SYMPOSIUM A
Amorphous and Heterogeneous Silicon Thin Films–2000
April 24 – 28, 2000

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*Invited paper
TUTORIAL
ST A: AMORPHOUS SILICON MATERIALS AND DEVICES FOR LARGE AREA ELECTRONICS
Monday, April 24, 2000
8:30 a.m. - 4:30 p.m.
Salon 7 (Marriott)

Hydrogenated amorphous silicon (a-Si:H) is an important technological material for large-area electronics, with applications to solar cells, liquid crystal displays, optical scanners, and radiation imaging. The course describes the growth, material properties, device physics, and large-area array technology of amorphous silicon. The relation between material properties and device performance of a-Si:H is emphasized.

Instructors:
Robert A. Street, Xerox Palo Alto Research Center
Michael Hack, Universal Display Corporation

SESSION A1: AMORPHOUS SILICON GROWTH
Chair: Hiroyuki Fujiiwara
Tuesday Morning, April 29, 2000
Salon 7 (Marriott)

8:30 A.M. *A1.1*
SURFACE MICROCHEMICAL REACTIONS DURING HYDROGENATED SILICON GROWTH STUDIED BY IN-SITU ESR TECHNIQUE,
Satoshi Yamazaki. Joint Research Center for Atom Technology (JRCA), Tsukuba, JAPAN.

To address the μ-Si:H and a-Si:H growth mechanisms, several groups have reported on the surface morphology and bonding configurations during film growth using real-time spectroscopic ellipsometry, ultrahigh-vacuum scanning-tunneling-microscopy, and infrared reflection spectroscopy. These measurements, however, give us information on the macroscopic change of surface structures. For the growth of μ-Si:H and a-Si:H, dangling bonds (db's) in the surface region play a crucial role in the reaction site for precursors to bond to the surface. From this meaning, elementary reactions of the film growth are equivalent to the process of termination, annihilation of and creation of db's. Therefore, in-situ electron-spin-resonance (ESR) measurements during film growth give us valuable information to understand growth kinetics. Previously, we have reported that (1) using in-situ ESR technique the dynamic change of Si db during and after deposition has been detected, in addition to the g=2.04 ESR signals both of atomic hydrogen and radicals related with silane molecules, (2) the surface region has high db density (~10^12 cm^-2) during film growth, (3) the surface db density during film growth is almost independent of the growth temperature in the temperature range below 200°C, (4) the db signal intensity decreases after stopping the deposition due to a structural relaxation, (5) during hydrogen plasma treatments hydrogen atoms create db's, rather than terminate them, which are spatially distributed within the deeper layers of the film (around 1000 nm from the top-surface). In this talk, I show the recent results obtained using the in-situ ESR technique and discuss the surface microchemical reactions during Si:H film growth.

9:00 A.M. *A1.2*
FRACTIONAL ANALYSIS OF TOPOGRAPHY AND SURFACE TRANSPORT DURING AMORPHOUS SILICON GROWTH, AND ITS RELATION TO DIFFUSION STATE ENERGY DETERMINED FROM AB-INITIO CALCULATIONS.
Gregory N. Parsons, Kevin R. Bray, Atul Gupta, Department of Chemical Engineering; Hong Yang, Department of Chemistry, North Carolina State University, Raleigh, NC.

A fundamental understanding of surface reactions in plasma-deposited amorphous silicon is critical to improve material properties. A combined approach to this problem, including atomic force microscopy analysis of surface topology and ab-initio calculations of surface reactions and stable configurations, is used to gain insight into growth mechanisms. AFM surface topography was compared for samples deposited over a range of temperatures (25 to 150°C) and film thicknesses (20-1500 Å). The surface transport mechanism active during deposition can be extracted from the fractal analysis of surface morphology by determining a static scaling coefficient (a). Individual models are observed to evolve after 15-20 sec, and the static scaling coefficient increases from 0.25 ± 0.1 for deposition time continues up to 60 seconds (corresponding to thickness <50Å), and saturates near a 1, consistent with surface transport controlled by diffusion. Moreover, the rate of evolution is thermally activated, with a small activation barrier of 1.6 kcal/mol between 25 and 150°C, suggesting a thermally activated diffusion process. Ab-initio calculations have been used to study reactions between SiH₃ radicals and a-Si:H surface, including adsorption states that could lead to low-barrier surface diffusion. Results show that the H radicals have a lower barrier to H abstraction than H abstraction by SiH₃ (~7.3 kcal/mol for H vs ~12 kcal/mol for SiH₃). Also, the H abstraction process, calculated using multiplet CI and BLYP DFT, shows a distinct saddle-point structure in the potential energy surface, with no evidence for a stable Si-H-Si bond on the surface. A static center bond is an important feature in the energy models based on adsorbed radical diffusion. The morphology and reaction analysis, however, indicate that some other process is occurring on the surface. For example, the observed growth evolution may be consistent with both static adsorbed radicals whose hopping rate is determined by the rate of H abstraction.

9:15 A.M. *A1.3*
ENHANCEMENT OF THE TRANSPORT PROPERTIES OF a-Si:H PECVD FILMS BY PROPER CONTROL OF THE ION BOMBARDMENT. Hugo Aguiar, R. Martins, I. Ferreira, E. Fortunato, Unv. Nova de Lisboa, Faculty of Science and Technology, Dept. of Materials Science. CENIMAT and CEMOS/UNINOVA, Monte da Caparica, PORTUGAL.

In this work we show how it is possible to enhance the transport properties of a-Si:H films while the growth rate of the films is kept constant. To do so, we used a modified PECVD triode reactor. The modification consists in applying a DC voltage to a set of grids placed in front of the rf electrode. By doing so, we control the energy of the ions striking the substrate during the film's growth. The films were deposited in large area substrates of 15 cm x 20 cm and presented good uniformity over the substrate area. The results achieved show that as the energy of the ions increase up to 100 eV, the SiH₃ concentration decreases at the substrate. A higher energy growth, the photodiodes shows a large increase in the conductance of the film at 1000 V. Under these conditions the films are more doped. These results indicate that in spite of the films microstructure being linearly dependent on the ion energy, the films defects are not. This means that the ion energy influences the Si bonding during the film growth and also implies that when the surface growth sustains a high ion bombardment, a different type of structure is achieved, which enhances the film stability. So, with a precise control of the energy of the ions that strike the substrate during the film growth it is possible to grow both dense and high quality films for optoelectronic applications, more stable than the ones produced by conventional rf glow discharge techniques.

9:30 A.M. *A1.4*
GROWTH PROCESSES OF α-Si:H. John Robertson, Engineering Dept., Cambridge University, Cambridge, UNITED KINGDOM.

The surface and subsurface processes occurring during the growth of a-Si:H are understood to underlie the formation of dangling bond defects and weak bonds, particularly at lower deposition temperatures. It is shown that abstraction and addition by SiH₃ radicals cannot account for the temperature dependence of the bulk defect density. We argue that hydrogen elimination to form the Si-Si network is the limiting process at lower temperatures, and we highlight the role of the formation of weak Si-Si bonds. The bonding defects form subsequently from weak bonds by a defect pool type process. Additional plasma-driven processes such as ion bombardment also help eliminate hydrogen, and so allow lower weak bond densities to be achieved at lower deposition temperatures.

SESSION A2: ORDERING AND ORDERING TRANSITIONS
Chair: Sigurd Wagner
Tuesday Morning, April 25, 2000
Salon 7 (Marriott)

10:30 A.M. *A2.1*
NUCLEATION MECHANISM OF MICROCRYSTALLINE SILICON STUDIED BY REAL TIME ELECTROSCOPY AND IR SPECTROSCOPY.
H. Fujiiwara, Y. Togoshima, M. Kondo and A. Matsuda, Thin Film Silicon Solar Cells Super Lab., Electrotechnical Laboratory, Tsukuba, JAPAN.

We have applied real time spectroscopic ellipsometry (SE) and infrared attenuated internal total reflection spectroscopy (ATR), in order to investigate the microcrystalline silicon (μ-Si:H) recrystallization mechanism in plasma-enhanced chemical vapor deposition using...
hydrogen dilution of SiH$_4$ source gas. The combination of these real time monitoring techniques provides a greater capability to characterize the Si$_{x}$H$_{4-x}$ reaction and following Si-H growth with sensitivity exceeding monolayer. In n-SiH$_{x}$ layers formed before the μ-Si:H nucleation at 200°C, we found no significant variation in bulk hydrogen contents for either hydrogen dilution ratio or Si-H layer thickness. In contrast, a drastic change in Si-H (n=1-2) bonding modes has been found in a two-monolayer thick sub-surface, and we observed a new peak centered at 1940 cm$^{-1}$. We assigned this peak to the Si-H complex that contains one hydrogen, which includes coordinated Si atom. In the high-dilution deposition conditions, the integrated absorbance of the Si-H complex increases with increasing film thickness, and reaches maximum just at the onset of the μ-Si:H nucleation. Thus, the Si-H complex within the two-monolayer thick sub-surface provides the structural localisation for Si-H nucleation. More importantly, upon H$_2$ plasma treatment of n-SiH$_{x}$ layer, we observed a rapid increase in the Si-H complex in the n-Si:H sub-surface. Based on the above results, we conclude that the structural relaxation by atomic hydrogen creates the flexible Si-H complex in the sub-surface, which in turn induces μ-Si:H nucleation.

11:00 AM A2.2

We have studied the effect of plasma power on the amorphous-to-microcrystalline (a→mc) transition in silicon thin films prepared by rf plasma enhanced chemical vapor deposition (PECVD) using moderate hydrogen dilution of silane. The nature of initial amorphous layer formation and subsequent a→mc transition has been examined by real time spectroscopic ellipsometry (RTSE). RTSE provides evolutionary phase diagrams for film growth; these diagrams describe the critical thickness d at which microcrystallinity first develops during growth, as a function of the H$_2$/Si$_x$H$_{4-x}$ gas flow ratio R. We find that for amorphous layer growth on a c-Si substrate at R=10, the initial enhanced smoothing during coalescence/growth, and thus suitability of the resulting films for devices, is not degraded by moderate increases in R power flux over a range of 0.1 to 0.2 W/cm$^2$, yet $d$ increases in deposition rate from 0.5 to 2 Å/s. Additionally the thickness at which microcrystallinity develops when using an amorphous silicon substrate film (as for the layer in a p-i-n solar cell) is not significantly affected by such moderate increases in power. Above a critical power flux of ~1 W/cm$^2$, however, both the smoothing and the a→mc transition are supressed by plasma and surface effects that may include SiH$_4$ depletion, ion bombardment, or simply kinetic limitations. The suppression of microcrystallinity is a manifestation of a shift in the a→mc phase boundary to higher R for the high power conditions. Detailed studies of the a→mc transition in films deposited at different rates provide insights into the evolutionary forces driving this transition. Finally, a consideration of the overall results suggests approaches for high rate layer preparation in p-i-n solar cells. As an example, we assess the benefits of a two-step process in which the initial stage of layer growth is performed at minimum power, whereas the latter stage is performed at moderate or high power.

11:15 AM A2.3
DISORDERED THIN-FILM SILICON. Xing Liu, SFA Inc; Largo, MD; Christopher L. Sjödell,Cornell University, Department of Physics, Ithaca, NY; Richard S. Crandall, National Renewable Energy Laboratory, Golden, CO; R.O. Poli, Cornell University, Department of Physics, Ithaca, NY.

We have recently shown that low temperature internal friction is a sensitive tool for the detection of disorder in amorphous silicon films containing hydrogen [1]. We have now extended these measurements to thin film silicon films deposited by PECVD. By increasing the hydrogen dilution of the silane used to prepare these films, their structure is known change from amorphous to micro-crystalline. We have found the expected result that the internal friction increased by over one order of magnitude as the crystallinity of the films increased. It is concluded that the micro-crystalline films are highly disordered. We are now exploring the origin of the disorder and the role played by the hydrogen.

11:30 AM A2.4
MEDIUM-RANGE ORDER IN HYDROGENATED AMORPHOUS SILICON MEASURED BY FLUCTUATION MICROSCOPY. P.M. Voyles, University of Illinois, Dept of Physics, Urbana, IL; and NEC Research Institute, Inc, 4 Independence Way, Princeton, NJ.

We examine the time scales of processes responsible for the metastable Si dangling bond defect creation by examining H-Si with sequences of intense laser pulse pairs of variable delay [1]. The defect creation by the second pulse of the pair will be modified by the non-equilibrium species left over from the first pulse. By changing the delay between the pulses, we determine the lifetime of these species. We observe that the defect creation efficiency by the second pulse remains strongly affected by the 1st pulse at delays as long as 0.65 microseconds. This phenomenon cannot be explained by the weak thermal effects or by the residual trapped carriers. The numerous recombination events during the intense 2nd pulse erase and reset all the preceding residual carrier populations, as shown by the residual photocurrent transients, so that these are unlikely to affect the defect creation by the 2nd pulse. The weak influence of the residual photocurrents is further demonstrated by applying a nanosecond flash bias pulse during the laser pulse degradation. To explain the origin of the observed robust long-living species affecting the defect creation, we suggest that metastable structural precursors are created by the initial 1st monolayer recombination transient that lies between the pulses. They survive until the 2nd pulse and affect the degradation efficiency. The possible origins of these precursors are discussed. We expand our study into submicrosecond and millisecond time scales by applying electronically-controlled Xe flash microsecond pulse pairs and by combining flash and ns laser pulse illumination. The lifetimes of the defect precursors are compared in samples with different H content and Si-H. Their dependences on exposure temperature, pulse energy,

SESSION A3: METASTABILITY
Chair: Martin Sturman
Tuesday, April 25, 2000
Salon 7 (Marriott)

1:30 PM A3.1
A STUDY OF THE TIME SCALES OF PROCESSES RESPONSIBLE FOR THE LIGHT-INDUCED DEGRADATION OF n-Si BY PULSE ILLUMINATION. Paul Strnad, Michio Kondo, and Akihisa Murata, Thin Film Silicon Solar Cells Laboratory, Electrotechnical Laboratory, Tsukuba, JAPAN.

We examine the time scales of processes responsible for the metastable Si dangling bond defect creation by examining n-Si with sequences of intense laser pulse pairs of variable delay [1]. The defect creation by the second pulse of the pair will be modified by the non-equilibrium species left over from the first pulse. By changing the delay between the pulses, we determine the lifetime of these species. We observe that the defect creation efficiency by the second pulse remains strongly affected by the 1st pulse at delays as long as 0.65 microseconds. This phenomenon cannot be explained by the weak thermal effects or by the residual trapped carriers. The numerous recombination events during the intense 2nd pulse erase and reset all the preceding residual carrier populations, as shown by the residual photocurrent transients, so that these are unlikely to affect the defect creation by the 2nd pulse. The weak influence of the residual photocurrents is further demonstrated by applying a nanosecond flash bias pulse during the laser pulse degradation. To explain the origin of the observed robust long-living species affecting the defect creation, we suggest that metastable structural precursors are created by the initial 1st monolayer recombination transient that lies between the pulses. They survive until the 2nd pulse and affect the degradation efficiency. The possible origins of these precursors are discussed. We expand our study into submicrosecond and millisecond time scales by applying electronically-controlled Xe flash microsecond pulse pairs and by combining flash and ns laser pulse illumination. The lifetimes of the defect precursors are compared in samples with different H content and Si-H. Their dependences on exposure temperature, pulse energy,

2:00 PM A3.2
SLOW DEFECT INCREASE DURING LOW-INTENSITY PULSED ILLUMINATION OF HYDROGENATED AMORPHOUS SILICON: NEW RESULTS. S. Heck and H. M. Braun, National Renewable Energy Laboratory, Golden, CO.

Illumination of hydrogenated amorphous silicon (a-Si:H) samples with short (25 ns, 410 mW cm⁻²) pulses produces a smaller metastable absorption increase in the defect region than continuous illumination of the same intensity for the same integrated exposure time. The defect absorption was measured by use of the constant photocurrent method (CPM). The smaller degradation parallels the photoconductivity results we reported previously [1] and suggests that, in addition to electron-hole recombination, there is a second, slower, precursor to the light induced metastable increase in defect density. Corelation of the film temperature with a predeposited nickel resistor confirms our previous measurement of internal film temperature: even under continuous illumination, the film temperature rises less than 2°C. The annealing behavior of the pulsed and continuously degraded samples will be reported, along with a detailed study of the pulse- and dark-time dependence. We have observed the slower metastable degradation for pulsed illumination on NREL plasmametnch (PE) and hot wire chemical vapor deposition (CVD) samples, and on University of Chicago and Electrochemical Laboratory PECVD samples. [1] S. Heck and H. M. Braun, Proc. MRS 1999 Spring Meeting, Symposium A, in press. This research was supported be the U.S. DOE under contract DE-AC36-96GO11337.

2:15 PM A3.3
A CRITICAL TEST OF DEFECT CREATION MODELS IN HYDROGENATED AMORPHOUS SILICON ALLOYS. Kimion C. Palacio, David Coker, and Robert W. Collins, Department of Physics, University of Oregon, Eugene, OR; Jeffrey C. Yang and Subhadea Guha, United Solar Systems Corporation, Troy, MI.

Recently a new mechanism, known as the "hydrogen collision model," was proposed to explain light-induced degradation of a-Si:H. [1] We have carried out measurements that directly test several predictions of this model. Our approach has been to examine a-Si:Ge:H alloys in the low Ge fraction (≤ 2%) regime and measurements of the different defects can be monitored using modulated photocurrent (MPC) spectroscopy which clearly discloses the existence of two bands of majority carrier traps in these alloys. Correlating these with ESR measurements on matched films unambiguously demonstrates that the bands originate from neutral Si and neutral Ge dangling bonds. Somewhat surprisingly, our studies show that all of the films (even with 2% Ge) exhibit a predominance of neutral Ge dangling bonds in the light-soaked states. By monitoring the details of the creation and annealing kinetics of these two types of defects within a single sample we obtain a powerful method to test proposed models of metastability in a-Si:H. Many models explain metastable defect creation via band reconfiguration, while others invoke a global mechanism such as, in the case of the collision model, a remote center that traps and renews hydrogen. In our sequence of isochronal anneals, for example, we observe that the Si dangling bonds are annealed at a much faster rate than the Ge dangling bonds. While this may suggest that the two annealing processes are uncorrelated and essentially in nature, the changes in the densities in the two defects indicate that they are in direct competition in a manner which agrees with the collision model. Other viable models that could explain our experimental data will also be discussed. [1] H. B. Braun, Phys. Rev. B59, 5498 (1999).

2:30 PM A3.4
CREATION AND ANNEALING KINETICS OF LIGHT INDUCED DEFECTIONS BETWEEN 40 K AND 295 K IN INTRINSIC a-Si:H. N.A. Schultz, P.C. Taylor, University of Utah, Physics Dept., Salt Lake City, UT.

Using the technique of electron spin resonance (ESR), we measured the production and annealing kinetics of the light induced deep defects (silicon dangling bonds) in hydrogenated amorphous silicon (a-Si:H) between 25 K and 300 K. These experiments employed an illumination time of 1 h with approximately 100 mW/cm² of filtered white light (20% to 350 nm) from a Hanlu lamp. At approximately room temperature we find the commonly observed light induced degradation, which is generally referred to as the Steinhauer-Wronski Effect. At low temperatures (T < 100 K) the measurement of silicon dangling bonds is complicated by photoexcited, long-lived, band tail carriers that mask the dangling bond ESR signal. However, after removing most of these long-lived carriers by irradiation with white light, we find a significantly lower concentration of light induced defects created at low temperature, as compared to room temperature degradation. By annealing the degraded a-Si:H film to successively higher temperatures we are able to monitor the annealing kinetics of the photoinduced defects. The defects, which were produced at low temperatures, almost entirely anneal out at temperatures around 300 K. The concentration of defects, created at low temperatures and stable at room temperature, is only a factor of 10 less than the defect concentration created at room temperature. A broad distribution of annealing energies cannot explain this behavior. Although the defects created at low temperatures have the same ESR signal as the defects created at room temperature, the kinetics for growth and annealing are very different.

2:45 PM A3.5
MECHANISMS OF METAStABILITY IN HYDROGENATED AMORPHOUS SILICON. Rova Bawzer, Iowa State University, Dept. of Physics, Microelectronics Research Center, and Ames Laboratory, Ames, IA.

I will describe recent advances in understanding two types of metastability in a-Si:H. These involve i) local metastability of hydrogen atoms at Si-H sites and ii) metastable dangling bond formation (Steinhauer-Wronski effect). Recent experiments of light induced degradation find large changes of the network that exceed the low density of metastable dangling bonds. These include changes in infrared absorption, NMR intensities, and photodiffusion. We find that many of these changes can be explained by the 'H-site' defect where a H-atom at a monohydride site flips to the backbone of the SiH bond[1]. The dynamic dipole moment increases in the H-flip state leading to larger IR absorption. The model can explain increased intensity of the narrow NMR line after light soaking. In the area of Steinhauer-Wronski metastability, we will describe new results of the breaking of weak silicon bonds and generation of metastable dangling bonds. Dangling bond formation is accompanied by rebonding in the network. Relations between these two metastabilities will be discussed. Results are based on tight binding molecular dynamics. [1] R. Bawzer and Y.P. Li, Phys. Rev. Lett. 82, 2512 (1999). This research is supported by EUPR and U.S. DOE.

SESSION A4: HIGH RATE DEPOSITION MATERIALS AND DEVICES
Tuesday Afternoon, April 25, 2000
Salon 7 (Marriott)

3:45 PM A4.1
FAST GROWTH OF AMORPHOUS SILICON LAYERS BY AMPLITUDE MODULATION PECVD. A.C.W. Beberich, J. Bezermer, W.F. van der Weg, Debye Institute, Interfac Physics, Utrecht University, Utrecht, THE NETHERLANDS.

Plasma-enhanced CVD of amorphous silicon by a square wave amplitude modulated RF excitation has been studied by optical emission spectroscopy and plasma modelling. The deposition rate varies with the modulation frequency, depending on the plasma parameters. In the [powder-free] α-regime, the deposition rate is equal to the sum of the deposition rates in a similar continuously excited (cw) plasma. In the β-regime it is reached at a modulation frequency of about 100 kHz. This behavior is explained by the characteristics of the electron energy distribution, during the periodical on-off of the plasma. An overshoot in optical emission at the onset indicates a large production of radicals by high energy electrons. This is confirmed by a one-dimensional fluid model of the plasma which has been applied successfully before to the α-regime [1]. The optimum in deposition rate is determined by the decay time of the electron density. We present results on 50 MHz SiH₄/H₂ plasmas. In the γ-regime the deposition rate is reduced with respect to the deposition rate in a similar cw plasma, due to a reduction of powder in the plasma density (see figure). The microstructure parameter H decreases, the refractive index increases. In solar cell fabrication, amplitude modulation is not only a useful tool to optimize the growth rate of amorphous silicon. Another advantage is the increase in homogeneity of the layers due to production of radicals in a larger space of the reactor, during the plasma pulse. We found that the variation in thickness over an a-Si:H film can be reduced by a factor of two by using a pulsed plasma.


4:00 PM A4.2
RELATION BETWEEN GROWTH PRECURSORS AND FILM PROPERTIES FOR PLASMA DEPOSITION OF a-Si:H AT RATES UP TO 100 Å/s. W.M.M. Kennes, A.H.M. Smets, M.G.H. Boogarts, D.C. Schram and M.T.M. van der Gaste, Dep. of Appl. Physics,

and
Eindhoven University of Technology, Eindhoven, THE NETHERLANDS.

From a detailed study of the deposition of Si:H with a remote silane plasma, it is demonstrated that deposition of device quality Si:H with a defect density < 10^{14} cm^{-2} at 100 A/s is possible under conditions where SiH4 comprises < 30% of the film growth. The SiH4 flux, created by an intense atomic hydrogen source, is studied by threshold ionization mass spectrometry and cavity ringdown absorption spectroscopy, applied here for the first time for spatially resolved Si:H films. The films and the Si:H, deposited with the Si:H4 flux and at 300°C, have revealed an efficiency of 4.1% while the optimum substrate temperature at this deposition rate is 100°C. The optimum substrate temperature was determined for lower deposition rates for conditions where SiH4 governs the film growth and is about 250°C for 2 Å/s.

The contribution of radicals other than SiH3 and SiH2 + ions to film growth has been studied by mass spectrometry. Langmuir probes and optical emission spectroscopy, no direct correlation between film quality and contribution of ions (less than 9% for all conditions) has been observed from the fact that the average number of Si atoms in the ions decreases with decreasing deposition rate. The film quality however strongly deteriorates by an increasing contribution of Sil + radicals. An increasing contribution of these radicals corresponds with an experimentally determined increasing surface reaction probability, starting at ~0.3 for almost completely SiH4 controlled conditions, and agrees with an increasing surface roughness and void density. The reaction pathways leading to the different radical and ionic species and their influence on film quality are addressed and implications for depositing device quality Si:H at elevated deposition rates are discussed.

4:15 PM A4.3

EFFICIENT 18%/A SOLAR CELLS WITH ALL SILICON LAYERS DEPOSITED WIRE-CHIRAL VAPOR DEPOSITION
Qi Wang, Eugene Iwanszko, Xueqin Xu, Wei Gao, Brent P. Nelson, A.H. Makino, R.S. Crandall and Howard Brazz, National Renewable Energy Laboratory, Golden, CO.

We have fabricated hydrogenated amorphous silicon (a-Si:H) n-i-p solar cells with all doped and undoped a-Si:H layers made by hot-wire chemical vapor deposition (HWCDV). On untethered, stainless steel (SS), we achieved an initial efficiency of 7.46%, eclipsing the previous record of 6.02% for an all-HWCDV cell. This is also the highest untethered-substrate efficiency ever reached in any solar cell that contains HWCDV a-Si:H. The increased efficiency results primarily from improvement in the final 60A of a-i-n material, which is nearest the i-p interface. We first mapped H-dilution conditions for the transition from amorphous to microcrystalline Si layer growth on a-Si:H by UV-reflection and Schottky cell open-circuit voltage measurements. We then incorporated 60A of this a-Si:H material grown at conditions near the transition to microcrystalline into the i-p interface cells to obtain a fill factor increase from 0.60 to 0.68. The open-circuit voltage is 0.88V - our best results are with an n-Si:H p-layer grown near the transition to microcrystalline-Si. The n-layer is deposited at 14A/s, the 300A i-layer at 18 A/sec, the 60A i-layer at 3.6 A/sec, and the p-layer at 4.6 A/sec. Cell stability against light-soaking is now under test. Due to improved light-trapping, our earlier n-i-p solar cells yielded over 2% improvements in conversion efficiency when transferred to textured Ag/ZnO-coated SS supplied by United Solar Corp. Preliminary cell fabrications on textured SS with our recipe have already given an all-HWCDV record of 8.7%.

4:30 PM A4.4

FAST DEPOSITION OF MICROCRYSTALLINE SILICON FILM USING THE HIGH-DENSITY MICROWAVE PLASMA UTILIZING A SPOKESWIRE ANTENNA
Hajime Shira, Yoshihiko Sakuma, Saitama University, Faculty of Engineering, Saitama, JAPAN; Hirotsuki Ueyama, Nissan Koshuha Co. Ltd., Midori-ku, Yokohama, JAPAN.

Now, microcrystalline silicon (mc-Si:H) is one of the promising materials for thin film solar cell of lower cost, better stability and higher conversion efficiencies than that of hydrogenated amorphous silicon (a-Si:H). However, several problems remained to be unsolved for further improvement of the characteristics and performance of the device. These include low deposition rate, powdered formation and poor crystallinity at the initial growth stage. To overcome these problems, we have developed a novel high-density and low temperature microwave plasma utilizing a spokewise antenna for fast and uniform deposition of mc-Si:H(1). A high deposition rate is achieved up to 47Å/s from SiH4 and Ar without the use of H2 dilution gases. We will discuss the promotion of high-density microwave plasma and its characteristics including film properties and solar cell performance. (1) H. Shira et al., Jpn. J. Appl. Phys. 37 (1998) L1078

4:45 PM A4.5

PREPARATION OF MICROCRYSTALLINE SILICON BASED SOLAR CELLS AT HIGH-LAYER DEPOSITION RATES USING A GAS-JET TECHNIQUE
S.J. Jones, R. Cruick, X. Deng, and M. Iza, Energy Conversion Devices, Inc., Troy, MI.

A gas-jet technique has been used to prepare microcrystalline silicon thin film at high deposition rates. The technique involves the use of a gas jet flow which is subjected to a high intensity microwave source. With this technique, microcrystalline Si films have been prepared at deposition rates as high as 20Å/s. The films were made using rates near 16 Å/s. These materials have been used as i-layers for n-i-layer single-junction solar cells. The high deposition rates allow fabrication of the required thicker microcrystalline Si i-layers in a similar amount of time to those used for high quality a-Si:H i-layers (rates of 1.3 Å/s). The dopant layers for these cells were made using standard PECVD practices and different deposition equipment. Using a 0.1-μm cutoff filter which only allows red light to strike the device, photovoltaically soaked short circuit currents of 8.10 mA/cm2 and 2.7% red-light efficiencies have been obtained while AM1.5 white light efficiencies are above 7%. These efficiencies on average degrade only by 2% (stabilized efficiencies of 2.6%) after long-term light soaking (1000 hrs.). This small amount of degradation compares with the 15.1% degradation in efficiencies for a-Si:H cells subjected to similar irradiation treatments (final light-soaked red light efficiencies of 3.2%). The lower efficiencies for the microcrystalline Si cells are presently due to lower short circuit currents and lower open-circuit voltages (near 0.60V under AM1.5 white light measurements) due to the low bandgap of the material. The poorer performance could also be partially due to the fact that the doped layers used in these devices were optimized for a-Si:H n-i-p solar cells rather than for the microcrystalline Si i-layer and that a break between the microcrystalline Si-i and doped layers deposited in a different system, as required for now, may lead to unoptimized interface layers.
have confirmed that these samples contain in the case of 1 layers, single Si microcrystals embedded in a matrix that is predominantly amorphous. The Si microcrystals make up more than 40% of the Si microcrystalline phase. At the same time, the comparison between various properties of layers obtained in temperature 250°C and obtained in temperature 100°C was performed carrying out a number of systematic experiments on Schottky structures made on stainless steel, glass and Laminated C-Si polycrystalline substrates. Optical characteristics of undoped n-Si film and of phosphorus doped n-Si film have been determined using transmission and reflection measurements in a wide range of wavelengths. We also show how operate this complex photodiode in 40x40 matrix image sensor made by us. [1] A. Koldziej, P. Krewien, R. Tadeusiewicz, Mat. Res. Soc. Symp. Proc. 558 (1999), in press.

A.5.3 MICROSTRUCTURAL CONTROL OF THIN FILM Si USING LOW ENERGY ION BEAM-FREE INDUCED PHENOMENA IN SPUTTER DEPOSITION. J.E. Gerbi, J.R. Abelson, Coordinated Science Laboratories and the Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL.

Using plasma growth sources with concurrent particle bombardment, silicon thin films can be deposited with various phases and microstructures. DC Reactive Magnetron Sputtering (RMS) can produce amorphous, polycrystalline, mixed-phase, and nanocrystalline, polycrystalline, porous columnar, and epitaxial Si films. In particular, a high flux of low energy, heavy ion strongly affects phase and microstructure, and therefore modifies the quality of the deposited film. RMS is particularly suited for this type of plasma mass ion gun; we bias the substrate to produce the ion energy of choice, and use an external magnetic field to control the ion beam flux ratio, therefore decoupling the parameters of bombardment energy and flux. In this work, we study the influence of low energy, heavy ion bombardment in RMS deposition on the formation kinetics and microstructures of nanocrystalline, mixed-phase, and polycrystalline Si films. The analytical methods are in-situ real-time spectroscopic ellipsometry and reflection high energy electron diffraction (RHEED) absorption, as well as post-deposition characterization. RHEED and angle scattering, SIMS, TEM and photoluminescence. We will show how ion bombardment drives the nucleation of polycrystalline Si on glass at temperatures below 400°C, enhances the bulk crystallinity, and yields extremely smooth surfaces, as well as produces nanocrystalline films with tailored grain sizes at temperatures below 200°C. There are myriad applications for such films directly deposited onto plastic or glass substrates, for which tailored microstructural growth is extremely valuable. Enhancement of medium range order (the polycrystalline state) is another microstructural product that is of possible interest, particularly for electronically stable solar cells.

A.5.4 IN SITU MASS SPECTROSCOPY OF ECR SILANE PLASMAS FOR AMORPHOUS AND MICROCRYSTALLINE SILICON GROWTH. Young-J. Song, Ellen A. Galans, Wayne A. Anderson, State University of New York at Buffalo, Dept of Electrical Engineering, Amherst, NY.

ECR silane plasma for the deposition of n-Si:H and w-Si:H films were investigated in an in situ mass spectroscopy (MS) using a quadrupole residual gas analyzer. The results showed that the intensities of ionization and neutral species (H, H₂, He, Si, and SiH₄) in the 2% SiH₄/He plasma are strongly dependent on the deposition conditions such as chamber pressure, power and hydrogen dilution. In all cases, the predominance of Si ions was observed over the SiH₄ and SiH₂ ions, suggesting a high decomposition rate of the silane in the plasma. In particular, the population of atomic hydrogen in the plasma seems to play a key role in the properties of both films. For example, the increased intensity of atomic hydrogen, compared to that of molecular hydrogen, resulted in the better quality n-Si:H film, showing a higher photo and dark conductivity ratio (10). The intensity of the hydrogen species is mainly sensitive to the chamber pressure, and the correlation between MS data and film properties will be discussed in detail.

A.5.5 SOLEC-GROWN nm-Si FILMS GROWN BY ECR CVD. M. Birkholz, E. Conrad, K. Lipp, B. Selle, I. Sieber, J. Platen, W. Funke,Thilo-Meinek-Institut Berlin, Silicon-Fotovoltaik, Berlin, GERMANY.

The generation of silicon plasma by virtue of electron-cyclotron resonance (ECR) CVD holds the promise of high rates for Si thin film deposition at low temperatures. The authors report on the preparation of n-Si films from SiH₄/N₂ mixtures by ECR CVD at deposition temperatures ≤ 400°C on different substrates. For high quality silicon diode conditions could be identified, which for Si films with a high degree of crystallinity were grown as wafer confirmed by Raman spectroscopy. μc-Si films exhibiting line widths of the α-Si LO/LLO mode at 520 cm⁻¹ small as “7 cm⁻¹” (FWHM) could be produced with temperatures more than 40% of the Si microcrystalline phase. At the same time, the comparison between various properties of layers obtained in temperature 250°C and obtained in temperature 100°C was performed carrying out a number of systematic experiments on Schottky structures made on stainless steel, glass and Laminated C-Si polycrystalline substrates. Optical characteristics of undoped n-Si film and of phosphorus doped n-Si film have been determined using transmission and reflection measurements in a wide range of wavelengths. We also show how operate this complex photodiode in 40x40 matrix image sensor made by us. [1] A. Koldziej, P. Krewien, R. Tadeusiewicz, Mat. Res. Soc. Symp. Proc. 558 (1999), in press.

A.5.6 METHODS OF SUPPRESSING CLUSTER GROWTH IN SILANE RF DISCHARGES. Masahiro Shiraishi, Shinichi Matsunaga, Yasuo Hiro Matsuoka, Kenichi Tanaka, Kozo Ono, Yukio Watanabe.

KYOTO University, Dept of Electronic Device Engineering, Pukuck, JAPAN.

