material for the LTPS layer on plastic substrates.

A20.6 Chemical Annealing of Amorphous Silicon and Silicon-Germanium Films and Devices. Vikram Djalal and Nanlin Wang; Elec. and Comp. Eng., Iowa State University, Ames, Iowa.

Chemical annealing, which involves the layer-by-layer growth of a material in a thin layer, followed by annealing in a reactive or non-reactive beam of ions and radicals, has been previously used to change the hydrogen content and electronic and optical properties of a-Si:H. In this paper, we report on a systematic study of chemical annealing in both a-Si:H and a-SiGe:H films and devices. We use both reactive (quartz) and non-reactive helium and argon plasmas for chemical annealing. The films and devices were grown using a remote, low pressure ECR discharge using mixtures of silane, germane and either hydrogen or helium. The thickness of each layer was in the range of 2-3 nm. The total film thicknesses were in the range of 1-2 micrometers and of l layers in p-i-n devices, between 0.25 and 0.5 micrometers. The films were characterized using subgap absorption, FIBR spectroscopy, optical spectroscopy, activation energies and electron mobility-lifetime products. p-i-n devices were fabricated on stainless steel substrates, and were characterized using quantum efficiency spectroscopy and capacitance spectroscopy, in addition to the device I-V curves. It was found that hydrogen annealing always increased the bandgap, but did not improve the stability of either films or devices. In contrast, annealing with He decreased the H content and bandgap, and also seemed to improve the stability.

A20.7 Deposition Simulation of Si and SiGe Using a Bond Order Potential. Haydn Wadley and Brian Andrew Gillespie; University of Virginia, Charlottesville, Virginia.

Recently proposed Si-Ge heterostructure devices, such as the spin resonance transistor, require highly precise deposition techniques to realize the devices' complex structure. Molecular dynamics modeling techniques have proven successful in the past at simulating the vapor phase fabrication of metallic magnetoresistive systems (e.g. Ni/CoFe/Cu multilayers). This thesis explores extensions of the methodology to semiconductor systems based on Si and Ge. Many interatomic potentials for modeling these semiconductor systems have been proposed. A Bond Order Potential (BOP) developed by David Pettifor et al. at Oxford University, as well as the Stillinger-Weber (SW) and Tersoff potentials, is assessed for modeling the vapor phase growth of Si and SiGe thin films. It is shown that both the SW and BOP potentials predict similar radial distribution functions for amorphous deposition to those seen experimentally. Both the SW and BOP potential also predict crystallization under conditions that match experiments that result in crystalline growth.

A20.8 Low-Temperature Deposition of Silicon Oxide Thin Films using Alternating Exposures of SiH2Cl2 and O2/O3. Chan-Hoe Han1, Min-Ho Chun2, Sa-Kyun Rha3, Un-Jung Kim4, Sang-Wook Lee5, Won-Jun Lee6 and Youn-Seoung Lee7; 1Department of Materials Engineering, Hanbat National University, Daejeon, South Korea; 2Department of Advanced Materials Engineering, Sejong University, Seoul, South Korea; 3Division of Information Communication and Computer Engineering, Hanbat National University, Daejeon, South Korea.

Silicon dioxide (SiO2) has been one of the most widely used dielectric materials in the Si integrated circuits (ICs). Generally, SiO2 films have been deposited by low-pressure chemical vapor deposition (LPCVD) method at more than 700 °C in the IC manufacturing processes. However, the high processing temperature of LPCVD process is expected to be an issue in monocrystal ICs in the near future. Atomic layer deposition (ALD) is a promising technique for depositing ultrathin SiO2 films at lower temperatures in the processing of next-generation ICs. In this study, SiO2 thin films were deposited on p-type Si (100) substrates by alternating exposures of SiH2Cl2 and an O2/3% O3 mixture. Oxygen was generated by corona discharge inside the delivery line of O2, and the concentration of O3 was measured in the reactor. N2 was used as the purging gas between the pulses of precursors. The deposition of SiO2 films was investigated as a function of reactant exposures at the deposition temperature ranging from 250 to 450 °C. The growth rate was saturated at approximately 0.25 nm/cycle with the reactant exposures over 5.0 × 1014 [1 L = 10-9 Torr·sec] at 350 °C. The saturation growth rate increased with deposition temperature up to 350 °C, however, decreased with increasing deposition temperature from 350 to 450 °C.

SESSION A21: Poster Session: Solar Cells
Thursday Evening, March 31, 2005
8:00 PM
Salon 8-15 (Marriott)


New types of transparent conductive oxides with low indices of refraction have been developed for use in optical stacks for the...
amorphous silicon (a-Si) solar cell and other thin film applications. The alloys are ZnO based with Si and MgF added to reduce the index of the material that provides the creation of voids in the materials. Alloys with 12-14% Si or Mg have indices of refraction at λ=800nm between 1.6 and 1.7. These materials are presently being used in optical stacks to enhance light transmission by using MgF as a base reflector in a-Ag based solar cells to increase light absorption in the semiconductor layers and increase open circuit currents and boost device efficiencies. In contrast to Ag/ZnO back reflectors which have long term stability issues due to metal corrosion, Ag-based back reflectors should be stable and usable in manufactured PV products. In this manuscript, structural properties of the materials will be reported as well as the performance of solar cell devices made using these new types of materials.

A2.1.2 Abstract Withdrawn

A2.1.3 Effect of P-layer Nanostructure on the Open Circuit Voltage of Amorphous Si:H Solar Cells. Wenjuan Da, Xiaobo Lian, Xiexen Yang and Xueming Deng; Department of Physics & Astronomy, University of Toledo, Toledo, Ohio.

