Electronic Materials and Devices
Room: C-107 - Session EL+SC-TuA

Semiconductor Characterization
Moderator: P.H. Holloway, University of Florida

2:00pm **EL+SC-TuA1 Active-Device Scanning Voltage Microscopy Studies on a Forward and Reverse Biased InP pn Junction Sample**, ***ST.J. Dixon-Warren***, *R. Dworschak, G. Este, AJ. SpringThorpe, J.K. White*, Nortel Networks, Canada, *D. Ban, E.H. Sargent*, University of Toronto, Canada

Active-Device Scanning Voltage Microscopy (SVM) is a new Scanning Probe Microscopy (SPM) technique in which a two-dimensional voltage map is obtained on the cross-section of a biased semiconductor sample. The voltage is measured using a very high impedance voltmeter that is connected to a conductive doped-diamond coated SPM tip. Recently obtained results on a molecular beam epitaxy (MBE) grown InP pn junction sample will be reported, under both forward and reverse bias conditions. The results are compared to those obtained with Scanning Spreading Resistance Microscopy (SSRM) measurements under zero bias on the same sample. The SVM and SSRM results will be discussed in terms of the semi-classical model of the pn junction. The physics of the SVM measurement process will also be discussed. Finally, the results obtained on the simple pn junction sample will be compared with those obtained on more complex samples, such as InP based ridge waveguide and buried heterostructure laser samples under forward bias.

2:20pm **EL+SC-TuA2 Scanning Tunneling Microscopy Imaging of Charged Defects on Clean Si(100)-(2x1)**, ***G.W. Brown***, *H. Grube, M.E. Hawley*, Los Alamos National Laboratory, *S.R. Schofield, N.J. Curson, M.Y. Simmons, R.G. Clark*, University of New South Wales, Australia

We have used scanning tunneling microscopy (STM) to image charged defects on the clean Si(100)-(2x1) surface. In the absence of "C"-type defects, band bending can occur during STM imaging, allowing near surface charge to influence the state density contributing to the tunnel current. As in the case of cleavage faces of III-V semiconductor crystals, the charge-induced band bending produces long range enhancements superimposed on the periodic surface lattice. We observe this in empty-state STM images taken on n-type Si(100). No band bending signature is seen in the filled-state images. This can be understood by considering the band structure at the surface, which has surface states within the gap. The charged defects observed in this work are of the types commonly observed in clean Si(100)-(2x1) STM studies, however, not all defects of a given type appear charged. This would indicate subtle differences in defect structure or the influence of impurities. This work demonstrates the ability to observe charged features on the clean Si(100) surface, which will be important for current and future research focussed on producing atomic scale electronic structures. Predictions for signatures on p-type material will also be made.

2:40pm **EL+SC-TuA3 The Surface Photovoltage and Photoelectron Spectroscopy**, ***J.P. Long***, Naval Research Laboratory **INVITED**

Frequently, the surface of a semiconductor in equilibrium exhibits "band bending," an electrostatic shift of the surface relative to the bulk that arises from the built-in electric field associated with a surface depletion layer. When such a surface is illuminated, photogenerated electrons and holes move to screen the built-in field, thereby reducing the band bending and shifting the surface energy levels, an effect known as the surface photovoltage (SPV). Because the energy levels measured by photoelectron spectroscopy shift with the electrostatic potential of the surface, the technique is sensitive both to equilibrium band bending, a fact often exploited to characterize Schottky barrier heights, and to the SPV, which makes photoemission a useful SPV detector. However, under certain conditions, the ultraviolet or x-ray photoemission source itself can induce a sizable SPV that seriously hampers the measurement of equilibrium energy levels. This talk will introduce the SPV at a tutorial level, and will discuss the interplay between photoelectron spectroscopy and the SPV. Illustrations of photoemission as a SPV detector include the use of synchrotron radiation to characterize SPV decays in laser-excited Si and to detect, via SPV-induced band-flattening, inhomogeneous band bending on GaAs caused by Ga islands. In addition, the problem of SPV's induced by photoemission sources themselves will be addressed. Usually encountered below room temperature where the SPV is enhanced, source-induced SPV's become an important issue at and above room temperature in wide band-gap materials, which are acutely prone to a SPV when large equilibrium band bending is present. A striking example of current relevance is p-type GaN, which exhibits source-induced SPV's at room temperature exceeding a volt when examined by ordinary UPS and XPS laboratory sources.