Size and density of clusters, which are believed to degrade film quality, in silane parallel plate RF discharges are measured using a novel double pulse (DP) method and a high-sensitivity phase-matching interferometry (PCLI), respectively. Small neutral clusters of about 1 nm in size and about 10¹⁶ cm⁻³ in density are found to exist over the discharge space even under so-called device quality conditions. In order to suppress such cluster growth, effects of gas temperature gradient, rf discharge modulation, and hydrogen dilution on growth of clusters below about 10 nm in size are studied. The thermophoretic force due to the gas temperature gradient between the electrodes drives neutral clusters above a few nm in size towards the cold RF electrode, which is at room temperature. The rf discharge modulation is much more effective in reducing the cluster density when it is combined with the gas temperature gradient and clusters above a few nm in size cannot be detected by the PCLM method even over 2 hours. A high H/SiH₄ concentration ratio above about 6 is also useful in suppressing cluster growth in the radial production region around the plasma/shroud boundary near the RF electrode. The hydrogen dilution is revealed to reduce the cluster growth rate even for small clusters such as Si₂H₂. Correlation between cluster density and n-SiH film quality will be presented at the meeting.


n-Si films deposited in the regime (P = 0.5 to 1.8 Torr) of RF PECVD with helium dilution exhibit very fast kinetics of light-induced degradation, with stabilized mobility-lifetime products (independent of Fermi level positions) which are comparable to those of state-of-the-art materials in the amorphous state. These materials are reproduced in a different reactor, and 10% bulk Si solar cells have been fabricated on glass substrate. Spectroscopic ellipsometry analysis of these materials shows that the experimental curve of the variation of imaginary part of the dielectric constant vs. photon energy can not be simulated accurately using a single layer dielectric model, i.e. with the n-Si consisting of an amorphous network and voids. Moreover the interference fringes in the low energy portion of the curve can only be reproduced by the inclusion of a fraction of crystalline component (2%) in the model. However, the amorphous structure of the materials has been verified by Raman and x-ray diffraction (XRD), although the width of the first scattering peak of the XRD systematically increases with P, indicating improvement of medium-range order (MRO). Consistently, the volume fraction of MRO, the carrier mobility (by Time Resolved Microwave Conductivity) is found to improve by a factor of 2.3. Small angle x-ray scattering (SAXS) and their density methods (small angle neutron scattering) on the mesoscale (nanovoid density < 0.01 vol%) and compact (density ≥ 2.23±0.01 g/cm³, density deficit < 0.43%) network structure however show a small amount of large-scale features ( > 20 nm) exists, which reduces with P, up to 1.8 Torr. Concurrently the density of states (by Modulated Photocurrent method) above 3 eV

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A5.8 STRUCTURE OF Si H FILMS FABRICATED BY PLASMA ENHANCED CVD USING HYDROGEN DILUTED PLASMA


The addition of hydrogen to silicon during plasma enhanced chemical vapor deposition (PECVD) improves the photovoltage characteristics of intrinsic n-Si:H films. The PECVD process with hydrogen-diluted SiH4 can also produce microcrystalline Si:H films on glass substrates at temperatures below 200°C. We present results of structure studies of undoped Si:H films deposited by PECVD at high power as an RF frequency of 13.56 MHz over SiO2/Al2O3 substrates held at temperatures T, in the range of 140 to 240°C and employing a hydrogen dilution d (d=SiH4/H2) from 0.8% to 1.5%. The deposition rate was 6 to 9 Å/s. In-situ TEM, high resolution TEM, XRDF, photoluminescence, infrared absorption, and etching methods were used for the Si:H film structure characterization. Using the films, n-µ-Si:H thin film solar cells with efficiencies of 7% were produced. The samples of the cells, stable efficiencies of 10% were achieved. The Si:H films deposited at T=140°C with strongly diluted SiH4 (d=0.8%) were microcrystalline (average grain size of 20 nm) in the as-deposited state and after vacuum annealing up to 800°C for 1 h. For intermediate d, i.e., d=1.5%, a stable mixed amorphous/microcrystalline structure was observed both for the as-deposited state (T=140°C) and after vacuum annealing up to 600°C for 1 h. Weakly diluted (d=1.5%) Si:H films were found to be amorphous in the as-deposited state, crystallizing at temperatures of 700 and 800°C via the nucleation-growth Avrami mode with an incubation time t0 of about 10 and 1 minute, respectively. After 1 h annealing at 800°C these films were microcrystalline, having an average grain size of the order of 1 nm. Diffusion measurements show release of hydrogen predominantly between 300 and 700°C. Both H effusion spectra and IR absorption measurements show only moderate microstructure in the a-Si:H films and µc-Si:H films. Raman spectroscopy data were used to estimate the amorphous to crystalline ratio.

A5.9 THICKNESS AND INTERFACE LAYER EFFECTS ON THE ABSORPTION AND TRANSMISSION PROPERTIES OF VARIOUS PHOTOLUMINESCENCE EXCITATION WAVELENGTHS

Guozhong Yue, Daqing Han, Dept of Physics & Astronomy, Univ of North Carolina at Chapel Hill, Chapel Hill, NC; Jeffrey Young, Subhanker Guha, United Solar Systems Corp., Troy, MI.

We have used photoluminescence (PL) as a spectroscopic tool to study the microstructure of hydrogenated amorphous silicon (a-Si:H) films. The PL spectra of undoped films after high density ion implantation were studied. The films were deposited onto stainless steel subgrade coated with textured Ag/ZnO. With the three types of structures, type I consists of ~0.5 µm n-Si film deposited directly onto substrate, type II has the same structure as type I except that a thin amorphous a-layer was inserted between the substrate and the n-Si film, and type III is the same as type II except that the n-Si film has a larger thickness of ~1.5 µm. These three structures are identical to those recently studied by Guha et al. using X-ray diffraction spectroscopy and capacitance profiling technique. [Appl. Phys. Lett., 74, 1860 (1999).]

They observed that type I film contains partial microcrystallinity in an a-Si matrix, type II film remains fully amorphous, and type III film exhibits partial microcrystallinity toward the top surface. In this study, we used HeCd, Ar8, and HeNe lasers to provide excitation beams at 325 nm (3.81 eV), 488 nm (2.54 eV), 514 nm (2.41 eV), and 632 nm (1.98 eV) to probe the film property at the depth of 10 nm, 50 nm, 80 nm and 1 µm, respectively, from the top surface. The results indicated that the type I and type III have evident microcrystalline components which manifest themselves in the low energy PL peak at ~0.8 eV. For type II film, we found that for 325 nm excitation, the PL peak energy decreased at 1.39 eV for 488 and 514 nm excitation, the PL peak at 1.41 eV. However, by increasing the penetration depth by using 632 nm excitation, the peak is shifted to 1.37 eV. These imply non-uniform electronic states in the growth direction. Detailed conduction band model is presented in correlation with PL spectra temperature dependence as well as Raman measurements. The work at UNC and United Solar was supported by NREL subcontract under thin film PV partnership, XAK-8-17004.11, and ZAK-817610.9, respectively. Use is partially supported by NSF-NRI-9634915.

A5.10 SURFACE CHARGE TERMINATION OF SILICON FILMS PRODUCED UNDER GLOW DISCHARGE PLASMA OF DICHLOROSILANE-HYDROGEN MIXTURE

Yaotake Toyoshima, Michio Kondo, Akihisa Matsuda, Electrotechnical Lab, Tsukuba, JAPAN.

The growing surface of silicon films prepared under glow discharge of dichlorosilane (DCS)-monosilane-hydrogen mixture is investigated using IRIRAS (infrared reflection absorption spectroscopy), which is capable of detecting the surface submonolayer coverage. It is surprising that when DCS/hydrogen mixture (no monosilane) is used even at a high dilution condition (DCS/hydrogen = 2/100ccm), no surface hydrogen is detected by IRIRAS. Instead, surface chlorine is detected as the absorption band at the frequency of Si-Cl stretching mode. It is noteworthy that surface chlorine coverage is found to be stable to the hydrogen plasma exposure, which phenomologically explains the dominance of chlorine at the growing surface in the DCS/hydrogen mixture. When a small amount of monosilane is added to the DCS/hydrogen mixture, surface hydrogen absorptions are appeared. The surface hydrogen signals are increased whereas surface chlorine signal is decreased when monosilane to DCS fraction is increased. The deposited films, which are basically microcrystalline due to the high hydrogen dilution, degrade their crystallinity with this increase of monosilane fraction. However, the crystallinity recovers when no DCS is added to the mixture. This behavior suggests that hydrogen and hydrogen dilution at the growing surface is detrimental to the microcrystalline formation.

A5.11 THERMAL OXIDATION OF Si NANOPARTICLES GROWN BY PLASMA-ENHANCED CVD. J. Farjas, D. Das, J. Costa, P. Roura, Grup de Recerca en Materia, Universitat de Girona, Girona, SPAIN; G. Viera, E. Bertran, Dept. de Fisica Aplicada i Optica, Universitat de Barcelona, Barcelona, SPAIN.

The growth of nanostructured thin films of amorphous silicon has a potential interest due to its physical and optical properties for photovoltaic conversion. Thin films of silicon nanoparticles embedded into an amorphous Si matrix are currently grown by plasma-enhanced chemical vapor deposition (PECVD). The residence time of the nanoparticles inside the plasma and the plasma conditions determine, among other structural characteristics as crystallinity and size, the hydrogen content which, in turn, plays an important role in the oxidation kinetics. The oxidation of hydrogenated amorphous Si nanoparticles is studied by thermal analysis (differential scanning calorimetry and thermogravimetry) and TEM in order to assess the influence of the hydrogen content on the oxidation kinetics. At high hydrogen concentration, the oxidation takes place at temperatures below 300°C in which case the process is not influenced by the nanoparticles. The oxidation kinetics slows down when the hydrogen content diminishes. Therefore, at the temperatures where oxidation takes place simultaneously crystallization is observed. The use of nanoparticles to study the thermal oxidation of amorphous silicon involves a much higher sensibility than with thin films due to its higher specific surface. The first steps of oxidation resulting in very thin oxide layers (<10 nm) can be easily recorded through the relative increase of mass. This results can be useful in the technology of amorphous thin films.

SESSION 1G: POSTER SESSION

HOT-WIRE CVD 1

Chair: Qi Wang

Tuesday Evening, April 25, 2000

Salon 1-7 (Marriott)

A6.1 Si + SiH4 REACTIONS AND IMPLICATIONS FOR HOT-WIRE CVD OF a-Si:H: COMPUTATIONAL STUDIES. Richard P. Moller1, William A. Goddard, III2, Jason K. Knowles3 and David G. Goodwin3. 1Materials and Process Simulation Center, Division of Chemistry and Chemical Engineering, 2Division of Engineering and Applied Science, California Institute of Technology, Pasadena, CA.


glass phase chemistry is believed to play an important role in hot-wire CVD of amorphous silicon, serving to convert the highly-reactive atomic Si produced at the wire into a less-reactive species by reaction with ambient SiH4. In this paper, we use quantum chemistry (B3LYP density functional theory with the cam-B3LYP functional) to examine the energetics and rates of possible glass phase reactions between Si and SiH4. The results indicate that formation of...
Hydrogen radical density is one of the key deposition parameters on the growth of hydrogenated microcrystalline silicon (µc-Si:H). The effect of the hydrogen radical density on the properties of µc-Si:H film deposition and the incorporation of hydrogen into µc-Si:H, however, has not been understood yet. The incorporated hydrogen into µc-Si:H has been studied using FTIR absorption and gas effusion spectroscopies [1]. We found the polycrystalline structure mostly forms in situ in µc-Si:H films [2]. This structure would be related to the electrical properties and the oxidation in the µc-Si:H. Recently we demonstrated Hot-Wire Metals Plasma Enhanced CVD (Hot-Wire CVD), which can be used for high-quality deposition and Hot-wire for exiting hydrogen, as a new preparation method for µc-Si:H [3]. The advantage of this method is that the hydrogen radical density is controlled by film deposition temperature without changing the subsequent conditions. In this report, the effect of these hydrogen radicals on the hydrogen in µc-Si:H has been studied using FTIR absorption spectroscopy and gas effusion spectroscopy. Samples are prepared at 250°C by HWAPECD from SiH4 diluted in hydrogen. HF (15.50MHz) frequency is varied from room temperature to ~1750°C. The amplitude of the polycrystalline phase decreases with increasing the film temperature. This result indicates that the amplitude of the polycrystalline structure can be controlled by varying the hydrogen radical density. Hydrogen density of the sample decreases with increasing the film temperature. The decrease in the polycrystalline phase and the hydrogen density would be increased by hydrogen etching. The mechanism of the hydrogen radicals and the incorporated hydrogen into µc-Si:H film is discussed with the results of gas effusion spectroscopy and ESR.


A6.5 n-TYPE SILICON FILMS PRODUCED BY HOT WIRE TECHNIQUE. I. Ferrera, R. Martin, A. Cabrera, F. Fortunato, P. Villarino, Univ. De La Campana, Faculty of Science and Technology, Dept. of Materials Science, Montevideo, URUGUAY.

The role of the deposition pressure and of the type of films (tungsten or tantalum) used to produce large area n-type Si films by the hot wire technique was investigated under a design system that allows the definition of highly uniform 10cm-10cm films. The data achieved show that Ta films are more adequate to produce large area amorphous or poly-Si films than W films. The reason is that the Ta films are more resistant than the W films, after being used, not leading to any significant contamination, when film temperatures up to 2200°C are used as the SIMS data reveal. Apart from that, we also noticed that the electro-optical properties of the films produced are highly dependent on the pressure used. In the pressure range from 0.1 Torr to 1.0 Torr, the film's conductivity varies by more than two orders of magnitude, for films produced at same hydrogen dilution and film temperature, reaching values of about 104 cm, as deposition pressure of about 0.4 Torr. On the other hand, high conductive films are produced using specific deposition conditions concerning hydrogen dilution and film temperature. These data are well the performances of p-i-n devices produced using the improved n-layer deposited by hot wire technique will be presented.

A6.6 THE INFLUENCE OF W FILAMENT ALLOYING ON THE ELECTRONIC PROPERTIES OF HCVD DEPOSITED n-Si FILMS. A.H. Mahan, J. Thiesen, A. Macon, A. Swartzlander-Guest, and A.C. Gallagher, National Renewable Energy Laboratory, Golden, CO. *JILA, University of Colorado and NIST, Boulder, CO.

In depositing n-Si by HCVD using W films, one issue common to this technique is that of film lifetime. When using undoped silicon, a buildup of electrical activity at the ends of the film is routinely observed, and it is here that film breakage usually occurs. Less well understood is the effect of alloy formation on n-Si electronic properties. As this alloying is usually confined to the film ends, with proper buffer designs this alloying does not normally affect the growing film surface. However, by using shorter filaments where the growing film surface sees the entire film length, we can probe this issue. In this work we combine optical (UV-Vis) measurements of undoped n-Si films with sputter Auger depth profiling of the deposited Si/W composition to track film electronic properties as a function of the Si buildup on these short films. With increased run time, this alloying (thickened region) propagates further and further along the film length, so that at the end of the experiment, approximately half of the film was alloyed (thickened). Further, even the non-thickened central regions contained appreciable Si. This alloying had two major consequences: film deposition rate could be quantitatively understood by considering the decreased
fraction of the hot filament length, which accounts for the large majority of film deposition. However, the film electronic properties also deteriorate with time, and photovoltaic efficiency decreases by the sharp drop in the film SSIP value. We detail the results of these measurements, and suggest that the nature of the filament surface must be carefully considered when optimizing a-Si:H film electronic properties. Finally, we discuss the extent of this alloying by pre- or post-deposition treatments, different filament run temperatures, and the possible use of other filament materials.

SESSION A7: POSTER SESSION:
HIGH-RATE DEPOSITION
Chair Hajime Shirai
Tuesday Evening, April 25, 2000
8:00 PM
Salon I-7 (Merritt)

A7.1
ION-ASSISTED DEPOSITION OF SILICON EPITAXIAL FILMS WITH HIGH DEPOSITION RATE USING LOW ENERGY SILICON IONS. Linn Oberbeck, Ralf B. Bergmann, Jürgen H. Werner, Univ. of Stuttgart, Inst. of Physical Electronics, Stuttgart, GERMANY.

Ion-assisted deposition (IAD) enables low-temperature (<550°C), high-rate (<0.5 cm/min) epitaxial growth of silicon films. These features make IAD an interesting deposition technique for microelectronic devices and crystalline thin film silicon solar cells on glass substrates. Ion-assisted deposition is based on electron-gun evaporation and subsequent ionization of a small fraction of evaporated silicon atoms. An applied voltage of several 10 V accelerates the silicon ions towards the substrate. This hyperthermal kinetic ion energy allows lower deposition temperatures and higher deposition rates compared to other low-temperature epitaxial growth techniques. To evaluate the structural and electrical properties of epitaxial layers we use monocrystalline Si substrates to exclude influences of grain boundaries. The electron and hole mobilities of our in-situ doped films reach values of 800 cm²/Vs in the doping range between 10¹⁵ and 10¹⁶ cm⁻². The minority carrier diffusion length substantially increases with deposition temperature. Source etching demonstrates that a decreasing density of extended defects such as dislocations and stacking faults is responsible for the increase of short circuit current density and minority carrier diffusion length of test solar cells with increasing deposition temperature. Structural investigations of epitaxial growth on large and fine grained polycrystalline Si substrates demonstrate the possibility of low-temperature epitaxial growth on arbitrarily oriented grains. Growth on fine grained Si substrates, however, exhibits influences of growth rate anisotropy during epitaxial growth. We apply epitaxial Si layers with in-situ emitter deposited by IAD to microcrystalline seeding layers on glass substrates and study the influence of deposition parameters and hydrogen treatment.

A7.2

The use of VHF for deposition of large area amorphous silicon films leads to a non-uniformity of the film thickness due to the generation of standing waves and evanescent waveguide modes at the electrode surface. One possibility to process large area substrates with very high frequencies (50-100 MHz) is the use of an linear plasma source in combination with a moved substrate. The VHF plasma source is electronically screened to prevent electromagnetic and plasma emissions. Several kinds of power feeding were investigated, e.g. dual power feeding, single power feeding with load resistances, and multiple power feeding. But multiple power feeding is the only way for using VHF at any source length up to 2000mm and more. Using a source length of 600mm, experiments were done with 81.506MHz at RF power densities of 25...550W/cm², nitrogen and silane pressures of 5...500mbar, and flow rates of 10...1000sccm. The measured potential distribution error was ±2%. Optical emission spectroscopy delivers discharge intensity errors of ±3...10% in opposition to ±25...100% as single power feeding. Deposition rates up to 15μm/h (40 Å/s) and film thickness inhomogeneity less than ±5% were achieved. The best deposition parameters were 100Pa/1000Pa, 35mm electrode distance. More experimental results will be discussed in dependence on the deposition parameters.

A7.3
OPTIMIZATION OF HIGH RATE a-Si:H TECHNOLOGY FOR SOLAR CELLS. B.G. Badzian, A.A. Sherdenkov, A.A. Aivazov, MIET, Materials Science Dept., Moscow, RUSSIA.

For the application of the low band gap a-Si:H alloys as an active layer in tandem and triple solar cells it is necessary to increase the deposition rate and photovoltaic efficiency. Several approaches are being investigated to increase by pre- or post-deposition treatments, different filament run temperatures, and the possible use of other filament materials.
does not depend strongly on the growth rate and correlates with the hydrogen content. The Urbach edge at $T_{\text{uc}} > 1000$ K are around 50 meV and defect densities as determined from Deep Level

Photoconductivity measurements for our best samples are below $10^6$ cm$^{-3}$ even at growth rates as large as 25 Å/s. The results indicate that with increasing growth rate the substrate temperature at which we obtain device-quality film properties should be increased. The results will be interpreted in an n-Si:H growth model for hydrogen, weak bond and defect incorporation as a function of growth rate and substrate temperature.

### A7.6 Roughness Evolution of High Rate n-Si:H Growth Using an Expanding Thermal Plasma

**Authors:** H. S. Kim, K.W. Shin, J.Y. King, Microsystems Technology Laboratory, University of Maryland, College Park, MD, USA

The expanding thermal plasma (ETP) deposition technique, developed at the Eindhoven University, combines high growth rate (100 Å/s) with device quality opto-electronic n-Si:H film properties. In this paper we report results on film growth, dominated by silyl (SiH$_4$) radicals and atomic hydrogen species impinging the growing surface, as studied using single wavelength rotating compensator ellipsometry. An optical growth model is formulated similar to models as proposed by Collins et al. (J. Vac. Sci. Technol. B 7 1115 (1989)) to simulate the ellipsometric measurements. This model enables us to monitor the surface roughness evolution, characterized by a roughness decrement layer thickness $d_{\text{dec}}$ in time. Results are presented as function of growth rate ($3-120$ Å/s) and substrate temperature ($100-950$ °C). The post initial roughness evolution film thickness $d_{\text{dec}}$ can be described by $d_{\text{dec}} \approx t^\beta$ where $\beta$ is a scaling exponent being 1/2 for random growth and $< 1/2$ if a surface smoothing processes during growth is active. For growth rates $\leq 23$ Å/s, $\beta$ decreases with increasing temperature reflecting the decreasing adsorption rate of hydrogen on the wafer, as follows from the decreasing $\beta$ values as function of temperature are explained in terms of surface diffusion of weakly adsorbed silyl radicals. In this paper we will argue that $\beta$ values smaller than 1/2 not necessarily implies that the dominant smoothing mechanism is surface diffusion of weakly adsorbed radicals but rather by the ability of surface dangling bonds to preferentially reside on surface valleys. Possible mechanisms for dangling bond transport on the n-Si:H growth surface will be discussed.

### A8.3 Resitivity and Hall-Voltage Investigation of P- and N-Doping in Polycrystalline SiGe Thin Films

**Authors:** W. Qian, D.G. Ast, Cornell University, Department of Materials Science & Engineering, Ithaca, NY; T.I. Kamins, Hewlett-Packard Laboratories, Palo Alto, CA.

It is known that n-type dopants, such as P and As, segregated to the grain boundaries in poly-Si, where they become electrically inactive. Our previous STEM microanalysis showed that grain-boundary segregation also takes place in P-doped, polysilicene Si$_{1-x}$Ge$_x$ thin films but left the electric activity of segregated P unresolved. To investigate this issue, the electrical properties of atmospheric-pressure CVD deposited, 300 nm thick, polysilicene Si$_{1-x}$Ge$_x$ thin films were measured. Hall measurements, feasible only in heavily doped samples, showed that less than 20% of dopants in Si$_{0.8}$Ge$_{0.2}$ and 42% in Si$_{0.5}$Ge$_{0.5}$ were electrically inactive. The difference between carrier and dopant concentration is attributed to inactive P segregated to grain boundaries.
could be found. In general, less substructure was seen in the poly-silicon reference samples. Consistent with this trend, wider twin bands were observed in silicene than in Si_{1.06}Ge_{0.34} films. Finally, the density of multiple twins was lower in Si. Since the grain size of the two film types is similar, the observed structural differences must reflect the addition of Ge, which being a larger atom, both introduces more local strain (promoting twinning), and by replacing Si atoms under tensile stress, offers the opportunity to lower the strain associated with joining together larger substrates, such as those making up 5-fold twin structures. In the case of the second order symmetrical twins, analysis of resolution images showed that in Si_{0.66}Ge_{0.34}, the boundary structure was identical to that reported for the second-order symmetric twin boundary in Si. The structure, again, is based on a zigzag arrangement of five-membered rings. Within the accuracy of HREM, the repeat length of this boundary in Si_{0.66}Ge_{0.34} is the same as in Si. A previous STEM microanalysis showed that Ge does not segregate to GBS in Si_{0.66}Ge_{0.34}. Thus, the ratio of Si to Ge at GBS is that of the bulk, leading to the conclusion that replacement of about 1/3 of the Si atoms by Ge does not significantly influence the boundary structure of the second order twin boundary.

A8.5 EFFECT OF DEPOSITION CONDITIONS ON THE STRUCTURAL AND MECHANICAL PROPERTIES OF POLY-SiGe. Ingred DeWolf, IMEC, Leuven, BELGIUM, Shervin Sedky, Cairo University, Faculty of Engineering, Dept of Engineering Physics, Giza, EGYPT; Ann Wirtzov, Marc Cuyvers, IMEC, Leuven, BELGIUM.

In this paper, we analyze the effect of decreasing the deposition temperature of poly SiGe from 650°C to 500°C on the growth rate, germanium concentration and structural and mechanical properties of the grown films. Poly SiGe has been deposited on eight-inch wafers using chemical vapor deposition (CVD) in an EPSILON I reactor, at atmospheric pressure and using a reduced pressure (RP) of 40 Torr. 10% /90% Germane/Hydrogen has been used as the germanium gas source, whereas, the silicon gas source is either silane or dichlorosilane. The gas flow rate has been adjusted to yield a germanium concentration varying from 20% to 40%, as determined by Rutherford Backscattering Spectroscopy (RBS). The deposition rate of RPCVD poly SiGe decreases from 7.5 nm/min to 4.2 nm/min by reducing the deposition temperature from 650°C to 550°C, with a fixed silane and germane flow rate of 10 and 200 sccm, respectively. For RPCVD poly Ge, the growth rate increases from 0.64 nm/min to 2.8 nm/min by increasing the deposition temperature from 500°C to 550°C. The texture, the transition temperature from amorphous to polycrystalline and the microcrystalline structure of the grown films have been determined by means of X-ray diffraction spectroscopy (XRD) and transmission electron microscopy (TEM). The structure of poly SiGe deposited at atmospheric pressure has been found to be more columnar than that deposited at reduced pressure. Finally, the impact of the deposition temperature, pressure, germanium concentration and annealing temperature on stress is presented. It is shown that the stress is reduced at 550°C.


Homoeptaxial growth on top of laser-crystallized poly-Si seed layers is one important route for realizing polycrystalline Si with large grains for thin-film solar cell. Ion-milled deposition techniques and, in particular, electron cyclotron resonance chemical vapor deposition (ECR-PECVD) have been shown to enable epitaxial growth at low temperatures and with reasonably high deposition rates. Here we report on results obtained with ECR-PECVD using systematic variations of the deposition parameters (substrate temperature, ion energy, gas composition) with crystalline Si-substrates of different orientations. Structural properties of the films are investigated by transmission electron microscopy techniques (TEM), Rutherford backscattering (RBS), and X-ray diffraction (XRD). Highly phosphorus and boron doped films on Si[100] substrates turned out to be of high structural quality with defect densities of less than 10^6 cm^-2 (2 dimensionals). The structural order is superior in case of doped Si films. For Si[100] orientation the crystallinity is significantly improved with substrate temperature (325 - 500°C). Simultaneously, we observed an enhancement of the lattice strain. Ion energy was varied by applying a variable ion chamber holder. Negative V_b accelerates the ions which results in enhanced ion damage of the lattice structure and increased surface roughness. In contrast, positive V_b reduces the density of lattice defects by decreasing the ion energy. Under so far optimized conditions we obtain an epitaxial growth on differently orientated substrates. However, two-dimensional, extended defects are observed the density of which depends on the substrate orientation. Moreover, we find nanocrystalline material inclusions of material of different orientations with a separation of about 1 μm. By reducing the hydrogen dilution and adding Ar to the excitation gas the deposition rate increases substantially, but the structural quality is diminished. At present it is not clear as to whether the reason is the higher rate or the enhanced ion bombardment.

A8.7 POLYCRYSTALLINE SILICON THIN FILMS FOR MICRO-ELECTRONIC APPLICATIONS. Elena A. Galieni, Young J. Song and Wayne A. Anderson, SUNY at Buffalo, Dept of Electrical Engineering, Buffalo, NY.

For years, thin Si films grown by Physical Vapor Deposition techniques have been known to be inferior in both structural and electrical properties compared to those grown by Chemical Vapor Deposition. This study is aimed at restoring the importance of the sputtering technique as a convenient, safe and low-cost method to produce quality Si films at a high deposition rate. Poly-crystalline silicon thin films with thickness of 0.5-5 μm were grown on 5-100mm thick Ni prelayers by dc magnetron sputtering from a Si target. In contrast to the conventional sputtering, the use of a thin Ni film on a variety of substrates allowed the production of the high crystallinity silicon at temperatures below 600°C. The Ni-diluted grains formed at the Ni growing Si film interface were shown to provide sufficient sites for the epitaxial growth of Si. The resulting met-in-induced grown Si film exhibits a columnar structure. The cross-sectional diameter of the Si crystals is in the 50-500Å range with length equal to the film thickness. Moreover, the Si crystal size is found to be strongly dependent on the thickness of the Ni film. The Ni-Si interdiffusion kinetics plays a dominant role in the silicon formation and the subsequent silicon growth. The dynamics of the Si crystal growth on a Ni prelayer is briefly discussed. The Si films with resistivity of 10^5-10^6Ω-cm possess up to 11μs carrier lifetime which makes them applicable to various microelectronic devices. The Ni silicide layer at the bottom of the silicon film provides a satisfactory back contact contact. As an example, Schottky diodes fabricated on a 0.5μm thick silicon film grown at 350°C exhibited a forward-to-reverse current ratio of 10. The results of a detailed investigation of both Schottky and p-n junction diodes will be presented. The influence of such post-deposition techniques as annealing and hydrogenation on the device performance will also be reported.

A8.8 IN- SITU CHARACTERISATION OF THIN POLYSILICON FILMS BY VARIABLE ANGLE SPECTROSCOPIC ELIPSOMETRY. Steffen Pagnotta, Kai van Reeser, Ruediger Ferrari, Uwe Hannover, Dr. Proksch, J. Weis, H. Gröschl, W. König, Dirk Kiehler, Josef Hame, Centrotherm, Blaubeuren, GERMANY.

Up to now an in-line method for parameter determination of deposited polysilicon films is not available. In this paper a method for monitoring the polycrystalline deposition process in device manufacturing by variable angle spectroscopic ellipsometry (VAE) is demonstrated. Therefore a wide range of polysilicon films is deposited on silicon wafer (100) with different SiO2 interlayers. These samples are characterised by VAE in the optical range of 450 - 850 nm. Parameters are determined by simulation using a multilayer model consisting of air, interface layer (surface roughness), polysilicon, SiO2, and silicon substrate. Different recently used optical models representing properties of polysilicon are tested. The free parameters are the oxide thickness, the composition and the thickness of the interface layer (air/poly-silicon), the thickness and the complex refractive index of the polysilicon layer. Results of the spectroscopic analysis are verified by surface profiler, AFM, SEM and TEM measurements. It can be shown that parameters of the deposited polysilicon films, which up to now could only be determined by complex and expensive measurements, are also accessible by non-destructive in-line VAE measurements.
A9.1 CHARACTERIZATION OF SIMPLANTATION INDUCED Si LAYER AND ITS RECRYSTALLIZATION THROUGH THERMAL ANNEALING: Ran Liu, Rich Gregory, Peter Fejes, Zhong Lu, Semiconductor Products Sector, Motorola Inc., Mesa, AZ.

In an effort to develop advanced SiCMOS devices, Si implantation is used to create a Si layer to prevent BF$_2$ implant channeling and thus to reduce the base junction width. Information about the crystallinity and thickness of the Si layer and the lowest thermal budget needed to re-crystallize this layer after BF$_2$ implantation are of great technological importance. This paper presents the characterization results from samples implanted with different doses of 80 keV Si ions and samples annealed at different thermal budgets using Rutherford Backscattering Spectroscopy (RBS), ion channeling, Transmission Electron Microscopy (TEM), Raman spectroscopy, and spectroscopic ellipsometry. Good agreements on the crystallinity and thickness of the Si-implanted layer were found between different techniques. The results indicate that the thickness of the implanted layer follows a logarithmic relationship with Si ion dose and the crystallinity of the layer is also dose dependent. An implantation with 5e14 cm$^{-2}$ Si at 80 keV can only partially amorphize Si surface through 1400 Å. Dose above 5e14 cm$^{-2}$ will fully amorphize the Si substrate through 1600 Å and greater. Experimental results from the samples after two different Rapid Thermal Annealing (RTA) processes (900°C/15 Sec. And 1000°C/5 Sec.) show evidence of remaining end-of-range defects after the lower-thermal-budget RTA. The higher-thermal-budget RTA was found to be sufficient to re-crystallize the implanted layer.


The formation and properties of large grain polycrystalline silicon films on low-cost substrates such as glass are of prime interest for applications in solar cells devices. Since use of glass constrains process temperatures, our approach to large-grain polycrystalline silicon films used for solar cells is to use micro-crystalline silicon (m-Si) films, also known as \'poly-Si\', as a template substrate. Upon a long annealing process of typical poly-Si film, the crystallization of m-Si film is obtained with a growth rate of about 1 mm/s. Ni-induced crystallization leads to a seed-like subgrain structure of low-angle boundaries, with a length scale of 10-100 nm. The maximum achievable grain size is limited by these subgrain boundaries. Studies have shown, by transmission electron microscopy (TEM) and optical image analysis, the variation of the solid phase epitaxy and the nucleation time as a function of Ni dose in the 10$^{-14}$ cm$^{-2}$ range. The results show that the nucleation density increases with Ni dose and decreases with film thickness, which is consistent with the earlier observations. The crystal quality is very good, with a high degree of orientation, as determined by x-ray diffraction and TEM. The crystallization behavior is dependent on the Ni dose and the film thickness. Studies of the crystallization behavior of Ni-induced polycrystalline silicon films will be presented.

A9.3 THIN SINGLE CRYSTAL Si ON OXIDE BY LATERAL SOLID PHASE EPITAXY OF AMORPHOUS Si AND SiN$_x$: J.S. Reddy, J. Scudder, J. Jovel, and J.F. Gibbons, Solid State Electronics and Photonics Laboratory, Stanford University, Stanford, CA, 1Villanova University, Villanova, PA.

Processes to generate single crystal Si on oxide are of interest for the fabrication of multiple layers of Si MOSFETs. One method under investigation is lateral solid phase epitaxy (LSPPE) of amorphous Si on oxide, using the Si substrate as a seed. In this work, we characterize the LSPPE growth process for amorphous films grown by low-pressure chemical vapor deposition at 550°C on oxide-patterned, 100 nm Si substrates. For sub-50 nm gate length devices, a Si layer thickness on the order of 10 nm will be required. Previous work on LSPPE has shown significant faceting and lack of a well-defined growth front for Si layer thicknesses less than about 0.5 μm. Here, we demonstrate the fabrication of 25 nm-thick epitaxial Si regions on oxide, by LSPPE of an amorphous Si/Si$_{0.2}$Ge$_{0.8}$/Si$_x$N$_{1-x}$ seed structure. A thin Si$_{1-x}$Ge$_x$ layer (x=0.2) is used as an etch stop. Following LSPPE of the 0.33 μm-thick stack by annealing at 550°C, the two layers are selectively removed by wet chemical etching. The resulting structure achieves a 25 nm-thick single crystal Si region on oxide with a lateral epitaxial growth distance of 2.5 μm from the seed window. In this structure, the Si$_{1-x}$Ge$_x$ serves as an etch stop, and the addition of Ge to amorphous Si impacts the LSPPE process itself. In a separate set of experiments we find that the activation energy for LSPPE growth is reduced for 20% Ge alloys compared to pure Si. At 550°C, this amounts to an enhancement of roughly a factor of three in the LSPPE growth rate, which enables reduced substrate thermal exposure. However, the Ge fraction and anneal temperature must be optimized, and this also increases the rate of random crystallization of the amorphous film over the oxide.

A9.4 CRYSTALLIZATION TEMPERATURE EVOLUTION TIME IN THE SOLID-PHASE CRYSTALLIZATION OF Si$_{1-x}$Ge$_x$/Si FILMS: O.H. Roh, J.K. Lee, Chonbuk National University, Dept. of Physics, Chonju, KOREA.

We have investigated the solid-phase crystallization (SPC) of n-type Si$_{1-x}$Ge$_x$-Si films by using x-ray diffraction (XRD), electron spin resonance (ESR), and x-ray diffraction (XRD) measurements. The films were deposited on Corning glass 7059 substrates, using a chemical vapor deposition system using SiH$_4$ and GeH$_4$ gases. The substrate temperature was 200°C and the r.f. power was 3 W. The film thickness ranged 2.8 - 3.3 μm. The films were then annealed at 600°C in a N$_2$ atmosphere. The total spin density first increased with annealing time due to hydrocarbon evolution, and then rapidly decreased as the film was crystallized. The variation of spin densities due to the annealing was found to be slowly reduced to the variation of the crystalline fractions in the SPC process. In the SPC process, the hydrogen bond was formed by Ge dangling bonds rather than Si dangling bonds for the Ge-rich samples (x = 0.12 and 0.67). Also, it was observed that the H evolution time from the Si-H bond or Ge-H bond was strongly affected by the Ge composition of the films. The H evolution time from Si-H bond for x = 0.67 film was faster than for x = 0.12 film, and the H evolution from Ge-H bond for x = 0.67 film was significantly faster than x = 0.12 film. Our results were attributed to the varying Si-H dissociation energy and the Ge-H dissociation energy depending on the Ge composition x of the films. The atomic environments around the H of the Si-H or the Ge-H bond would be varying with the Ge composition of the films.

A9.5 CONTROL OF AMORPHOUS Si CRYSTAL CRYSTALLIZATION USING GERMANIUM DEPOSITED BY LOW PRESSURE CHEMICAL VAPOR DEPOSITION: Makoto Aoki, K. Komiya, Micro Systems, Tokyo, JAPAN; Pradeep Kulkarni, Krishan C. Saraswat, Stanford University, Dept of Electrical Engineering, Stanford, CA.