Amorphous hydrogenated Silicon solar cell (a-Si:H) have high conversion efficiencies when the intrinsic layer is made just prior to the amorphous to nanocrystalline (a+nC) mixed phase transition by radio frequency plasma enhanced chemical vapor deposition (RF-PEDV). The phenomenon of a-nC transition to nc-Si is well known at high H2 dilution. It is also dependent on substrate temperature, substrate as well as the film thickness. This paper reports that p layers made after the amorphous to a+nC transition showed the best IV properties of solar cells. Several samples of Boron doped a-Si:H p-layers were made with different nc-Si volume fractions. Amorphous silicon with low nc-Si volume fraction p-layers were deposited at low substrate temperature and high power. High nc-Si volume fraction materials were deposited at high substrate temperatures and low power. The nc-Si volume fractions of these layers were determined by Raman spectroscopy. Standard a-Si:H solar cells were made using these p-layers. We found the open circuit voltage increased from 0.67V when p-layer was amorphous but close to the phase transition, to 1.04V when the p-layer had a small nc-Si volume fraction. When the nc-Si volume fraction was increased further the voltage decreased to 0.89V. The explanation is that for small nc-Si volume fraction material nc-Si particle size is about 5nm and quantum size effect produces a bandgap larger than amorphous Si bandgap (1.8eV). The bandgap of p-layer limits its Fermi energy level position and built-in electric field in the i-layer, therefore, a-Si:H solar cells with small nc-Si volume fraction has a large open circuit voltage. When the nc-Si volume fraction is increased, nc-Si particle size is increased and quantum size effect disappears. The bandgap of p-layer decreases and reduces the open circuit voltage.


Nanocrystalline Si:H is an increasingly important material for photovoltaic devices. The properties of the devices depend critically upon the physical properties of the materials, as well as on the interaction between the base layer and the front and back junction layers. In this paper, we report on the properties of nanocrystalline Si materials and devices made using different, well controlled techniques. Among these are VHF plasma deposition with varying amounts of hydrogen/silane ratios and varying growth temperatures, use of mixtures of helium and hydrogen instead of hydrogen alone for achieving crystallinity, ECR deposition, also with varying helium/hydrogen ratios, and chemical annealing with helium which can also lead to the formation of a crystalline phase. This last result is unexpected, and it points up the role of controlled ion bombardment in converting an amorphous phase into a crystalline one. We measure systematically the structure using both x-ray diffraction, electron microscopical properties such as mobility, defect density, carrier lifetimes and diffusion lengths, and device properties for the materials made using the varying deposition conditions described above. From a careful examination of x-ray diffraction, we show that significant stresses exist in the materials, and that the degree of stress varies as a function of grain size and growth temperature. Small grain sizes lead to higher stress values. Both compressive and tensile stress is in the same material. The shift in the peak position of the Raman spectrum is directly correlated with the stress in the film. The electronic measurements show that the defect density is correlated with the presence of amorphous transition shows the best IV properties of solar cells. A shift in the peak position of the Raman spectrum is directly correlated with the stress in the film. The electronic measurements show that the defect density is correlated with the presence of amorphous to nanocrystalline phase transitions. The measurements are made within a device structure by using quantum efficiency under appropriate conditions. Special devices have been constructed to make sure that QE corresponds to only a single pass of light, thereby avoiding light-trapping effects on the measurement of absorption coefficient.

A2.1.5 Metal Induced Growth of Poly-Si Solar Cells and Silicide Nanowires by use of Multiple Catalyst Layers. Joondong Kim, Chunhui Ji and Wayne A. Anderson; Electrical Engineering, University at Buffalo, Buffalo, New York.

Poly crystalline Si solar cells have been fabricated by the Metal Induced Growth (MIG) method. Several types of metal alloys (mixtures of Co and Ni) were deposited to provide a quality poly-Si solar cell as well as a spontaneous back ohmic contact on the bottom of the grown poly-Si film. A catalyst metal film was thermally deposited on tungsten or a SiO2 coated Si wafer. Using a D.C. magnetron, a doped Si target was sputtered onto the metal seed layer at a substrate temperature of 550 ~ 650 °C leading to a ~25 nm poly-Si film by solid phase reaction. The use of Ni as a catalyst caused a higher leakage current. The Co-induced poly-Si provided a better performance in open circuit voltage (Voc) while reducing the short circuit current density (Jsc). Multiple layers of Co and Ni (Co/Ni) as catalyts gave better results rather than use of a single metal layer. Voc and Jsc improved from 141 mA/cm2 to 241 mA/cm2 and 4.78 mA/cm2, respectively. The use of a Co coating on the Ni reduced the Ni diffusion into the grown poly-Si resulting in less leakage current. Two poly-Si layers grown by repeating the single step process significantly improved the performance. The surface morphological changes and cross-section have been observed by Scanning Electron Microscopy (SEM). Silicide nanowires (NWs) were also fabricated by the MIG method similar to the MIG-poly Si. X-ray diffraction (XRD) pattern and Auger depth profile have been performed to analyze mechanisms to provide the poly-Si film and single crystalline NWs. Optical reflectance results showed MIG-poly-Si to give much lower reflectance than a Si wafer and lower than a MIG-NW grown poly-Si. Optical reflectance at 100 nm was 53.1 % for the bare Si wafer, 29.3 % for the MIG poly Si and 14.08 % for the NW-topped Si wafer. This implies improving the MIG-solar cell performance by topping the Si with a MIG-NW layer.

A2.1.6 Polyaniline/Amorphic Silicon Heterostructure Solar Cells. Weining Wang and Eric A. Schiff; Physics, Syracuse University, Syracuse, New York.