3:20pm **EL+SC-TuA5 Direct Measurement of the Electrical Potentials in $GaInP_2$ Solar Cells**, ***C.-S. Jiang***, *H.R. Moutinho, J.F. Geisz, D.J. Friedman, M.M. Al-Jassim*, National Renewable Energy Laboratory

We report the application of electrostatic force microscopy (EFM) to photovoltaic devices. The built-in electric field plays a major role in photovoltaic devices, because it collects photo-excited carriers and is a key factor in determining the open-circuit voltages of solar cells. However, the measurement of the built-in potential has been limited to indirect ways such as the characteristics of current-voltage and capacitance-voltage. In these measurements, it is hard to distinguish the contributions from the multi-junctions or interfaces of a modern solar cell device. In this presentation, we report a direct measurement of the electric potential on cross-sectional planes of a $GaInP_2$ device both quantitatively and spatial-resolvedly, by using the Kelvin probe force model of the EFM technique. Two features on the potential profile are assigned respectively to the p-n junction of $GaInP_2$ and the band offset between the $GaInP_2$ base and the GaAs substrate materials. With varying the light intensities irradiated at the sample, we found that, in addition to the flattening of the p-n junction, two changes in the potential profile happened in the locations of the front window or the back surface field (BSF) layers under the condition of a lower or a higher light intensities, respectively. The two potential changes, together with the flattening of the p-n junction, contribute positively to the open-circuit voltage of the device, indicating the importance of the window and the BSF layers in solar cell designs. Furthermore, the potential change at the window layers is understood in terms of the band offset between the $AlInP_2$ window and the $GaInP_2$ emitter layers, and the potential change at the BSF layer is understood in terms of the total effect of the photo-induced flattening of the band bending and the band offset at the interface between the base and the BSF, respectively.

3:40pm **EL+SC-TuA6 Deep Level Defect Characterization of InGaAsN Layers Grown by Molecular-Beam Epitaxy**, ***S.W. Johnston***, *R.K. Ahrenkiel, A.J. Ptak*, National Renewable Energy Laboratory

The quaternary alloy $In_xGa_{1-x}As_{1-y}N_y$ can be grown lattice-matched to GaAs and can potentially be used as the 1-eV bandgap material in a four-junction, high-efficiency solar cell. We have characterized a series of $In_xGa_{1-x}As_{1-y}N_y$ samples with varying N content by measuring deep level transient spectroscopy (DLTS). The samples were grown by rf plasma-assisted molecular-beam epitaxy and contain N concentrations $0 \leq y \leq 0.02$. Our data show that each as-grown sample contains a hole trap whose peak occurs near 350 K for the 0.2-ms rate window. Analysis of these peaks indicates activation energies of 0.62, 0.62, and 0.75 eV for samples with y = 0.003, 0.013, and 0.02, respectively. Electron traps were also detected, even though the DLTS measurements were performed with Schottky contacts deposited on p-type material. This is attributed to a large Schottky barrier. For the sample with y = 0.003, an electron trap with an activation energy of 0.50 eV was detected. As N-content increased, the detected electron-trap activation energies decreased to 0.22 and 0.27 eV for the y = 0.013 sample, and to 0.13 eV for the y = 0.02 sample. We also show DLTS data correlating to varying growth conditions and the effects of annealing processes.

4:20pm **EL+SC-TuA8 Thermal Quenching and High Temperature Cathodoluminescent Degradation of Sulfide-Based Powder Phosphors**, ***B.L. Abrams***, *L.C. Williams, J.-S. Bang, P.H. Holloway*, University of Florida