Statistical variations in electrical characteristics of polysilicon thin film transistors (poly-Si TFTs) result from random distribution of the grains in devices. The density and location of grain boundaries in the channel region strongly affect transistor’s electrical characteristics. Therefore, control of grain size and location in a poly-Si thin film is necessary for realizing uniform and scaled TFTs. Germanium seeding is an effective way to achieve such controllability. In this paper, we have studied solid phase crystallization (SPC) behavior of amorphous Si films with and without Ge seeding. Oxidized Si(100) wafers were used as substrates. Ge was deposited by LPCVD from GeH$_4$ at 550°C. 1000 Å films on 100 nm-thick amorphous Si films that were also deposited by LPCVD. Amorphous Si films without Ge layer (uncovered Si) were also prepared as control samples. Films were annealed at 550°C or 600°C for 30 min to 2 h to obtain several degrees of crystallization. TEM was used to determine crystallization behavior of Si films. SEM was also used, in which case, amorphous portion of a film was selected etched with a HF and HNO$_3$ based solution to observe crystal grains. Grain population is the same as measured on TEM. The incubation period specific to each annealing temperature. Incubation time for nucleation of Ge-covered Si was about twice as much as uncovered Si. On the other hand, nucleation rate was larger for Ge-covered Si than for uncovered Si. Activation energy for nucleation of Ge-covered Si (3.3 eV) was approximately the same as uncovered Si (3.3 eV). However, activation energy for nucleation was significantly lower for
Ge-covered Si (2.3eV) than for uncovered Si (2.5eV). We conclude that, to make LPCVD Ge an effective seed layer for spatially controlled crystallization of amorphous silicon, annealing should be started at relatively low temperature (for example, 500°C).

A9.6
THICKNESS-DEPENDENT MICRO-RAMAN MEASUREMENT OF POLY-SI FILMS PREPARED BY METAL-INDUCED CRYSTALLIZATION USING Ni LAYER. Shin-ichi Muramatsu, Yoshiaki Minagawa, Fumio Oka, Advanced Research Center, Hitachi Cable, Ltd., Inakawa, Yokohama, Kanagawa, Central Research Laboratory, Hitachi, Ltd., Tokyo, JAPAN.

This paper presents the thickness-dependent characteristic features of micro-Raman spectra from a cross section of polycrystalline silicon (poly-Si) films prepared by metal-induced-crystallization (MIC) of amorphous silicon (a-Si) films using a thin Ni layer. We found that a 1-nm-thick Ni layer gives the same crystalline volume fraction and the same crystalline volume fraction as a 12-nm-thick Ni layer at a lower annealing temperature as low as 550°C. A Ni layer thicker than 10 nm also gave the same result. For a solar cell application, relatively thick poly-Si film (~1000 nm) is preferable for light absorption. Using MIC is quite effective to prepare such a thick film, because it allows us to prepare a high-quality film at a high-deposition rate. However, to reduce the metal (Ni) contamination in poly-Si, Ni thickness should be kept at a minimum for complete crystallization. Thus, we examined the thickness dependence of the MIC feature by using Raman measurement. A 0.001-mm-thick a-Si film was evaporated on a glass substrate. Then, 1-nm or 10-nm Ni layer was evaporated on it. After that, samples were annealed in N2 ambient for 10 or 60 min. at 550°C. Micro-Raman spectra were measured at 1000-nm intervals on the cross-section of Si films from Ni/Si interface to glass substrate. Crystallized from the surface to 2000 nm in 10 min. and 4000 nm in 60 min. with the Ni layer of 1 nm and 10 nm. The polycrystalline volume fraction in the crystallized region were also the same for both samples. This means that a few monolayers are sufficient for MIC. These results suggest that the crystallization process can be used as a catalytic reaction. We will also present the crystalline size and orientation at the conference.

A9.7
EFFECT OF RAMP ANNEALING ON NI INDUCED LATERAL CRYSTALLIZATION OF AMORPHOUS SILICON. S. Shiven, M. C. Poon, M. Chiu, Dept. of Electrical and Electronic Engineering, Hong Kong University of Science & Technology, N. Kung, HONG KONG.

Nickel Metal-Induced-Lateral-Crystallization (MICL) has been used to enlarge the grain size and improve the quality of poly-silicon (poly-Si) Thin-Film Transistor (TFT). However, the MICL temperature is still high and the grain size is still small. We have studied the feasibility of forming very large grains (single crystal like) from amorphous silicon (a-Si) by combining MICL on a-Si with ramp annealing. 7000 Å of oxide was grown on substrate by wet oxidation at 1000°C. After 2-hour deposition of 10000 Å of a-Si at 550°C. A 30000 Å of LTO layer was then deposited at 425°C, and windows are patterned next to the desired region for crystallization. Thin nickel (Ni) was then deposited and MICL was carried out subsequently by ramp annealing at 650°C for 2 hours. We have found that the grain size after ramp annealing is remarkably enhanced and can reach the order of several tens of microns. The velocity of MICL with ramp annealing is faster than that of MICL with constant annealing. The grain size becomes maximum at 625°C/2hrs, and saturates at higher temperatures of 655-1000°C. We have also determined the effect of the MICL temperature and time and the other parameters to maximize the grain size and quality. MICL with ramp annealing at 625°C can greatly lower the process time and reduce the need of subsequent annealing to enhance the grain size. The new technology can have numerous novel applications such as providing a low-cost alternative to form silicon-on-insulator (SOI) substrates and a breakthrough in performance TFTs and novel multi-layer SOI like devices and circuits.

SESSION A10 POSTER SESSION
METASTABILITY AND EQUILIBRICATION
Chair: Peter A. Fedders
Tuesday Evening, April 25, 2000
8:00 PM
Salon 1-7 (Merritt)

A10.1
X-RAY PHOTOEMISSION SPECTROSCOPIC STUDY OF STRUCTURAL CHANGES IN AMORPHOUS SILICON. Sharan Sheng, Edward Safer and Arthur Yelen, Groupe de Recherche en Physique et Technologie des Couches Minces & Departement de Genie Physique et de Genie des Matériaux, Ecole Polytechnique de Montreal, Montreal, Quebec, CANADA.

It is now recognized that defect creation is not the only light-induced metastable change in a-Si:H: there is now considerable evidence for large light-induced metastable structural changes in a-Si:H in addition to changes in electronic properties. Recently, we reported a preliminary X-ray photoelectron spectroscopy (XPS) study of light- and X-ray-induced structural changes in a-Si:H [1]; we observed metastable, simultaneous, identical shifts in both Si2p and Si2p peaks to lower binding energies with light-soaking or X-ray irradiation time. In this contribution, we present detailed XPS investigations of light- and X-ray-induced structural changes in undoped a-Si:H, as well as pure n-Si and c-Si, and their annealing behavior. The shifts in both the 2s and 2p peaks of a-Si:H, with illumination or X-ray irradiation, were found to follow a stretched exponential (XPS) law for a threshold exposure time, and to nearly reach saturation after about one hour of exposure at the intensity used. In contrast to the XPS changes in electronic properties, these light- and X-ray-induced shift changes were found to be independent of the light source, and to be reduced by annealing, with a lower activation energy (0.6 eV) than that for the XPS (1.1 eV). The absence of metastable XPS changes in pure n-Si suggests that hydrogen is actively involved in the process. Furthermore, visible light produces XPS changes in a-Si:H in a more complicated way, and less efficiently, than X-rays. The shifts in the measured XPS lines, without any change in the line widths, require that the entire network structure change uniformly. In this sense, this effect may present a greater challenge to modeling than do the other observations of structural changes. These structural changes may be an independent phenomenon or a precursor process of the XPS. [1] S.R. Sheng, E. Safer, A. Yelen, H.M. Branz, and P. Muscat, Mat. Res. Symp. Proc. 557, 1999 (in press).

A10.2
METASTABLE DEFECT FORMATION AND ANNEALING INFLUENCE ON TWO-LEVEL HOPPING CURRENT FLUCTUATIONS IN MESOSCOPIC a-Si BASED STRUCTURES. N. Daria Seguin, Andrew Yakimov, Anatoliy Dyurenchitskii, Institute of Semiconductor Physics, Novosibirsk, RUSSIA.

Two-level hopping current fluctuations (random telegraph noise - RTN) have recently been investigated in mesoscopic structures based on small grain thin layers of c-Si. Amplitude of noise was 1% of 0.1-100% dependence on the feature size of device. Effective lifetimes in low-conductive (τ1) and high-conductive states (τ2) were observed to be independent of the sample sizes and conductivity, and fluctuate by up to 100% from one device to another. Two types of structures were obtained: the first type is characterized by > 70% fluctuation amplitude value, which was found to reduce with applied voltage. In the second one, the amplitude value is equal to 10% and didn't depend on voltage applied to the sample. Field and light assisted switching acceleration have been observed while the field affect τ1 rather than τ2. Light illumination reduces both lifetimes. Microscopic model involving the unit atomic transitions in hydrogen-related two-level systems (TLS) has been proposed to explain the observed RTN signal. Conductivity of this system was described by mesoscopic carrier transport via 1D chains of localized states. Hopping current switching were suggested to arise from leading chain rearrangement due to optical transport between localized and metastable TLS. Having appeared in the vicinity of the leading chain, a new localized state changes the resistance of main hop and transforms system to high-conductive state with the time τ2. Metastable defect formation is determined by weak bond breaking and not by hydrogen diffusion from SiH bond and its migration to a bond-on state. Initial low-conductive state is recovered through metastable defect annealing during τ2 and depends on hydrogen traps concentration. Voltage rise results in carriers redistribution between dangling bonds in different change states, with hydrogen traps concentration falling and τ2 dropping. We have found that the discrepancy between switching frequency change under light emission and estimated magnitude of photon flux on leading order of 3. The discrepancy is assumed to arise from the contribution of longer-range excitations within the hydrogen diffusion length. Voltage dependence of fluctuation amplitude was demonstrated to determine by whether the new localized states produces an additional hop through the leading chain or creates a new chain and thus depends on leading chain configuration.

A10.3

In many generation-recombination models describing the dark current-voltage (I-V) characteristics of a-Si:H p-i-n diodes, a spatially uniform distribution of defect states throughout the intrinsic part of
the junction is assumed. However, according to the defect pool model the density of states is usually higher near the interfaces than in the center of the intrinsic region, when the material is allowed to equilibrate during deposition.

In this work, the \( I - V \) characteristics of lateral p-i-n diodes are presented, which do have a spatially uniform defect distribution. These devices provide an excellent opportunity to study defect equilibration in different materials. Devices have been fabricated by deposition of an n-layer on an insulating substrate, lithographic patterning, and room temperature ion implantation of boron and phosphorus for the p- and n-regions, respectively.

The forward \( I - V \) characteristics of these devices show a clear dependence of the ideality factor on the width of the intrinsic region, \( W \). When \( W \) is varied, the internal electric field changes and hence the recombination in this width that increases the diode's lifetime. These diodes the recombination takes place throughout the bulk of the intrinsic region rather than near the p-i interface. Obviously, the spatial defect distribution in the intrinsic layer is uniform and has not equilibrated during sample fabrication. In conventional lateral p-i-n diodes, recombination occurs near the interfaces only. In these regions the band bending is significant, by which the electric field does not depend on \( W \).

After annealing for 15 min. at 240°C, the dependence of the \( I - V \) characteristics on \( W \) has almost disappeared, implying that the recombination occurs near the p-i interface. During the annealing treatment, the density of states equilibrates in the intrinsic region and a situation similar to conventional layered p-i-n diodes is obtained. The obtained results are supported by numerical simulations.

A 10.4 MODEL FOR STABILIZER-WRONSKI DEGRADATION DEDUCED FROM LONG-TERM, CONTROLLED LIGHT-SOAKING EXPERIMENTS. Bodo van Roodeen, Joseph A. del Cuelo, National Renewable Energy Laboratory, Golden, CO.

We carried out controlled light-soaking experiments simulating outdoor operating-temperature conditions (about 5 to 60°C device temperature of amorphous silicon (a-Si) photovoltaic (PV) modules. After consecutive degradation cycles, the stabilized performance declined as the modules were exposed to light at lower and lower temperatures. Depending on the conditions used and the prior exposure history, this additional degradation may be almost completely recoverable, partially recoverable, or almost non-recoverable - there is as much additional degradation with 0-times intensity and 5°C conditions, as previously observed for L-i (laser) intensity and 25°C exposure. At a certain temperature and light dose, no recovery occurred when the modules were returned to L-i intensity and 25°C conditions. Earlier, we had observed that modules stabilized under L-i, 50°C indoor exposure conditions degraded in an additional 15% when exposed outdoors, which was not recovered by returning to the previous indoor conditions at 50°C. We suggest that the PV parameters are much more sensitive than film properties (e.g., photoconductivity) to changes in light-soak exposure temperature (in the 5 to 60°C range) or to prior exposure history. However, history-dependent (hysteresis) effects and more easily recoverable photoconductivity degradation mechanisms are well documented after light-soaking at very low temperature [1], suggesting that degradation and stabilization are caused by thermal annealing (i.e., high time constant of an annealing mechanism). We will quantitatively analyze how multiple degradation mechanisms with different time constants and annealing activation energies lead to a given stabilization level depending on the operating condition history.

The convergent is helpful to predict at which level a module will stabilize for a given exposure history, and how much recovery can be expected with increases in module operating temperature. This will allow us to better predict how a-Si PV modules will perform in different climatic environments.

A 11.1 UPS of a-Si:H/Er: PREPARED BY PECVD Cinthia Pinzonete, Leandro R. Tesaker, IFGW, UNICAMP, Campinas, BRAZIL, Helo dc Barrios, LNLNS, Campinas, BRAZIL. Herlind Weiser, Marburg University, Marburg, GERMANY. E. Terukov, Ioffe Institute, St. PETERSBURG, RUSSIA.

Evaporated a-Si:H is a material with potential applications in photonics due to the intra-4f level transition of Er\(^{3+}\) at 1.5\(\mu\)m. This transition is electric dipole forbidden in the free ion and requires a non-centrosymmetric environment to be partially permitted. It is well known that in sputtered a-Si:H, Er\(^{3+}\) is surrounded by an oxygen-first coordination shell. To obtain material with better electronic properties and high luminescence efficiency, we have prepared evaporated a-Si:H by PECVD using Er\(^{3+}\) as a metallic precursor. In this molecule, Er is surrounded by a very distorted oxygen octahedron, which is expected to induce dipole moments by large electric field gradients. Such a-Si:H:Er\(^{3+}\) samples show intense 1.5\(\mu\)m photoluminescence in addition to intrinsic luminescence which is absent in sputtered samples. In this work we present the results of a study of the chemical environment of Er in Er(TMHD)\(_3\) and in the PECVD a-Si:H:Er\(^{3+}\) samples. Extended X-ray Absorption Fine Structure (EXAFS) measurements of the Er L\(_{2,3}\) edge were undertaken in powder Er(TMHD)\(_3\) and a thin film of PECVD a-Si:H:Er\(^{3+}\), and compared to an Er\(^{3+}\) reference.

We observed that: 1) In Er(TMHD)\(_3\), Er is coordinated to oxygen atoms, as expected. We find an average Debye-Waller \(\sigma^2\) factor and average interatomic distance \(r = 2.28 \pm 0.01\AA\), compared with 2.26\(\AA\) in the Er\(^{3+}\) reference. The negative \(\sigma^2\) is probably due to the occurrence of different Er sites in Er(TMHD)\(_3\). In the co-deposited a-Si:H:Er\(^{3+}\) sample Er is also coordinated to oxygen with average coordination \(N = 7.2 \pm 1\) and interatomic separation \(r = 2.27 \pm 0.01\AA\) and \(\sigma^2 = 0.009 \pm 0.001\AA^2\), indicating a disordered Er\(_{2}\)O\(_5\) like environment. Annealing at 400°C in vacuum leaves the Er\(_{2}\)O\(_5\) environment essentially undisturbed within experimental error: \(N = 5.7 \pm 1\), \(r = 2.28 \pm 0.01\AA\) and \(\sigma^2 = 0.008 \pm 0.001\AA^2\). For annealing temperatures above 600°C, \(r\) and \(\sigma^2\) decrease. The coordination is always 6 within experimental error. The results indicate that the Er environment of Er(TMHD)\(_3\) becomes Er\(_{2}\)O\(_5\)-like during the deposition. Annealing at moderate temperatures does not affect the Er environment. Higher annealing temperatures relax the disorder around the Er atoms, and decrease the size of the oxygen cage that surrounds the Er in the Er environment in PECVD a-Si:H, Er(TMHD)\(_3\) is very similar to that of Er\(_{2}\)O\(_5\). The co-deposited first coordination shell has a relatively low free energy and evolves very little upon annealing. The luminescence efficiency is probably due to a better host quality (lower density of states in the gap) compared to sputtered a-Si:H:Er\(^{3+}\) rather than the incorporation of Er in more distorted lattice sites due to the metallographic precursor.

We report on the very strong Eu⁺⁺⁺ luminescence at 1.54 μm and in the visible region at room temperature for amorphous Si:O:H films and their dependencies on annealing treatments. The films are prepared by [DC+HF] magnetron sputtering of Si targets with additional pellets of metallic Er. As grown sample is characterized in structure and luminescence properties, and then is subjected to a careful cumulative anneal programme. After each anneal step the samples are cooled down to room and characterized for the luminescence at 77 K and 300 K and then subjected to a subsequent anneal at 350°C higher temperature. Among others, the optimal annealing temperature was 350°C, at which the highest luminescence intensities and at 1.54 μm and at 0.7-1.0 μm region are obtained. The structure of the films, as revealed by high resolution transmission electron microscopy, remains remarkably stable during annealing, and consists in small Si crystallites (about 30-40 nm in diameter) embedded in an amorphous matrix, identified as α-Si by Raman scattering. Already prepared, the films exhibit pronounced luminescence at 1.54 μm at room temperature. Annealing enhances the PL intensity by 100 at 1.54 μm and 20 times in the range of 0.7-1.0 μm. Moreover, annealing temperatures beyond 150°C cause very marked Stark splitting of the 1.54 μm peak at 77K. Above 250°C, the intensity decreases, however, the structure of this characteristic peak smears and practically it is difficult to resolve the fine picture. After 350°C anneal the PL peak at 1.54 μm is highly broadened and substantially increased in intensity. Since the above effect is observed on the nm scale (HRTEM) and local atomic order (Raman) do not change with temperature we shall interpret these prominent changes of the PL spectra with changes brought about in the atomic vicinity of the Eu⁺⁺⁺ ions during hydrogen oxidation.

A11.4 PHOTOELECTRICAL AND PHOTODETECTION OF Eu⁺⁺⁺ IN Si:SiO₂ NANO-STRUCTURE FILMS. Hui Wei Liu, Anit M.J. Makoff, G. Nery, Luis F. Fonseca, *Z. Wang, C. Pena, *Department of Physics, University of Puerto Rico, Mayaguez, PR. *Department of Physics, University of Puerto Rico, Rio Piedras, PR.

Eu⁺⁺⁺-doped Si:SiO₂ nanocomposites were successfully prepared by electrochemical etching of c-Si surfaces. The optical properties were studied using time-resolved laser spectroscopy. Excited by intense picosecond laser pulses with the energy greater than 100 mJ/cm² and wavelength at 532nm the observed photoluminescence consists of a rapidly decaying component with the life time of ~1 microsecond and a slowly component with the life time of ~2 ms. The former was recognized as a typical Si/SiO₂ interface recombination emission and the latter as coming from the impurity Eu⁺⁺⁺ ions. With the intense laser excitation a two-photon absorption by silicon matrix occurred, resulting in charge carriers produced in conduction band. A direct recombinations gives a weak but fast emission from Si/SiO₂ nanostructure host, creating a large number of nonequilibrium phonon. For Eu⁺⁺⁺ emission a set of T₂ → F multiplet transitions were identified. In addition to the direct excitation by 532nm the excited state T₂ of Eu⁺⁺⁺ ions was also found to be populated by excitation transition from silicon matrix. The mechanism of the phonon-assisted excitation transfer is discussed.

SESSION A12 POSTER SESSION: AMORPHOUS SILICON DETECTORS AND OTHER DEVICES

Chairs: Manuel Vieira and Reinhard Schwarz
Tuesday Evening, April 25, 2000
8:00 PM
Salon 1-7 (Merriott)

A12.1 CORRELATION BETWEEN SURFACE INTERFACE STATES AND THE PERFORMANCES OF MIS STRUCTURES. Hugo Agost, Elvira Lanzano, Isabel Ferrera, Francisco Giulini, Rodrigo Martinez, Materials Science Department, CENMAT, Faculty of Sciences and Technology, New University of Lisbon, Quinta da Torre, Caparica, PORTUGAL.

Recently hydrogenated amorphous silicon (α-Si:H) has been used in a wide variety of technological applications such as solar cells, image sensors, position sensors and thin film transistors. In all of these applications surface and interface states play an important role in determining the final performances of the devices. In the particular case of a metal-insulator-semiconductor (MIS) structure the incorporation of a thin oxide layer drastically modify the electrical properties of such interfaces. In order to understand the kinetics of formation of interface surface states and its correlation on the final device performances, a detailed study was performed on MIS structures, before and after surface oxidation, using different oxidation techniques and oxides: thermal (in air), chemical (in hydrogen peroxide) and physical (by SiO₂ sputtering).

The devices used in this work are based on a glass/Co-f/α-Si:H(i)/SiO₂/Pd structures, where the amorphous silicon was deposited by conventional plasma enhanced chemical vapour deposition (PECVD) system. The electrical properties of the α-Si:H MIS structures were investigated by measuring their diode current-voltage characteristics as a function of temperature and the way how oxygen was incorporated by means of infra-red spectroscopy. The surface/interface states distribution was measured through the ellipsometric analysis (using a spectroscopic ellipsometer) of the variation of the optical constants, before and after oxidation.

A12.2 ITO/α-SiNₓ/α-Si:H PHOTODETECTOR WITH ENHANCED PHOTOCURRENT AND REDUCED LEAKAGE CURRENT BASED ON POLYCRYSTALLINE ITO DEPOSITED AT ROOM TEMPERATURE. Q. Ma, A. N. R. Wang, University of Waterloo, Dept of Electrical and Computer Eng, Waterloo, Ontario, CANADA.

We report a MIS photodiode structure using indium tin oxide/silicon nitride/hydrogenated amorphous silicon (ITO/α-SiNₓ/α-Si:H) based on room temperature deposition of optically transparent polycrystalline ITO for applications in large area optical and X-ray imaging. The photodiode exhibits device characteristics with dramatically enhanced photocurrent and reduced leakage current giving rise to a hundred-fold improvement in dynamic range. This notable improvement in performance stems from reduced oxygen contents originating from the ITO (due to the PECVD deposition temperature of the ITO), and the increased barrier height and reduced surface recombination at the ITO/α-Si:H interface due to presence of the α-Si:H layer. As a result, the leakage current stemming from the thermionic emission and diffusion is reduced. In this work, the deposition gas ratio of N₂/SiH₄ for the barrier layer was chosen to be 20 to yield a N-rich film, characterized by a low defect density and high band gap energy. When the thickness of α-SiNₓ is increased from 0.5 to 200Å the leakage current decreases by a factor of 5 from 60 pA to 12 pA for a 300x300 µm² detector with 0.5µm thickness α-Si:H. Correspondingly, the photocurrent is increased by a factor of 50 and the dynamic range (Iph/Ileak) from 10 to 1000.

A12.3 NONLINEAR OPTICAL GAIN IN BULK BARRIER AMORPHOUS-SILICON PHOTOTRANSFORMER. D. Caprara, G. de Cerati, A. Novotti and F. Palma, Dept. of Electronic Engineering, University of Rome "La Sapienza", Rome, ITALY

In this work we present a study of the dependence of the optical gain of the bulk barrier amorphous silicon phototransistor with the incident light intensity. Phototransistors provide an output signal current which is greater than the photogenerated current making them suitable for low intensity radiation detection. Conventional devices do not have a wide dynamic range of operation, showing saturation of the output signal under bright illumination. Our work is focused on the possibility to manufacture an image with a large dynamic range based on the amorphous silicon α-Si:H, bulk barrier phototransistor. Operation of this two terminal device relies on the modulation of the potential barrier existing in correspondence of the low doped p-type base. Under illumination, carriers photogenerated in the intrinsic layer (primarily photoconductive) induce the formation of the potential barrier leading to an increase of the total current (secondary photocurrent) giving rise to the amplification mechanism of this device. Simulations, performed using an analytical model which describes the behavior of the amorphous silicon phototransistor both in dark conditions and under illumination, show that the gain increases with increasing light intensity. The self-adaptive-gain features allow to emphasize low intensity signal and to properly detect high intensity signals. Experiments performed on samples prepared by glow discharge with 75Angstrom thick 4p layer and B⁺/H⁺ = 0.1 equal to 5x10⁻⁷. First measurements performed at 5V bias voltage under white light illumination are in agreement with model results showing a 200% increase of the gain for incident radiation varying of one order of magnitude.

A12.4 AMORPHOUS SILICON/AMORPHOUS SILICON GERMANIUM NEAR IR PHOTODETECTOR. Yen-Ling Cheng, National Chung Hsing Univ, Dept of Electrical Engineering, Taichung, TAIWAN, REPUBLIC OF CHINA; Tsong-Yi Yew, National Tsing Hua Univ, Hsin-Chu, Taiwan, REPUBLIC OF CHINA.

The α-Si/H:SiGe:H NIPN photodiodes are fabricated to block visible light and detect near infrared light. The first 1 layer is the absorption region of the short wavelength portion. All layers above layer 1 are the absorption region of the long wavelength one. The visible
light response is suppressed and the infrared light is detected when the first NIP and the second PIN diodes are under forward bias and reverse bias, respectively. The photoresponse of different regions of their device structure with the first I layer (1.42 eV and 2000 A) and the second I layer (1.42 eV and 4000 A) at the bias of 0.05 V is about 500. The photo current under the reverse bias larger than 0.5 V is over 1 A, and its mechanical stress is released. Photothermal. The peak response of the device width was 790 nm. It could be used for the near infrared light detection

A125 COLOUR CHARACTERISATION OF \( \alpha \)-Si:H-BASED THREE-TERMINAL THREE-COLOUR DETECTORS. János Kec, Marko Topic, Franči Smole, Faculty of Electrical Engineering, University of Ljubljana, SLOVENIA

Hydrogenated amorphous silicon (\( \alpha \)-Si:H) based colour detectors and arrays may in future have a potential to compete with standard CFA (Colour Filter Array) based image arrays for low-cost optical recognition. Their multi-terminal structure of vertically stacked PIN photodiodes with appropriate spectral responses - determined by optical gaps and layer thicknesses - enable filter-free colour detection omitting Moiré effect, which is found to be a relevant drawback of CFAs. The \( \alpha \)-Si:H-based detector's spectral responses for three fundamental colour spectra - Red, Green and Blue (RGB) - can be quite well matched with three characteristic responses of standard human eye, but to achieve an exact colour recognition and qualification, a specific transformation from the detector to standard colour space is required. Therefore, we performed colour characterisation of three-terminal three-colour detectors in a separate test structures/TCS/TCO/PIN/Si layers/assembly with either smooth or rough TCO layer. The transformation from the detector to standard colour space was defined with polynomial functions of different order, using MunSELL (64 chips) and D秾ONT (16 chips) as test colour sets. The metameric errors for the detectors with smooth and rough TCO layer, obtained with both test sets will be presented and their deviations discussed. The trade-off between polynomial order and errors will be estimated. Furthermore, the errors will be compared with standard CFAs and three multi-terminal devices. Finally, an optimisation criteria - based on minimal metameric errors - for three fundamental spectral responses of detectors will be discussed.

A126 TEMPERATURE INDUCED STRESS EFFECTS ON A FLEXIBLE POSITION SENSOR. F. Giuliani, E. Fortunato, I. Ferreira, R. Martins, Material Science Department, CENMAT, Faculty of Science and Technology of the New University of Lisbon, Caparica, PORTUGAL

We have developed a working large area flexible \( \alpha \)-Si:H position sensor\(^1\) for angular position detection. The effects of mechanical stress due to the different thermal expansion coefficient of the substrate and the sensor itself have been studied. In fact, the chosen flexible substrate (Kapton - polyamide foil) has a thermal expansion 4 times greater than corning glass and about 7 times greater than \( \alpha \)-Si:H. So, when the sensor is extracted from the deposition chamber, it cools down to ambient temperature and becomes strained. If the sample is heated up again its internal stress is released. Photothermal Deflection Spectroscopy and Constant Photocurrent Method [when applicable] have been employed to estimate the variation in the density of states (DOS) inside of the gap between the single layers and the whole structure.


A127 LARGE AREA FLEXIBLE THIN FILM POSITION SENSITIVE DETECTORS. Elvira Fortunato, Isabel Ferreira, Francesco Giuliani, Rodrigo Martins, Materials Science Department, CENMAT, Faculty of Science and Technology, New University of Lisbon, Caparica, PORTUGAL

In this paper we present the electro-optical performances of one dimensional (1D) \( \alpha \)-Si:H thin film position detector deposited on polymeric substrates (Kapton - polyamide foil) with 2 cm long and 0.5 cm wide. It is also demonstrated that when improved interfaces are produced the back metal contact does not need to cover the entire back area of the sensor to produce the required reference equipotential. The technical and theoretical concepts of large area thin film position sensitive detectors based on the amorphous silicon technology was introduced some years ago. Of most interest in the research done was the development of the devices deposited on rigid substrates, such as glass. Nevertheless, in applications where the device is mounted on a rotating axis of a motor or determines position of the angular position of a motor is required, it should be of great importance to have a curved sensor with a cylindrical shape. To do so, it is important to have the sensing element deposited on a flexible substrate with the required position accuracy and reliability, besides having a high enough response frequency.


A128 EFFECTS OF BURIED INSULATOR-SENSOR INTERFACE ON THE LATERAL CONDUCTION OF HIGH FILL FACTOR \( \alpha \)-Si:H IMAGERS. M. Melano, P. Lammi, S.E. Bendy, J.P. La, R.A. Street, J. H. Lee and J.B. Boyce, Xerox Palo Alto Research Center, Palo Alto, CA.

The new high fill factor design for two-dimensional amorphous silicon (\( \alpha \)-Si:H) image arrays is an intrinsic requirement for the achievement of higher sensitivity and resolution for X-ray medical applications, like mammography and also CMOS sensors. The increased performance is achieved by depositing a continuous amorphous silicon imager layer over the surface of the imager, but it is important to minimize lateral image spreading. A buried dielectric is used to insulate the TFT addressing electronics from the sensors. This introduces a parasitic capacitance, which can be reduced by using a thick insulator with a low dielectric constant. We have explored thick dielectric layers and compared the lateral conduction at the interface with \( \alpha \)-Si:H with the previous silicon-oxynitride (SiON) layers. Arrays with pixel size of 75 \( \mu \)m were used, as well as separate test structures. Polymer- and polyimide-based insulators (PBR) allow thickness up to 5 \( \mu \)m, and epoxy-based photoresists allow thickness of 50 \( \mu \)m. Experimentally, the case of PBR, image blooming - as determined from line spread function measurements - starts at low illumination intensities, and increases as a function of illumination. In the case of SiON, blooming is significantly lower since pixel saturation, being one order of magnitude lower than the PBR case. The blooming is correlated to a lateral leakage current between crossing pixels, which takes place at the interface of the insulator material and the intrinsic \( \alpha \)-Si:H. When PBR is copped with SiON, the array characteristics lie between the previous cases. Analysis of the lateral leakage current as a function of temperature gives nearly the same activation energy of 0.5 eV for the cases of PBR and SiON, which suggests that the conduction mechanism might be the same in both kinds of interfaces. The results are interpreted in terms of band bending at the interface.

A129 \( \alpha \)-Si:H THIN FILM DIODE FOR DIGITAL RADIOGRAPHY. I. A. Popov, G. Van Dooscheh, A. Van Caster, H. De Smet, J. De Brue, ELIS-TFCG/MIEC, Univ. Ghent, Ghent, BELGIUM, F. Callens, E. Bossuain, CCSI, Univ. Ghent, Ghent, BELGIUM

Recent developments in the area of cost effective 2D direct X-ray sensors are making the use of high speed high density photodiodes and no switching devices per pixel are presented. Discussion focuses on two major aspects: (i) X-ray sensitivity of the sensor itself; (ii) the overall performance of the sensor array. Comparison with the AM plus sensor approach is given.

A1210 PHASE TRANSITION IN Cr/\( \alpha \)-Si:H/V/THIN FILM DEVICES. Jian Hu, James Hajo, Nagler University, School of Engineering, Edinburgh, UNITED KINGDOM; Tony Smell, Univ of Edinburgh, Dept of Electrical Engineering, Edinburgh, UNITED KINGDOM; Mervyn Rose, Univ of Dundee, Dept of Applied Physics and Electronics & Manufacturing Engineering, Dundee, UNITED KINGDOM.

Experimental results on the electronic properties of conditioned Cr/\( \alpha \)-Si:H/Na thin film devices are presented. The devices were electrostatically charged, had resistances in the range from several hundred k\( \Omega \)s to several kilo\( \Omega \)s. Further ‘conditioning’ was carried out at room temperature by biasing the device using either a dc voltage (\( \leq 10 \) V) or a voltage ramp (10 \( \sim \) 20 V, 0.5 \( \sim \) 1 V/sec, 50 \( \sim \) 200 V/\( \mu \)s). During this conditioning, the device initially increased linearly with the bias until the voltage reached a critical value where the current fell by several orders of magnitude. After the conditioning treatment, the electrical properties of the conditioned device had changed. At low bias, the current varied non-linearly with the bias, but exhibited a ‘jump’ at a threshold voltage (\( V_{th} \) typically 2 – 3\( V \)), leading to a resistance change of 1 – 2 orders of magnitude. Above \( V_{th} \) the current increased almost linearly with a change in current transport from an insulating or semiconducting regime into a more conducting (metallic) state. This was confirmed by a characteristic of the conditioned devices, which showed a transition from a capacitative to an inductive behaviour at \( V_{th} \). In addition, the current-voltage characteristic of conditioned devices, measured under
constant current conditions, exhibited a distinct negative resistance region at $V_{th}$, suggesting that the transition at $V_{th}$ involved the creation of conducting filaments (n) in which the current density differed from that of surrounding material. It was noted that the threshold voltage for the current jumps decreased with increasing temperature and eventually disappeared at $\sim 340$K, but recovered on resuming normal operation. We suggest that the observed transition at $V_{th}$ could involve vanadium oxides such as VO$_2$, which experiences a phase transition at 340K. It has previously been shown that during the initial forming process some of the top metal is incorporated into the amorphous silicon, presumably by a process of diffusion and/or electromigration [1], while oxygen is also present in the ambient atmosphere, resulting in thermodynamically favourable conditions for VO$_2$ formation. It was also generally observed that at the transition the neutral conducting states $G_{2}$, $G_{3}$ and $G_{4}$, where $i = 1, 2, \ldots n$ as reported previously [2]. It is possible that nano-size filament(s) are created as a result of the field-induced conditioning, in which ballistic transport of electrons could occur. References [1] J. Hajto, A.E. Owen, A.J. Snell, P.G. LeComber and M.J. Rose. Chap. 14, pp 641-701 in Amorphous and Microcrystalline Semiconductor Devices, Ed: J. Kanicki, Artech House, 1992 [2] J.J. Hajto, A.E. Owen, S.M. Gage, A.J. Snell, P.G. LeComber, and M.J. Rose, Phys. Rev. Lett. 66, 1118 (1991).

A12.1.1 THE EMERGENCE OF AN AMORPHOUS SILICON-BASED PHOTONIC TECHNOLOGY OPTICAL MEMORIES TO 3-D PHOTONIC CRYSTALS. C.M. Fortmann, Tokyo Inst. Tech., Dept. Innovative and Engineering Materials, Yokohama, JAPAN; N. Hata, Electrotechnical Laboratory, Tsukuba, JAPAN.

The ability of amorphous silicon to absorb large quantities of impurities combined with its tunable optical parameters make it an ideal base for a new generation of photonic materials. Fortmann and co-workers [1] described how the refractive index of amorphous silicon could be varied by over 50% in some cases by changing the hydrogen content and how in-situ patterning of the amorphous silicon hydrogen content can be used to define photonic devices. Photonic devices include 3-D photonic crystals with features scaled to interact with visible light. Increasing the optical band gap depends on a subset of the total hydrogen content which is bonded into Si-H$_2$ sites [2]. More recently Hata et al. [3] described reversible, light induced gap changes observed at amorphous silicon/glass interfaces. By taking advantage of this effect, for example, a write-read optical memory can be proposed. The memory state (of an unaltered sample) is changed by short wavelength laser light impinging on the device. Local heating to $\sim 200$ C is used for erasing. The amplitude ratio and phase difference of reflected p- and s-polarized light provides the differentiation needed to define an on and an off state. The above optical gap changes were also consistent with at least some degree of structural rearrangement.