Hole-transporting, doped polymers are an intriguing alternative to conventional inorganic materials for the p-type layer in amorphous silicon solar cells. In particular, polymers can offer better bandgaps than the inorganic materials usually used as p-layers, such as (boron-doped) microcrystalline silicon and amorphous silicon-carbide. Simple models of devices with wider bandgap p-layers suggest the possibility of improved open-circuit voltage and better conversion of blue light with the use of a polymer p-layer. In the present experiments we have cast doped polyaniline from solution onto the top of an amorphous silicon based a/n interface. The structure was immediately annealed at 100 °C. No buffer layer was used. After annealing, a small gold electrode was evaporated onto the polyaniline to serve as a top contact. Current-voltage characteristics of the device under illumination were similar to those in devices with conventional p-layers, indicating both that the polymer layer (about 200 nm thick) was transparent and that series resistance was negligible. The largest open-circuit voltage Voc we have obtained with these devices is 0.76 V, which is at least 0.1 V smaller than expected with conventional inorganic p-layers. Voc also declined more rapidly with intensity than for conventional p-layers. One possible mechanism for this suppression of Voc is the growth of an oxygen-reacted silicon film following the reaction of the polymer solution (and subsequent annealing). Earlier work by Middya [1] using a polymer (PEDOT:PSS) cast onto a-Si:H n/i structures from an aqueous solution achieved open-circuit voltages as large as 0.73 V; these differences suggested the present experiments with polyaniline, for which the solvent was non-aqueous. We believe that the present work indicates that casting of the polymer from solution is not yielding an acceptable interface, although we cannot presently exclude polymeric contamination as an alternative mechanism. Significant improvement in Voc was obtained in this case. This research was supported by the Thin Film Photovoltaics Partnership of the National Renewable Energy Laboratory. 1. National Renewable Energy Laboratory Report SR-520-33164 (December, 2002; http://www.nrel.gov/docs/fy033164.pdf).
It has been accepted that general solid-phase (SP) annealing in ultra-shallow junction (USJ) formation cannot achieve dopants on time scales <1µsec. In order to investigate the possibility of activation on such short time scales using the diode-pumped solid-state (DPSS) laser annealing process that we had developed, we adopted double-laser irradiation controlling a delay time between two short green-laser pulses (pulse duration ~100nsec), and challenged forming the USJ below 10nm depth in spite of the deep penetration depth (crystalline Si ~1000nm). As-implanted samples were prepared as follows: 1) The Ge pre-amorphization impant was performed at an energy of 3keV to a dose of 3x10^{14} ions/cm^2, and the amorphous layer formed is limited to a depth of 8.3nm from the measurement. 2) After the amorphization, the B implant was performed at 0.2keV to 5x10^{14} ions/cm^2 and 1x10^{15} ions/cm^2. From the result of SIMS analysis at 1x10^{18} at/cm^3, the B dopants (5x10^{14} ions/cm^2) extend to the depth of 7.9nm into the Si wafer and stay in the amorphous layer (depth: 8.3nm) according to the process design. Post-implantation laser annealing, which the double pulses were irradiated at 1kHz, was performed overlapping a uniform 0.1mmx17mm line beam at an overlap ratio of 90% with scanning a sample stage at a constant velocity. To search a process window of SP activation in the wide range of pulse energy density, a delay time between double pulses as a parameter was changed from 0nsec to 900nsec at intervals of 150nsec. Distinction between single- and double-pulse activation was judged based on the threshold that surface roughness measured by AFM abruptly increases with the increase of pulse energy density. The threshold point for the B dose of 5x10^{14} ions/cm^2 is put between 780mJ/cm^2 and 790mJ/cm^2 at a delay time of 300nsec. The junction depths are about 9nm in the range less than 780 mJ/cm^2, and the sheet resistance shows the minimum value of 1.0 KΩ/sq in the same range of pulse energy density. Increasing the B doses from 5x10^{14} to 1x10^{15} ions/cm^2, the sheet resistance was reduced to 0.65 KΩ/sq at the 300nsec delay time. The increase of the B dose is effective in obtaining the SP process window wider in pulse energy density versus sheet resistance. To overcome the issues of the short annealing time <1µsec, we positively made the most use of a-Si:H solar cells. We used single-junction pin solar cells with varying intrinsic layer thickness over the issues of the short annealing time since it introduces an excessive number of grain boundaries leading to poor cell properties. Therefore poly-Si film was prepared by metal induced low temperature crystallization. The structures of the single amorphous cells, single microcrystalline and polycrystalline cells were studied by Cross-Sectional TEM and X-Ray Analyzing. There were carried out the analyses of FF, Voc and Isc of the structures for various conditions. Finally, we present the parameters for optimal tandem devices.


To perform this work the electrical and optical properties of ZnO:Ga, ITO and ZnO:In deposited on glass were studied under different hydrogen plasma time exposition. The electrical and optical properties were respectively studied through conductivity, Hall effect, spectroscopic impedance and UV-VIS-NIR spectroscopy measurements that allow the determine the role of hydrogen plasma on the parameters like conductivity, capacitance, mobility, Hall mobility, carrier concentration, sheet resistance, transmittance and optical gap. Apart from that, the performances of such TCO on solar cells based on nanocrystalline silicon will be also studied and presented. The data presented show the electrical properties of solar cells using as back contact ZnO:Ga present the best properties, allowing high current density collection with solar cells with efficiencies exceeding 13%.


A conclusive understanding of the as-deposited characteristics of a-Si:H solar cells would be an important advance, albeit one that does not directly address the origins of their degradation. A number of models have been proposed that are capable of accounting satisfactorily for these characteristics at room-temperature. Most of these models would likely be excluded by temperature-dependent measurements, but a satisfactory set of such measurements has not, to the best of our knowledge, been done. To provide measurements that will more rigorously test these models, we prepared a series of a-Si:H single-junction pin solar cells with varying intrinsic layer thickness (200 nm ~ 800 nm), and did standard room-temperature characterization of the cells under a solar illuminator. To simplify comparison with earlier work, we measured the temperature-dependent characteristics of these cells under intense illumination from a 685 nm laser; illumination at this wavelength is nearly uniformly absorbed throughout the intrinsic layers. The range of temperatures was 293 K ~ 350 K. A 1x10^{-6} A/cm^2 was taken for the temperature-dependent characteristics of several light-soaking states. We compared these measurements with the predictions of the “simplest reasonable” model for a-Si:H cells. The model incorporates only bandtail-related trapping and recombination, so for the intrinsic layer, and neglects deep levels altogether; the model parameters were published earlier [1]. Despite its simplicity, this model accounts well for the temperature-dependence and thickness-dependence of the open-circuit voltage and of the power density. These successes suggest that the as-deposited characteristics of the cells under solar illumination do derive primarily from the bandtail properties. However, the measured short-circuit current density declined markedly less with temperature than predicted. We speculate that this discrepancy could be evidence for variation of the bandtail trapping coefficient with trap depth, as has been proposed previously by Movaghar and Yelon. This research was supported by the Thin Film Photovoltaics Partnership of the National Renewable Energy Laboratory [H.K. Zhu et al., in Amorphous and Nanocrystalline Silicon-Based Films-2003 (MRS Symposium Proc. Vol. 762), 297].

A21.9 Matching of the Amorphous Si Top Solar Cell and Low Temperature Crystallized Si Bottom Solar Cells. Andrzej Koleckaj and Pawel Krenklat; Department of Electronics, AGH University of Science and Technology, Krakow, Poland.