Temperature effects on cathodoluminescent (CL)intensity, spectrum and degradation of ZnS:Ag,Cl powder phosphor have been investigated. Thermal quenching was studied by increasing the phosphor temperature without exposure to a continuous electron beam and measuring the decreased CL intensity. A characteristic thermal quenching temperature of 150^oC with an activation energy (E_a) of 0.87eV was observed for ZnS:Ag,Cl. Along with reduced CL intensity, the spectra shifted to longer wavelengths and changed shape at elevated temperature. The shift was dominated by band gap narrowing at high temperatures. Shape change was attributed to Cu contamination from the heater stage. The CL spectral distribution and intensity were 100% recoverable upon cooling back to room temperature when electron beam exposure was minimal ($<1C/cm^2$). With continuous electron beam exposure, CL intensity upon cooling to RT (after $24C/cm^2$, 2keV primary beam energy) was <40% of the original intensity before heating. The loss of CL intensity at high temperatures was less than at RT for the same primary beam energy and coulombic dose. This is consistent with the Electron Stimulated Surface Chemical Reaction

(ESSCR) Model of degradation which predicts that elevated temperatures will reduce the mean stay time of physisorbed gases, decreasing the rate of the surface reactions leading to CL degradation. Electron beam heating was calculated using a simple heat transfer model and was significant for powder samples. This is consistent with morphological erosion observed on the surface of the ZnS particles degraded at elevated temperatures or high power densities. It is speculated that at temperatures of about 300^{o}C, surface chemical reactions in combination with heating leads to removal of S and evaporation of Zn. Work supported by DARPA Grant MDA 972-93-1-0030 through PTCOE.

4:40pm **EL+SC-TuA9 Analysis of Ion Implantation Damage in Silicon Wafers by a Contactless Microwave Diagnostic**, ***R.K. Ahrenkiel***, National Renewable Energy Laboratory*, B. Lojek*, Atmel Corporation

Rapid thermal annealing (RTA) of ion implantation damage is required to maintain the integrity of submicron integrated circuit devices. A quick, efficient, and contactless diagnostic of the implantation damage is highly desirable. The residual radiation damage drastically reduces the recombination lifetime in the implanted region. Here, we will demonstrate the use of resonance-coupled photoconductive decay (RCPCD) technique allows us to to probe this region in boron and arsenic-implanted silicon wafers. Using a tuneable optical excitation source, we excite electron-hole pairs in the implanted region only. We compare these recombination times with those of the non-implanted bulk of the crystal. The lifetime is independent of excitation wavelength for the as-grown, oxidized wafers with typical values larger than 50 ms in semiconductor-grade silicon. After ion implantation with either arsenic or boron, the near-surface (711 nm) lifetime drops more than two orders of magnitude because of recombination at implantation-produced defects. After an RTA process, the lifetimes increase and again approach the bulk lifetime. One first group of wafers was processed in a standard rapid thermal processing (RTP) system SHS 2000 with a Hotliner. A second set of wafers were exposed to constant wavelength irradiation with maximum photon energy of approximately 1.4 eV for about 5 seconds, which has been called a "spike anneal". Our studies showed that the latter process produces wafers of lower recombination center density that the standard process. We propose some possible models to explain the improved properties of the "spike-annealed" wafers.

5:00pm **EL+SC-TuA10 Gas-phase Nanoparticle Formation during AlGaN MOCVD**, ***J.R. Creighton****, W.G. Breiland, M.E. Coltrin*, Sandia National Laboratories

The AlGaN MOCVD process is often plagued by parasitic chemical reactions that diminish the group-III deposition efficiency and make it difficult to control alloy composition. We have explored many possible mechanisms for the parasitic reactions using a variety of experimental techniques and complex reactive flow simulations. Results indicate that the reactions require high temperatures and occur in the boundary layer near the growing surface. These reactions ultimately lead to the formation of nanoparticles, which we have recently observed using in situ laser light scattering. Thermophoresis keeps the nanoparticles from reaching the surface, so the material tied-up in nanoparticles cannot participate in the thin film deposition process. In the case of AlN, the particle size was determined to be 48 nm, and the particle density was in the range of 10^{8-9} cm^{-3}. At these densities a significant fraction (20% or more) of the input Al is converted into nanoparticles. Analysis of the polarization dependence of the scattering from GaN nanoparticles indicates that they are non-spherical. This makes determination of their size and density more difficult, but they are in the range observed for AlN nanoparticles. For GaN and AlN nanoparticles the balance of thermophoretic and viscous forces results in a sharp height distribution centered at ~6 mm above the surface, which is in good agreement with the theoretical prediction.[1]

[1]Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

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