A12.1.2 HETERJUNCTIONS BETWEEN SEMICONDUCTORS WITH AMORPHOUS PHASE INTERFACES. Yu Vygruzenko, A. Fantoni, M. Fernandez and M. Viera, Electronics and Communications Dept., ISCTE, Lisbon, PORTUGAL; N. Carvalho, G. Loureiro, CPM, Lisbon; R. Schwartz, ISCTE and IST, Lisbon, PORTUGAL.

Heterojunctions with a TCO/α-Si:H/μc-Si:H/$n$-Si/metal configuration were obtained by depositing $p$-type hydrogenated amorphous silicon on $n$-type single crystalline silicon substrate. To improve the conversion efficiency an intrinsic thin amorphous layer with different thicknesses ($70\AA$ to $500\AA$) has been inserted between the substrate and the amorphous layer. Details concerning material and device characterization, structure and geometry optimization are presented and correlated. Junction properties, carrier transport and photogeneration are investigated from dark and illuminated current-voltage and photoresponse characteristics. The collection efficiency is evaluated from spectral response measurements under different applied bias voltages (+1 V to -1 V). Both open circuit voltage and fill factor were improved with the increase of the intrinsic amorphous layer thickness, however, the short circuit current presents a decrease as the thickness of the undoped $n$-Si layer increases. For a 120 $\AA$-thick $n$-Si layer a maximum in the fill factor is obtained. The insertion of the undoped $n$-Si layer improves the collection efficiency in the blue range while the interfacial region and depletion width of the substrate are active for the longest wavelengths. The heterojunctions were compared with entirely microcrystalline $p$-$n$-Si solar cells. Additionally, numerical solar cells modeling based on the band discontinuities near the interfaces and for grain boundary compliments the study and gives insight into the internal physical process. Considerations about the drift-diffusion and the generation-recombination are used to explain the correlation between the basic device output (short circuit current, open circuit voltage, fill factor, efficiency), the $L$ layer characteristics (structure, thickness), the incident radiation intensity and photon energy.

A13.1 RECOMBINATION AND RESISTIVE LOSSES IN AMORPHOUS SILICON/CRYSTALLINE SILICON HETEROJUNCTION SOLAR CELLS. Nik Jensen, Uwe Rau, and Juergen H. Werner, University of Stuttgart, Institute fuer Physikalische Elektronik, Stuttgart, GERMANY.

Production of crystalline silicon ($c$-Si) solar cells requires usually several high temperature processing steps. The low-temperature formation of the $c$-Si crystalline grains between amorphous and crystalline silicon promises a cost saving alternative. In our group, cell efficiencies of 12.5% are reached using $p$-type single $c$-Si as a base material and $n$-type hydrogenated amorphous silicon ($n$-Si:H) emitter. These results are due to high efficiencies for structural features such as back surface fields and surface texturing. This contribution systematically investigates the electronic properties of $n$-Si:H/$p$-Si solar cells and explains the limitation of open circuit voltage, short circuit current density, and fill factor. Our device analysis is based on measurements of internal quantum efficiency and temperature dependent IV measurements. On the one hand, this model reveals carrier recombination within the crystalline silicon base material to be responsible for the limitation of the open circuit voltage. On the other hand, the short circuit current is bound by collection limiting and, in addition, by absorption in the electrically inactive $n$-Si:H emitter. Resistive losses affecting the fill factor originate from the transport of minority carriers across the interface. The IV-curves measured across the heterojunction reveal a Seidel behavior. This interesting phenomenon is the result of carrier transport, which is hindered by the band offset between $n$-Si:H and the crystalline absorber. We propose a new analytical model which describes this anomalous conduction band discontinuity of $500$V-$550$V for $p$-type $n$-Si:H/$n$-type $c$-Si.

A13.2 INVESTIGATION OF CRYSTALLINE SILICON SURFACE TREATMENTS IN AMORPHOUS/S/CRYSTALLINE SILICON HETEROJUNCTION VIA CAPACITANCE MEASUREMENTS. M. Tucci, D. Ramasamy, F. Rocca, ENEA Research Centre, Portici, ITALY; D. Caputo, F. Palmita, Department of Electronic Engineering University of Rome "La Sapienza", Roma, ITALY.

In this work we investigate amorphous-crystalline silicon interface that play the key role in the heterostructure solar cell application. Our devices are based on p-doped textured wafer of $<100>$ oriented crystalline silicon on which ndoped films of hydrogenated amorphous silicon are deposited by Plasma Enhanced Chemical Vapour Deposition after plasma treatment of the crystalline surface. These treatments are able to easily create a surface having features that greatly influenced the electrical properties of the device. In particular we present a systematic study on the effect of hydrogen and CF$_{x}$/O$_{2}$ plasma dry treatment on the properties of the heterojunction. We used low temperature ($290$K-$300$K) capacitance measurement performed in different bias conditions and in a wide range of frequency of signal probe (1mHz-1MHz). The value of capacitance against the temperature depends on the depletion edge in the device, and, consequently, on the trapping/detrapping at the time-scale of the measurements. Differences in the capacitance profile between samples with various plasma dry treatments indicate different defect density profile at interface. With the aid of a finite difference model of the capacitance as a function of the defect density and the frequency, we extract information from the measurements about the defect energy distribution at interface. As a result, the density and the nature of defects at interface will be correlated to the technological parameters as: wafer doping level, hydrogen plasma treatment, type and concentration of dopants in the buffer layer.
A13.4
AMORPHOUS CRYSTALLINE SILICON HETEROJUNCTION WITH SILICON NITRIDE BUFFER LAYER. G. Claudio, R. De Rosa, E. Rocca, M. Tucci, ENEA Research Center Località, Granaiello Portici, ITALY.

Hydrogenated amorphous silicon grown by plasma enhanced chemical vapour deposition is currently used for a large class of photovoltaic applications, in particular for heterojunctions with crystalline silicon. One of the problems involved with these structures is the high recombination rates observed at the amorphous-crystalline interface that significantly degrades the characteristics of the device. The introduction of a thin buffer layer of intrinsic amorphous silicon between the doped materials reduces the recombination of carriers at the interface level, giving an appreciable improvement to the photovoltaic conversion efficiency. In this work we study the possibility to use amorphous silicon nitride, grown by plasma, as an alternative way to realise the buffer layer of a Si/i-Si heterojunction. We experimentally observed several growing conditions for silicon nitride depending on deposition parameters obtaining samples highly transparent and with optical gap varying in the range 2.4 - 5.2 eV. We found evidence that the growth of the amorphous region is controlled by quantum yield measurements. Dark current voltage characteristic of these devices indicates a decrease of reverse current, confirming a lower recombination rate at interface respect to standard p-n heterojunction. Also capacitance measurements are performed to evaluate the trapping kinetics at the heterojunction.

A13.5
MEASUREMENT OF IMPURITY PROFILES IN MICROCRYSTALLINE SILICON SOLAR CELLS BY SIMS. Arup Dasgupta*, Uwe Zastrow, Andreas Lambertz, Oliver Vetters, Friederike Finger, Wolfhard Bayer, Institut fuer Schicht- und Ionentechnik, Forschungszentrum Juelpisch GmbH, GERMANY.

Permanent Address: Energy Research Unit, Indian Association for the Cultivation of Science, Calcutta, INDIA.

To investigate the influence of impurity contamination on the performance of microcrystalline silicon (μc-Si:H) solar cells prepared by PECVD we have measured the concentration profiles of B, P, Zn, Al, O and C in the active intrinsic (μc-Si:H) layer and across the various interfaces in n and p structures with secondary ion mass spectrometry (SIMS). In particular, the interface in the intrinsic layer are e.g. etching and consequent re-deposition of dopant atoms during the μc-Si:H layer deposition under high hydrogen dilution or migration or diffusion of impurities along grain boundaries or through the bulk materials on ZnO(A:Al) covered glass or Si wafer. The deposition temperature was 200°C. For the TCO/μc-p/μc-μc-s sequences, an apparent B profile extends over several hundred nanometers into the μc-layer. Oxygen and carbon concentrations are also apparent in the boron profiles. In addition, high levels of Zn and Al can be found in some cases. These B profiles are not affected by annealing at the deposition temperature for 15 h. Therefore a diffusion or migration process is ruled out. These findings are characteristic of the presence of pin holes in the material such that the SIMS probe is able to look directly to the μc-layer and in some cases down to the substrate. If instead the SIMS profile is measured away from the μc-layer like at μc-p/μc or μc-p/μc-s interfaces, such pin hole effects can be excluded. Indeed the boron profiles at the μc-p/μc-s interface is sharp and extends only a few tenths of nanometers. But for μc-p on μc the B-profile still extends about 150 nm into the μc-layer. Surprisingly though, it seems not to effect the solar cell efficiencies. It will be discussed in more detail for these B profiles an indication for etching and re-deposition during the μc-Si:H layer deposition.

A13.6
MICROSTRUCTURES OF MICROCRYSTALLINE SILICON SOLAR CELLS PREPARED BY VERY HIGH FREQUENCY GLOW DISCHARGE. J. Dalal, E. Vallés-Sauvin, J. Meier, S. Dalal, L. Petkevič, E. Kroll and A. Shah, Institut de Microtechnique (IMT), Université de Neuchâtel, Neuchâtel, SWITZERLAND.

A series of undoped microcrystalline hydrogenated silicon samples was deposited on glass substrates, at various silicon concentrations in the plasma phase, and studied by Transmission Electron Microscope (TEM) [1]. This TEM investigations gave a variety of microstructures resulting from the sole variation of the dilution parameter (ratio of silicon flow to total gas flow of the hydrogen/silane mixture) in the deposition process. The series of samples reveal an evolution of the microstructure from small silicon nanocrystals embedded in an amorphous matrix to columnar grains [> 750 μm].

The question raised by these observations is to what extent a certain microstructure is better than another w.r.t. the performance of the corresponding microcrystalline silicon solar cells. For μc-Si:H solar cells, where transport takes place parallel to the growth direction. It is assumed that columnar grains should be appropriate because of the reduced number of grain boundaries across the electronic transport path. As it is currently becoming clear that the film microstructure is critically substrate-dependent, the authors will address this question on actual solar cell devices fabricated at IMT Neuchâtel [2]. The goal of this study is, thus, to identify the microstructure of inherently μc-Si:H devices and to correlate the structural results with solar cell performance. A comparison of the microstructure of inherently μc-Si:H cells with the microstructure found on the film series deposited on glass will be presented and discussed as well. [1] E. Vallés-Sauvin et al., to be publ. in J. Non-Cryst. Solids (ICAMS 18, 1999). [2] J. Meier et al., to be publ. in Solar Energy Mat. and Solr cells (PVSEC-11).

A13.7
NEAR INFRARED DETECTORS AND SOLAR CELLS BASED ON MICROCRYSTALLINE SILICON GERMANIUM. Mathias Krause, Helmut Stiebig, Reinhard Chius, Herbert Wagner, Inst. für Schicht- und Ionentechnik, Forschungszentrum Jülich GmbH, Jülich, GERMANY.

A highly near infrared (NIR) sensitive pin diode is of great interest for the application either as NIR detector or bottom cell in tandem and triple stacked solar cells. Compared to microcrystalline silicon (μc-Si:H) microcrystalline silicon germanium alloys (μc-Si1-x-GeHx) show an increasing absorption in the NIR region with increasing germanium content in addition to the shift of the bandgap. Thus these alloys are promising materials for the application as thin absorber layers in thin film devices. In previous investigations we used SiH4 and GeH4 as source gases which limited microcrystalline growth to alloys with a germanium content to less than 40% due to our deposition conditions. In this study μc-Si1-x-GeHx films and devices with comparable and higher germanium content were prepared by PECVD (210°C, 0.5 MHz, 200m Torr, 10W) using SiH4 and GeH4 diluted in hydrogen up to 480. For monolayer instead of disilane we find a shift of the transition region from amorphous to microcrystalline growth towards lower hydrogen dilution. Raman spectroscopy shows a high crystalline volume fraction, good structural quality and homogeneous composition. PDS spectra exhibit the expected shift of the bandgap and an increasing sub-bandgap absorption with increasing Ge content. The sub-bandgap absorption is larger in films prepared with SiH4 than with SiH4,GeH4 of similar composition which indicates a higher defect density for SiH4 p-pin solar cells with μc-SiGeHx layers showing an increasing dark current due to a decreasing bandgap and increasing defect density with increasing germanium content. This leads to a increasing fill factor (FF) and open-circuit voltage (VOC) of μc-SiGeHx diodes. The strong reduction of VOC and FF with increasing Ge content restricts the application of μc-Si1-x-GeHx for pin solar cells presently to the low and medium Ge range while NIR detectors can be realized with a high Ge concentration.

A13.8
MICROCRYSTALLINE (Si,Ge) SOLAR CELLS. Vikram L. Dalal, Yong Liu, Iowa State University, Dept. of Electrical and Computer Engr, Ames, IA.

We report on the growth and fabrication of microcrystalline (Si,Ge) solar cells on stainless steel substrates. The devices were grown using remote ECR plasma deposition using H and He dilution. The device structure was n/a/p+/p/. Graded gap buffer layers were interposed between the middle n microcrystalline layer and the two contact (n+ and p+) layers to improve performance. It was found that the performance of the device depended critically upon the design of the front (p+) buffer layer. The devices had significant QE beyond 800 nm and measurements of hole properties in the devices were made and will be reported.

SESSION A14: DETECTORS, SENSORS, AND MEMORIES
Chair: Hiroaki Oikawa
Wednesday Morning, April 26, 2000
Salas 7 (Marriott)

NOTE EARLY START
8:15 AM AH 4.1
HIGH SENSITIVITY PHOTOTRANSISTORS IN HYDROGENATED AMORPHOUS SILICON. John M. Shannon, Edmund G. Gerstner, School of Electronic Engineering, IT and Mathematics, University of Surrey, Guildford, UNITED KINGDOM.

26
It has been shown that useful current gains can be obtained in hot-electron devices containing thin a-Si:H layers of nanometer dimensions in hydrogenated amorphous silicon [1]. The a-Si:H/a-CrSi$_2$/Si-H device structure made using PECVD and sputtering techniques naturally forms a hot-electron transistor device where the electron transit across a high potential barrier on one side of the silicide and are collected on a low barrier on the other. Recent results [2] have shown that current gains can be in excess of 40 in structures having a-CrSi$_2$ layers as 1.5 nm thick. Here we outline the relevant physics and technology used in these devices and examine their performance as transistors in which the photo-current is amplified by the hot-electron transistor action. Particular attention is paid to the linearity of the output with light intensity and the uniformity of the device properties. The current gain dependence of the light of response can be maximized by operating the photo-transistor with high electric field across the collector since it is the transit time of the photo-induced carriers that determines the response time. We show that the device is a useful element for future area array monolithic silicon electronics. [1] J.M. Shannon, A. Kovarik, and J.E. Curran, Electron. Lett., 33, 2007 [1997]. [2] E.G. Gerstner and J.M. Shannon, submitted to IEEE Electron Device Lett.

8:30 AM A14.2
IMPROVED RESOLUTION IN A PL-L IMAGE SENSOR BY CHANGING THE STRUCTURE OF THE DOPED LAYERS.

TCO/μc-pins-HI/metal structures can recognize an image contour or a light pattern projected onto the photosensitive surface of a small-signal scanning beam is used to read out the transverse photocarrier concentration as the light beam sweeps across the surface. Different microcrystalline hydrogenated silicon layers top layers (10$^{-4}$ - 10$^{-5}$ cm$^{-2}$ $< \phi < 10^{-1}$ - 10$^{-2}$ cm$^{-2}$) were deposited. Both n- and p-type layers with varying doping levels were employed. Details concerning sensor characteristics and optimization of the configuration are presented and discussed. The results show that all configurations and a representation of the object contour is achieved. When the top layer resistivity increases the spatial resolution is improved. A 50% increase in the spatial resolution was obtained by decreasing the p-layer conductivity. A physical model for the transducer supported by an electrical circuit simulation is presented. Simulated results confirm our experimental findings. As the top layer resistivity increases the ratio between the lateral to transverse photocurrents decreases allowing a better thresholding of the transverse photocurrent. By increasing $\phi$ the ratio between the dynamic spatial resistance (that models the top layer) and the transverse one (that models the active layer) a 40% $P_{dc}$ in the spatial resolution is obtained for the same threshold level. An analysis of the image geometrical distortion, restoration, and enhancement is presented. A low level image processing is performed to suppress the noise and to enhance details. Algorithms and tools are proposed for digital image analysis.

8:45 AM A14.3
μc-Si:H PHOTOELECTRODE TECHNOLOGY FOR ADVANCED CMOS ACTIVE PIXEL SENSOR IMAGERS.

Amorphous silicon photodiode technology is a very attractive option for image array integrated circuits because it enables large size reduction and higher light collection efficiency than c-Si arrays. We have developed a ‘μc-Si:H’ technology that is fully compatible with 0.35μm CMOS processes to produce image sensors arrays with 1.8bit dynamic range that are 30% smaller than comparable c-Si diode. The work presented here will discuss performance issues and solutions to lend itself to cost-effective high-volume manufacturing. The various methods of interconnection of the diode to the array and the advantages will be presented. The effect of device thickness and concentration on quantum efficiency will be discussed. The effect of μc-Si:H defect concentration on diode performance will be discussed.

9:00 AM A14.4
AMORPHOUS SILICON MICROBOLOMETER TECHNOLOGY.

This paper will discuss the current status of amorphous silicon (a-Si) for microbolometer infrared detector arrays. Amorphous silicon is an ideal material for detection of optical radiation from the UV-VIS to the IR spectral range. In the IR part of the spectrum a-Si thin films are used in microbolometer or thermal detector structures. Highly sensitive microbolometer arrays have been developed that take advantage of the high temperature coefficient of resistance (TCR) of a-Si and its relatively high optical absorption coefficients. TCR is an important design parameter for material parameters such as doping concentration. The IR absorption of the bolometer detectors is enhanced by using quarter wave resonant cavity structures and thin metal absorber layers. Ultrathin (~200Å) SiN/a-Si/Ni membranes with low thermal mass yield higher integral response. Integrated circuits are built using RF plasma enhanced chemical vapor deposition (PECVD) and surface micromachining techniques. To ensure high thermal isolation the microbolometer arrays are vacuum packaged using wafer-level vacuum packaging. Imaging and non-imaging sensor applications of a-Si bolometer arrays will be also discussed. Imaging applications include a 128x128 a-Si bolometer pixel array II camera operating at ambient temperature. Non-imaging applications are multi-channel detectors for gas sensing systems.

SESSION A15: SOLAR CELLS I-FROM MATERIALS TO DEVICES
Chair: Klaus Lips
Wednesday Morning, April 26, 2000
Salon 7 (Marriott)

10:00 AM A15.1
HYDROGENATED MICROCRYSTALLINE SILICON: FROM MATERIAL TO SOLAR CELLS. M. Wyczynski, L. Feitknecht, C. Droz, P. Torres, J. Meier, E. Vallier-Sauvan, A. Shiya, Institut de Microtechnique, Université de Neuchâtel, Neuchâtel, SWITZERLAND.

Microcrystalline hydrogenated silicon (μc-Si:H) is a very attractive material for the active layer of thin film solar cells. Efficiencies of up to 8.5% have been demonstrated on entirely microcrystalline μc-Si:H cells with no sign of light-induced degradation [1]. Despite numerous studies on μc-Si:H solar cells and on μc-Si:H layers used as n-layers in these cells, it is yet unclear in which respect the material must be optimized to improve solar cell efficiency. Furthermore, microcrystalline material is not a unique and well defined material, but can exhibit various forms of microstructure [2], the latter depends crucially on the deposition conditions and substrate. Here, the authors will investigate material properties such as unipolar diffusion length $L_{diff}$ (deduced from steady-state photocarrier generation), diffusion length $L_D$ (deduced from surface photocurrent), μc-Si:H products (deduced from photococonductivity and $L_{diff}$) and defect densities (deduced from the absolute constant photocurrent method a-CMP) measured on series of μc-Si:H layers deposited under various plasma powers and hydrogen dilutions of silane. The transport properties and their anisotropy (seen in some samples) will be discussed in relation with the microstructure prevailing in these layers. Performance of solar cells incorporating the same layers will also be compared with layer characteristics in order to suggest path for μc-Si:H material optimization [1]. J.D. Meier et al., Proc. 2nd World Conf. on Photovoltaic Solar Energy Conversion, Vienna, 1998, 375. [2]. M. Vallier-Sauvan et al., Proc. of the ICAM 18.

10:30 AM A15.2
EFFECTS OF STRUCTURAL PROPERTIES OF μc-Si:H ABSORBER LAYERS ON SOLAR CELL PERFORMANCE.
Olive Vetterle, Reinhard Gürig, Leutar Houben, Andreas Lambert,
For microcrystalline silicon (µc-Si:H) absorber layers in thin film solar cells a key topic in current research is the link between material properties and the performance of the corresponding solar cells. We found that, surprisingly, not the material with the highest crystalline content but the material prepared close to the transition to amorphous growth yields the best solar cell performance - in particular, high open circuit voltage $V_{OC}$. This is demonstrated for a series of µc-Si:H nip structures prepared with PECVD at 95 MHz and substrate temperatures of 200°C. The plasma power, source gas composition and absorber layer thickness were varied aiming at high deposition rates and still high good solar cell performance. The highest achieved conversion efficiencies for a growth rate of 1.9 A/s and 5.0 A/s are 8.1% and 6.2%, respectively. Structural properties were investigated by Raman spectroscopy and cross section TEM measurement. Using confocal scanning laser microscopy, the Solar Energy). Employing different laser wavelengths (418 nm - 799 nm) the probe depth of the Raman experiment was varied over a wide range (~100 nm - ~3 μm). For cells produced under growth conditions yielding high crystallinity the Raman spectra are independent of the incident laser wavelength, i.e. the structure does not change during growth of the absorber layer. This finding is supported by the TEM images. In contrast to this, preparation conditions near the transition to amorphous growth result in a gradual decrease of the detected amorphous phase with increasing thickness. Furthermore amorphous phase can be detected even in the surface near volume of several μm thick solar cells. The results emphasize the importance of the material preparation and, possibly, of its evolution with thickness will be required for further improvement of µc-Si:H solar cells.

10:45 AM A15.3
GROWTH OF HIGH QUALITY, LOW BANDGAP, n-Si(Ge) MATERIALS AND DEVICES. Vikram D. Dalal, Zhiyong Zhou, Iowa State University, Ames, IA.

We report on the growth of high quality n-Si(Ge) H materials and devices across the entire range of Ge concentration, from 0% to 100%. The materials and devices were grown using low pressure, reactive RCH plasma deposition. The material properties were measured in films, in diagnostic n-in-p devices deposited on stainless steel substrates, and in p-i-n solar cell devices, also on stainless steel substrates. All three sets of measurements indicate that high quality (low Urbach energy, good fill factors, low defect density) materials can be made if one controls the plasma carefully. In particular, it was discovered that low pressure plasmas which produced a high flux of H ions and radicals were important in making good films. By doing experiments which changed either the ion energy or the flux density impinging on the substrate, we discovered that the critical factor determining film and device quality was the radical and ion flux, not the ion energy.

11:00 AM A15.4
AMORPHOUS SILICON ALLOY SOLAR CELLS NEAR THE THRESHOLD OF AMORPHOUS TO MICROCRYSTALLINE TRANSITION. Jeffrey Young, Kenneth Lord and Subhendu Ghata, United Solar Systems Corp., Troy, MI.

A systematic study has been made of amorphous silicon (a-Si) n-i-p solar cell performance using various hydrogen dilution ratios (R) during the growth of the intrinsic (i) layer. We found that the open-circuit voltage ($V_{OC}$) of the cells increases as $R$ increases; it then reaches a maximum before it decreases dramatically. This sudden drop in $V_{OC}$ is attributed to the transition of the amorphous silicon network to microcrystalline inclusion in the i layer. We have studied i-layer thicknesses ranging from 1000 to 5000 Å, typically used for solar cells, and found that the transition occurs in all thicknesses investigated. Furthermore, for R values approaching the amorphous-to-microcrystalline transition, the formation of microcrystallites as indicated by $V_{OC}$ can occur within a very small increment (~1000 Å) in the i-layer thickness. Based on the study, we have made a-Si i-p i n solar cells suitable for use in the top cell of a high efficiency triple-junction structure. By selecting an appropriate R value, $V_{OC}$ greater than 1 V can readily be achieved. In fact, we have obtained a $V_{OC}$ exceeding 2 V in n/a-Si/a-Si double-junction structure, which is believed to be the highest value reported to date for a two-cell configuration.

Solar cells made near the threshold not only exhibit higher initial characteristics but also better stability against light-soaking. We have compared two thresholds near the threshold with our previous data, and found that both the initial and stable efficiencies are superior for the near-threshold cell. We have achieved an AM1.5 initial efficiency of ~15% in n/a-Si/a-Si double-junction device of ~0.25 cm$^2$ active area. Light-soaking experiments are underway, and we expect a record stabilized efficiency for this structure.

11:15 AM A15.5
KINETICS OF LIGHT INDUCED CHANGES IN PROTO.
CRISTALLINE THIN FILM MATERIALS AND SOLAR CELLS. R. Koval, J. Lino, X. Niu, Z. Lu, G. Ganguly1, J. Yang2, S. Guha2, R.W. Collins, CH Wronski, Center For Thin Film Devices, The Pennsylvania State University, University Park, PA; 1BP Solares, Torance, VA; 2United Solar Systems Corp, Troy, MI.

Studies have been carried out on the light induced changes in a-Si:H under conditions that result in "protocrystalline" materials which are amorphous but close to the microcrystalline boundary [1]. Detailed characterization of degradation kinetics was carried out on the results obtained on a-Si:H films, as well as Schottky barrier and p-i-n solar cell structures, to a degraded steady state (DSS) with illuminations from 1 to 10 suns and at temperatures from 50°C to 100°C. The effects of improved microstructure on light induced defect states in these materials are clearly indicated by the rates at which the electron mobility-lifetime products change under 1 sun illumination, being directly different from that of amorphous silicon fabricated without hydrogen dilution of silane. They are also reflected in the large differences in these light induced changes, as well as those of solar cells, at temperatures well below 100°C.

Although the DSS in films and cells is reached in the same time frame, there are significant differences in the form and the temperature dependence of the kinetics for the mobility-lifetime products and the fill factors. There are however strong similarities between the systematic changes in the corresponding DSS with temperature, recovery under illumination, and the dependence of DSS on the intensity of illumination in both films and solar cells. The significance of these results on the characterization of gap state distributions, the densities of states, defects in crystalline and a-Si:H, and methods used in evaluating the stability of solar cell materials is discussed. [1] R. Koval, et al, Appl. Phys. Lett., 75, 1553 (1999).

11:30 AM A15.6
PROTOTRANSITIONAL SILICON DEPOSITED AT 75° AND 40°C FOR SOLAR CELL APPLICATION. Christian Koch, Mark S. Tzo, Markus B. Schubert, Juergen H. Wenzel, Univ of Stuttgart, Inst of Physical Electronics, Stuttgart, GERMANY.

Inexpensive substrates such as PET [polyethylene-terephthalate] foils for amorphous silicon a-Si:H solar cells limit the temperature dependence of the technique, $T_{0} < 80°C$. Unfortunately, as such low temperatures a-Si:H by amorphous silicon enhanced chemical vapor deposition (PECVD) exhibits very poor density quality. Our contribution presents a modified PECVD process that results in device quality very low temperature silicon. A systematic investigation of the hydrogen dilution ratio $R_H = [H_2]/[SiH_4]$ at $T$ = 75°C and 40°C allows us to identify a process window which yields so-called protocrystalline silicon (pc-SiH). This material at the edge of crystallinity between amorphous and nanocrystalline silicon (nc-Si:H) exhibits remarkable electronic quality. An extensive electrical (photo carrier mobility-lifetime product, dark conductivity), optical and structural (Urbach energy, crystalline volume fraction) characterization gives us detailed insight into material properties at the transition from amorphous to nanocrystalline silicon. Thermal annealing and light soaking of our a-Si:H, pc-Si:H, and nc-Si:H reveals surprisingly stable material (but low in controlled) window of $R_H$. Apart from investigating films, we fabricate and characterize p-i-n and p-i-n solar cells in the regime of amorphous, protocrystalline, and nanocrystalline silicon at $T = 75°C$ and 40°C. Quantum efficiency measurements, as well as current-voltage characteristics of as-deposited, thermally annealed, and light soaked cells show strong correlations to properties of equal single layers and underline the benefit of pc-Si:H for solar cells. Modeling of the n-side and p-side illuminated structures reveals an unexpected behavior: in a certain regime of $R_H$, we find an effective hole drift length exceeding the electron drift length. This result is in contrast to all previous investigations on either amorphous or nanocrystalline silicon solar cells and an important step towards higher efficiencies.

SESSION A16: STRUCTURE AND HYDROGEN
Chair: Rana Biwas
Wednesday, Afternoon, April 26, 2000
Salon 7 (Marriott)

1:30 PM A16.1
SELF-INTERSTIALS HAVE NEVER BEEN OBSERVED DIRECTLY IN CRYSTALLINE Si. HOW ABOUT AMORPHOUS Si? Sjoerd Boorain, Département de physique, Université de Montréal, Montréal, CANADA.

In the early days of point defect studies in electron irradiated crystalline silicon, it was surmised that the Si self-interstitial is highly mobile even at 4 K and escapes direct detection. The existence of
The heterogeneity of hydrogen and deuterium on the nanometer scale has been probed by small-angle neutron scattering (SANS) from a-Si:H and a-Si:D films. Deposites were made by two techniques, plasma-enhanced chemical vapor deposition (PECVD) and hot-wire chemical vapor deposition (HWCVD) using conditions that yield high quality films and devices, as well as conditions known to yield material with somewhat inferior optoelectronic properties. The SANS measurements were made at the NIST Center for Neutron Research beamline NG-3. Data were collected over a momentum transfer range from $q = 0.015$ to $3 \text{ nm}^{-1}$. The four samples made under conditions that yield high quality material (high hydrogen or deuterium dilution in CVD) and conditions that yield inferior quality material in HWCVD were examined in both a light-soaked state (300 h, AM1) and an annealed state (10$^\circ$C, 1 h) to look for a Streater-Wronski effect-induced change in structure as reported in a SANS experiment several years ago. No detectable difference in SANS intensity from the two states was observed in the four samples to a precision that could have readily detected the 35% change reported previously. We do find significant differences in the heterogeneity of the films grown by PECVD and HWCVD as well as in the samples made with each technique, but under different conditions. A. Cheminat-Paule, R. Bellissent, M. Roth, and J.I. Pankove, J. Non-Cryst. Solids 77-78 (1985) 373.

Amorphous silicon is known to exhibit a 450% enhancement of its diamagnetic susceptibility relative to the crystalline phase, and this effect is attributed to bond length and bond angle disorder in the amorphous lattice. Further, it has been predicted theoretically that the enhancement increases smoothly with increasing disorder. Therefore, diamagnetic susceptibility may provide a direct probe of the degree of intrinsic disorder in a-Si related materials. We have recently made precise measurements of the bulk magnetic susceptibility of ~1 micron thick, ~0.5 mg a-Si:H and µc-Si:H films using the NMR frequency of the incorporated hydrogen as an effective magnetometer. Other means of measuring susceptibility (e.g., SQUID, etc.) require much larger amounts of sample so that the diamagnetic response of the sample holder can be reliably subtracted out. The resolution of this method is enhanced by using a multiple-pulse line-narrowing technique in order to average out the i-H dipolar interaction, and the results of the NMR measurements of the bulk samples with varying deposition temperature as well as standard PECVD samples have been investigated. Preliminary results will be discussed.

1:25 PM A16.4 ANISOTROPY IN HYDROGENATED SILICON TIN FILMS

We investigated spatial and optical anisotropy in hydrogenated silicon thin films using infrared spectroscopy and other techniques. The films ranged in morphology from amorphous to microcrystalline, as determined by x-ray diffraction. Structural analysis of the films was carried out using scanning and transmission electron microscopy (SEM, TEM, respectively). We used polarized attenuated total reflection (ATR) measurements together with Fourier transform infrared (FTIR) spectrometry to investigate a series of H- and C-doped a-Si:H thin films with the H content bonding structure of the films, and also to detect oxide impurity phases present at certain sites in some samples. The FTIR-ATR measurements were performed using a germanium (Ge) contact microprobe sampling technique, as well as by deposition on standard crystalline Si and Ge ATR substrates. The Ge contact ATR microprobe enabled interference-free measurement of the IR spectra of µc-Si:H and a-Si:H films deposited on conductive substrates such as stainless steel and transparent conductive oxides. This measurement is difficult or impossible using transmission or reflection IR spectroscopy, and is also sensitive to the spatial distribution of potentially lithium-limiting oxide precipitates in the films.

2:30 PM A16.5 SURFACE COMPOSITION DURING PLASMA DEPOSITION OF HYDROGENATED AMORPHOUS SILICON STUDIED AS A FUNCTION OF ION FLUX AND SUBSTRATE TEMPERATURE
Denise C. Marra, Univ of California Santa Barbara, Dept of Chemical Engineering, Santa Barbara; M.C. Kessell, M. C.M. van de Sanden, Eindhoven Univ of Technology, Dept of Applied Physics, Eindhoven, THE NETHERLANDS; Frey S. Aydil, Univ of California Santa Barbara, Dept of Chemical Engineering, Santa Barbara, CA.

We investigate plasma deposition of hydrogenated amorphous silicon films from SiH4/Ar discharges using in situ multiple total internal reflection Fourier transform infrared spectroscopy (MITIR-FTIR) and spectroscopic ellipsometry (SE). By applying a technique that combines surface-sensitive, attenuated total reflection (ATR) FTIR and a brief Ar+ sputtering of the surface hydrides, we report on the surface hydride composition as a function of the substrate temperature. As expected, fewer higher hydrides exist on the surface at elevated deposition temperatures. Based on the IR data, we propose a set of thermally activated surface reactions in which higher hydrides decompose sequentially via reaction with dangling bonds. In our ATR-FTIR spectra, Ar+ and ArH+ are the dominant ions, therefore we manipulate the rate of dangling bond generation through ion sputtering by varying the plasma power. By monitoring the surface species as a function of ion bombardment over a range of substrate temperatures, we find a synergy between thermal activation and ion flux. The effect of ion bombardment is shown to be negligible in the limits of high and low substrate temperature. Using MITIR-FTIR, we monitor the bulk hydrogen concentration and, with spectroscopic ellipsometry, the index of refraction of films grown under the various conditions. Thus, we investigate the relation between the dynamics of the surface reactions and the properties of the bulk film, with particular focus on understanding the mechanism of incorporation into the bulk. Furthermore, hydrogen-rich or at isolated Si-H locations in the films or at Si-Si bond center sites has been detected during Ar plasma exposure of a-Si:H films as well as by application of thermal energy.
proceeded in Osaka University and Ritsumeikan University since 1970. In the last half period of 1980s, I had conducted the research on band structure of various semiconductors by the modulation spectroscopy, and also been interested in an electronic activity of Justice defects in semiconductors. A strong motivation to start amorphous semiconductor research was to produce a new kind of synthetic semiconductors having continuous energy gap controllability with valency electron controllability in both chalcopyride and tetrahedrally bonded semiconductors. The first material we have struggled is $\text{Si}_3\text{As}_2\text{Te}$ chalcopyride semiconductor which form as a very wide vitreous region in GeH$_2$'s Triangle. A series of systematic experiments here was conducted in the terrestrial environment since 1971, and also within the TT-500A Rocket experiment in 1980. On the basis of these data, the Sprake-J experiments have been accomplished in the EMFT (First Material Processing Test) project in 1992. In the presentation, some basic technical data on electrical, optical and optoelectronic properties, energy gap and also valency electron controllabilities are demonstrated and discussed.

The second material is hydrogenated amorphous silicon ($\alpha$-Si:H) and its alloys started in 1970 just after the Garmisch Partenkirchen ICALS-6 where the first report on the valency electron controllability with hydrogen passivation by Prof. Spear's Dundee group. Then, 4.5% efficiency was achieved with p-n hetero junction solar cells in 1978, which triggered high efficiency competition in the $\alpha$-Si basis solar cells. Our continuous effort to improve the efficiency brought the tandem type solar cells in 1979, and also new products of $\alpha$-SiCH and $\alpha$-SiGe:H in the early period of 1980s. These innovative device and materials have been bloomed in the middle of 1980s in R&D. D-pHjem of heterojunction solar cells $\alpha$-Si/InP-$\alpha$SiGe:H tandem type solar cells, and industrialized in recent few years. New kind of trials on full-color thin film light emitting devices has also been recently initiated with wide range of band gap controllability of $\alpha$-Si:H.