Proper choice of layer thicknesses and current matching between the series connected top and bottom cell is required for tandem solar cells to obtain effective in conversion efficiency. The current matching means that both cells are operating at their maximum power point (MPP) and simultaneously the output current of each cell is the same. The current of the top and bottom cell depends on the thickness of each cell and also on the absorption in successive layers of the tandem structure. In this case we analyze a double terminal (DT) structure instead of the classical tandem cell. Thickness variations of the absorber layers, degradation effects and spectral changes of the illumination under outdoor conditions lead to a shift of the top and bottom cell operating points. While the µc-Si:H bottom cells are stable or show only little degradation, still considerable degradation is introduced by the a-Si:H top cell. In our case the top cell is a stable filter for changing bottom cells. The deposition of µc-Si:H structure was performed at high pressure and high plasma power of RF PECVD process. However, poly-Si films deposited by the method on ordinary glass or other substrates typically have an average grain size of 10-20 in- a grain structure presents a problem for device performance since it introduces an excessive number of grain boundaries leading to poor cell properties. Therefore poly-Si film was prepared by metal induced low temperature crystallization. The structures of the single amorphous cells, single microcrystalline and polycrystalline cells were studied by Cross-Sectional TEM and X-Ray Analyzing. There were carried out the analyses of FF, Voc and Isc of the structures for various conditions. Finally, we present the parameters for optimal tandem devices.
timming controllers.1) Their reliability thus has a direct impact on the product lifetime. One of the most important reliability parameters is gate oxide integrity (GOI), which is the semiconductor (MOS) device to remain operational for many years with the gate voltage applied.2, 3) The breakdown electric field of thermally grown silicon dioxide insulator used in integrated circuits is typically around 15-15 MV/cm while that of plasma-enhanced chemical vapor deposited (PECVD) SiO2 insulator used in low temperature polysilicon TFTs is around 4-10 MV/cm.5) The breakdown field of the deposited insulator depends on polysilicon surface roughness, metal-originated pits (COPs), and metal precipitates as these are responsible for locally high electric fields.2, 3)

The low breakdown electric field of insulator deposited using PECVD is also attributed to porosity oxides contaminated with metallic or ionic impurities and which also lead to enhanced leakage currents. Here we present an experimental study of the gate oxide breakdown and evaluate its integrity on the three types of poly-Si active layers: Exximer laser crystallized (ELC) poly-Si, MLC poly-Si and SPC poly-Si. In this paper, we present the results of PECVD gate oxide (SiO2) integrity on ELx (exximer laser crystallized), MILC (metal induced lateral crystallized) and SPC (solid phase crystallized) polysilicon films. We observed that gate oxide strength of poly Si TFT strongly depends on the crystallization method for the active silicon layer. In the case of ELC films,features on the silicon surface reduce the SiO2 breakdown field significantly. The metal containing impurities in MILC films are responsible for a decrease in gate oxide integrity. Among the three cases, the SPC breakdown field was the highest for the SPC silicon films. The breakdown fields at the 50% failure points in Weibull plots for the ELx, MILC and SPC cases were 5.1MV/cm, 6.0 MV/cm and 9.2 MV/cm, respectively. We conclude that the roughness and metal contamination of the poly-Si films are the main factors that cause enhanced breakdown of SiO2 films.

A22.1 Low Temperature Metal-Free Fabrication of Polycrystalline Si and Ge TFT's by PECVD Hydrogenation. Pouya Hashemi1, Jaber Derakhshandeh2, Bahman Bekmatshooy3, Shahroodrood Mortezaie2, Yaser Abd-Elrahman4, and M. D. Robertson5.

1) ECE Department, McGill University, Montreal, Canada. 2) Department of Physics, Acadia University, Wolfville, Nova Scotia, Canada.

We report the fabrication of polycrystalline Si and Ge thin film transistors (TFT's) on glass substrate at reduced temperatures. The multi-step PECVD hydrogenation-assisted crystallization method is used to create polycrystalline structures. This method allows crystallization of amorphous Si and Ge films without any metal seed contamination and at a considerably reduced temperature. Using e-beam evaporation, a layer of 1000Å Si (Ge) is deposited on the glass substrate at a temperature of 200°C and a base pressure of 2×10^-6 torr. The samples are then carried to a conventional RF-PECVD system to perform the multi step metal seed-free crystallization.

Samples are initially treated in RF plasma for 30 minutes in hydrogen ambient. The optimum RF plasma power is 300 W for Si and 150 W for Ge. The hydrogen flow is kept at 50 sccm in all cases. Each step is followed by an annealing treatment of 30 minutes. In total, five successive steps are applied to complete the crystallization process. The temperature of the process is 300°C for Si and 200°C for Ge. In each step, the total annealing time varies between 2 and 5 hours. The crystallization of the samples is verified by SEM analysis. Both Si and Ge samples have an average grain size of 0.2 μm. We have exploited this crystallization technique to fabricate Si and Ge TFT's. The Ge-based TFT's operate in a depletion mode whereas the Si-based TFT's operate in an inversion mode and their fabrication process is similar. Fabrication process starts with deposition of a 100 Å Cr layer on the glass substrate using e-beam evaporation. After patterning the gate metal, a 300 Å layer of SiO2 is deposited following by a multilayer of 600 Å Si/100 Å Si/100 Å Ge to form Si TFT's. The active regions and the source and drain contacts are patterned using standard lithography. The amorphous TFT's are then loaded onto the RF-PECVD system to perform the dopant activation as well as hydrogenation-assisted crystallization processes. The annealing process is performed in the PECVD system at a pressure of 10 mtorr and at a temperature of 300°C for Si-based devices. In the case of Ge-based TFT's no doping incorporation is needed since such devices operate in a depletion mode. The process is similar. Fabrication process starts with deposition of a 100 Å Cr layer on the glass substrate using e-beam evaporation. After patterning the gate metal, a 300 Å layer of SiO2 is deposited following by a multilayer of 600 Å Si/100 Å Si/100 Å Ge to form Si TFT's. The active regions and the source and drain contacts are patterned using standard lithography. The amorphous TFT's are then loaded onto the RF-PECVD system to perform the dopant activation as well as hydrogenation-assisted crystallization processes. The annealing process is performed in the PECVD system at a pressure of 10 mtorr and at a temperature of 300°C for Si-based devices. In the case of Ge-based TFT's no doping incorporation is needed since such devices operate in a depletion mode. The process is similar. We conclude that the roughness and metal contamination of the poly-Si films are the main factors that cause enhanced breakdown of SiO2 films.

A22.2 Hydrogenated Amorphous Silicon Thin Film Transistors for an Active Matrix Organic Light Emitting Diode. Jae-Hoon Lee, Kwang-Sub Shin, Chi-Heon Kang and Min-Koo Han; Electrical Engineering and Computer Science, Seoul National University, Seoul, South Korea.

Hydrogenated amorphous silicon thin film transistors (a-Si:H TFTs) are widely considered as pixel elements for AMOLED. The stability of a-Si:H TFT in the electrical characteristics is critical. As an a-Si:H TFT exhibits the hysteresis phenomenon due to presence of interface traps, which means the OLED current from high gray to low gray differs that from low gray to high gray in the current driven AMOLED display. The analysis of hysteresis is required to solve the trouble some phenomenon. The purpose of our work is to report a simple experimental method to validate the cause of hysteresis. We have fabricated the a-Si:H TFT of the inverted staggered structure employing the standard process, with W=200μm and L=6μm. For the study, we measured the transfer characteristics depending on the starting gate voltage. The hysteresis in the transfer characteristics depends on the starting gate voltage. Shift in the transfer characteristics was observed for reverse-voltage sweeps with different gate voltages. As the starting gate voltage becomes less positive, the parallel shift toward negative direction in the transfer characteristics was observed. The hysteresis and shift in transfer curves are attributed to differences in an initial Ferri-level at the starting gate voltage. It varies an interface trap occupancy resulting in changes of effective insulator charges. Under channel pinch-off conditions, charge balance equation can be written as (Qg=Qg+Qp=Qp), where Qg is gate charge, Qg is an insulator charge and Qp is depletion charge. For less positive starting gate voltage, due to the negative shift of transfer curve, an extra gate voltage is required for the same drain current. Under pinch-off conditions, since Qp is constant, an extra gate charge is the result of an increase in effective insulator charges Qg>0. For less positive starting gate voltage in the reverse voltage sweep, the transfer curve exhibits the negative shift toward the positive direction. The shift in the transfer curve. Our experimental results show that difference of interface trap occupancy is the cause of hysteresis in the forward and reverse gate voltage sweeps. It is imperative to lower the interface trap occupancy for high quality of AMOLED display.
Low Hydrogen Concentration Silicon Nitride as a Gate Dielectric in TFTs for Flexible Display Application. Joong Hyun Park, Chang Yeon Kim, Kwang Sub Shin and Sang Geun Park; School of Electrical Engineering and Computer Science, Seoul National University, Seoul, South Korea.

Liquid crystal displays (LCDs) using hydrogenated amorphous silicon thin film transistors (a-Si:H TFTs) on flexible plastic substrate is attractive for flexible display. The fabrication temperature on plastic substrate is limited less than ultra low temperature (<180 Celsius). The hydrogenated amorphous silicon nitride (a-SiNx:H) as a gate dielectric in TFTs has poor characteristics. Especially, hydrogen concentration is strongly influenced on fabrication temperature, and a-SiNx:H fabricated at 180 Celsius has a high hydrogen concentration. It makes a-SiNx:H become porous, low density, and weak bonding. The purpose of our work is to obtain a low hydrogen concentration a-SiNx:H. We used inductive coupled plasma CVD (ICP-CVD), with SiH4, N2, NH3 instead of SiH4, N2, NH3. From FT-IR measurements, we estimated hydrogen concentration in a-SiNx:H. And we investigated film density in various condition by wet etch rate. We carried out experiments with various helium dilution. As helium dilution rate increases, film density increases and hydrogen concentration in a-SiNx:H decreases. Helium dilution increases the release of the hydrogen bonded to silicon atoms because helium gives many excited species, which is dissociates and bonds with hydrogen atoms. As hydrogen concentration decreases, film density increases due to its light and weak bond strength on ultra low temperature. Film density is closely connected with atom bonding. In our FT-IR data, as the amount of N-H bond peak decreases and Si-H bond peak increases relatively, etch rate increases. In our silicon nitride as a gate dielectric deposited on 180 Celsius, He dilution results in low hydrogen concentration (<0.15 at. %), high breakdown voltage (>6 MV/cm) and low etch rate (300-400 Angstrom/min). a-SiNx:H is useful in TFT fabrication on flexible plastic for high performance.

SESSION A23: Solar Cells II
Chair: Gautam Ganguly
Friday Morning, April 1, 2005
Room 202 (Moscone West)

8:30 AM A23.1
Characterization of the Silicon-Based Thin Film Multi-Junction Solar Cells. Yoshibito Hisakawa, Research Center for Photovoltaics, AIST, Tsukuba, Ibaraki, Japan.

Procedures and technical issues for the characterization of the performance of silicon-based thin film multi-junction devices, such as the a-Si/thin-c-Si structure, are discussed. The superposition of the current-voltage curves of the multi-junction devices is strongly affected by the balance of the photocurrent generated in each component cell. Especially, the total output current tends to be limited by the minimum photocurrent among the component cells, due to the requirement of current continuity. High-fidelity solar simulators, which incorporate xenon lamps and halogen lamps, in order to simulate the AM1.5G standard sunlight, have been employed for characterizing the multi-junction devices. It is shown that they can accurately reproduce the current generated in each component cells and the I-V curve of the devices under the standard sunlight, with simple spectral adjustment procedures, thanks to their basic good spectral fidelity to the standard sunlight. Irradiance dependence of the I-V curve is important for translating the I-V curve for different irradiance conditions. Although the translation is not straightforward for multi-junction devices, experimental results of the present study suggests that it is possible under the spectral conditions where the relative value of the photocurrent among the component cells is constant. Determination of the I-V curves of each component cell, based on the I-V curves of the multi-junction devices, is also discussed.

9:00 AM A23.2
High Efficiency Solar Cells with Intrinsic Micromorph Ceramic Solar Absorbers Deposited at High Rates by VHF-PECVD. Yoshinori Ma1, Stefan Klein, Reinhard Carst1, Xinlin Guo2 and Friedhelm Finger1; 1Institute for Photovoltaics, Forschungszentrum Juelich, Juelich, Germany; 2Institute of Photovoltaics, Nankai University, Tianjin, China.