The third material is microcrystalline silicon ($\mu$-Si) and its alloys, which we have reported firstly in 1984. This class of materials has been utilized mostly as a buffer layer for wide-gap window heterojunction electrodes in the period of 1980s, and also wide-area TFT's for Liquid Crystal Display devices in the recent few years. Quite recently, a tremendous R&D effort has been piled on this material as the bottom cell of the $\alpha$-Si/InP-$\mu$-Si tandem solar cells aimed for the all-round plasma CVD process for the next age thin film photovoltaic devices.

In the final part of presentation, a brief discussion will be given on a technological evolution from "bulk crystaline age" to "multiplier thin film age" in the semiconductor optoelectronics toward 21st century.

4:00 PM A11.3
AN EUROPEAN ADVENTURE IN AMORPHOUS MATERIALS FROM PAST TO FUTURE, Ioan Schomer, Ecole Polytechnique, Laboratoire PME, Palaiseau, FRANCE.

The early work on amorphous silicon in Europe was dominated by the activity of the Dundee group, who demonstrated the feasibility of substitutional doping, which was quite a surprise at the time [1]. The publication of the famous curve, showing a variation of resistivity of more than 10 orders of magnitude with small amounts of phosphorus or boron, mushroomed in the industry in semiconductors. The role of hydrogen in this new "good" disordered semiconductor, $\alpha$-Si:H, was not immediately accepted, and the controversy was finally settled by the crude experiment of post-hydrogenation by D. Kaplan [2]. It is little known that this process of post-hydrogenation, currently used for the improvement of devices, was covered by a patent, which turned out to be quite inapplicable! The high hopes raised by this "new" material, in particular for photovoltaic applications, rendered the field highly competitive. It produced a "pollution by the applications" effect which resulted in some surprising neglect of the basic principles of physics. A striking example is the sweeping under the rug of the effect of band bending at the surface of intrinsic $\alpha$-Si:H. This effect makes the surface much more conducting than the bulk, rendering a large number of published transport measurements in planar geometry completely meaningless. Research in Europe has been less application-oriented than in USA and Japan. For example, spin-dependent effects in amorphous $\alpha$-Si:H have been extensively studied in France (Ecole polytechnique) and Germany (Marburg); so far no commercial devices have been found just yet. On a similar front Europe was not completely absent from industrial application to photovoltaics: a spinoff adventure "in la French" will be described. The problem of disordered materials is one of the timely solid-state topics, to become a subject of more and more concern in the near future. In that respect, amorphous silicon is an exemplary system, and the hydrogen glass picture, pioneered by R.A. Street et al., is an open field of research for the improving of disordered semiconductors. [1] W. E. Spear, L. H. Haas, L. C. LeComber, Sol. Energy, Vol. 17, 115 (1975) [2] D. Kaplan, P. A. Thomas, N. Sol and G. Velasco, Appl. Phys. Letters Vol 33, 440 (1978). French patent #17295, June 1977.
The open-circuit voltage \( V_{OC} \) in amorphous silicon based pin solar cells behaves relatively simply compared to most device parameters. \( V_{OC} \) varies little with the thickness and the density of deep levels in the undoped absorber layer, and varies essentially one-to-one with changes in absorber layer bandgap. It is crucial to further improvements in solar cell efficiency to establish whether \( V_{OC} \) in optimized cells is determined solely by absorber layer properties, or is reduced by effects at the p-i-n interfaces. The simplicity of the behavior of \( V_{OC} \) suggests that it is determined by the bulk properties of the film, rather than by interface states, which are usually not so well understood. In this paper we summarize \( V_{OC} \) measurements for cells from several laboratories. We present experimental estimates, mainly from electrophotoluminescence, of the built-in potential \( V_{BE} \) for a number of amorphous-silicon based solar cells. Typical \( V_{OC} \) estimates are sufficient to explain measured open-circuit voltages (up to 1.05 V) to suggest some reduction of \( V_{OC} \) by interface effects. Finally we present computer simulations of \( V_{OC} \) using the AMP* computer code. These simulations use simplified parameter sets chosen for consistency with drift-mobility and electroreflection measurements. The results indicate that open-circuit voltages may be reduced about 0.1 V by electron diffusion to and recombination in the p-layer. We discuss implications for future improvements in \( V_{OC} \). This research was supported through the Thin Film Photonics Partnership of the National Renewable Energy Laboratory and by the Korean Science and Engineering Foundation.

SESSION A10: HETEROGENEOUS MATERIALS

Chair: Nicola Wysrach
Thursday Morning, April 27, 2010
Salon 7 (Marriott)

10:15 AM A10.1
GAS-PHASE AND SURFACE REACTIONS OF DECOMPOSED SPECIES IN CATALYTIC CVD
Naroku Hondoh, Atsuaka Maeda, Hiroki Matsumura, Japan Advanced Institute of Science and Technology (JAIST), Ishikawa, JAPAN.

Catalytic CVD, often called hot-wire CVD, is a novel low-temperature and high-rate deposition technique for amorphous silicon films, silicon nitride films, etc. Influence of gas flow on the film uniformity and efficiency of gas use, lifetime of deposition species were clarified using the specially designed tube reactor. Here, gas-phase and surface reactions of decomposed species in catalytic CVD are also clarified using the tube reactor by comparative study on source gases between \( \text{H}_2 \text{Si}_2 \text{H}_6 \) and \( \text{H}_2 \text{SiH}_4 \). In addition to the shape and the surface area of the catalyst, directly determine the deposition rate of Si films. Crystallization of Si films occurs by the exothermic reaction only at the growing surface. Therefore, with the exchange between bonded surface and atomic H in gas phase. Not only the deposition rate but also the crystalline fraction are influenced by the gas flow, suggesting that control of the gas flow in the chamber design is important for not only the thickness uniformity but also the crystallinity.

10:30 AM A10.2
MANIPULATION AND CONTROL OF NUCLEATION AND GROWTH KINETICS WITH HYDROGEN DILUTION IN HOT-WIRE CVD-GROWTH OF POLY-Si. M. Sievert, J. M. Burton, T. Watanabe, A. A. A. A. University of California, Los Angeles, CA.

Hot wire chemical vapor deposition (CVD) is an attractive method for growth of polycrystalline silicon for application in thin film polycrystalline silicon photovoltaics. A key issue is to identify growth conditions that enable the largest possible grain size at a given growth temperature with low intragranular defect density. Hydrogen is known to play a critical role in development of a crystalline microstructure in both amorphous and polycrystalline films grown by hot wire CVD at low temperature. We systematically explore the relationships between gas-phase kinetic and film microstructure in the hot-wire CVD technique using diluted silane (1%) in He) and additional hydrogen. Using a wire temperature of 2000°C, films were grown on Si (100) at 300°C using 1 mTorr SiH4 and 99 mTorr He at hydrogen pressures from 0-100 mTorr. Transmission electron microscopy and atomic force microscopy measurements indicated that the resulting microcrystalline films had a columnar grain structure and that grain size increased from 400 nm using 0.1 mTorr He to 800 nm using 100 mTorr He with 16.1 H2:H4 ratio due to the etching by hydrogen of amorphous silicon. Etching rate measurements using a quartz deposition monitor show that, under the current deposition conditions, a transition from non-dissociative (2 J/sec) to dissociative etching (15 mTorr of additional 80 mTorr hydrogen) takes place. The influence of selective nucleation at nucleation sizes defined by metal nanoparticles on grain size in polycrystalline silicon films will also be discussed.

10:45 AM A10.3

The importance of the existence of the excited hydrogen (hydrogen radicals) for preparing hydrogenated microcrystalline silicon (\( \mu \)-Si:H) films has been studied. For increasing the density of the hydrogen radicals, VHF plasma CVD is one of the key technologies. However, it requires complicated instruments for preparing \( \mu \)-Si:H with higher crystalline volume fraction at lower hydrogen dilution ratio. We have previously suggested a new method for preparing \( \mu \)-Si:H named hot-wire assisted PECVD (HWAPECVD) [1]. This method is constructed by two parts, plasma-enhanced CVD (PECVD) and hot-wire (W filament) [2] for exciting hydrogen. This technique has an advantage that the hydrogen-radical density is controllable without influencing the deposition conditions of the PECVD. Samples were prepared at a substrate temperature of \( \approx 250^\circ \text{C} \) and an RF (13.56 MHz) power of \( \approx 10 \text{ W} \). The temperature of the W filament was varied from room temperature to \( \approx 1700^\circ \text{C} \). The hydrogen dilution ratio to silane was also varied from \( \approx 10 \text{ to } 60 \). From the Raman spectroscopy and x-ray diffraction, it was found that both the crystalline volume fraction and the crystalline grain size become larger with an increase of the filament temperature at a fixed hydrogen dilution ratio of \( \approx 60 \). It is also found that the sample crystallinity or hydrogen dilution ratio of \( \approx 10 \) with a filament temperature of \( \approx 1700^\circ \text{C} \), in which the crystalline volume fraction is \( \approx 60 \% \). Note that the sample is normally amorphous for the later deposition condition in the conventional PECVD (without the filament). Also note that the deposition rates for all samples are \( \approx 0.5 \text{ A/sec} \). These results directly suggest the importance of hydrogen radicals and the HWAPECVD technique is promising for preparing \( \mu \)-Si:H. [1] H. Hara et al., submitted. [2] A. Sutoh et al., Jpn.

11:00 AM A10.4
COMPARISON OF GROWTH OF SI THIN FILMS ON LOW TEMPERATURE AMORPHOUS SUBSTRATES BY MBE AND PECVD. J. A. A. A. University of California, Los Angeles, CA.

Hydrogenated microcrystalline and amorphous Si films are of commercial interest because of their potential applications in solar cells, liquid crystal displays, image sensors and printer arrays. The growth techniques and mechanisms are of crucial importance for the control of the microstructural properties of these films. A two-step method for the growth of Si thin films is PECVD. In this work, we have grown Si films on amorphous substrates by Molecular Beam Epitaxy (MBE) as well as by a new configuration of DC remote PECVD. The growth mechanisms of Si films for both methods are explained and the two techniques are compared. We show that with MBE, one can obtain high quality Si films with grains larger than those obtained by any other known growth method at low temperature. The films exhibit a highly columnar texture with a surface texture at 100 °C and a pronounced surface texture. By DC remote PECVD, we were able to precisely control the growth of Si films by varying the growth conditions. The optimized films have reduced point defects, passivated grain boundaries with a high growth rate of 6 A/sec. The ratio of the Raman signals corresponding to the crystalline (at 520 cm\(^{-1}\)) and amorphous (at 480 cm\(^{-1}\)) signals in the films is substantially higher in the Si films grown by MBE than in the films grown by PECVD. The electrical resistivity of the intrinsic Si films grown by both methods is on the order of 1000 \( \Omega \cdot \text{cm} \) when measured along the surface. The mobility perpendicular to the surface increases in samples with highly columnar growth. In MBE grown films, the reflectance shows two prominent maxima at around 3.4 and 4.5 eV due to the high crystallinity of these films.
The role of hydrogen is an important issue in microcrystalline silicon formation but is not well understood. We have deposited microcrystalline silicon films by plasma enhanced chemical vapor deposition (PECVD) at an excitation frequency of 60MHz using hydrogen diluted silane as a source gas, and have studied the role of hydrogen in the hydrogenation and densification processes. In the present work, it is found that the better crystallinity can be obtained at a same growth rate when using D2 dilution as compared to H2 dilution. The ratio of deuterium content C2H to hydrogen content CH in the film showed a correlation with its crystallinity independent of the deposition conditions.

Microcrystalline silicon films were deposited at 250°C in a capacitively coupled diode reactor under high pressure-deposition (HPD) conditions as reported previously[1]. The silane fraction to hydrogen was kept constant at 10%, and the pressure was 2 Torr. The input power density was increased from 0.1 to 1.1W/cm² at an excitation frequency of 60MHz. The Raman crystallinity, the intensity ratio of the Raman band at 519(5 cm⁻¹)/(480(6 cm⁻¹)) as a function of growth rate reflect marked improvement for D2 dilution in comparison with H2 dilution. The ratio of number of H and D atoms (C/H/Cp) has a good correlation with the crystallinity, i.e., crystalline phase is observed for the film having C2H/Cp=0.5, and this empirical rule is observed universally for different deposition conditions such dilution ratio and power. The improved crystallinity for D2 dilution is ascribed to lower electron temperature and to more stable surface coverage by D. These characteristics of D arise from heavier mass than hydrogen. The empirical correlation for C2H/Cp to the crystallinity suggests that H-D exchange events on the surface promotes crystal formation above a certain threshold numbers if we assume that atomic deuterium content is D2 dilution and surface hydrogen originating from SiH fragment of SiH source gas molecules.[1] L. Guo et al., Jpn. J. Appl. Phys. 37 L1111 (1998).
H the vanishing of the LVM at 210 cm\(^{-1}\) could be due to a structural change of the samples from a-Si:H to \(\mu\)c-Si:H. However, the Raman spectrum did not reveal the presence of the TO mode at 520 cm\(^{-1}\) but only the broad gaussian peak centered at 480 cm\(^{-1}\) characteristic of a-s-Si:H. On the other hand, \(\mu\)c-Si:H reveals two new LVM's centered around 1920 and 2140 cm\(^{-1}\). These lines are also found in polycrystalline films, in which helicopters or disclination modes occur with considerable strength even before the TO line at 520 cm\(^{-1}\) is detectable. Thus, these LVM's can be used to detect crystalline fractions in material prepared in the photocoaxial regime. The results are discussed in terms of current models for the properties of H in silicon.

2:30 PM A20.4
DEPENDENCE OF H DIFFUSION IN HYDROGENATED SILICON ON DOPING AND THE FERMI LEVEL. W. Beyer and U. Zastrow, IBL-PV, Forschungszentrum Jülich, Jülich GERMANY.

The dependence of hydrogen diffusion in a-Si:H and \(\mu\)c-Si:H on doping and the Fermi level is of considerable importance for H stability. The nature of this effect is not fully understood. The doping effect was first observed in hydrogen diffusion experiments of a-Si:H [1] and was also reported for \(\mu\)c-Si:H, \(\mu\)c-Ge:H as well as Si-rich a-Si:H alloys with C, O and N. It was studied extensively by hydrogen-deuteron intermix.

However, in these experiments the hydrogen concentration \(c_{H}\) which is also known to affect H diffusion [2] was not kept at a fixed level. Here we report on results of HD interdiffusion studies on doped c-a-Si:H wafers and low \(c_{H}\) \(\mu\)c-Si:H and a-Si:H films which were post-hydrogenated by hydrogen implantation in the range from less than 1% to more than 10%.


2:45 PM A20.5
A CASE FOR MOLECULAR HYDROGEN BEING THE MOBILE H SPECIES IN a-Si:H Peter A. Fedder, Washington University, Dept. Physics, St. Louis, MO.

The mechanism (or mechanisms) for the transport of hydrogen in a-Si:H is of great interest, but understanding of a number of phenomena including light induced defects. The standard picture for hydrogen migration is that a hydrogen atom leaves a trap site for a higher energy transport site, migrates to the transport site, and eventually falls back into a trap site. Presumably the transport sites are bond-centered sites and the trap sites are H-passivating dangling bonds although other possibilities do exist. We find that the literature includes many calculations for the activation energy of hydrogen diffusion that are at best misleading and often interpreted incorrectly. In this work we exhibit the results of a number of calculations that apply to particles hopping and apply the results to a-Si:H. These calculations coupled with existing estimates of the energy of various hydrogen configurations in a-Si:H show that the standard picture is very likely to be incorrect. However, using past and present molecular dynamics calculations, we show that the mobile species of hydrogen in a-Si:H may well be molecular.
sacrificial layer. Different generic mechanical microstructures such as cantilever beams, bridges, and membranes have been fabricated by using surface micromachining and MEMS techniques. Several issues regarding film stress and adhesion of amorphous silicon on glass substrates, and stiction problems after structure release will be discussed.

4:30 PM A21D
NOVEL MICRO-PHOTODIODES FOR RETINA SIMULATION
Martin Rajkovic, Markus B. Schulz, University of Stuttgart, Institute of Physical Electronics, Stuttgart, GERMANY.

The retinal layer of photoreceptor cells transforms incoming daylight into electrical pulses, thereby stimulating the ganglion cells as part of the neural visual system. Certain degeneration of photoreceptor cells, result in degeneration of photoreceptor cells whereas all other parts of the neural visual system remain functional. In 1995, a German research program was started to develop an eye implant which would functionally replace the degenerated rod and cone cells. We deposit micro-photodiodes based on amorphous silicon (p-i-n and n-i-n) structures at 100°C so that flexible plastic or biodegradable substrate films may be used. The capacitive coupling of our photodiode's electrodes to the nervous tissue is crucial for the actual electrical stimulation of the ganglion cells. In vitro experiments [1] with retinas and a variety of micro-electrodes and photodiodes show that electrical activation of ganglion cells upon illumination requires a potential change of about 40V. Our approach investigates the fabrication of different sizes of micro-photodiodes with photolithography and several lift-off processes. Photodiodes of 200x200μm² in size show an open circuit voltage of about 1.5V. Laterally series-connected micro-photodiodes of a tandem structure (p-p-p-i-n and n-p-p-i-n) enable us to reach the required 2V. However, the performance of our photolithographically structured amorphous cells is still inferior to that of thin-film Si:H cells using shadow masks for the front- or back-contact. The correlation of parameters of our photolithographic process with the text resistivity of the photoreceptor during the deposition of the p-i-n layers, with the current-voltage-characteristics of the cell, shows that a low parallel, and high series resistance limit the efficiency of our micro-photodiodes. Improved results of our technology enabled us to realize local light induced stimulation of the ganglion cells of the retina in in-vitro experiments.


4:45 PM A22
SELECTIVE AREA CELL ADHESION ON AMORPHOUS SILICON USING PATTERNED SELF-ASSEMBLED ALKYL MONOLAYERS
LL Smith, K. Wang, G.N. Parsons, Dept. of Chemical Engineering; R. Hernandez, D.T. Brown, Dept. of Biochemistry, North Carolina State University, Raleigh, NC.

The compatibility of inorganic materials with living cells and tissues is crucial in many areas, including medical diagnostics, biosensors, drug delivery, and tissue engineering. We have examined the potential of an in vitro model of living mammalian cells with semiconductor surfaces for novel thin-film biosensor devices. Amorphous silicon may give advantages over crystalline silicon for some devices because of its large area, low-temperature compatibility, and its optical absorption coefficient in the visible spectrum. Amorphous silicon thin films (500Å) deposited on quartz were cleaned using ambient UV/O₃ treatment, leaving the surface largely O₃-terminated and hydrophilic. The hydrophilic/quasi-polar surface of an aqueous solution of octyltrimethoxysilane (CH₃(CH₂)₇Si(OMe)₃) creates a molecular layer formation on the surface. XPS confirms that the organic hydrolyzes, leading to a monolayer bound to the oxide surface through Si-O-Si linkages, with the Cl completely removed. The resulting surface is strongly hydrophilic, with advancing contact angles >100°.

The organic surface was patterned to patterned area of uncoated hydrophilic substrate, and placed in a cell culture to observe cell adhesion and proliferation. The cells were baby hamster kidney epithelial (BHK-21) cells in a buffered culture medium of fetal bovine serum. A high degree of cell attachment and spreading was observed on the UV/O₃-treated surfaces (≥400 cells/mm²) compared to 500±50/mm² on the culture dish control surface, indicating cell proliferation and growth. Little cell adhesion occurred on the hydrophilic organic-coated surface (≥400 cells/mm²), and the cells remained rounded and only minimally attached. On patterned surfaces, the organic-free areas showed dense, well-aggregated cell growth while the coated areas showed much fewer and more rounded cells. On all samples as well as control surfaces, cell death was ≤1%. These results suggest a means for selectively controlling cell adhesion to thin film electronic device surfaces, through the patterning of hydrophilic surface coatings.

A22.1 Si:H VIBRATION ONLY AT 2000/cm IN FULLY POLY-CRYSTALLINE SILICON FILMS MADE BY HWCDV J.K. Ruhl, H.E. Schropp, Utrecht University, Interface Physics, Utrecht, THE NETHERLANDS.

The Si:H vibration in our device quality poly-Si made by hot-wire chemical vapour deposition (HWCDV) at low wire temperature (T_w=1000°c) is at 2000/cm in IR spectra whereas in a poly-Si film made at high wire temperature (T_w=1900°c) both 2000/cm as well as 2100/cm are observed. On the other hand, the Raman spectra (probing the upper part of the film) of Si:H vibration measured for both these samples show only as 2000/cm micrographs of these films show that whereas the low T_w film has a structure made of closely packed crystalline columns, the high T_w film has columnar crystalline structures with amorphous regions between them. For the high T_w film, the columnar cones meet each other towards the top of the film and form a closed structure. This is confirmed by Raman spectra at 520/cm. We attribute the 2100/cm mode to the Si-H bonds at the surface of the cones touching the amorphous regions. The Si-H vibration shifts around 1150/cm when the crystalline cones coalesce with each other, as is the case in the upper part of the film. This explains the existence of both the frequencies in IR spectrum. The Raman spectrum (penetration depth of 5-5.5 nm laser beam 5 - 100nm) essentially detects Si-H bond in the top region at 2000/cm. For the low T_w film, the Si-H bonds are between closed packed crystal columns throughout the length of the film due to which all the Si-H bonds have vibration at 2000/cm, which explains why Raman (bulk) and Raman (top region) have similar stretching mode characteristics. We attribute the Si:H vibration at 2000/cm in our HWCDV poly-Si films to the hydrogen at compact sites which, in addition to XTEM in defocussed condition, is also confirmed by hydrogen effusion and deuterium diffusion experiments.

A22.2 OPTICAL PROPERTIES OF MICROCRYSTALLINE SILICON THIN FILMS PREPARED BY HOT WIRE CHEMICAL VAPOR DEPOSITION M. ZHU, Y. CAO, X. GUO, Graduate School, Univ of Science and Technology of China, Laboratory of Semiconductors Materials Science, CAS, Beijing, CHINA.

Undoped microcrystalline Si thin films (μc-Si:H) were prepared by HWCDV with different H₂/SiH₄ ratios. The optical properties of the μ-Si:H films were characterized by optical transmission spectra, Raman scattering and Fourier transform infrared spectroscopy (FTIR). The microcrystalline volume fraction Xc of film was determined by Raman spectra to be 0.74 varying with the H₂ concentration ratio. Correspondingly, the optical absorption coefficient in the visible spectrum is in the range of 1.80-1.40 eV. The absorption spectra intersect at energy 1.86 eV (E₅). Above E₅, the absorption coefficient decreases with Xc and the opposite behavior was observed below E₅. Raman peak at around 513 cm⁻¹ in Raman spectra (at the backside incident, Raman measurement for films with Xc = 0.52 and 0.62 was observed. The result of the TEM is, it is suggested that silicon crystallization on the glass substrate occurs in the initial stage of growth in HWCDV. The FTIR data show that the intensities of the 2000 cm⁻¹ stretching modes and 885 cm⁻¹ - 889 cm⁻¹ SH₂ bend modes decrease with increasing Xc and disappear as the Xc > 0.62. While the 2100 cm⁻¹ stretching mode is getting strong with Xc and then splits into two modes at 2086 cm⁻¹ and 2082 cm⁻¹. The ratio of intensity at 2086 cm⁻¹ to 2082 cm⁻¹ promotes with increasing Xc. Cardona has proposed that the stretching modes at 2085 cm⁻¹ and 2100 cm⁻¹ are corresponding to the SiH bonds on two different crystallographic surfaces possibly (111) and (110).

Combining our observations of a preferential growth orientation along the [111] direction and the absence of the SH₂ groups in 840 to 900 cm⁻¹ as Xc > 0.62, we suggest that the 2086 cm⁻¹ mode is corresponding to the Si:H stretching vibration at the microcrystalline Si (111) surface in μc-Si:H.

A22.3 EFFECT OF GROWTH METHOD ON THE COMPOSITION AND MICROSTRUCTURE OF HYDROGENATED AMORPHOUS SiC ALLOYS M. Neer-Sook Le, S. Bent, Dept. of Chemical Engineering, Stanford University, Stanford, CA.

Amorphous and hydrogenated silicon carbide and its alloys are finding wide use for photovoltaics and flat panel displays. A common method for these materials is plasma-enhanced chemical vapor deposition (CVD), but hot-wire CVD is becoming an attractive alternative because it provides a way to generate reactive species such
as radicals with less ion-induced damage to the growing film. Here we compare the use of both electron cyclotron resonance (ECR) plasma and hot-wire assisted growth for Si:H deposition on single-crystal silicon-carbon alloys. Alkyl-substituted silanes were used as single source precursors in a low pressure regime between 200 and 600 K. In situ multiple internal reflection Fourier transform infrared (MIR-FTIR) spectroscopy was used to obtain a detailed identification of the hydride bonding in the film, and near-edge X-ray absorption fine structure (NEXAFS) measurements provide supporting information on carbon and silicon bonding. The differences between films grown by various CVD methods are more significant at the higher growth temperatures. We show that HW-CVD affords greater control of the film bonding and microstructure. By using hydrogen dilution and varying growth temperature over the range of 25°C to 600 K, the film structure can be varied from poly (methyl)silane and polycarbosilane forms of Si:H, to micro-crystalline material. Studies using IR and real-time mass spectrometry point to the role of hydrogen atoms and indicate that the temperature dependence of H atom reactions influences the growth process.

A22.4 NANOCRYSTALLINE UNDOPED SILICON FILMS PRODUCED BY HOT WIRE AND HOT WIRE PLASMA ASSISTED TECHNIQUE. I. Ferreira, R. Martins, A. Cabreira, E. Fortunato, P. Villanueva, Univ Nova de Lisboa, Faculty of Science and Technology, Dept of Materials Science, Monte de Caparica, PORTUGAL.

One of the main weak points of amorphous or micro/nano-crystalline undoped silicon films produced by the hot wire technique is that the films present a rough surface with a high density of pinholes. The formation of this type of structure leads to a fast oxidation of the films once exposed to air, which increases with the time of air exposition. On the other hand, the production of polycrystalline undoped silicon films by the conventional plasma enhanced chemical vapor deposition is very difficult it requires the use of high rf power and/or high rf frequencies. In order to overcome the difficulties and to produce high compact structures at high growth rates with the performances required to device application, we introduce the plasma assisting the hot wire deposition technique. By doing so, we were able to produce high compact structures presenting regular distributed grains with sizes in the range of hundreds of nanometers, where post-oxidation is prevented. In this work, we show SIMS results concerning the morphology of the films produced by hot wire with and without plasma assisting the process. There, it is observed that the films produced by hot wire hot wire present a multilayer structure while the films produced by plasma assisting the hot wire show a compact granular structure. On the other hand, the IR results show no post-oxidation for the films produced with plasma assisting the hot wire. On the contrary, a strong peak in the range of 1100-1200 cm⁻¹ is observed, after two months of the deposition of the films by the hot wire process. This behaviour is associated to a porous like structure. The influence of hydrogen dilution on the properties of the films was also investigated. The data reveals that the hydrogen dilution improves the overall electrical properties of the films. Furthermore, the films produced by hot wire technique are more porous when hydrogen dilution is used.

A22.5 p-TYPE WINDOW LAYERS FOR n-SiH BASED SOLAR CELLS BY THE THERMO CATALYTIC CVD. M. Koob, U. Weber, H. Seitz, B.O. Dausa, and B. Schroeder, Dept. of Physics and Research Center of Materials, Kaiserslautern, GERMANY. 1Indian Institute of Technology, Bombay, INDIA.

We report the results of our investigations on p-type amorphous and microcrystalline silicon window layers deposited by the thermocatalytic chemical vapor deposition (TCCVD) method to be used in the TCO/p-n/amorphous solar cells. An important consideration in depositing the cell structure is the danger of the TCO/film interface due to reduction reactions of the TCO. An independent study on the effect of the atomic hydrogen present in TCCVD method on TCO revealed that the substrate temperature is important in this regard. So we prepared the p-type silicon carbon alloy (p-Si:CH₄) using trimethyl boron (TMB) and methane p-type microcrystalline silicon (p-Si:H) using diborane and TMB independently at low substrate temperature as possible. We obtain a p-Si:CH₄ layer with band gap 1.9 eV and 10¹⁸ (cm⁻³)² conductivity which yield an open circuit voltage (V_{oc}) of 850 mV for a cell made on ASAHI TCO. Important correlations between the process parameters and film properties were achieved. For n-Si:H layers the carbon incorporation is more sensitive to absolute silicon flow than to the silane to methane ratio. From signatures observed in the infrared spectra (Si₂CH₄, Si₂CH₂, Si₂CH₃) we propose that in TCCVD the hot wire alone is not effective in desorbing the CH₄, insufficient precursors without sufficient collisions of CH₄ and SiH radicals with CH₄ are needed to obtain C-containing precursors which get incorporated in the alloy film. For the p-Si:H layers the filament temperature and pressure play important role in inducing microcrystallinity in the films. Also p-Si:CH₄ made with TMB requires higher gas pressure compared to those made with diborane. However this increases the atomic hydrogen concentration which damages the TCO/p-layer interface yielding lower V_{oc} in the present TCO/p-Si:H p-n/p-Si:H cells. Cells with p-Si:CH₄ made using diborane comparatively higher V_{oc}. Further understanding of the role of other process parameters is required to obtain high V_{oc} using TCCVD p-cp layers.

A22.6 N-TYPE AND p-TYPE DOPING OF AMORPHOUS AND MICROCRYSTALLINE SILICON FILMS BY HOT-WIRE CVD AND RF-PECVD AT LOW SUBSTRATE TEMPERATURES ON GLASS AND PLASTIC SUBSTRATES. Antonio Cia, INESC, Instituto de Engenheiria de Sistemas e Computadores, Lisbon, PORTUGAL, J.P. Conde, Department of Materials Engineering, Instituto Superior Tecnico, Lisbon, PORTUGAL.

Deposition of amorphous (a-Si:H) and microcrystalline (µc-Si:H) silicon thin films at very low (<150°C) substrate temperatures is motivated by the necessity of using novel substrates, like plastic, to extend existing areas of microelectronics or to make possible entirely new ones (microwave electronic systems on flexible substrates or integration with organic or biomaterials for biological applications). In this paper, the gas phase deposition of n-SiH and µc-SiH deposited at substrate temperatures, T_{sub}, of 25°C and 100°C by hotwire CVD (HW-CVD) and r-fPECVD on glass and plastic (PET) substrates using hydrogen dilution is studied.

N-type and p-type doped a-Si:H films were obtained by RF using trimethylboron and trimethylborazine as doping gases, respectively, at both T_{sub} = 25°C and 100°C. While p-type samples showed the same conductivity at both T_{sub} = 0.1 - 2 x 10⁻¹⁴ (Ω⁻¹ cm⁻¹) and E_{a} = 0.58 eV, n-type samples showed higher σ at T_{sub} = 0.1 - 10⁻¹⁴ (Ω⁻¹ cm⁻¹) and E_{a} = 0.13 eV. The doping of n-type and µc-Si:H films by HW-CVD at T_{sub} = 25°C and 100°C has so far been successful only in the case of n-type Si:H films. Preliminary work shows that the properties of doped films deposited at low T_{sub} depend critically on the substrate temperature and deposition to substrate distance. Raman, XRD and SIMS will be used to study the structure and composition of these films in connection with its transport properties. Diborane (B₂H₆), due to its easier decomposition into fragments by the HW filament, will be also studied as dopant gas. The quality of the doped layers will be tested by incorporation in Schottky and p-n diodes made on glass and plastic substrates.

A22.7 PHOTODEGRADATION IN n-SiH PREPAIRED BY HOT-WIRE CVD AS A FUNCTION OF SUBSTRATE AND FILM TEMPERATURES. Jing Lin, Guangming Wang, Dept. of Physics & Astronomy, Univ of North Carolina at Chapel Hill, NC; Qi Wang, National Renewable Energy Laboratory, Golden, CO; Daming Hua, Dept. of Physics & Astronomy, Univ of North Carolina at Chapel Hill, Chapel Hill, NC.

Device quality n-SiH prepared by hot wire chemical vapor deposition (HW-CVD) is attractive because of the high deposition rate and improved stability as compared to phosphine-based chemical vapor deposition (PECVD) materials. The device quality films can be deposited at substrate temperature, T_s, ranging from 280 to 440 °C. However, there was more or less photo-degradation effects. In order to optimize deposition conditions for stable materials, we have studied the photo-sensitivity, activation energy and density of defect as well the degradation kinetics for two group of films deposited at temperature range from 280 to 440 °C at film deposition temperature 150°C and 2000 °C. A pair of micro-probe system with vacuum port was used to mount the sample. Light-soaking was performed by a 100 mW/cm² white light through a water filter. The sample temperature was kept at 35 °C during light-soaking. A Keithley 615 programmable electrometer was used to record the current. After a light-soaking exposure time, State A was reached after the sample was annealed in a vacuum for two hours at 150 °C; state B was reached after light-soaking of 28 hours. For these two groups of films, the quality varies with substrate temperature obviously. For the samples deposited at T_s = 280 °C, the photo/dark current ratio was 1.00 at State A and decreased a factor of 8 at state B. For the samples deposited at T_s = 320 °C, the photo/dark current ratio was 1.00 at state A and decreased a factor of 3 at state B. The sample deposited at 150 °C showed the highest dark current ratio with the lowest defect DOS. Interestingly, for all the films deposited at T_s = 320 °C, the Fermi level position was around 0.9 eV below conduction band edge at State A and did not move further downwards even slightly upwards compared to the phosphine-based CVD. This indicates that the defects density distribution in HW is different from PECVD samples.
The work is supported by NREL sub-contractor XAK-8.1769.11 and thin film PV partnership. Lin is supported by Chinese Educational Fellowship. Yue is partially supported by CSF, NSF-Int. Ruan is partially supported by CFP, NSF-Int. Wang is supported by DOE sub-contract DE-AC02-84CH10093.

A22.8

DEVICE QUALITY AMORPHOUS SILICON FILMS GROWN AT RATES UP TO 1 MICRON/MIN BY HOT-WIPE CHEMICAL VAPOR DEPOSITION

Brent P. Nelson, A.H. Malan, Yuejun Xu, R.S. Crandall, Eugene Ivaninac, National Renewable Energy Laboratory, Golden, CO.

We grow hydrogenated amorphous silicon (a-Si:H) from silane gas by hot-wire chemical vapor deposition (HCVD). By using more than one W filament, and decreasing the filament to substrate distance, we are able to increase our deposition rate from our typical single-filament HCVD process of 0.2 microm/min to 150 microm/min. By optimizing our deposition parameters we are able to grow a-Si:H films with AM1.5 photoreponses in excess of 10^7 at deposition rates up to 33 nm/s. This is a significant increase over the 4 nm/s deposition rates we have previously reported for films of the same quality. The main deposition parameters we optimize are the substrate temperature, silane gas flow, chamber pressure, and filament current.

The as-grown dark conductivity of these films is between 10^3 to 10^6 S/cm. The photoconductivity of these films all degrade with light exposure at an average rate of ~5 x 10^-6 S/cm. In this paper, we report other electrical properties of these films as a function of deposition rate. The deep defect density (obtained by dielectric relaxation measurements) of a deposition rate of 0.7 microm/min is less than 4 x 10^15 cm^-3 after degradation by light, similar to that of the low deposition rate HCVD a-Si:H.

SESSION A23: POSTER SESSION

SILICON-CARBON ALLOYS

Chair: John Robertson
Thursday Evening, April 27, 2000
8:00 PM
Salon 7 (Marriott)

A23.1

STRUCTURE AND COMPOSITION OF SiC-H FILMS FORMED BY PLASMA IMMERSION ION IMPLANTATION FROM A METHANE PLASMA. Kerstin Voit, Wolfgang Esslinger, Philips University, Materials Science Center, Marburg, GERMANY.

Plasma Immersion Ion Implantation (PII) of silicon in a methane plasma has been used to form SiC-H films. PII can be a low temperature technique if desired (T < 150 °C). During PII it is possible to controll a complex-shape object from all sides simultaneously, as the workpiece is immersed into the plasma, which contains the ions to be implanted in the plasma not only the silane, but hydrogen ions as well are implanted. In order to determine the concentration-depth distribution of the elements Nuclear Resonance Analysis (NRA) has been applied for the H and Rutherford Backscattering Spectrometry (RBS) has been used to depth profile Si and C. It is shown that by using PII all C/Si ratios of 0-1/10 can be obtained. The H depth profile is shown not to be an implantation profile. Rather, the H depth profile is chemically governed by the C depth distribution. Si with its stoichiometry close to unity can tranup by far the most H. Increasing or lowering the C/Si ratio results in a decreasing trapping possibility for H. The chemical bonding in the layer systems is investigated by using vibrational spectroscopic methods. Infrared spectroscopy indicates that the H is mainly attached to C. The microstructure of the films is investigated in dependence on the film preparation conditions by high resolution transmission electron microscopy. The onset of crystallization of SiC is monitored as a function of the implantation temperature. In this work, a nano-second X-ray nanocrystalline SiC-X samples with a nanocrystalline X-ray nanocrystalline SiC-X samples are found. The results of the structural analysis are correlated to the different trapping behaviour for H in dependence of the temperature.