In this report, we focus on the structural, electrical and optical properties of intrinsic hydrogenated micromorph ceramic silicon (µc-Si:H) material and the properties of corresponding solar cells. The material was grown using a VHF-PECVD system at high-pressure, high-power (hp-VHF), yielding high deposition rate (RD) up to 15 Å/s and at low-pressure, low-power (lp-VHF), yielding RD below 3 Å/s. Different structure phase compositions from highly crystalline to amorphous were obtained by the variation of the silane concentration. Solar cells with intrinsic layers prepared by both methods were compared. As a result, optimum cells in both hp-VHF and lp-VHF series exhibit high efficiency over 9%. A µc-Si:H single junction p-i-n solar cell with an efficiency of 9.8%, the highest value reported so far, was obtained at a RD of 11 Å/s. Although in a number of aspects, the lp-VHF and Ip-VHF materials show distinct differences and spectroscopy with different excitation wavelength provides structural information on the top or close to the bottom in the film and solar cells prepared by the two methods. The Raman intensity ratio (RIR), a qualitative measure for the crystallinity, both series show similar dark- and photo-conductivities for the same ICRS and high photosensitivities between 200 and 500 at the µc-Si:H to a-Si:H transition, where high efficiency µc-Si:H solar cells were previously found. The optical absorption coefficient measured by PDS. A low absorption coefficient below the silicon band gap indicates a low defect density and thus a high quality of both materials. With increasing amorphous volume fraction, a higher hydrogen content and lower microstructure factor, determined by FTIR-spectroscopy, were observed. hp-VHF samples show higher hydrogen content but similar microstructure factor R in the transition region, when compared with Ip-VHF samples with the same ICRS. The atmospheric gas in-diffusion behaviour was monitored by FTIR measurements after deposition. The Ip-VHF material is resistant to post-oxidation. The growing absorption band between 1000-1200 cm-1, due to Si-O bonds, indicates a higher porosity of the hp-VHF material, contrasting to the similar R for both series. In contrast to the remarkable structure development in the growth direction in the films on glass, particularly in the hp-VHF material, the material in the silicon cells appears to be very homogenous. It is proposed that the highly crystalline µc-Si:H passivates the defects in the p-type a-Si:H solar cells, suppressing thick incubation layer and leading to high FF. Optimum hp-VHF solar cells show no degradation of performance after 1000 hours' exposure to air, indicating no detrimental effect of post-oxidation as found in the hp-VHF material on glass. Either the homogeneous growth or the protection of the amorphous a-Si layer and silver back contact is believed to be the reason.

9:15 AM A23.3

Hydrogenated amorphous silicon (a-Si:H) and silicon germanium (a-SiGe:H) alloy based solar cell technology is one of the most attractive photovoltaic technologies due to low cost and large-scale manufacturing abilities. Among the technologies for improving cell performance, light trapping with textured back reflector (BR) is an important method for enhancing short-circuit current density (Jsc). A textured Ag/ZnO BR was used for achieving 14.6% initial and 13.0% stable efficiencies in an a-Si:H/a-SiGeH/a-SiGeH triple-junction structure.[1] Recently, hydrogenated nanocrystalline silicon (nc-Si:H) solar cell has attracted remarkable attention because of its superior long wavelength response and improved stability over a-SiGe:H. However, because of the nature of the nc-Si:H structure, the optimized Ag/ZnO BR used for the a-SiGe:H solar cells may not necessarily be the best choice for the nc-Si:H solar cells. Optimizing the Ag/ZnO BR has the potential to improve the cell efficiency further. In addition, an improved Ag/ZnO BR may result in an improved efficiency for a-Si:H/a-SiGe:H/a-SiGeH triple-junction cells. In this paper, we present recent results on the optimization of Ag/ZnO BR for both nc-Si:H and a-SiGe:H solar cells. We deposit Ag/ZnO BR on specular stainless steel substrates using a sputtering method. The texture of the Ag and ZnO layers is controlled by deposition parameters. The surface morphology is investigated by atomic-force-microscopy. To characterize the scattering effect from the textured surface, scattered light intensity from a He-Ne laser perpendicular to the sample surface is measured at different angles. Finally, nc-Si:H and a-SiGe:H solar cells are deposited on the BR substrates made under various conditions. For the nc-Si:H solar cells, large micro-features on the Ag/ZnO layer eliminate interference fringes otherwise observed in the quantum efficiency measurement and result in high Jsc. The result is consistent with an enhanced scattering light intensity. For a-SiGe:H, we find that the improved Ag/ZnO BR with large micro-features leads to an enhanced open-circuit voltage and fill factor. We believe that the 1.0% increase in Jsc reduces the density of the sharp peaks on the BR surface and consequently reduces the back diffusion of photo-generated carriers at the n/i and i/p interfaces. Hence, the cell performance was improved. We also deposited a-Si:H/a-SiGe:H triple-junction cells on the optimized Ag/ZnO BR and achieved a high initial active-area efficiency of 14.6%. [1] A. Banerjee and S. Guha, J. Appl. Phys. 69, 1030 (1991). [2] J. Yang, A. Banercjea, and S. Guha, Appl. Phys. Lett. 70, 2075 (1997).
Silicon heterojunction cells (SHJ) using crystalline silicon wafers and deposited heterojunction thin film emitters are interesting from an economical, technological, and scientific point of view. Modules using such cells (so called HIT cells) are commercially produced by Sanyo using single crystal silicon wafers. Recently reported alternatives still comprise a high-temperature diffused back surface field (BSF). In order to provide a low cost alternative, our goal is to develop SHJ using multicrystalline silicon wafers with both a deposited emitter and a deposited back surface field, which is in-situ formed. The present approach truly allows the development of a cheap, low temperature, all-deposited alternative for the HIT cell. We presently made a bifacial silicon heterojunction solar cell, with an emitter consisting of a 7 nm intrinsic a-Si:H layer and a 15 nm n-type uc-Si:H layer. The back surface field is formed by a 15 nm p++ uc-Si:H layer. In order to achieve a functional deposited BSF the thin p++ layer needs to have a higher effective dopant concentration than the substrate (a 375 um thick p-type FZ wafer 1 Ohmcm) with an activation energy of 0.2 eV. The uc p++ layer has an activation energy of E_a = 0.04 eV (for a 100nm thick layer). To detect the operation of the BSF the cell was made bifacial. The cell has an efficiency of 14.8 %, Voc = 608mV and Jsc=35.4 mA/cm^2, Rs = 1.1 Ohmcm^2 and Rp = 1.3 kOhmcm^2. The cell, illuminated from the back, shows a Voc of 100mV and Jsc of 7mA/cm^2. Reference bifacial cells without BSF illuminated from the back show no cell behavior. These results show evidence for the feasibility of a truly functioning deposited BSF combined with a SHJ with deposited emitter.


Thin intrinsic and doped n-type hydrogenated amorphous silicon (a-Si:H) double layers are investigated as the emitter layer of crystalline silicon solar cells based on p type wafers. The a-Si:H is deposited by hot-wire chemical vapor deposition from silane gas using Ta or W filaments. Using a substrate temperature below 150'C the a-Si:H intrinsic layer and conditions that normally promote edge or protocrystalline Si for the doped n layer, record efficiencies of 17% and 15% are achieved on 1-cm^2 planar p-type float-zone silicon and Czochralski silicon wafers, respectively. We obtain open-circuit voltages as high as 0.50 V and fill factors above 80%, on simple, untextured, ITO / a-Si:H / c-Si base / Al back-surface-field structures. High performance requires nearly perfect passivation of the c-Si interface by the a-Si:H in addition to good a-Si:H electrical conductivity for lateral current collection. We characterize cells by their photovoltaic properties and study passivation by photovoltaic decay minority-carrier lifetime measurements. Real-time spectroscopic ellipsometry (RTSE) and high-resolution transmission electron microscopy are employed to detect phase change and material evolution. We find that the cell performance is best when all crystallinity is avoided in the intrinsic layer. The crystallinity of the deposited layer is found to be very sensitive to the deposition temperature and crystal orientation of the substrate. Deliberous epitaxial growth is promoted by higher substrate temperatures and is more likely on (100) substrates than on (111) substrates. When epitaxy occurs, especially if the epitaxial growth extends beyond the intrinsic layer, open-circuit voltage decreases dramatically to below 600 mV for 1 W-cm Czochralski wafers. The RTSE permits us to control and optimize the a-Si:H layer thicknesses. With a smooth, abrupt, a-Si:H/c-Si interface and a highly conductive n-type doped layer, high performance silicon heterojunction solar cells are consistently obtained.

SESSION A24: Characterization of Microcrystalline Silicon

Chair: Sigurd Wagner
Friday Morning, April 1, 2005
Room 202 (Moscone West)

10:30 AM A24.1
Structure of Microcrystalline Solar Cell Materials: What can we Learn from Electron Microscopy? Martina Luysberg 1,2 and L. Houben 1,2; 1Forschungszentrum Juelich, Institut of Solid State Research, Juelich, Germany; 2Research Center Juelich, Ernst-Ruska Center for Microscopy and Spectroscopy with Electrons, Juelich, Germany.

Microcrystalline silicon and its group IV alloys are widely explored as absorber layers in thin film solar cells. Despite the extended research in recent years the fundamental understanding of the relation between microstructural properties, i.e. microcrystallinity and the microstructure is poor. Clearly, the structure of microcrystalline materials consisting of a phase mixture between "amorphous" material, crystalline grains and voids, is too complex to allow for a detailed atomistic description. Is the disordered phase really amorphous? What is the atomic structure of the coherent and heterogeneous grain boundaries? How large is the amorphous volume fraction? Which chemical composition contain the crystallites, if we group the regions into group IV (amorphous) and into the few, which are relevant to both, the understanding of the microstructure and the performance of a solar cell, are posed on the electron microscopist. To demonstrate the strengths and limitations of transmission electron microscopy in the study of microcrystalline silicon cells, we will discuss different techniques employed to investigate grain sizes and morphologies, crystallographic orientations, amorphous volume fractions and lateral arrangements of crystallites. In particular, we focus on the potential for using in-situ observations of phase changes and the amorphous phase in microcrystalline silicon and silicon carbide by the most advanced techniques in atomic resolution imaging in the transmission electron microscope.

11:00 AM A24.2
Structural and Electronic Properties of Hydrogenated Nanocrystalline Silicon Films Made with Hydrogen Dilution Profiling Technique. Keda Wang 1, Daixing Huo 1, Breanna Yan 1, and Subhendu Guha 2; 1Physics Department, Boston College, Chestnut Hill, Massachusetts; 2Department of Physics & Astronomy, University of Connecticut, Chapel Hill, North Carolina; 3United Solar Ovonic Corporation, Troy, Michigan.

Hydrogenated nanocrystalline silicon (nc-Si:H) has attracted considerable attention due to the higher long wavelength response and better stability than hydrogenated amorphous silicon. However, the low density of hydrogen in the silicon prevents structural studies. In this paper, we report the use of a new and effective method for improving the cell performance [1]. In this paper, we present recent results of material characterization for the nc-Si:H films made with different hydrogen dilution profiles. Raman spectroscopy with wavelengths of 610 (red), 514 (green), and 480 nm (blue) is used to probe different depths of the materials. The results show that the crystalline peak at 515-520 cm^-1 is much larger on the samples made with a constant hydrogen dilution ratio, which is normally aligned to the recombination due to grain boundaries. The width of the peak increases with increasing hydrogen dilution ratio, associated with an increase of the band-tail width. The second, the sample made with hydrogen dilution profiling shows two peaks consisting of an amorphous peak at 1.4 eV and a grain-boundary peak at 0.8-0.9 eV. The amorphous peak reveals that a significant amount of amorphous component exists in the top layer. In addition, the grain-boundary peak becomes narrower than those made with constant hydrogen dilution ratios. Both the Raman and PL results are consistent with the defect density measurement and solar cell performance from other works [1].

11:15 AM A24.3
Material Science and Nanocrystalline Silicon: Simulation of Material Properties. Rama Biswas 1,3, Bical Por 4 and Venkatesh Selvaraj 5; 1Physics & Astronomy; and Electrical & Computer Engineering, Iowa State University, Ames, Iowa; 2Dept. of Physics, Univ. of Science and Technology of China (USTC), Hefei, China; 3Microelectronics Research Center, Iowa State University, Ames, Iowa.