A23.2

Silicon Carbon Alloys Deposited by Electron Cyclotron Resonance Chemical Vapor Deposition.

Mark B. Moran and Linda F. Johnson, Naval Air Warfare Center, Weapons Division, Naval Aviation Science and Technology Office, China Lake, CA.

Silicon-carbon (SiC) alloys were deposited by electron cyclotron resonance chemical vapor deposition (ECR-CVD) using either trichlorosilane (SiHCl3) or tetrachlorosilane (SiCl4) with either ethylene (C2H4) or tetrachlorotetrahydrothene (C2H4Cld4) in a high-density argon (Ar) plasma. Deposition temperatures ranging from 150 to 750 °C and plasma powers ranging from 600 to 3000 W were explored. A SiC deposited film using SiHCl3, C2H4Cl4 and Ar at 1200 °C and a deposition temperature of about 150 °C is electrically resistive with a resistivity value of about 0.07 ohm-cm. Electron spectroscopy for chemical analysis (ESCA) shows that the atomic Si-C ratio of the films is about 3%. A Fourier transform infrared (FTIR) spectroscopy indicates that the chemical bonding is associated with enhanced electrical conductivity in these SiC alloys. The intense asymmetric stretching mode of single-bonded Si-C which occurs at about 860 cm^-1 is shifted to about 960 cm^-1 in the films. In addition, we find an increase in the intensity of the double-bonded Si-C stretching mode at 1580 cm^-1 increases. Additional results show that etching of the substrate by the plasma can have a dramatic effect on the microstructure, porosity and moisture stability of ECR-CVD films. Plasma containing chlorine (Cl) etch Si wafers rapidly at powers above 2000 W. The C-Si films are more much more stable than Si-C films, because they are deposited at lower plasma powers that do etch the Si substrate. Switching to more C-resistance substrate like sapphire or growing the substrate with Al2O3 should improve the microstructure.

A23.3

DEVICE QUALITY SILICON CARBON THIN FILMS.

Christian Gemmer, Markus B. Schubert, University of Stuttgart, Institute of Physical Electronics, Stuttgart, GERMANY.

For stacked amorphous silicon based solar cells, high quality material for the top cell is of crucial importance to achieve both high efficiencies and high open circuit voltages. Amorphous silicon carbonyl having a gap of about 2.0 eV meets these prerequisites. Thus, the optical, electrical and structural properties of this alloy are subject of our investigations. The deposition of the samples proceeds in a plasma-enhanced chemical vapor deposition system at a frequency of 13.56 MHz and at a substrate temperature of 150°C. The hydrogen dilution ratio rH2 = [H2]/[SiH4]+[CH4]/[SiH4]+[CH4]) ranges in our series of intrinsic silicon carbon films from rH2 = 1 to rH2 = 21 whereas all other deposition parameters and the layer thickness remain constant. The optical gap Eg drops from Eg = 2.26 eV to 2.02 eV as rH2 increases from rH2 = 1 to rH2 = 21. We measure the photocurrent mobility-lifetime product µτ under monochromatic illumination (energy E = 2.26 eV, photon flux ϕ = 2.5 x 10^4 cm^-2 s^-1) and the dark conductivity σd. At rH2 = 10 the µτσd ratio shows a maximum of 1 x 10^6 cm^3 V^-1 s^-1, which originates from a strong increase of µτ. The dark conductivity only ranges between σd = 5 x 10^-14 Ω^-1 m^-1 and σd = 5 x 10^-11 Ω^-1 m^-1. The electrical properties correlate with the structural findings of silicon carbon. In the low hydrogen dilution range of our series (0 < rH2 < 10) the carbon measurements reveal no crystalline fraction Xc whereas the sample prepared with the highest hydrogen dilution (rH2 = 21) shows Xc of 25%. Hence, the transition from amorphous to nanocrystalline phase coincides with rH2 = 10 and rH2 = 21. These results affirm the analogous to amorphous silicon, device quality silicon carbon near the transition from amorphous to nanocrystalline phase.

A23.4

MICROSTRUCTURE CHARACTERIZATION OF AMORPHOUS SILICON BASED ALLOYS BY INFRARED EMISSION STUDIES. W. Beyer, 15-PV, Forschungszentrum Jülich, Jülich, GERMANY, S. Carneiro, Jr., Univ. Federal, Rio de Janeiro, Coppe Inst., BRAZIL. R. Slech, Universidade de São Paulo, Depok, INDONESIA.

One major defect in amorphous silicon-based alloys is an interconnected void structure, as detected e.g. by hydrogen effusion measurements. However, H-effusion measurements give little information about void sizes. In order to obtain knowledge about this important parameter, we implanted inert gases and studied their effusion by effusion experiments. Since these gases interact not to react with silicon, their effusion temperature is expected to be related to the size of network spaces and voids. Results for several series of a-Si:C:H and a-Si:OH samples are presented. The film microstructure is characterized by hydrogen effusion and infrared measurements. While in samples without an interconnected void structure implanted argon and neon atoms effuse at temperatures exceeding 700-800°C, i.e. near or below the crystallization temperature, neon and argon effusion shifts to lower temperature when an interconnected void structure according to H-effusion measurements is present. For plasma-grown a-Si:OH samples with an oxygen concentration near 20%, we find a neon effusion peak near 500°C and an argon peak near 800°C while standard plasma-grown...
Si:SiH films of about 20 nm thick show argon effusion near 500°C, suggesting that the void size in the latter case. On the other hand, for the monochromatic Si:SiH films plasma deposited under conditions of high carbon content, the effusion results suggest the presence of smaller voids similar in size as observed for the void-rich Si-OH samples. In this case, the void size is found to increase an increasing carbon concentration. Observation of impurities and implications on the structure of as-Si-based alloys will be discussed.

A 23.5

P-TYPE MICROCRYSTALLINE SILICON CARBON ALLOY FILMS BY VHF-PECVD TECHNIQUE. Tapati Jana, Arup Dasgupta and Srini Ray. Energy Research Unit, Indian Association for the Cultivation of Science, INDIA; Freidhelm Finger and R. Carus, ISF-JV, GERMANY.

P-type μc-Si:H layer having high conductivity and transparency can effectively replace doped amorphous window layers of the p-i-n solar cell. Its potential and promising series resistance. Now the very high frequency (VHF) PECVD technique becomes very much important for the growth of microcrystalline material, leading to high quality material at low power and low deposition temperature with high deposition rate. However, p-type μc-Si:H films having high optical transparency than μc-Si:H material with high conductivity can also be used as the window layer of p-i-n solar cells to improve the conversion efficiency. But till date only a limited work on μc-Si:H films by VHF-PECVD has been reported.

The samples were prepared in a capacitively coupled multichamber PECVD system with plasma excitation frequencies between 13.56 to 120 MHz using silane [SiH₄] and dichlorine CH₂H₂. The effect of substrate temperature and plasma excitation frequency on the electrical and structural properties was investigated at a low power of 55 mW/cm². The initial decrease of substrate temperature from 250°C to 200°C at 500°C increases the density of defects from 1.8 GHz cm⁻³, where as further lowering of substrate temperature decreases the conductivity again.

The optical absorption decreases continuously with the decrease of substrate temperature. At higher substrate temperature, hydrogenation radicak C from the growing surface and liberated in CH₂. Whereas, at sufficiently low substrate temperature (150°C) desorption of H from the surface is low as a result more hydrocarbon radicals may be adsorbed on the growing surface. As the substrate temperature decreases from 250°C to 200°C the conductivity increases due to better crystalline structure and the lowering of absorption is accompanied by increase in carbon incorporation as well as improvement in crystallinity as shown. However, further lowering of temperature (180°C to 150°C) suggest that there has been a remarkable increase of carbon content in the film which suppresses the increase of absorption due to loss of crystallinity, as a result σₒ decreases. The grain size has been calculated from the TEM micrograph. The diffraction pattern shows well defined crystallographic planes of c-Si. The frequency variation at 180°C shows that optimum frequency is 81 MHz having 2:32 GHz cm⁻³ conductivity and 26 Å deposition rate for an optical gap of 2.00 eV. Whereas, at frequency under the same deposition conditions, materials becomes amorphous.

A 23.6

Abstract Withdrawn.

A 23.7

EFFECTS OF THERMAL ANNEALING ON THE PROPERTIES OF PECD-Si:SiH VLSI ELECTRONICS. L.F. Málaga, J. Palacios, Departamento de Ingeniería Electrónica, Universitat Rovira i Virgili, Tarragona, SPAIN; A. Orpella, D. Bardeis, J. Piugdollers and R. Alcubilla, Departamento de Ingeniería Electrónica, Universitat Politécnica de Catalunya, Barcelona, SPAIN.

Hydrogenated amorphous silicon carbon alloys deposited by Plasma Enhanced Chemical Vapour Deposition (PECVD) are of great interest because they are deposited at low temperature on large area substrates. Main applications are wide band gap emitter in bipolar transistors, thin film transistors, solar cells, displays, etc. [1] However, amorphous silicon carbon alloys (a-SiC) have a high density of states and high resistivity. One of the approaches to improve the properties is to promote crystallites formation in the amorphous film through thermal annealing. Nano or microcrystalline regions within the amorphous network increase the electrical conductivity and reduce the state density. One of the most promising approaches is the use of plasma enhanced chemical vapor deposition (PECVD) to deposit a-SiC:H films. In this work, we present the characterization of hydrogenated amorphous and nanocrystalline silicon-carbon films, the knowledge and comparability of the physical properties is difficult because the depend strongly on the preparation conditions and on the particular process used for deposition. In this work, we report the structural characterization of hydrogenated amorphous and nanocrystalline silicon-carbon alloys layers at different temperatures by using Raman and Fourier Transform Infrared Spectroscopy (FTIR). In addition, the optical properties obtained by Photothermal Deflection Spectroscopy (PDS) and Optical Transmission Spectroscopy (OTS) are also reported. REFERENCES [1] Kancz, Amorphous and micro-

SESSION 23: POSTER SESSION

CLUSTERS, NANOCRYSTALS, AND POROUS MATERIALS

Chair: Arthur Yelon and Reinhard Gruis

Thursday, April 27, 2000

Salon 7 (Marriott)

A 24.1

DEPOSITION OF SILICON CLUSTERS ON SILICON: A MOLECULAR DYNAMICS STUDY. A.M. Mazzore, C.N.R.-Istituto LAMEL, Bologna, ITALY.

The synthesis of nanostructured material is of primary technological importance. Preparation of this material can be achieved by depositing elementary units or already formed units onto a support. This last possibility has stimulated the interest on the physics of cluster deposition and theory and experiments show a wealth of new phenomena. This study presents molecular dynamics simulation of deposition of silicon clusters on a silicon substrate with a [100] surface. The package is to gain insight into cluster-cluster coalescence, cluster-abliteration and surface interaction and diffusion. We are specifically concerned with the structural aspects of these mechanisms and the aim of the simulations is to clarify whether or not crystallinity in the growing film may be sustained by properly selected cluster size and deposition temperature.

A 24.2

MECHANICAL CHARACTERIZATION OF SIC ISLANDS AND THIN FILM HETEROSTRUCTURES BY ULTRASONIC FORCE MICROSCOPY. Bryan D. Haug, G. Andrew D. Briggs, Ole V. Kolosov, Oxford University, Department of Materials, Oxford, UNITED KINGDOM.

The capability to measure nanoscale mechanical properties is vital for the continued miniaturization and hybridization of semiconductor devices, microelectromechanical systems, chemical sensors, etc. Frequently these properties can be significantly modified by the presence of materials in the nanoscale regime. Studies of mechanical properties at the nanoscale can be performed using the non-linear detection of oscillating surface forces in an atomic force microscope during ultrasonic oscillation on a silicon wafer [1]. These experimental results are compared with simulations from a new surface mechanics interacts (Hertz, JKR, ESAG) and experimental parameters (load, cantilever tip effects). UFM can therefore be used to characterize low volume mechanical properties of thin film heterostructures.

A 24.3

SPECTROSCOPIC ELLIPSOMETRY FOR THE CHARACTERIZATION OF THE MORPHOLOGY OF ULTRA-ThIN THERMAL CVD AMORPHOUS AND NANOCRYSTALINE SILICON THIN FILMS. Hiroshi Uchida, Katsuyuki Yamamuro, Isao Sakuma, Toshiaki Tsumi, Tatsuro Mihara, Hiroshi Tabuchi, and Eiichi Suzuki, Electrotechnical Laboratory, Electronic Devices Division, Tsukuba, Ibaraki, JAPAN.

Thermal CVD (chemical vapor deposition) μc-Si:H films can be dense and have flat surfaces due to the absence of ion bombardment during growth, and thus can be a candidate for a thin film material in the fabrication of novel quantum of memory devices. In the present study we have introduced for the first time spectroscopic ellipsometry (SE) to find out optical functions and structural properties of ultrathin thermal CVD μc-Si:H and to study the formation processes of nanocrystalline Si from μc-Si:H by rapid thermal annealing/oxidation (RTA/RTO) processes. A new characterization i.e., the combination of Sellmeyer law and the four Lorentzian peaks, has been successfully introduced in data analysis. Widths of peaks are directly related with the change of optical functions with the μc-Si:H film thickness. It has been clarified that the dense Si matrix with smaller degree of disorder is formed when the film thickness exceeds 8 nm and the films with the thickness less than 3.5 nm becomes voided, which suggests that the presence of Si clusters takes place around this thickness during growth. It has also been confirmed that ultrathin thermal CVD μc-Si:H films have smooth surfaces and expected. The formation of Si nanocrystals from ultrathin thermal CVD μc-Si:H films by RTA/RTO processes has also been studied by SE. Three layer model consisting of poly-Si + void, μc-Si:H + void, and SiO₂ has been adopted to interpret the data. It has been shown that the formation process of nanocrystalline Si can be systematically
controlled by the morphology of starting n-Si:H films and RTA/RTA conditions.

A 24.4 TEM AND HREM STUDY OF SILICON AND PLATINUM NANOSCALE ENSEMBLES IN 3D DIELECTRIC OPAL MATRIX. N.A. Fedorov, D.V. Efros, D. Nitze, C. Söndergaard, L. M. Scrogin, Ioffe Physico-Technical Institute, St. Petersburg, Russia, J.L. Hutchison, J. Sloan, Department of Materials, Oxford University, Oxford, UNITED KINGDOM.

One of the promising methods of nanoscale engineering is based on filling of the dielectric matrix, possessing by a regular void structure, with metals or semiconductor. It allows obtaining regular 3D cluster systems with the cluster size from 1 to 100 nm and density of elements as high as $10^{17}$ cm$^{-3}$. In the present work regular systems of silicon and platinum clusters have been fabricated in a void substrate of artificial SiO$_2$ opal. The opal consisted of 256 nm diameter close packed amorphous silicon spheres and had the regular interstitial voids (45-90 nm) up to 26% accessible to filling by other substances. To incorporate silicon into opal voids the thermal CVD technique was used [1]. The fill factor of opal pores was varied by the parameters of the thermal CVD process. The samples were filled with platinum from a solution of platinum tetrachloride in ethanol to fabricate metal contacts to silicon. The detailed TEM and HREM structure study of “opals-Si” and “opals-Pt-Si” composites was carried out using electron microscopes JEM4000FXII and JEM2010EX. The microstructure images both in diffraction contrast and high-resolution modes were taken. It was found that in composites “opals-Si” the silicon spheres were surrounded by platinum and in composites “opals-Pt-Si” the silicon particles were included in a platinum layer with thickness ranging in 0 - 25 nm. Volume fraction of nanocrystalline silicon was increased up to 50% by thermal annealing and Si monocrystals with linear sizes about 300 nm were fabricated. To form contacts the silicon spheres were coated with a uniform 5 nm-thick platinum film before incorporation of silicon. The results obtained demonstrate a possibility of creating 3D multilayer semiconductor electronic structures [p-n junctions, Shottky barriers] on the inner surface of opal voids. D.N.C. Bogomolov, V.G. Goheber, N.F. Kartenko, D.A. Kurdyukov, A.B. Pavlov et al., Techn. Phys. Lett., 24, 326 (1998).

A 24.5 THERMAL CRYSTALLIZATION OF NANOMETRIC PARTICLES OF Si:C:N PRODUCED BY RF-PLASMA ENHANCED CHEMICAL-VAPOR-DEPOSITION E. Bertran, G. Viera, M.C. Polo, E. Garcia Casaux, Universitat de Barcelona, Depart Fisica Aplicada i Optica, Barcelona, SPAIN; D. Das, J. Forja, Universitat de Girona, Dept Fisica, Girona, SPAIN.

The compatible technology for producing Si-based materials both in the form of thin films and nanometric particles opens new possibilities, as it is the case of heterogeneous thin films based on nanocrystals of Si-alloys embedded in amorphous matrix, which have potential applications at low temperature resistant films, buffer layers, amorphous thin films or inorganic membranes. Before inserting nanocrystals in an amorphous matrix, we have carried out a preliminary study, in which nanometric particles of Si, Si:N, Si:C and Si:N:C were grown at 1000°C. An increase in carbon content from mixtures of silane, methane and ammonia. Among the diverse conditions for particle formation, we chose moderate low pressure (below 100Pa) and RF-power lower than 200W in all the cases. The particle size was controlled by a low frequency square-wave modulation of the RF-power in order to get a narrow size-distribution in the 3-10 nm range. Depending on the conditions used during the plasma process mainly due to the bombardment and the gas dilution, we can vary the structure of the nanometric particles from polymeric (amorphous) to crystalline. To study the thermal crystallization process of the particles, the RF-plasma conditions were tuned to have polymeric particles with a high yield. The annealing of these particles at 1400°C during one hour under argon or nitrogen led to different results depending on the composition of the samples as revealed by HRTEM and electron-diffraction analysis. SiCN particles developed nanocrystals for the amorphous matrix, Si:C particles showed a notable internal crystallization and Si:N remained amorphous. In the case of Si:C particles, the results depended strongly on the atmosphere: they resulted fully crystallized in argon, whereas, in nitrogen atmosphere were long whiskers 50-200 nm wide of the α-Si:C:N phase grew from the particles.

A 24.6 X-RAY OF SINGLE CRYSTALINE SILICON DOTS ON CURVED SUBSTRATE FOR OPTICAL IMAGING APPLICATIONS Hyun-Chul Jin and John R. Ahlborn, Univ. of Illinois, Dept. of Materials Science and Engineering, Materials Research Laboratory, and the Coordinated Science Laboratory, Urbana, IL; Mark K. Erhard and Ron Nuzzo, Dept. of Chemistry and the Materials Research Laboratory, Urbana, IL; Robert S. Sposili and James S. Im, Columbia University, Materials Science and Metallurgy Program, New York, NY.

We have fabricated an array of single crystalline silicon dots (islands) on a curved glass substrate using soft lithographic patterning and pulsed excimer laser crystallization. The polymer template with an inverted copy of the dots is first patterned on glass using MICM (micromolding in capillaries) and a 0.1 µm thick hydrogen-free amorphous silicon layer is subsequently deposited by dc magnetron sputtering at 125°C. Finally the dots are formed by liftoff, and selectively excimer crystallized by pulsed laser excimer sequential lateral solidification (SLS). In the pulsed excimer laser processing with SLS, the melt/crystallization zone has a defined shape in the plane of the substrate, and is laterally translated to produce a continuous single crystal silicon layer. We have fabricated an array of dots on a curved glass substrate without the complicated optical setup which would be required to use projection photolithography. In the soft lithography technique, a polymer template is formed by (i) placing an electron-beam-claymold against the curved glass and (ii) injecting a pre-polymer into microchannels on the mold. Upon curing the pre-polymer and removing the mold, this leaves the desired pattern. We produce an array of 50 µm diameter islands, spaced 200 µm apart. We characterize the structural and electrical properties of these islands, and will discuss application of this structure.

A 24.7 MULTI-BAND ELECTRON PARAMAGNETIC RESONANCE STUDY OF MICROCRYSTALLINE OR CLUSTER SILICON ENVELOPED IN SiO$_2$. Akhara, Ishinomiya, School of Science and Engineering, Ishinomiya, Japan; Tadashi Ikoma, Shozo Turo-Kubota, Tohoku University, Institute for Chemical Reaction Science, Sendai, Japan.

Dangling bond defects in the silicon grains embedded in SiO$_2$ have been studied by X- and Q-band electron paramagnetic resonance (EPR) spectroscopy. Cluster and microcrystalline silicon grains in the SiO$_2$ thin film were prepared by co-sputtering of silicon and oxygen followed by thermal annealing. It has been clarified from the Raman spectra that the microcrystalline silicon has been produced at an annealing temperature of 1000°C, while the clusters have been formed after annealing at 800 or 900°C. A charge state-unresolved EPR signal with the line width of 13 G and the average g-value of 2.006 was observed in the microcrystalline containing film. The line width observed in the Q-band EPR is 2.6 times of that in the X-band. The signal can be simulated by using the anisotropic g-values of g$_{zz}$ = 2.0022 and g$_{xx}$ = 2.0108. The g-values of the defects in the silicon clusters was determined to be g = 2.0135, and g$_{zz}$ = 2.0100, g$_{xx}$ = 2.0045 in SiO$_2$, respectively, in the sample annealed at 600°C by Q-band.

A 24.8 OPTICAL AND STRUCTURAL PROPERTIES OF Si NANOCRYSTAL ARRAYS FORMED BY ULTRA LOW ENERGY Si IMPLANT INTO THIN GATE OXIDES. S. Coffa, E. Castagnoli, C. Bogomolov, CNR-IMETEM, Genoa, ITALY; D. Fiore, S.TMicroelectronics, Genoa, ITALY.

Advanced electronics and opto-electronics devices can be fabricated using wire carrier confinement and Coulomb blockade effects in Si quantum dots. In this work we show that a ultra low energy (< 5keV) Si implantation into thin (5±10 nm) oxides is a suitable technique for producing a well localized array of small (1.3 nm in diameter) Si nanocrystals with a sharp size distribution. Thermally grown SiO$_2$ layers were implanted with 0.5 keV Si ions to fluences of 5x10$^{12}$ - 5x10$^{15}$ ions/cm$^2$ and annealed at temperatures of 800-1150°C for times up to 4 hrs. Transmission electron microscopy (TEM) measurements show that, when the Si peak concentration is below 1x10$^{15}$ ions/cm$^2$, annealing at T > 1000°C is necessary in order to form Si nanocrystals. Their size distribution is critically dependent on the implanted fluence and no significant ripening is observed after their nucleation. Photoluminescence (PL) measurements reveals strong light emission in the 600-800 nm range which can be unambiguously associated to the recombination of confined excitons. A strong correlation between the grain size distribution and the PL lineshape has been found. When the Si peak concentration exceeds ~3x10$^{15}$ ions/cm$^2$ a buried planar Si layer is formed even when the implantation procedure is carried out at temperatures as low as 900°C. This striking reduction in the thermal budget is due to the coexistence of the high density of small Si aggregates formed at the Si projected range. The depth location of this layer is determined by the Si energy and its width is equal to the range of the ions. Post oxidation of these layers in N$_2$O$_2$ ambient produces the separation of the Si monocrystals and the formation of an array of Si.
quantum dots with an extremely sharp size distribution. The advantage of this approach with respect to alternative methods such as chemical vapour deposition or aerosol techniques are elucidated.


Structural study of nc-Si layers formed by high fluence hydrogen or deuterium implantation (up to ~5x10^{17} cm^{-2}) using high current beams with means of current up to 4 mA/cm^{2} was carried out in the present work. The nc-Si:H(D) silicon films were characterized using FTIR spectroscopy, spectroscopic ellipsometry, transmission electron microscopy and secondary ion mass spectrometry. Hydrogen solubility in crystalline silicon is low but ion implantation allows introducing of 10^{22} cm^{-3} of the hydrogen atoms or even more in thin silicon layer. High defect concentration in combination with the very active hydrogen impurity causes the formation of mixed amorphous and nanocrystalline phases with pores similar to porous silicon produced by electrochemical etching. The formation of optical properties of these films during annealing in temperature range of 200-1050°C was investigated. The changes in optical characteristics and number of Si-H or Si-D bonds in the spectra of IR absorption is correlated with the increase in crystalline sizes with a temperature.

A 24.10 ELECTROREFLECTANCE STUDY OF LIGHT-EMITTING POROUS SILICON THIN FILMS. Toshikiko Teyama, Akihito Shimode, Hiroaki Okamoto, Dept. of Physical Science, Graduate School of Engineering Science, Osaka University, Toyonaka, Japan.

Electroreflectance (ER) spectroscopy is a powerful tool for a precise analysis on optical transitions in nanocrystalline Si (nc-Si) [1]. We have measured the ER spectrum of light-emitting porous Si (LPS) which is the most intensively studied nc-Si, and found 4 transition bands in the ER spectrum. The LPS thin films were made by modification in HF aqueous solution (5000H2O:D1 = 1:1) from yttrium-doped polycrystalline Si (100) substrates at different resistivities of 0.018, 0.1, and 4-10 ohm cm. The modifying current density was 147.8 mA/cm^{2} and the modifying time was determined by the LPS thickness of 350-100 nm (typical 1-5 sec). Visible photoluminescence (PL) at ~325 nm is observed with a peak energy of ~1.6 eV and the PL intensity is increased with an increase in the resistivity of the c-Si substrate. The ER features are observed at 260 K at photon energies of ~1.2, ~1.9, ~2.9, and ~3.4 eV. The 2.9 eV ER feature would be attributed to the direct-to-Valence optical transitions at the fundamental gap of LPS as found in that of nc-Si thin films made by plasma-CVD and post-modification [1]. The 3.4 eV ER feature was found from direct transitions at the E_{2g} (E_{1g}) gap of LPS as found in both the nc-Si thin films and c-Si. Whereas the 1.6 eV and 2.8 eV ER features have been found in the nc-Si thin films nor c-Si. The ER signal of LPS made from 0.018 ohm cm substrate is different from those made from 0.1 ohm cm substrate with higher resistivity, the 3.4 eV ER feature seems to be shifted toward lower energies and the ER signal is quite intense. 1. T. Teyama et al., Appl. Phys. Lett. 74, 3328 (1999), Mater. Res. Soc. Symp. Proc. 557 (in press).

SESSION A 25 POSTER SESSION: CRYSTALLIZATION II
Chair: Wollard Beyrer
Thursday Evening, April 27, 2000
8:00 PM
Salon 7 (Mariott)

A 25.1 AFLM AND HREM OBSERVATION OF PULSED LASER INTERFERENCE CRYSTALLIZED nc-Si:H/α-SiN_{x}H MULTILAYERS. Li Wang, Xinfan Huang, Jun Li, Jun Xu, Qilin Li, Xinxian Yu, Wenhe Fan, Wei Li, Jianning Zhu, Mu Wang, Zhigao Liu, Kunji Chen National Lab of Solid State Microstructure and Department of Physics, Nanguang University, Nanguang, PR. CHINA.

Nanocrystalline crystalline silicon (nc-Si) has attracted wide attention due to the possibility of a multigeneration quantum size effect. In nc-Si systems, the visible photoemission (PL) and electromoluminescence (EL) have been reported. Although a great progress has been accomplished in the investigation of nc-Si systems, some difficulties, such as how to accurately control the size and the location of nc-Si, are still present in the fabrication and investigation of nc-Si. Based on the present works on the constrained crystallization of amorphous silicon [1], we employed a KrF excimer pulsed laser source through a phase shifting mask grating to irradiate a-Si:H/α-SiN_{x}H multilayers to achieve the control of the size and the location of nc-Si. The a-Si:H/α-SiN_{x}H multilayers were deposited on silicon or fused quartz substrate by co-evaporation at 100°C and then annealed in an improved chemical vapor deposition (PECVD) technique. The sublayer thickness of samples was 5 nm for a-Si:H and 10 nm for α-SiN_{x}H, respectively. A KrF (λ = 248 nm) excimer pulser with a 200 fs pulse length and 100 kHz repetition rate was used. The irradiation processes were performed in air at room temperature. AFM images of the irradiated samples show that under all laser energy density used in this paper, the stripes corresponding to the irradiated regions are present on the surfaces of the samples with the same periodicity of the phase-shift grating mask, 2.0 μm. And under higher laser density, 300 mA/cm^{2}, the surfaces of the irradiated samples were seriously damaged. In the micro-Raman spectrum of the irradiated nanocrystalline silicon, a broad peak attributed to amorphous silicon has been observed in the non-irradiated regions and a weak shoulder attributed to nc-Si is present in the irradiated regions. TEM and HREM observations show that nc-Si are formed and the size of nc-Si is determined by the thickness of a-Si:H sublayer. Moreover, the distribution of nc-Si has the periodicity of 2 μm in transverse direction and 10 nm in longitudinal direction. The visible PL and EL have been also observed in laser interference crystallized a-Si:H/α-SiN_{x}H multilayers. The origin and difference between PL and EL is briefly discussed in this paper. [1] K.J. Chen, X.P. Huang, J. Xu and D. Peng, Appl. Phys. Letts. 61, 1009 (1992).

A 25.2 POLYSILICON THIN FILMS OBTAINED BY CVD AND PULSED LASER CRYSTALLIZATION SOURCES FOR TFT ACTIVE LAYER. Gasper Žgank, M.L. Addonizio, P. delli Veneri, A. Ippolito, C. Minervi, E. Terzini, ENEA Research Center, Pontinia, ITALY.

Polysilicon thin films, obtained by Laser Induced Crystallization, are very promising materials for low cost realization of Thin Film Transistor (TFT) and thin film solar cells. This work reports on the comparison between polysilicon thin films obtained by pulsed Ni-YL lamp and cw Ar+ laser crystallization of amorphous silicon thin films. The starting intrinsic and Si doped materials have been deposited on Corning 1737 glass by LPCVD technique at a deposition temperature of 570°C. The film thickness range is 50-200 nm. A Q switched diode pumped, frequency-doubled Ni-YL lamp at 320 nm wavelength and a cw Ar+ laser, at 514 nm wavelength, having a power of 2W, have been used for crystallization process. The influence of laser power, scanning speed on material properties has been evaluated for both the laser sources. Electrical and optical properties of as-deposited and crystallized films have been determined. SEM analysis of Secco etched crystallized material have been used to evaluate grain size and their distribution. Film structure and crystallite size have been analyzed by XRD and XPS spectroscopy. The main results of crystallization controlled by power and energy of the source are in the larger grain size observed in the intrinsic material compared with n type material. Grain size of about 1 μm was obtained on intrinsic material having thickness of 50 μm, utilizing an energy density of 600 mA/cm^{2} 50 μm and an overlapped energy density of 400 mA/cm^{2} 70 μm. The crystallization data of cw source crystallization realized at different scanning speed and at a power of 550 mW point out a wide distribution of grain size in the 45-300 nm range achieved on intrinsic material with thickness of 100 nm. Further investigation is under way in order to improve the cw laser crystallization process by optimizing the optical system and by holding the substrate during irradiation.

A 25.3 EXCIMER LASER RECRYSTALLIZATION OF α-SI EMPLYING ALUMINUM MASKING WINDOW. Jae-Hong Jeon, Min-Choel Lee, Sang-Heon Jung, Min-Koo Han, Seoul National University, School of Electrical Engineering, Seoul, South Korea.

Excimer laser recrystallization of amorphous silicon (α-Si) film is widely used for the fabrication of polycrystalline thin film transistors (poly-Si TFTs). In order to improve the characteristics of poly-Si TFT, the number of poly-Si grain boundaries should be reduced by increasing the grain size. It has already been reported that the lateral temperature gradient in molten α-Si film induces the lateral grain growth, so that the grain size could be increased considerably. Recently, we have reported that an employment of the masking window during laser irradiation induces the lateral temperature gradient effectively. Our previous experimental results verified that the lateral grain growth took place near the edge of the masking window due to an abrupt temperature difference between molten α-Si and unmasked α-Si. The purpose of our work is to report that a metal masking window, which is directly deposited and patterned on α-Si film, increases the lateral growth rate because the conductive metal pattern cook down the unmasked solid region so the
internal temperature gradient becomes more significant. We employed 3000 Å thick aluminum (Al) layer for the masking material. Aluminum exhibits high optical reflectance exceeding 90% at 380 nm, the wave length of XeCl excimer laser, so it is suitable for the masking pattern. We examined the grain growth with two types of samples using TEM observation. The one employs an intermediate oxide layer, which is thermally insulating material, between Al masking pattern and a-Si film, and the other has direct contact of Al pattern with a-Si film. After laser irradiation, the sample without the intermediate oxide showed the considerably enhanced grain size in micrometer order near the edge of masking pattern, compared with the sample with the intermediate oxide. This result may be attributed to the enhanced temperature gradient in the sample where a-Si film directly contacts with high thermal-conductive metal pattern. We will also report TFT characteristics fabricated by the proposed method.

A 25.4 THE REGULAR ARRANGEMENT OF ENLARGED POLY-Si GRAINS BY SELECTIVE SI ION-IMPLANTATION AND EXCIMER LASER ANNEALING. Min-Ched Lee, Joo-Hong Jeon, Jin-Woo Park, Min-Koo Han, Seoul National Univ., School of Electrical Engineering, Seoul, KOREA.

Polycrystalline silicon (poly-Si) film with low defect density and uniform grain size is essential to fabricate the high performance poly-Si TFTs for AMLCD application. To improve the uniformity of poly-Si film, several investigations have been focused on the ion-implantation and high temperature thermal annealing. It is well known that ion-implantation with high acceleration energy may form artificial nucleation seeds in amorphous silicon film. Following thermal annealing at around 600°C could increase the grain size larger than 1 micrometer and arrange the poly-Si grains rather uniformly. However, this technique cannot be applied to the low temperature poly-Si TFTs fabrication on glass substrate due to thermal damage. We propose the new laser annealing method to obtain the reproducible low temperature poly-Si film with low defect density and large grain employing the combination of the selective self ion-implantation and excimer laser annealing. Selective self-ion-implantation is utilized to form artificial nucleation seeds in a-Si film prior to excimer laser annealing. Through specifically designed implantation mask, we could control the grain boundary location in poly-Si film and then increase the grain size in a specific area without any other treatment. We observed the grain boundary distribution in the excimer laser annealed film by TEM and crystallinity of the enlarged grain by TEM diffraction image. In our poly-Si film, we observed well arranged grains in which the size is larger than 1 micrometer. We fabricated poly-Si TFTs successfully employing the proposed excimer laser annealing method and measured the performance of poly-Si TFTs. Our experimental data shows that field-effect-mobility is 5 times higher than that of TFT fabricated by conventional excimer laser annealing method and leakage current of new TFT is 2 order lower than that of the conventional TFT due to low defect density.

SESSION 26: POSTER SESSION

HYDROGEN

Chair: P. Craig Taylor and Jang I. Dijkhuis
Thursday Evening, April 27, 2000
8:00 PM
Salon 7 (Merriot)

A 26.1 HYDROGEN INCORPORATION IN n-Si: AN AB INITIO SUPERCELL APPROACH. Fernando Alvarado, Ariel A. Valdeschines, UNAM, Instituto de Investigaciones en Materiales, Mexico DF, MEXICO.

We have carried out extensive ab initio study of hydrogen incorporation in amorphous silicon supercells that contain at least 64 atoms. Hydrogen were placed evenly distributed throughout the cells, with and without voids, which were then annealed at 300 and 400 K and quenched to 0 K using the Fast Structure Simulated Annealing code of MSI. Results will be presented concerning the dynamics of the hydrogen atoms both as a function of annealing temperatures and the presence of voids. The effect of hydrogen incorporation on the radial distribution functions and the electronic structures of the cells will be reported.

A 26.2 TRAPPED MOLECULAR HYDROGEN IN n-Si:H. R.E. Norberg, D.J. Leoquad, P.A. Reddick, R. Borel, P.H. Chen, J. Hergen, N. Tomic, Department of Physics, Washington University, St. Louis, MO.

Proton-29Si double resonance NMR measurements on high quality plasma-enhanced chemical vapor deposition a-Si:H deposited from SiH4 show that more than one third of the contained hydrogen is present as H2 molecules residing in the amorphous equivalent of T

sites. The NMR signal from these trapped H2 appears primarily in the narrow 2 kHz proton line, which arises from the less clustered hydrogen population. Very little of the molecular component is in the broad ~ 2kHz line, which is mostly comprised of clustered hydrogen tightly bonded to silicon.