We have simulated nano-crystalline silicon and microcrystalline silicon structures with varying crystallite volume fractions, using molecular dynamics simulations. The crystallite regions reside in an amorphous...
matrix. Both embedding approaches and melt-quenching approaches have been utilized. We find the amorphous matrix is better ordered in microcrystalline-Si than in the homogenous amorphous silicon networks, consistent with the observed higher stability of H-diluted films and nanocrystalline silicon. We consider crystallite nuclei sizes ranging from sub nm to a few nm in size. There is a critical size above which the crystallites are stable and may grow. In micro-crystalline silicon models we find a relatively uniform H distribution in the amorphous region and a crystal-amorphous phase boundary that is not well-defined. We will discuss calculations on the electronic states at the interfacial boundary region. The vibrational densities of states of nc-Si has been calculated and show the sharp crystallite-derived features typical of Raman measurements. There is a marked density difference between the crystallite and amorphous regions, consistent with measurements. Atomistic mechanisms of grain growth will also be discussed. Supported by NREL.

11:30 AM A24.4
Doping Dependence of Chlorine Incorporation in SiCl₄ Based Microcrystalline Silicon Films. Wolfram Beyer, Reinhard Carius and Uwe Zastrow; IPV, Forschungszentrum Juelich, Juelich, Germany.

Recently high electrical conductivities were observed in plasma-grown boron-doped chlorinated microcrystalline Si films [1]. For films deposited at temperatures near 250°C using SiCl₄ - H₂ - H₂Cl₂ gas mixtures, conductivities near 300 (Ωcm)⁻¹ were found [2] making this material of interest for application as a p-layer in microcrystalline Si-based thin-film solar cells. Films with high conductivities usually show rather low concentrations of chlorine and hydrogen and, when deposited near the amorphous-microcrystalline transition, a small oxidation effects when exposed to ambient. The other hand, phosphorus-doped and undoped SiCl₃H were found to have much higher chlorine concentrations and rather rapid oxidation is generally observed. Thus, by variation of rather small B and P dopant concentrations, the incorporation of much higher amounts of Cl and H can be controlled. Here we study the effect of B and P doping (doping range 0.1 to 1 %) on the Cl concentration (and the oxidation) in more detail by investigating films containing both boron and phosphorus. SIMS depth profiling and IR absorption measurements were used for chemical analysis. Raman spectroscopy was employed to characterize crystallinity, and conductivity and thermoelectric power measurements were performed for electrical characterization. The results show that indeed not the presence of B and P, but rather the relative amount (P-B) is observed for (P-B) > 0.3 while for (P-B) < 0 the Cl concentration never exceeds 2 at%. This was found for a wide range of Raman crystallinities. For the explanation we propose a similar model as has been applied for the modeling of hydrogen surface desorption in doped a-Si:H which has also been found to be Fermi level dependent [3]. The model assumes that the rupture energy of silicon-bonded atoms can be decreased by simultaneous electronic transitions which charge the resulting Si dangling bond positive or negative, depending on the Fermi level. The result of a doping dependence of the oxygen takeup in atmosphere suggests, furthermore, that Cl incorporation favors the porosity of the material. 1. Wolfhard Beyer, Bernd Rech, Reinhard Carius, Matthias Albert, Ralf Terasa, Proceedings PV in Europe Conference, Rome, Italy, 7-11. October 2002 (WIP Munich and ETA Florence, 2002) p. 75. 2. Wolfhard Beyer, Reinhard Carius, Michael Lejeune and Uwe Zastrow, MRS Symp. Proc. 808 (2004) S89 3. W. Beyer, J. Hertin and H. Wagner, J. Non-Cryst. Solids 114 (1988) 217

11:45 AM A24.5
Annealing Characteristics of Al-Doped Hydrogenated Nanocrystalline Cubic Silicon Carbide Films. Shinsuke Miyajima1, Keisuke Haga1, Akira Yamada2 and Makoto Konagai1; 1Physical Electronics, Tokyo Institute of Technology, Tokyo, Japan; 2Quantum Nanoelectronics Research Center, Tokyo Institute of Technology, Tokyo, Japan.

Crystalline cubic silicon carbide (3C-SiC) is a wide gap material with bandgap of 2.2 eV. Owing to this high bandgap and indirect-bandgap characteristic, optical absorption of this material is very low in the visible light region. In general, monocrystalline and polycrystalline 3C-SiC films are deposited at high substrate temperature using a thermal chemical vapor deposition, however hydrogenated microcrystalline cubic silicon carbide (uc-3C-SiC:H) films can be deposited on glass substrates below 300 degrees centigrade by a hot wire chemical vapor deposition (HWCDV) technique [1]. Therefore, uc-3C-SiC:H is one of the promising materials for window layer of silicon based thin film solar cells. We have already studied deposition of aluminum (Al) doped uc-3C-SiC:H films by HWCDV, and we found that thermal annealing is required to activate Al acceptors. In order to obtain highly conductive films, we should understand effects of the thermal annealing on the films. However, the effects have not been clear yet. In this study, we investigated the effects of thermal annealing on the film properties. First, we investigated the effect of annealing temperature on the conductivity of the films. We performed the annealing at 300, 400, 500 and 600 degrees centigrade. Annealing time was changed from 10 to 165 sec. The conductivity of as-deposited films was about 1e-8 S/cm. After annealing, the conductivity increased up to about 1e-4 S/cm for annealing at 400, 500 and 600 degrees centigrade. The conductivity increased from 1e-8 to 1e-4 S/cm with increasing the annealing time, and finally the conductivity saturated. The time for the saturation decreased with increasing the annealing temperature. This result indicated that activation of the Al acceptors occurred above 400 degrees centigrade and p-type uc-3C-SiC:H films can be prepared at process temperature above 400 degrees centigrade. Next, we carried out thermal desorption spectroscopy for the Al-doped and undoped uc-3C-SiC:H films. In case of the Al-doped film, hydrogen desorption started from about 400 degrees centigrade. For the undoped film, hydrogen desorption started from about 600 degrees centigrade. This result indicates that hydrogen configuration in the Al-doped film is different from that of the undoped film, and hydrogen plays an important role on the conductivity of the Al-doped uc-3C-SiC:H films. Reference [1] S. Miyajima, A. Yamada, M. Konagai: Jpn. J. Appl. Phys. 43 (2004) L1190