A 26.3 A STUDY OF NON-INFRARED ACTIVE HYDROGEN BONDING IN n-Si:H THIN FILM USING COMBINED CALIBRATED TEMPERATURE DESORPTION SPECTROSCOPY AND FTIR. D. Marini, J.C. Corno, Murdoch University, Dept of Physics and Energy Studies, Perth, AUSTRALIA.

Problems which have not been completely resolved in the n-Si:H based solar cells arise from the microstructural degradation caused by Steiner-Wronski effect (SWE). Hydrogen concentration and its bonding configuration in the film play a significant role in the stability and performance of the devices. A transmission FTIR technique has been adopted to calculate hydrogen concentrations and the SWE-activity of the bonding hydrogen in the n-Si:H films. However, some samples trapped in the film structure may not be detected by means of FTIR technique. This phenomenon was observed during light-soaking experiment, where the peak at 680 cm⁻¹ increases during the first 10 hours. This may be explained if non-IR active hydrogen is present in the film and is converted to active Si-H bonds by photon interactions. This work describes a combined method of FTIR and calibrated TDS to measure quantitatively the hydrogen released from the film. Temperature Desorption Spectroscopy (TDS) as a complementary technique is used to analyze the structure of the film. This technique has previously been a qualitative measurement and has not been used to calculate the hydrogen concentration. The non-infrared hydrogen species will be investigated by analyzing the infrared spectra and the TDS spectra of hydrogen released during the annealing or degrading process in four stages. Samples will be exposed to light and then annealed at 180°C and degraded gradually using a linear temperature ramp (5°C)/h. At each stage corresponds to a temperature at which the hydrogen effusion peaks can be found (~580°C, ~450°C, ~575°C, and ~700°C). Differences in the amounts of hydrogen obtained from the TDS spectra and the TDS measurement correspond to the non-IR active occluded hydrogen.

A 26.4 TO STUDY THE HYDROGEN DISTRIBUTION IN THE SURFACE, BULK AND INTERFACE OF n-Si:H FILMS EMPLOYING THE INFRARED SPECTROSCOPY. G. Tahakder, J.C. Corno, P.J. Jennings, Department of Physics and Energy Studies, School of MPS, Murdoch University, Murdoch, WA, AUSTRALIA.

We present the characterisation of both sputtered and GD samples of n-Si:H through thermal hydrogen desorption and infrared spectroscopies. Both types of samples were deposited onto crystalline silicon substrates held at ~100°C. However, depending on other deposition parameters, the sputtered samples contained predominantly, the higher hydrides, whereas, the GD samples contained, predominantly, the mono-hydride. In fact, we have studied the effects of thickness on the (ir) spectra and those of annealing on both the thermal effusion (TE) and (ir) spectra of sputtered n-Si:H samples. From the results obtained and in a comparison of the ir spectra of sputtered and GD samples, we have found the distribution of different configurations of Si and H in the n-Si:H films. Thus, we have demonstrated how we can analyze the infrared absorption spectra (or infrared spectroscopy) to get information about the distribution of hydrogen in the surface, bulk and substrate-film interface of n-Si:H films.

A 26.5 FAST IN-DIFFUSION OF HYDROGEN AT THE INITIAL STAGE OF HYDROGEN PLASMA TREATMENT ON n-Si:H FILMS OBSERVED BY IN-SITU ESR MEASUREMENTS. Ujiwal Kaila, Tetsuji Yasuda, Shoji Yamanaka, Japan Research Center for Atom Technology, NAIIR, Tsukuba, Ibaraki, JAPAN.

Time evolution of Si dangling bonds (DBs) in hydrogenated amorphous silicon (a-Si:H) has been suggested as an important factor in hydrogen plasma treatment using in-situ ESR technique, in which a high diffusion coefficient of hydrogen atoms (D_H) was detected at the very initial stage of hydrogen plasma treatment. A remote H plasma, triggered by a high intensity power of 50 W, was used to treat the films in the ESR cavity. Apart from the DB terminating properties of H, it can create DBs as well and eventually some additional DBs (ΔNDBs) are observed during H treatment. These additional DBs are not created only at the top surface, but a spatial distribution of (ΔNDBs) is sensitive from the film thickness dependence of H treatment study. From the time evolution of dangling bond it is speculated that the atomic H initially diffuses very fast (D_H > 10⁻¹⁰ cm²/s at ~ 200°C) and then is preserved by SiH4 study after long time deuteron plasma treatment of n-Si:H) to some depth of the...
film and react with the network to form dibs. The characteristic depth of the dib distribution is found to be ~0.3 nm at a H treatment temperature of 200°C. Interestingly, the depth of dib distribution increases with the decrease of H treatment temperature and does not depend on the film deposition temperature, varied in the range of 80°C-210°C. Such a temperature dependence of dib distribution suggests that the spatial variation of dib is not controlled by any possible increase in the diffusion coefficient of H with temperature, rather it is determined by the activated type of cross section of the reactions between H and the Si-H network.


We have found that hot-wire (HW) deposited amorphous and heteroepitaxial silicon films can be deuterated to anomalously high concentrations using atomic deuterium as produced by the dissociation of D2 at a hot wire. Usually, hydrogen in amorphous silicon films can be substituted by deuterium through hydrogen migration into strained Si-Si bonds [1]. Remarkably, in HW material we find a substantial supplementary incorporation of deuterium. For instance, HW-deposited amorphous silicon with an as deposited hydrogen content of 8 at. % exhibits a deuterium content of more than 12 at. % after hot-wire hydrogenation at 350°C, while a residual amount of 1 at. % of hydrogen is still present. The diffusion coefficient of deuterium at 350°C in this material is measured to be in the order of $10^{-15}$ cm$^2$/s, similar to what is found in glow-discharge deposited amorphous silicon in this temperature regime. 

Techniques applied are elastic recoil detection (ERD) for hydrogen/deuterium and depth profiling, infrared spectroscopy and Raman spectroscopy.

The investigations of the behaviour of hydrogen/deuterium in HW deposited silicon have been carried out since the bonding characteristics of the residual microstructure of the material is of crucial importance for its (sometimes) excellent device performance. Specifically, the field-effect stability in transistors based on hot-wire deposited silicon is strikingly good [2]. Our results on HW incorporated hydrogen/deuterium indeed indicate the peculiar character of HW deposited silicon and HW processing.


A 26.7 DIFFUSION OF HYDROGEN AND DEUTERIUM IN STACK SYSTEMS OF SiNc/Nh/Sl/Nh/D, AND CRYSTALINE Si: Christoph Boehme, Gerald Lucey, North Carolina State University, Department of Physics, Raleigh, NC.

In recent years it was confirmed several times, that post deposition anneal of amorphous SiNc/Nh/D, re-oxidation increases the efficiency of c-Si solar cells beyond an anticipated improvement through reflectivity changes. This improvement, which is clearly due to an increase of bulk internal quantum efficiency, was explained by two hypothesis: Bulk passivation, through saturation of crystal defect states by hydrogen that diffuses into the c-Si bulk. Surface passivation by formation of a thin oxide layer during the anneal. To see which mechanism is actually most responsible for the improvement, the diffusion of hydrogen between crystalline silicon and silicon nitride was investigated by observation of $H/D$, N$_c$H/D, and Si$_c$H$_n$/D$_c$H$_n$. During rapid thermal anneal. The stacks were grown with remote plasma enhanced chemical vapor deposition (RPECVD). This is a low temperature (~200°C) reaction of downstream injected silicon (Si$_c$H$_n$) and all-Si$_c$H$_n$ activated by an upstream injected He-plasma, produced through r-f radiation (13.5MHz). Thermal treatment was executed by ex situ rapid thermal anneal in Ar ambient. For the measurements of $H/D$, Si$_c$H$_n$/D$_c$H$_n$, FTIR was used while SIMS determined defects of $H/D$, N$_c$H$_n$/D$_c$H$_n$. The experiments showed that the transport in silicon nitride is determined by several mechanisms including diffusion and dissociation processes where molecular species like Si$_c$H$_n$ and H$_2$ can develop. Dissociation is dominant at high $H/D$, densities and leads to a rapid decrease of $H/D$ from the system since molecular species have high diffusivities. At low $H/D$, dissociation reduces strongly, allowing atomic $H$ diffusion between covalent bonding sites to prevail. 

A 26.8 ISOTOPE EXCHANGE IN HYDROGENATED SILICON OXYNITRIDE [SiON] FOR 1.5 µm OPTICAL WAVEGUIDE APPLICATIONS: Jiajie Lee, Kangguo Cheng and Joseph W. Lyding, Beckman Institute for Advanced Science and Technology, Urbana, IL; H.W.M. Salomie, IBM Research Division, Zurich Research Laboratory, Rüschlikon, SWITZERLAND.

It has been reported that SiON layers can be used for planar optical waveguides in the 1.55 µm wavelength region. SiON can be made with a relatively high refractive index of 1.56. A structure in which SiON is sandwiched between two silicon-oxide (refractive index of 1.45) cladding layers is an effective waveguide candidate for Si-based opto-electronic integrated circuits. Due to the hydrogenated precesses, the deoxygenated SiON layers contain NH bonds. An intrinsic infrared absorption peak at a wavelength of 1.51 µm and the peaks low-energy tail tends to an unwanted absorption loss in the wavelength region of interest (1.545 to 1.565 µm). We report a novel way of eliminating the absorption loss by replacing NH bonds with NH+ (D) bonds in an isotopic exchange process. D was introduced to SiON layers in an atmospheric D anneal after the deposition of SiON. The propagation loss was measured by moving propagation technique. The SiON showed a reduction in absorption loss of 2.3% in SiON layers at 1.51 µm before the D anneal. The loss in the wavelength region of interest, therefore, is significantly minimized. The annealing temperature varied from 450 to 950°C. There seems to be an onset of thermal activation temperature for D to replace H in these structures. This mechanism is being studied carefully by Fourier transform infrared spectroscopy (FTIR) and secondary ion mass spectrometry (SIMS).

SESSION A37: POSTER SESSION:

DEFECTS AND TRANSPORT

Chair: Satoshi Yumazaki and J. David Cohen

Thursday Evening, April 27, 2000

8:00 PM

Salon 7 (Marriott)

A 27.1 TRANSPORT PROPERTIES OF POLYCRYSTALLINE SILICON WITH VARIOUS TEXTURES AND MICROSTRUCTURES: Toshihiko Kamiyama, Kouichi Nakashima, Atsushi Suzuki, Kenjiro Aoki, C.M. Fortunato and Isamu Shimizu, The Graduate School, Tokyo Institute of Technology, Midori-ku, Yokohama, JAPAN.

We previously reported that high quality polycrystalline silicon (poly-Si) was grown at low temperatures (<400°C) from SiF$_4$/H$_2$ gas mixtures using a very high frequency (VHF: 100MHz) plasma enhanced CVD (PECVD). Randomly, (230) or (400) orientation structures were chosen by the selection of SiF$_4$/H$_2$ gas flow ratio and their microstructures were found to be a strong function of the orientation structure. In this study, we focused on transport properties of polyc-Si in relation with their orientation and microstructures. Film structure was varied by the selection of substrate temperature and SiF$_4$/H$_2$ flow ratio. (230) oriented films were grown at small SiF$_4$/H$_2$ ratios (<30/40/secm) and (400) oriented films were grown at larger SiF$_4$/H$_2$ ratio of ~30/50/secm. VHF power of 20W and reaction pressure of 400torr. Film thickness was varied from 200 to 1000nm. Transport properties were evaluated from current-voltage measurements in dark and under 10W white light illumination for undoped poly-Si, and from Hall measurements for P-doped poly-Si. Intermittent hydrogen treatment was also examined to modify defect-density and transport properties of undoped poly-Si. Film structures were studied by X-ray diffraction, Raman scattering spectrum, scanning microscope (SEM), atomic force microscope (AFM), secondary ion mass spectroscopy and spectral ellipsometer. Lattice quality of ~8cm/$^{2}$/m for low temperature CVD poly-Si was obtained with 1 µm-thick (400) oriented film and this value was larger than that of (220) oriented films (~6cm/$^{2}$/m). While undoped (400) oriented film showed high dark conductivity >10$^{-2}$cm/s for intrinsic crystalline silicon. Intermittent hydrogen treatment successfully reduced the low dark conductivity (400) oriented film with the Fermi level located near the middle of bandgap.

A 27.2 INFLUENCE OF THE GRAIN BOUNDARY BAND OFFSET ON CHARGE TRANSPORT MECHANISM IN MICROCRYSTALLINE SILICON ANALYSED BY NUMERICAL SIMULATION. A. Fasani, Electronics and Communications Dept., ISEL and PCT-UNIL, Liege, PORTUGAL, M. Vieira, J. Martins, DEEE-ISEL, Lisbon, PORTUGAL, R. Schwierz, DEEE-ISEL and IST, Lisbon, PORTUGAL.

Microcrystalline silicon can be considered as a two-phase material. We interpreted its composition as grains of crystalline silicon imbedded in an amorphous silicon tissue, with a high concentration of dangling bonds in the transition regions. The boundary regions between the crystalline grains and the amorphous matrix can be treated similarly
to a hetero junction interface. When the band structure of a solid becomes non-uniform, and material parameters like the dielectric constant, the mobility and energy gap become position dependent within the structure, forces in addition to those from the macroscopic electric field act on the carriers, and the non uniform DOS modifies carrier transport. The non-uniform material composition is described through the introduction of band-parameters into the standard drift-diffusion transport equations. The results we obtained show the band offset at the grain boundaries to cause a complete reverse of the local electric field peak sign at the grain boundaries. An analytical comparison of two-dimensional solution of the semiconductor equations is required for a correct description of the device operation. We present here results obtained with one and two dimensional simulations of a \( \mu \)-Si:H p-i-n junction in short circuit condition. The charge transport mechanism is described in terms of the internal electric configuration (carrier concentrations, electric field and potential distribution, drift and diffusion currents) assumed by the junction in thermodynamic equilibrium and illuminated with different monocromatic radiations. Different configurations of the band offset at the grain boundaries are also considered and related to the transport properties in microcrystalline silicon.

A 27.3 DEFFECT AND TAIL STATES IN MICROCRYSTALLINE SILICON INVESTIGATION USING PULSED EPR ON ART PENTACENE, W. L. Foerster, W. Stiller, A. W. Petsch, W. Hahn, M. Kneissl, Institut für Silicium Photovoltaik, Berlin, GERMANY; Helmut Mell, Philips University, Marburg, GERMANY.

We report on a detailed study on paramagnetic states in microcrystalline silicon (\( \mu \)-Si:H) performed by pulsed EPR. In contrast to cw EPR the echo detected field sweep spectra are nearly baseline free and allow the determination of band tail states with relatively low spin densities. All EPR spectra obtained for a doping series deposited by PECVD are fitted by a unique set of peaks. This set consists of: (i) Two dangling bond like resonances at \( g = 2.063(2) \) with a nearly constant density of states distribution [DOS] and \( g = 2.094(2) \) centered in the lower half of the gap, respectively; (ii) the CE line at \( g = 1.997 - 1.998 \) which is known to correlate with n-type doping; (iii) two hyperfine satellites with a splitting of \( n = 119 \) \( G \) centered at the CE line. Their spin density does not directly correlate with the spin density of the central CE line; (iv) a broad resonance \( g = 2.075(10) \), \( \Delta H_{FWHM} = 220 \) \( G \) which we find to correlate with B-doping. Further insight into the nature of these states is gained by the study of light induced changes of their population. We demonstrate that both the CE and the broad line are enhanced in undoped and slightly doped samples while they are quenched in case of higher doping. Light induced changes of the hyperfine satellites are found not to correspond to the relative changes of the DOS distribution. From our results we assign the CE and the broad resonance to electrons and holes, respectively, trapped on dopant sites and in tail states of their respective bands. Neither free electrons in the conduction band nor free holes in the valence band are detected in \( \mu \)-Si:H. We will discuss our results in terms of a qualitative DOS model for \( \mu \)-Si:H.

A 27.4 NUMERICAL MODELING OF BETA-CONDUCTIVITY IN TRITIATED AMORPHOUS SILICON: Stefan Caster, Franko Gaspé, Tomasz Kostek, Stefan Zakutinsky, University of Toronto, Dept. of Electrical and Computer Engineering, Toronto, Ontario, Canada; Nazir P. Khemani, Walther T. Shinoda, Ontario Power Technologies, Toronto, Ontario, CANADA.

Tritiated-hydrogenated amorphous silicon (\( n \)-Si:H:T) films were prepared using the middle-field glow discharge deposition method. The decay of a tritium atom produces beta-particles with a mean energy of 5.7 keV. The energetic beta particles create electron-hole pairs in the film which recombine through an Auger assisted hopping band. We analyze the time evolution of the density of dangling bonds (DB) in the films in terms of beta-conductivity. A model correlating the change in conductivity with the evolution of different types of gap states is presented.

A 27.5 LIGHT INTENSITY EXPOENTS AS SENSITIVE TOOLS FOR THE DIAGNOSIS OF PHOTOVOLTAIC DEVICES: S. Z. Weitz, University of Puerto Rico, Dept. of Physics, Río Piedras, PR; P. Alquim, V. Chu, Instituto de Engenharia, Lisbon, PORTUGAL; J.P. Conde, Instituto Superior Tecnico, Dept. of Materials Engineering, Lisbon, PORTUGAL; R. Naldes and L. Balberg, Racah Institute of Physics, The Hebrew University, Jerusalem, ISRAEL.

We have shown recently [1,2] that the temperature dependence of the two carriers phototransport properties can yield information regarding the space distribution in the forbidden gap of semiconductors. Of these properties the light intensity exponents of both, the majority carriers, \( \gamma_m \), and the minority carriers, \( \gamma_n \), were found to be very sensitive to the details of the distribution. In particular, noting that sub 1/2 values of the exponents are very unusual, we studied their origin in some \( n \)-Si:H materials. Finding experimentally [3,4] such sub 1/2 values of \( \gamma_m \) and of \( \gamma_n \) and running computer simulations, of the recombination processes in \( n \)-Si:H, lead us to the conclusion that these new values are due to the recombination of states, which have a discrete level. For example the \( \gamma_n \) = 1/2 results are associated with acceptor-like centers which have a relatively high capture coefficient for holes. We attribute these centers to the unintentional oxygen dopant of the \( n \)-Si:H sample under study. We will show that the oxygen presence, usually ignored in the discussions of \( n \)-Si:H, appears to be, in many cases, the dominant factor in the phototransport properties of \( n \)-Si:H. [1] Y. Lubinski, J. Balberg and C. Fonseca, Phys. Rev. B 55, R15097 (1997). [2] L. Fonseca, S.Z. Weisz, R. Rappaport and I. Balberg, Mat. Res. Soc. Symp. Proc., (1999) in press. [3] P. Broueira, V. Chu and J.P. Conde, Mat. Res. Soc. Symp. Proc., 57, 1995. [4] R. Rappaport, Y. Lubinski and I. Balberg and C. Fonseca, Appl. Phys. Lett. 75, 103 (1999).

A 27.6 IMPROVED HIGH RESOLUTION POST-TRANSIT SPECTROSCOPY FOR DETERMINING THE DENSITY OF STATES IN AMORPHOUS SEMICONDUCTORS: C. Man, S. Raghunathan, School of Science, Undergraduate Studies, Dundee, UNITED KINGDOM; R.I. Budman, Dept. of Physics, The Hashemite University, JORDAN; J.M. Marshall, Dept. of Materials Engineering, Univ of Wiles Swansea, UNITED KINGDOM.

Post-transit spectroscopy is a variant of the time-of-flight technique in which excess carriers are created by pulsed illumination in a semiconductor structure (e.g. p-i-n). A high reverse field ensures that any excess carriers emitted from traps will transit the structure, to be collected, before re-trapping can occur. The resulting 'post-transit' photocurrent decay \( I(t) \) then simply reflects progress of the rate of release of charge from traps distributed in the semiconductor energy gap \( g(E) \). This situation is clearly simpler than the 'transit' photocurrent case in which re-trapping occurs, and so is relatively easier to model and analyse. In principle, a numerical Laplace inversion of the \( I(t) \) data allows \( g(E) \) to be found. In practice, a delta function approximation of the release time distribution for any given trap results in the simple expression \( g(E) \propto \sigma(\varepsilon) \) where \( \varepsilon \) is the trap attempt-to-escape frequency. Several authors have reported on using this expression, e.g. [1]. What may not be generally known is that even this simple analysis yields a better energy resolution than the various general purpose Fourier and Laplace - based methods which we and others have recently developed [2]. However, in the present work we show how the resolution can be still further improved, without delta function approximation or numerical transformations, by solution of an implicit equation set, (for a finely discretised \( g(E) \) rather than a continuum) needing only a least-squares fitting technique with exponential decomposition, to obtain \( g(E) \). We demonstrate this remarkable power of the energy resolution afforded by this straightforward method, using computed post-transit currents for systems containing discrete levels and distributed traps. [1] A. Feigl, G. Juska and J. Kocka, J. Non-Cryst. Solids 210, 199 (1996). [2] C. Man, S. Raghunathan, D.P. Webb, and S. Reynolds, Solid State Comms 83, 401, (1992).

A 27.7 ON THE ROLE OF CHARGED DEFECT STATES AND DEEP TRAPS IN THE PHOTO CARRIER DRIFT AND DIFFUSION IN n-Si:H: Paul Stradiu and Akihisa Masaoka, Thin Film Silicon Solar Cells, Sgef Laboratory, Electrotechnical Laboratory, Tsukuba, JAPAN.

We re-examine the photo carrier continuity equations used to evaluate the drift and diffusion length in various photocarrier generation technique experiments in \( n \)-Si:H [1,2]. In contrast to earlier works, we make a clear distinction between the carriers contributing to the drift and diffusion currents, and carriers captured into deep traps waiting for recombination. Only the carriers in the shallow traps experience multiple trapping and contribute to currents according to their drift mobilities and diffusion coefficients. Numerous photocarriers, however, are in the deep traps (especially in defect states) and remain immobile until recombination. The drift mobilities are very much reduced from free carrier continuity equations. Nevertheless, they directly affect the charge balance via the Poisson’s equation. Due to the asymmetry of the conduction band and valence band tails, most of the negative charge is accumulated in the Si:H electron gas, whereas the positive charge lies in the valence band tail holes. As a result, the positive charge grating of the VB tail holes is approximately counterbalanced by the
grating of the negatively charged defects, while the modulation of the CB tail electron concentration is much smaller. Attribution of the drift mobilities and diffusion coefficients to the whole photocurrent populations [1, 2] rather than to their fraction in shallow traps and neglecting the defect states as charge reservoirs may lend to a notable underestimate of the carrier drift mobilities, especially for the majority carriers. A discussion of the implications of our considerations on the values of the mobility-lifetime products obtained by the Steady State Photocurrent Grating technique (SSPG) and compare our calculations with the SSPG data in a-Si:H for various defect concentrations and exciting light intensities is made.


A 27.8

DIGITAL LAPLACE TRANSFORM TECHNIQUE FOR DIRECT DETERMINATION OF DENSITY OF ELECTRONIC STATES IN DISORDERED AND UNCONDUCTING MATERIALS FROM TRANSIENT PHOTOCURRENT DATA. M.J. Guentherov, C.M. Main and S. Reynolds, School of Science and Engineering, University of Alberta, Edmonton, Alberta, UNITED KINGDOM.

A technique for direct determination of the density of electronic states (DOS) in disordered semiconductors is presented. This method involves digital Laplace transform of transient photocurrent data \( I(t) \) followed by the numerical solution of the system of linear algebraic equations (LAE) obtained from the Fredholm integral of the first kind for a discrete DOS. No approximations are used in the solution, and no prior assumptions as to the form of the DOS are made, i.e. the method is truly spectroscopic. By representing the DOS as a set of closely spaced discrete values the Fredholm integral relating \( I(t) \) to the DOS in the LAE is solved as a summation, with a simple mathematical procedure then leading to the LAE system. An appropriate choice of Laplace variable prevents the problem becoming ill-posed, and a unique solution, avoiding the simplifications necessary in earlier Laplace transform analyses [1, 2, 3], is obtained.


A 27.9

ELECTRONIC DEFECTS AND INTERFACES IN a-Si:H MULTILAYERS. F. Galli, D. Ferrari, D. Martino, Material Science Department, CENMAT, Faculty of Science and Technology of The New University of Lisbon, Cacupé, PORTUGAL.

Constant Photocurrent Method (CPM) and Photothermal Deflection Spectroscopy (PDS) are used to determine the absorption coefficient arising from intragrain states in single layer films. By a simple analysis of this intragrain absorption spectrum, it is possible to evaluate the defect density. When this method is applied to structures with an insulating layer, only an effective absorption coefficient is determined, and no quantitative information about defect density can be obtained. But given the already measured single layer spectrum, it is possible to simulate the effective absorption spectrum to be expected by a multilayer without interface defect states. Comparison of simulated and real PDS data yields information about such states. If the multilayer structure has an ohmic current-voltage characteristic, it is possible to apply also CPM. Since CPM is not sensitive to surface states, comparison of PDS and CPM data gives a check of the simulation reliability. In order to do such check a, b, and c in the a-Si:H structures, along with single layers of a-Si:H, have been deposited and characterized.

SESSION A28 POSTER SESSION 6: THIN FILM TRANSISTORS
Chair: Richard L. Weisfeld
Thursday Evening, April 27, 2000
8:00 PM
Salon 7 (Marriott)

A 28.1

SIMULATION AND DESIGN OF AMORPHOUS SILICON THIN FILM TRANSISTORS FOR DRIVING THREE COLOR ATOC DETECTOR. D. Ferrer, P. Ivera, E. Paredes, Dept. of Electronics Engineering, University of Rome La Sapienza, Rome, ITALY. L. Colombo, University of Bologna, DEIS, Bologna, ITALY, F. Lenotti, Xerox PARC, Coyote Hill Road, Palo Alto, CA.

Use of Adjustable Threshold Color Detectors (ATCD) in large-area arrays requires periodic readout of the photocharge stored in the capacitance of the device by a transient technique of ATCDs, as in my stacked-junction devices, color information is obtained by the self-biasing process: during the integration time, the three junctions independently lose charge, during the readout pulse, the capacitances of the three junctions in electrical series are recharged. Equilibrium is reached after a few cycles, when the charge lost in a cycle by each junction is the same, and equals the readout one. The amount of this charge is determined by the reverse bias junction voltage and accounts for the light intensity. Dimensional analysis of the n+ a-Si:H Thin Film Transistor (TFT) used as a pixel switch for the ATCD is a critical part of the project of a color image. The actual design determines the self-bias process duration of the readout accuracy. The charge difference between the ATCD junctions makes the constraints for the switching process extremely demanding: since a greater capacitance is expected in the thinner top junction detecting blue radiation, the reverse bias must be reduced. On the other hand, the reverse bias junction does not ensure complete rejection of green and red light, so that a calculation must be performed to extract the information on blue radiation implying a high accuracy in the sensing process. In this work we present a simulation study of the self-bias process. Both n+Si TFT and the a-Si:H ATCD are simulated by a finite-elements two-dimensional, which allows to study in detail the timing and the accuracy of the self-bias process. A set of design rules for the TFT is also achieved in terms of on-current design including electrostatic capacitance and trapped charge.

A 28.2

NITRATED AMORPHOUS SILICON AND SILICON NITRIDE DEPOSITED AT LESS THAN 100°C BY ECR-PECVD FOR THIN FILM TRANSISTORS. A.J. Flewitt, A.P. Dyson, J. Robertson, W.I. Milne, Engineering Department, Cambridge University, Cambridge, UNITED KINGDOM.

Thin film transistors (TFTs) for active matrix liquid crystal displays use hydrogenated amorphous silicon (a-Si:H) for the channel and silicon nitride (a-SiN) for the gate insulator. Plasma enhanced chemical vapour deposition (PECVD) of these materials usually requires substrate temperatures over 200 °C which are too high for plastic substrates. Electron cyclotron resonance (ECR-PECVD) produces a highly ionized plasma with very low ion energies (<10 eV). These ions allow the efficient removal of hydrogen from a-Si:H and a-SiN during growth at <100 °C. A systematic study has been made of the growth of both a-Si:H and a- SiN by ECR-PECVD. For a-Si:H, silicon and hydrogen gases are injected into the ECR zone and silicon is injected downstream. Control of the deposition rate and ion energy is critical. a-Si:H has been deposited with a low dark conductivity ~10^-11 Ω^-1 cm^-1 and high photosensitivity >10^5. Preliminary characteristics of TFTs made using these materials will be presented.

A 28.3

A PHYSICALLY-BASED SPICE MODEL FOR THE LEAKAGE CURRENT IN a-Si:H TRANSISTORS INCLUDING DEPENDENCIES ON PROCESS, GEOMETRICAL, AND BIAS CONDITIONS. Peyman Servati, Arick Nadan, University of Waterloo, Dept of Electrical and Computer Engineering, Waterloo, Ontario, CANADA.

In this work, we have developed a physically-based analytical model of the static current-voltage characteristics of the hydrogenated amorphous silicon (a-Si:H) inverse staggered thin film transistors (TFT) in the reverse (leakage) regime \( V_g < 0 \). We have modeled the leakage current density of the a-Si:H active layer, which in turn affects leakage characteristics atlow \( V_g \). The transport mechanisms underlying the leakage behavior can be varied in terms of charge generation in the p+ drain in the vicinity of the n+ drain contact layer and subsequent charge transport along the p-channel at the n+Si:H/a-Si:H interface. Because of this diode-like behavior at the drain contact area, the leakage current characteristics of the TFT is determined by the profile of the drain contact layer and carrier density in this region, which in turn is affected by defects induced by the diffusion of phosphorus in the region. The mechanism of current flow along the p-channel to the source end is considered to be dominated. With case studies including analysis (based on measurement data) the dependence of the leakage current on process...
A 28.4 FLOWING BODY INDUCED TRANSIENT CHARACTERISTICS IN POLY-Si TFTs. Y.Z. Xu, F.J. Clough, E.M.S. Sankar, and R. Crossman. Intellect1993, R. Crossman, Intellect1993, Department of Electrical and Electronic Engineering, De Montfort University, Leicester, UNITED KINGDOM.

The realization of 'system on glass' flat panel displays requires poly-Si TFTs capable of high frequency operation. It is well known that the thin film SOI FET has a body effect, which results in a current surge in the transient procedure for the partially depleted device and it is a limiting factor in high frequency applications. Recent reports have investigated the transient characteristics of poly-Si TFTs[2] and a 'capacitance overshoot' effect[3], the full impact of the flowing body effect remains unclear. Therefore, it is necessary to investigate the impact of the flowing body effect on the transient performance of TFTs. This paper reports, for the first time, the results of the transient behavior of TFTs induced by the flowing body effect. N-channel poly-Si TFTs, fabricated using a polysilicon compatible low temperature process, are investigated. Using a 2D numerical simulation[4], the insights of the mechanism governing the transient procedure are obtained and compared with the single crystal FETs. It is found that the flowing body effect arises from the defect of states in poly-Si thin film. The differences of transient behavior between the poly-Si TFTs and SOI FETs suggests that existence of defect states is equivalent to doping of the channel region in SOI FETs. By investigating the transient behavior at elevated temperature, it is also found that capture rates of defect states have a significant impact on the flowing body effect.

References:

A 28.5 THIN FILM TRANSISTORS MADE OF 550°C POLYSILICON ON STEEL FOIL, Ming Wu and Sigurd Wagner, Princeton University, Department of Electrical Engineering, Princeton, NJ.

Amorphous silicon can be crystallized on steel foil preheated with SiO₂ at temperatures up to 950°C. The resulting polycrystalline films form channel material for thin film transistors (TFTs) with good electrical performance. Our motivation for developing this silicon-on-steel process is threefold. (1) The time to crystallization drops from hours at 600°C to seconds at 550°C. (2) Polycrystalline on steel form a self-aligned, flexible transistor for matrix and driver circuits. (3) A TFT on steel foil process may be amenable to manufacture on continuous web. Stainless steel foil substrates are coated with 8 µm of SiO₂ for photolithographic silicon etching. 200 nm thick a-Si:H films are deposited by PECVD at 150°C and then crystallized by furnace anneal at 650°C to 950°C, for 6 hours to 20 seconds. The films are processed to top gate TFTs with 200 nm PECVD SiO₂ gate dielectric. We use both a self-aligned and a self-aligned process. For the former an n⁺-µ-Si source/drain is deposited at 350°C, and for the latter P is ion implanted into the source/drain openings and the gate silicon. Thermally evaporated Al is used for source, drain, and gate contact. The self-aligned process has a channel length of 180 µm long, and a self-aligned channel is 50 µm long.

To date the best TFT performance has been obtained with polysilicon crystallized at 650°C, where the electron field effect mobility is 64 cm²/V·s in the linear and saturated regime. The TFTs made from the 950°C polycrystalline have 12 cm²/V·s in both regimes. The OFF current in all TFTs is about 1 nA. These characteristics suggest that contamination from the steel substrate is not important at any of the crystallization temperatures. At the same time, we will report results of current experiments on crystallization and device processing.

A 28.6 ROUGHNESS OF TFT GATE METALIZATION AND ITS IMPACT ON LEAKAGE, THRESHOLD VOLTAGE SHIFT AND MOBILITY. A. Noshad, R.V.R. Murthy, B. Park, A. Sasanov and S.G. Chamberlain, Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, CANADA. #DALSAR Inc., Waterloo, Ontario, CANADA.

A systematic study of the spatter deposition conditions for Al thin films employed as gate metal in the fabrication of gate insulators and spatter parameters such as deposition temperature, process pressure, and power, all of which have a strong bearing on the surface roughness of the film. For example, films deposited at low temperature (300°C) and low process pressure appear to have a significantly reduced roughness with corresponding transistors yielding a leakage current (~10mA at V_Drain) an ON/OFF current ratio better than 10³, and a mobility of 1 cm²/V·s, values comparable to those reported for Mo or sputtered gate TFTs. In contrast, films deposited at 1500°C and 15mTorr yield a degradation in mobility to 0.7cm²/V·s and an increase in leakage current to 1mA, caused by the high interface roughness due to hillock formation on the Al gate. Also the corresponding shift in threshold voltage is ~5V, as compared to the small shift ~2.5V associated with the source/drain gate. We attribute this to the [and perhaps even singular] kink and the high electric field present at the surface/insulator interface that generates a significant surface non-uniformity in the channel. The same reasons hold for the increased leakage current, which we believe is due to an electric field dependent Frankel-Poole type generation in the active region. The field effect mobility in these transistors, retrieved from the associated transfer characteristics, clearly shows the impact of surface roughness on mobility degradation. For comparison, we have also studied a TFT whose Al gate is now capped with 20um of Mo to minimize propagation of the gate surface roughness to the active channel. SEM cross sectional views show high interface smoothness to yield significantly improved leakage, stability, and mobility.

A 28.7 TRANSITION METAL SILICATE ALLOYS, ADVANCED GATE DIELECTRIC MATERIALS FOR HIGH PERFORMANCE THIN FILM TRANSISTORS, B. Regmi, R. Theron, H. Himi, and Gerald Locowsky, North Carolina State University, Raleigh, NC.

In order to meet the year 2010 challenges presented in the ITRS Roadmap for Semiconductors, high-k alternative gate dielectrics are being developed to replace SiO₂, and silicon nitride and oxynitride alloys. As TFT technology evolves from hydrogenated amorphous Si, a-Si:H, to polycrystalline silicon, polycrystalline, and advanced gate stack technology developed for these scaled c-Si devices can be translated to the polycrystalline Si TFT technology and thereby provide opportunities for enhanced device performance. This paper describes materials and device research performed on two qualitatively different SiO₂ transition metal oxides: i) one in which there is a chemically-ordered compound silicate phase: ZrO₂-SiO₂, and ii) a second in which there is no compound phase: ThO₂-SiO₂. Thin films have been prepared by 300°C remote plasma enhanced chemical vapor deposition using i) plasma excited O₂/He mixtures, and ii) downstream injected alkalis in source gases for the transition metal alloy constituents, and SiO₂ as the source gas for Si. To suppress reactions between the Si source surface and the oxygen and metal at organic precursors, a ultra-thin passivating layer of nitrided SiO₂ is formed by plasma assisted oxidation and is followed by interface nitridation. Composition, local atomic bonding and film morphology have been derived from Rutherford back scattering, RBS, X-ray photoelectron spectroscopy, XPS, infrared absorption spectroscopy, IRAS, Ramn scattering, X-ray diffraction, XRD, and high resolution transmission electron microscopy, HRETEM. Composition, and structural information has been constructed for as-deposited and annealed films. For the ZrO₂-SiO₂ system, these diagrams are separated into two qualitatively different regions by the compound composition, ZrSiO₄ whereas in the ThO₂-SiO₂ system, the absence of a compound means that the corresponding diagram is continuous between the end-member oxides. Finally, the paper will present the results of current- voltage, I-V, and capacitance-voltage, C-V, measurements from which dielectric constants, tunneling masses and noise effective energies. Supported by the SEMATECH/SRC FET center, ONR and AFOSR.

SESSION A 29: POSTER SESSION:
HETEROGENEOUS SILICON DEVICES
Chair: Domenico Caputo
Thursday Evening, April 27, 2000
8:00 PM
Salon 7 (Marriott)

A 20. METAL EFFECTS IN MOS CAPACITORS WITH SILICON RICH OXIDE INSULATORS. S. Lombard, I. Orup, S. Coffa, C. Spinella, C. Bongiorno, CNR-IMET, Catania, ITALY; C. Gerardi, B. Farina, M. Melanton, STMeletronics, Catania, ITALY.
Crystalline Si dots embedded in SiO$_2$ show electronic transport in the regime of quantum Coulomb blockade at room temperature for grain sizes of the order of a few nanometers. Thus, this composite material and in particular its Si dots have been proposed for the reversible storage of charge in the gate stack of single-electron memory devices, characterized by very compact one transistor structures. Such structures have a strong potential for ultralow power, multi-bit storage, and for capacities above 1 Gb. To form crystalline Si dots embedded in SiO$_2$, we have either deposited thin films of silicon rich oxide (SRO) by plasma-enhanced chemical vapor deposition of SiH$_4$ and O$_2$ or implanted Si into pre-existing Si$_3$N$_4$ layer. Then the Si dots have been annealed in N$_2$ ambient at temperatures between 950 and 1100°C. Under such processing, the supersaturation of Si in the amorphous SRO film produces the formation of crystalline Si dots embedded in SiO$_2$. The narrow dot size distributions, analyzed by transmission electron microscopy, are characterized by average grain radii and standard deviations down to about 1 nm. The memory function of such structures has been investigated in MOS capacitors with a Si dot density of 10$^{10}$ dots/mm$^2$ between a SiO$_2$ layer and with an n$^+$ polysilicon silicon gate. The operations of write, storage, and erase, are clearly detected by measurements of hysteresis in capacitance-voltage characteristics, and they have been systematically studied and a behavior and temperature in a number of different SRO structures.

A 29.2 CAPACITANCE-VOLTAGE CHARACTERISTICS OF POLY-SILICON POLYSILICON OXIDE POLYSILICON STRUCTURES FOR THREE-DIMENSIONAL MEMORY. John Lindsey and T.S. Kalkur, Microelectronics Research Laboratories, Department of Electrical and Computer Engineering, University of Colorado, Boulder, CO.

Three-dimensional integration offers a dramatic reduction in chip area required per bit, but is often limited by leakage and parasitic effects. Three-dimensional integration with thin film transistors (TFTs) requires detailed parametric analysis with techniques such as Capacitance-Voltage (C-V) characterization. CV analysis of polysilicon TFT utilizes polysilicon-oxide polysilicon thin film structures. Most of the C-V analysis involving polysilicon available to date, however, is with polysilicon-oxide bulk silicon structures. In this paper, we report the results of modeling and measuring of C-V characteristics of polysilicon-polyoxide polysilicon-oxide polysilicon for doped and undoped polysilicon. To increase the conductivity of the polysilicon, elevated temperatures were used for measurement. CV measurement matching the theoretical curves were made for these polysilicon films. Oxide thickness, series and shunt resistance were extracted and correlated to process problems and splits.

A 29.3 INFLUENCE OF ELECTRICAL MECHANICAL STRESS ON THE ELECTRICAL PERFORMANCE OF POLYCRYSTALLINE SILICON RESISTORS. M. Nakayama, Mitsubishi Electric Co., Nashigoshi, Kumamoto, JAPAN.

JAPAN.

Influence of the mechanical stress on the performance of polycrystalline silicon (Poly-Si) films, doped with different dopant species. Two types of Poly-Si films implanted with boron and phosphorous ions were used, respectively. Poly-Si films of 400 mm (to be used for boron doping) and 250 nm (to be used for phosphorus doping) thickness were deposited by LPCVD at 620°C on thermally oxidized silicon wafers. Film doping was done by ion implantation at 50 keV, with a dose of boron and phosphorus of 2 x 10$^{15}$ and 5 x 10$^{15}$ cm$^{-2}$, respectively. The samples were annealed in a N$_2$ ambient at 1000°C for 20 min to activate the implanted ions. The geometry of the devices was designed for standard photolithographical etching processes. The width and length of the resistors were 6 and 60 mm, respectively. A 600 nm SiO$_2$ film was deposited by LPCVD at 420°C, and subsequently sintered in a N$_2$ ambient at 950°C for 90 sec. The gate oxide was then prepared by RIE to allow contact between the electrodes and the Poly-Si. The metallization patterns were defined using photolithography and RIE etching. A silicon nitride film was deposited at 300°C to a thickness of 750 nm by plasma enhanced CVD and finally a H$_2$ treatment was performed at 450°C for 30 min. We investigated how mechanical stress affected the conductivity of the Poly-Si film, by measuring the resistance using convex wafer stages with a projection from 0.1 to 1 mm and contacting the stages with a pulling from 0.1 to 1 mm. The resistance of Poly-Si films implanted with boron ions was increased by mechanical stress, while the resistance of Poly-Si films implanted with phosphorus remained unchanged. It was concluded that this difference is related to the different differences between Poly-Si films implanted with boron and phosphorus, respectively.

A 29.4 FABRICATION OF PIEZORESISTIVE PRESSURE SENSOR BASED ON POLY-Si. Lim Jee Hong, Seok Jin Yoon, Young Soo Yoon, Korean Institute of Science and Technology, Thin Film Technology Research Center, Seoul, KOREA.

A pressure sensor based on poly-crystalline silicon thin film whose merits are nearly linear change in piezoresistance according to water level and no current leakage over 150°C was fabricated. Polysilicon diaphragm with various SOI fabricated to make a precise pattern. The polysilicon diaphragm was wet etched by EPW (Ethylendiamine, pyrocatechol, water). The etch rate is 71.109 micrometer/min at 110°C. After making diaphragm, silicon to glass bond was based on modified bond technique. The photolithographic process is little bit nonlinear at high-pressure level. The result is that the change in piezoresistance is 4.4E-40/psi. More detailed results will be presented.

SESSION A38: POSTER SESSION.

AMORPHOUS SOLAR CELLS.

Chair: Vikram L. Dalal and Scott J. Jones

Thursday Evening, April 27, 2000

8:00 PM

Salon 7 (Marriott)


Trinitrid-hydrogenated amorphous silicon (a-Si:H) was used for the intrinsically doped layer of a p-n hydrogenated amorphous silicon solar photovoltaic device. The bonded trinitrid atom decays to a benzene particle and He leaving behind a dangling bond. The photovoltaic properties of the device, namely the short circuit current (Isc), open circuit voltage (Vo) and fill factor (FF), were measured as a function of time. The decrease in Isc, Voc and FF were correlated with the increase in the dangling bond density of the intrinsic layer which manifests itself by decreasing the lifetime of carriers in the intrinsic region and also increasing the effective series resistance of the device.

A 30.2 CORRELATION BETWEEN FILM AND CELL PROPERTIES FOR DC PLASMA DEPOSITED AMORPHOUS SILICON.

Jennifer Heath, Yoram Lubinsbinder, J. David Cohen, Univ. of Oregon, Department of Physics, Eugene, OR; Gustam Gangle, BP Solar, Tenny, VA.

We have carried out measurements to correlate amorphous silicon film properties with companion solar cell device performance. The films and devices were deposited at Solar in a double-arc low pressure reactor using dc plasma decomposition. The films were p-type deposited onto glass substrates with a p-type underlayer and a n-type underlayer was deposited on a silicon wafer. The cell efficiency was measured in both the n-grown and light-soaked states. Cell efficiency decreased from a maximum of 8.5% to 7.5% in the n-layer growth rate was increased by a factor of 3 by increasing the plasma power, while the relative degradation of efficiency after 1000 hrs of light soaking remained about 20%. The film properties in the corresponding annealed and degraded states were determined using drive-level capacitance profiling (DCLP) and transient photocapacitance spectroscopy. The DCLP method was used to establish quantitative values of the deep defect densities in the films as well as the spatial uniformity of their electronic properties. Defect densities of annealed samples ranged from 2 x 10$^{13}$ to 2 x 10$^{15}$ cm$^{-3}$ and degraded by about a factor of 10 after light soaking. The photocapacitance method provided a fast bandgap spectrum of each film. These thin film characterization methods employ a sandwich device structure very similar to the of...
working solar cell devices, the material properties and cell parameters are more likely to exhibit clear correlations across the whole range of growth conditions studied. Distinct correlations are indeed observed in several regards and will be discussed.

A30.3 COMPARATIVE STUDY OF α-SiGe SOLAR CELLS AND MATERIALS DEPOSITED USING DIFFERENT HYDROGENATION DILUTION H. Povolny, P. Agrawal, S. Han and X. Deng, Univ of Toledo, Dept of Physics and Astronomy, Toledo, OH.

Although the correlations between amorphous silicon based solar cell device performance and a variety of intrinsic layer (i-layer) materials properties have been studied broadly, somewhat conflicting findings in terms of the existence of a reliable correlation have been reported, partially due to the different ways used for depositing these materials. In this paper, we report our study on the light soaking degradation of amorphous silicon germanium solar cells and the corresponding intrinsic i-layer deposited using different hydrogenation (R, hydrogen flow/germane-dilution flows). α-SiGe n-i-p solar cells with i-layer deposited with a germane to dilution ratio of 0.72 and R values of 1.7, 10, 30, 50 and 120 are deposited on stainless steel substrates without the use of a back-reflector. This germane to dilution ratio represents what we use for the backcell of our standard triple-junction solar cells. Solar cell IV and quantum efficiency were measured for these devices. Light soaking test has been performed for these devices under 1 sun light intensity at 50 C. While device with R=30 shows the highest initial efficiency (6.8%), the device with R=120 exhibit the highest stabilized efficiency (6.1%) after 100 hours of light soaking. Single-layer α-SiGe films deposited under the same conditions as the i-layer of these devices were deposited on a variety of substrates including crystalline silicon, 7059 glass, and stainless steel for the measurements of HR, Raman, refractive index, bandgap, dark and photo-conductivity, and hydrogen effusion. It is interesting to note that the bandgaps of α-SiGe with R=10 to 50 were around 1.48 eV while the bandgaps of α-SiGe with R=1.7 and 120 were both higher, at around 1.51 eV, most likely due to the increased amount of Ge incorporated in these films. We think that the additional H atoms in these two films are bonded to the Si network structurally differently. Detailed comparative study of the light induced degradation of solar cell performance and the structural and optoelectronic properties of the corresponding films will be reported at the conference.

A30.4 MODIFICATION OF ZnO WORK FUNCTION BY H OR O2 EXPOSURE AND EFFECTS ON n-Si SOLAR CELL PERFORMANCE. John F. Knecht, John R. Abelehn, University of Illinois, Department of Materials Science and Engineering, Urbana, IL, Tunning Bao, BP Solarex, Tokyo, VA.

The existence of a potential barrier at the interface between n-type transparent conductive oxide (TCO) and p-type α-Si:H layers is thought to reduce the efficiency of p-i-n photovoltaic devices. In previous work using an in situ Kelvin probe [contact potential] method, we showed that the work function of ZnO can be reversibly cycled by as much as 1 V using sequential surface treatments by atomic hydrogen and oxygen. * M. Musial and L. Wang at deposition of the p-type hydrogen and oxygen treatments the interface potential barrier was stable. In this work, we report how changes in the work function of ZnO films modify the efficiency of p-i-n photovoltaic devices deposited as the bottom layer of Thin Film Division and analyze the effect in terms of potential barrier, carrier recombination rate, and TCO conductivity. * A. Nurmadi and J. R. Abelehn, In-Situ Kelvin Probe Analysis of the p-i-N Interface Potential, spring MRS meeting (1196).

A30.5 SUPPRESSION OF PLASMA DAMAGE ON SnO2 BY MEANS OF A DIFFERENT CHLORINE CHEMISTRY. D. Z. D'ANSERIO, D. C. NICHOLSON, T. Nakashima, M. Kondo, Y. Toyoshima, A. Matsuda, Thin Film Silicon Solar Cells Super Laboratory, Electrotechnical Laboratory, Ibaraki, JAPAN.

The fabrication process of p-i-n solar cell with a superstrate structure includes the deposition of a p-layer on a transmittance conductive oxide (TCO) coated substrate such as SnO2. In this process, SnO2 is deposited by plasma enhanced chemical vapor deposition (PECVD). This reduction causes the darkening of SnO2 because of the appearance of metallic Sn, and is more significant at higher substrate temperatures, which limits the process temperature of the solar cell. Very recently it was found that surface coverage during the deposition of thin film silicon using dichlorosilane/hydrogen source gas is not hydrogen but chlorine. In this paper, we report the effect of different surface coverages on the properties of chlorine. Amorphous silicon was deposited on a SnO2 coated substrate (ASAHIL) using RF-plasuv discharge decomposition of Sn2H4Cl2 diluted by H2. Substrate temperature was 105 ± 250°C, and pressure was 20 ± 10 mTorr. We evaluate the degree of the damage by a ratio of transmission with and without Sn and layers in the HR region where Sn is transparent, but presence of Sn decreases the transmittance. At 180°C which is a usual n-Si solar cell process temperature, the transmittance for n-Si deposited from Sn2H4Cl2 shows higher transmittance than that from SnH4. This result is explained in terms of chemical reaction of chlorine at the interface which prevents from reduction of SnO2 by atomic hydrogen. [1] L. Guo, Y. Toyoshima, M. Kondo and A. Matsuda, Appl. Phys. Lett. 76 (1999) in press.

A30.6 LIGHT TRAPPING BY PERIODICALLY STRUCTURED TCO IN THE SUB-MICROMETER REGIME. C. Eische, C.E. Nebel, M. Stuttman, Walter Schottky Institute, TU-München, GERMANY.

The efficiency of thin film solar cells strongly depends on light trapping effects in the solar cells are generally thinner than the required thickness to absorb visible and near IR-light. Amorphous solar cells are therefore grown on textured TCO which shows a random roughness with about one micrometer periodicity. Whether this is the optimized geometry of light trapping structures for α-Si:H solar cells has up to now not been discussed. In this paper we present optical properties of solar cells deposited on well defined light trapping geometries. We use plasma TCO (Al doped zinc oxide) which is covered by photorecess (spin-on-process). The photorecess is illuminated by an interfering Interl beam to generate micro- and submicrometer masts on TCO. As etch mask HCl is used. The period of the masts, determined by atomic force microscopy (AFM), varies between 400 nm and 2 micrometer with rectangular or pyramidical geometries. The optical properties of these TCOs and the solar cells grown on top of these structures are measured by conventional transmission reflection experiments [microscopic] and by spatially resolved optical experiments [microscopic properties] with a lateral resolution of about 0.8 micrometer. These experiments show that optimal light trapping is achieved for periods smaller than one micrometer and amplitudes in the range of about 0.15 μm. By tuning the geometry, scattering governs the absorption of visible light and diffraction the IR-part of the solar radiation. A detailed discussion of the optical properties of these periodic light trapping structures will be given.

A30.7 MODELLING THE OPTICAL QUANTUM EFFICIENCY OF THIN FIlm AMORPHOUS SILICON SOLAR CELLS. Sally-Anne F. Rowlands, John Livingstone, University of Western Australia, Department of Electrical and Electronic Engineering, Perth, AUSTRALIA; Chris P. Lund, Murdoch University, Dept Physics and Energy Studies, Perth, AUSTRALIA.

The optical quantum efficiency and spectral response of p-i-n thin film (α-Si:H) amorphous silicon solar cells have been modelled using software based on optical admittance analysis. The optical constants of n-Si and TCO thin film layers have been measured by Variable Angle Spectroscopic Ellipsometry (VASE) and used as inputs into the optical admittance analysis program in order to model cells constructed from these films. Amorphous silicon (~α-Si:H) thin films and p-i-n assemblies have been deposited by Glow Discharge and Reactive Sputtering techniques. The optical constants were determined by VASE, the hydrogen content of the films has been determined by FTIR spectroscopy, and the thickness of the films verified by Scanning Electron Microscopy studies. The optical constants of commercially available transparent conducting oxide (TCO) coated substrates have been determined by VASE. The experimental U/V in transmission spectra of p-i-n assemblies are compared with those predicted by the model. Results of modeling different α-Si:H solar cell structures using these materials are presented, including a study of the optimal TCO layer thickness for p-i-n α-Si:H solar cells.


Calculating the spectroscopic reflection losses and absorption profiles for amorphous silicon-based multijunction solar cells is a necessary first step in optical modeling. We have applied ex-situ transmission and reflectance measurements, data reduction, optical spectroscopy, and ex-situ and real-time ellipsometric and Stokes
vector spectroscopies to extract the optical functions of the component layers used in multijunction solar cells, including intrinsic amorphous semiconductor layers of variable optical bandgap, microcrystalline doped layers 100 Å in thickness, transparent conducting oxides in textured and specular forms, and metallic back reflectors. For such layers, we have developed analytical expressions for the optical functions, using a minimum number of physically-meaningful parameters. For the layers, as an example, our expression for the dielectric function ε_Kramers-Kronig-consistent and is valid on a logarithmic scale. It includes the Urbach tail at low energies, a parabolic band-edge region at intermediate energies (applying a constant dipole matrix element), and a Lorentz oscillator extending to high energies. Using this expression for ε, we can fit experimental data in [ε, log(ε)] over the full solar spectrum, obtaining a set of seven parameters. For optimum n-layers of solar cells, these parameters are found to be polynomial functions of the optical gap.

As a result, [ε, log(ε)] spectra can be generated for amorphous semiconductors having arbitrarily-assigned optical gaps. Furthermore, the effects of material characteristics such as disorder and density on the reflection and absorption characteristics of the solar cell can be computed explicitly. Finally, we present absorption profiles for multijunction solar cells that demonstrate the utility of our analytical expressions.

SESSION A31: FROM MATERIALS TO TFFs
Chair: Naum Shimizu
Friday Morning, April 28, 2000
Salon 7 (Morrison)

8:30 AM A31.1
A JUNCTION FIELD EFFECT TRANSISTOR BASED ON HYDROGENATED AMORPHOUS SILICON. D. Capasso, G. de Tomasi, V. Kuzmenko, F. Capasso, and L. Cisel, Rome La Sapienza, Dept. of Electronic Engineering, Rome, ITALY.

An hydrogenated amorphous silicon junction field effect transistor suitable for analog and digital applications is presented. The device is composed of a p^+ - i - n junction, with the drain and source contacts patterned on the n-doped layer and the gate electrode patterned on the p^+ doped layer. As in the crystalline case, the device is a voltage-controlled resistor, and its drain-source resistance can be varied, with a voltage applied to the gate electrode, by modulating the width of the depletion layer extending into the n-type channel. The doping value of this layer has been chosen to ensure an ohmic contact between the semiconductor and the evaporated aluminum layer, the highest value of channel conductivity resulting from our deposition system and a relatively low defect density in the material. The manufactured device, with W/L = 500/200 μm, shows the typical current-voltage curves of a JFET, where the pinch-off and the triode regions are well distinguished. In particular, the JFET saturates for drain/source voltage, V_d, higher than 20 V and 10 V at gate/source voltage, V_g, equal to 0 V and ~10 V respectively. At lower V_g, the current presents the linear behavior of a diode zone, where the JFET operates as a linear resistance whose value is controlled by the gate voltage. Regarding its application in linear circuit, first results are very encouraging, since we have achieved transconductance values of 10 mS/V/A, which are comparable to those of state of the art TFT.

8:45 AM A31.2
THIN FILM TRANSISTORS WITH ELECTRON MOBILITY OF 36 cm²V⁻¹s⁻¹ MADE FROM DIRECTLY DEPOSITED INTRINSIC MICROCRYSTALLINE SILICON. L-Cheng Chang and Sigurd Wagner, Princeton University, Department of Electrical Engineering, Princeton, NJ; Marcelo Mulhovo, Xerox Palo Alto Research Center, Palo Alto, CA.

Microcrystalline silicon (μc-Si:H) with the electrical conductivity of intrinsic silicon, ~10⁻⁴ to 10⁻² cm⁻¹, can be deposited from a glow discharge containing polycrystalline silicon precursor. This low conductivity is due to a low off current in μc-Si:H thin film transistors (TFTs). Because the deposition temperature for this μc-Si:H is as low as that of hydrogenated amorphous silicon (a-Si:H), it has become of particular interest upon the recent demonstration of p-channel operation and of an integrated CMOS inverter. These devices suggest the potential for a full-fledged, ultra low temperature silicon technology, competitive with polycrystalline silicon made on glass at 600°C.

We report on Si:H TFTs with electron mobility up to 36 cm²V⁻¹s⁻¹ and ON/OFF ratio up to 10⁵. The μc-Si:H was grown from silane, dichlorosilane, and hydrogen. The glow discharge was excited at a frequency of 80 MHz to raise the growth rate above that achievable at 13.56 MHz. Deposition temperatures were 210°C for the i-layer and 380°C (the highest temperature in the process) for the n⁺ source and drain layer. The TFTs were fabricated on 340-μm thick μc-Si:H films, with a 500-nm gate insulator of plasma deposited SiO₂.

For TFTs with channel width/length of 180μm/45μm we obtained off current in the 10⁻¹⁰ A range and on currents in the 10⁻⁴ A range. In the n⁺ channel the linear mobility was 15 cm²V⁻¹s⁻¹, and the saturated mobility at 23±2 lo cm²V⁻¹s⁻¹. High threshold voltages of 1.5 to 25 V reflect an immature device fabrication technology. At present we are modifying the deposition of the μc-Si:H film as well as the device process, and will report the results at the symposium.

9:00 AM A31.3
LOW TEMPERATURE POLY-SI LAYERS DEPOSITED BY HOT WIRE CVD YIELTING A MOBILITY OF 4.0 cm²/Vs IN TOP GATE THIN FILM TRANSISTORS. R.E. Schropp, J.K. Rath, B. Sarnowski, Ch.M. van der Wel, Utrecht University, Delft Institute, The Netherlands, Y. Chen, S. Wagner, Princeton University, Princeton, NJ.

For better resolution, larger size, and integration of drive electronics in large area poly-Si applications, a depositions technique for high mobility top-gate TFTs is under development. Usually, excimer laser annealing and/or furnace pre- and postannealing steps are needed to produce high mobility top-gate TFTs. In contrast, the Hot Wire Chemical Vapor Deposition (HW-CVD) method has the potential to deliver as-deposited poly-Si TFTs with high electrical quality, due to the native passivation of grain boundaries at the low (T ≤ 500 °C) processing temperatures used. For the first time we have fabricated high-performance poly-Si TFTs using poly-Si that is directly deposited by the HW-CVD method. This material was deposited at Utrecht University in the Poly2 regime, leading to very compact, purely intrinsic poly-Si layers, that does not require any further annealing, crystallization and/or passivation treatments. After deposition of the polycrystalline layer (at a deposition rate of 0.55 nm/s), top gate TFTs were fabricated at Princeton University. The field-effect mobility in the saturation regime was 4.0 cm²/Vs. The TFTs also have a remarkably low OFF current (<10⁻¹¹ A at Vd = 10 V), suggesting high on/off ratios. As a result we attribute the very low OFF current to the concentration of oxygen and other impurities, leading to the intrinsic properties of the polysilicon bulk material. These poly-Si TFTs have the potential to be made uniformly on large glass backgrounds with large throughput. Their performance already is high enough for high resolution pixel switching and integrated drive circuitry.

9:15 AM A31.4
LASER PROCESSING OF AMORPHOUS SILICON FOR POLY-SI DEVICE AND CIRCUITS. J.B. Bryce, R. Foulk, J. Ho, J.P. Lu, P. Mei, R.A. Street, and Y. Wang, Xerox Palo Alto Research Center, Palo Alto, CA.

Pulsed excimer-laser processing of amorphous silicon on non-crystalline substrates is an important processing technology for large area polycrystalline electronics, such as flat-panel displays and two-dimensional imaging arrays. It allows for the fabrication of high-quality polycrystalline thin-film transistors (TFTs) and for the integration of amorphous silicon and polycrystalline devices on the same low-temperature substrate. It also provides procedures for doping self-aligned amorphous silicon TFTs. In addition, heavily-doped, fully polycrystalline silicon exhibits some interesting materials properties, such as, large lateral grain growth with a corresponding enhancement in the electron mobility. These relationships between laser processing conditions and materials and device properties will be reviewed along with the conditions that yield good devices. Under these optimized processing conditions, excellent polycrystalline TFTs with high mobilities, sharp turn on, and low off-state leakage currents (10⁻⁶ A/cm²) can be achieved. These improved parameters, particularly the low off-state leakage currents, enable not only displays but also the more-demanding flat-panel imaging arrays to be fabricated using polycrystalline silicon. In addition, the application of laser processing to the doping of self-aligned polycrystalline silicon/Source drain contacts of amorphous silicon TFTs allows devices with reduced source/drain parasitic capacitance to be fabricated. Excimer laser processing for both polycrystalline TFTs and self-aligned amorphous silicon TFTs will be discussed along with the application of these technologies to flat panel imagers.

9:45 AM A31.5
HIGH PERFORMANCE 200um SINGLE GRAIN TFFs FABRICATED USING A SELF-ALIGNED GERMANIUM SEEDING TECHNOLOGY. Praini Kalsweide, Amol R. Joshi, Vivek Subramanian and Kristina C. Svarno, Stanford University, Department of Electrical Engineering, Stanford, CA.

Sub-micron poly-Si TFTs exhibit performance variations caused by statistical variation in the number and location of grains within the channel. Recent advances in seeded lateral crystallization technology allow control over grain location, thereby increasing uniformity and performance of TFTs. Use of Ge seeding for lateral crystallization is especially attractive due to its CMOS compatibility. All-Laser processing techniques demonstrated to date have required the use of additional
masking steps, increasing process complexity and cost. We report on 200nm TFTs fabricated using a self-aligned Ge seeding technology requiring no additional lithography steps. Gate Oxide TFTs were fabricated using a conventional phase TFT process. After gate stack patterning, an oxide spacer was formed. Processing up to this point was performed at low temperature (≤ 500°C) to prevent random nucleation in the amorphous semiconductor. Ge was deposited selectively on the S/D regions and the films were then crystallized. The main advantage of this technique is that the seeding is self-aligned, requiring no additional lithography step. This was followed by S/D implants and back-end processing. Devices were seen to have a substantially higher performance than unseeded devices. Seeded device drive currents were ~ 100µA/µm (NMOS) and ~ 40 µA/µm (PMOS), compared to unseeded device drive currents of ~ 10 µA/µm. To determine the nature of crystallization, the epitaxial growth was carried out by implanting hydrogen ions into the channel region of the devices, followed by a 375°C forming gas anneal. Seeded devices showed little improvement after hydrogenation, indicating good crystallinity of the channel. However, other devices, on the other hand, showed a 3x drive current improvement, from 10 µA/µm to 30µA/µm. This implies that seeded devices are relatively defect free as compared to the unseeded devices. Ge-seeding is thus seen to be effective as it ensures the absence of grain boundaries within the channel region, thereby resulting in high performance TFTs.

10:00 AM A31.6
EFFECT OF NICKEL IN LARGE GRANULAR POLY-SI FILM FORMED BY NICKEL INDUCED LATERAL CRYSTALLIZATION AND NEW GRAIN ENHANCEMENT METHOD. A.M. Myryniec, M.C. Poon, M. Chan, Hong Kong Univ of Science and Technology Dept of Electrical and Electronic Engineering, Kowloon, HONG KONG.

Large grain poly-silicon film (poly-Si) with high material quality and uniformity can have numerous novel applications such as providing a low cost substrate for amorphous silicon thin-film transistors and a breakthrough technology to ultra-thin 3-dimensional multi-layer SOI like devices and circuits. Nickel Induced Lateral Crystallization (NLC) of amorphous Si (a-Si) has been studied intensively, yet the grains are still small (~ 1 µm). Recently, we have reported a novel method by combining NLC and a new annealing (at above 950°C) to form poly-Si film with very large grains ranging from 10 to 100 µm. The film has good quality and the TFTs formed are highly comparable to SOI TFTs. This work further reports the effect of Ni to the large grain poly-Si film. 3000 Å thermal oxide was formed on 200 mm p-Si. 1000 Å of a-Si was formed on the oxide by LPCVD at 550°C, and from 3000 Å of NiO. Windows were then patterned and 50 Å of Ni was deposited onto the a-Si using an electron beam evaporator. NiCl of Ni was then formed at 500°C for 20 hr in N2. The Ni and LT-O were then removed. A special annealing at 1000°C for 2 hours was then used to enhance the grains. SIMS results show that Ni is around 100 to 1000 ppm under the Ni, 10 ppm in the NiCl region, and negligible in the oxides. While size of Ni film and amount of Ni affect greatly the Si grain size, quality, and uniformity, the effect of TFT performance is not significant. The other effects of Ni to the quality of the poly-Si grains, the gate oxide underneath the poly-Si, the oxide grown on the poly-Si, and the quality of the fabricated TFTs, will be further reported and discussed.

SESSION A32: HETEROGENEOUS MATERIALS
II-STRUCTURE AND TRANSPORT

Friday Morning, April 28, 2000
Salon 7 (Merriot)

10:45 AM #A32.1
DEPOSITION OF HETEROGENEOUS SILICON THIN FILMS –STRUCTURE AND ELECTRIC PROPERTIES. Izumi Shinomi, The Graduate School, Tokyo Institute of Technology, Midori-ku, Yokohama, JAPAN.

Heterogeneous Silicon Thin Films (HFTFs) prepared by PE-CVD on glass at low temperature has been accumulated a great attention for its potential to improve the performances of large area devices such as solar cells or TFT. In practice, conversion efficiency higher than 10% was achieved so far in the micro-crystalline silicon solar cells with pin structure.[1] In addition, a TFT with the mobility of more than 30 cm²/Vs was successfully made using polycrystalline silicon thin film prepared by PE-CVD from a gas phase mixture of SiH₄ and Si₂H₆.[4] However, the structural factors i.e., volume fraction, size and microstructure of crystallites, specific textures and grain boundaries which offer great influence on electrical and optical properties depend markedly on the preparation methods. In this work, we reviewed some specific trends for controlling these structural factors in making HSTF by PE-CVD from fluorinated sources in comparison with from silane. In particular, we address on the effective parameters in respective processes: (1) formation of necks on glass, (2) growth and control of crystalline textures and (3) impurities’ doping and passivation of devices in view of controlling chemical reaction on growing surface or sub-surface. In addition, the optical and electrical properties, viz. carrier transport and its anisotropy or light scattering related to these structural factors are discussed as well. [1] K. Yamamoto, M. Yoshimi, T. Suzuki, Y. Furada, and A. Nakajima, Mat. Res. Symp. Proc. 507 (1998) 131. [2] T. Nagashima, K. Fujimoto, N. Kohno, Y. Kishiwaki, and H. Kukinoki. Jpn. J. Appl. Phys. 31 (1992) 4555.

11:15 AM A32.2
BARRIER-CONTROLLED TRANSPORT IN DOPED MICROCRYSTALLINE SILICON. Stephan Brehme, Peter Kauschat, Klaus Lipe, Walther Fuhs, Hahn-Meitner-Institut, Berlin, GERMANY.

Thin microcrystalline films are grown at 325°C on glass substrates by electron cyclotron resonance chemical vapor deposition (ECR-CVD). Films are doped in situ either with B⁺⁺ or B⁺⁺⁺, and structural and electronic properties are studied as a function of doping levels. Typical grain sizes are in the range 15-40 nm. Resistivity and Hall effect data obtained from van der Paw measurements reveal carrier concentrations between 3 x 10¹⁵ cm⁻³ and 3 x 10¹⁷ cm⁻³ and mobility values in the range 0.5-3 cm²/Vs at room temperature. The mobilities decrease with decreasing temperature in the entire temperature range investigated (20 K - 450 K). From a detailed investigation of the ESR signal related to conduction band electrons an in-grain mobility can be determined which is found to be much higher than the Hall mobility. These findings suggest that the electrical transport is limited by potential barriers at grain boundaries. By analyzing the temperature dependence of Hall mobility data we obtain barrier heights in the range of 20-30 meV. The results are discussed in terms of a simple barrier-limited model (J. V. Seto, J. Appl. Phys. 46 (1975) 5347) which assumes effective interface trap densities (ITD) being independent from doping level. However, in experimental films the effective ITD increases with increasing doping level following a power law for both p- and n-type doping. The results will be discussed in an extended Seto model including the temperature and doping level dependences of the Fermi level position EF.

11:30 AM A32.3
TEMPERATURE DEPENDENT TRANSPORT IN MICROCRYSTALLINE SILICON. Torben Brammer, Helmut Stiebig, Andreas Lemberg, Wilfried Reetz, Herbert Wagner, Institut für Schicht- und Ionenstruktur, Forschungszentrum Jülich GmbH, Jülich, GERMANY.

The optoelectronic behavior of microcrystalline silicon (µc-Si:H) diodes deposited by PE-CVD (50MHz, 50-80mW/cm², 300mTorr, 200°C) with pin and n/p deposition sequence were investigated for silane concentrations [SiH₄]/[SiH₄+H₂] from 2% to 80%. The open-circuit voltage V_{OC} of the cells increased from 450mV to 550mV with increasing silane concentration and the FF showed a maximum of above 70% for silane concentrations between 4% and 6%. The purpose of this work was to correlate device characteristics with µc-Si:H material properties. Therefore, dark and light I-V curves and quantum efficiencies (QE) were measured at temperatures ranging from 250K to 350K and compared with numerical simulations. The dark (I/V) curves and, therefore, the V_{OC} behavior of this series was dominated by the bulk properties of the lower temperature (higher silane concentration) as shown by numerical modelling. The temperature dependent QE of n/p and pin diodes allowed to distinguish between interstitial and bulk effects. Interface effects dominated the temperature dependent band response of pin diodes. The grain in blue response increased with temperature and silane concentration by up to 200% which revealed transport limiting material properties in the vicinity of the p/n interface. This behavior was attributed to the nucleation region extending deeper into the layer for higher silane concentrations. For pin diodes the nucleation region is located at the p/n interface. Consequently, the temperature dependent blue response of pin diodes was mainly controlled by bulk properties which lead to a negative mobility temperature coefficient. For temperatures above 300K the blue response decreased uniformly and the increase of the QE for longer wavelengths due to the optical band gap shift was pronounced. The simulated results were in good agreement with the experiments. The negative mobility temperature coefficient also explained the temperature dependence of FF which was more pronounced for smaller silane concentration.

11:45 AM A32.4
RESPONSE TIME MEASUREMENTS AND FLYING SPOT TECHNIQUE IN MICROCRYSTALLINE SILICON SOLAR CELLS. R. Pampuch, P. Sangiorgi, and S. Knappe, Dept. of Physics, Univ. of Lisbon, PORTUGAL. M. Fernandez, A. Macario, M. Vieira, Electronics and Communications Dept., ISEL, Lisbon, PORTUGAL.

We used two complementary methods, the Flying Spot Technique (FST) and Transient Photocconductivity (TPC), to measure essential
thin film solar cell parameters like carrier recombination lifetime and
ambipolar diffusion length. Transverse charge collection in a p-i-n
structure based on microcrystalline silicon (µc-Si:H) and lateral
transport in a coplanar structure were analyzed using the flying spot
technique FST and transient photocconductivity TPC, respectively.
The FST technique has been successfully applied to solar cell
structures based on hydrogenated amorphous silicon for the
determination of minority carrier diffusion length. In this contribution
we extend the study to the promising, however complex material of
hydrogenated microcrystalline silicon prepared by the cyclic CVD
technique. Using the FST technique we found an ambipolar diffusion
length, L_{amb} to be around 200 nm and recombination time, \tau_{rec} =
24 \mu s. It is an advantage of the FST method that both a complete
p-i-n device and a simple Schottky barrier metal contact can be
employed. Care has to be taken to reach a sufficient time
resolution, which is obtained when working in short-circuit current
mode and/or under additional bias light. In TPC measurements we
used two Cr contacts evaporated on top of a n-layer, that is also
used in p-i-n solar cell structures. The light source was a high power
Nd:YAG laser of 5 ns pulse duration (5 MW/cm² power density, green
line at 532 nm). The initial photocurrent decay is characterized by a
decay time constant of 4 \mu s, whereas at longer times the decay slows
down to values of about 15 \mu s. This shows that photocurrent decay
strongly depends on the carrier density present at a given moment. A
large number of trap states is assumed to be responsible for the large
response times. Optoelectronic parameters of minority and majority
carriers in microcrystalline silicon thin films obtained from this study
allow one to identify necessary steps for improvement of solar cell
device performance.