Thin Films
Room 329 - Session TF2-WeA

Optical Thin Films and Photovoltaics II
Moderator: R. Sargent, OCLI

2:00pm **TF2-WeA1 Magnetron Sputtering for II-VI Semiconductor PV Materials**, ***A.D. Compaan,*** University of Toledo **INVITED**

The deposition of polycrystalline, thin-film, II-VI semiconductors such as CdTe is possible by many different techniques, but the use of a plasma-based method such as magnetron sputtering can have significant advantages. In this paper we review recent advances in the fabrication of CdS/CdTe cells using rf planar magnetron sputtering and discuss some of the advantages that accrue from the use of sputtering in this class of materials. Some of these advantages take on increased relevance as the polycrystalline thin-film community begins to address issues related to the challenges of fabricating high efficiency tandem cells with efficiencies over 25%. Recently we have achieved improved sputtered cell performance (Voc= 814 mV, Jsc=23.5 mA/cm2, fill factor = 73.25, and efficiency = 14.0%) from superstrate cells based on window layers with sputtered ZnO:Al. In addition we have used reactive sputtering for the deposition of nitrogen-doped layers of p-ZnTe for possible use in transparent back contacts to CdTe. We shall also discuss recent results in the sputtering of wider and narrower bandgap alloys of CdTe with Zn, Mn, and Hg, and in the fabrication of cells with very thin CdTe layers having relatively little loss in performance and stability. Finally, the use of magnetron sputtering permits the fabrication of flexible thin-film cells on temperature-sensitive substrates such as polyimides. Work supported by the National Renewable Energy Lab and the U.S. Air Force.

2:40pm **TF2-WeA3 The Effects of Cu and Cl at the Device Junction on the Performance of CdTe-CdS Photovoltaic Cells**, ***T.J. Bukowski,*** *D. Albin, J. Pankow, S.E. Asher,* National Renewable Energy Laboratory

Current CdTe photovoltaic device design utilizes processing steps that incorporate both Cu and Cl into the cell structure. Such treatments produce an enhancement in the initial device efficiencies. However, there has been concern that Cu and Cl at the CdTe-CdS interface may have an effect on the stability of the device. In the unstressed state, CdTe devices are known to have significant amounts of both Cu and Cl at the interface. In addition, Cu placed at the back contact has been proven to diffuse toward the interface as the device is stressed, increasing the amount of Cu at the junction. There is thought to be a correlation between the amounts of Cu diffused to the interface from the back-contact and the resulting observed degradation in performance, the origin of which has yet to be determined. We have begun experiments studying how direct incorporation of Cu and Cl at the interface affects device performance. In this study, we detail the correlation observed between CuCl vapor-deposited at the CdS/CdTe interface prior to CdTe deposition with resulting device performance. X-ray diffraction, x-ray photoelectron spectroscopy, SIMS, Raman spectroscopy and optical absorption techniques are used to characterize the resulting change in the CdS films as a result of incorporating Cu and Cl. It is shown that at treatments below 250°C a CuCl layer forms on the surface of the CdS. Above 250°C, additional compounds begin to appear such as Cu@sub x@S. Absorption data shows that the band edge of the CdS shifts from 2.61eV down to 2.41eV as the CuCl treatment temperature increases. Devices are then made from the treated CdS films and their J-V data compared with data from both untreated controls and degraded devices. Device performance results are then correlated with the amounts of CuCl deposited at the interface.

3:00pm **TF2-WeA4 Cu Diffusion from Back Contacts in CdS/CdTe PV Devices**, ***S.E. Asher,*** *T.A. Gessert, C. Narayanswamy, D. Albin, R. Dhere,* National Renewable Energy Laboratory*; C. Ferekides,* University of South Florida*; M.R. Young,* National Renewable Energy Laboratory

It has been shown that for nearly all polycrystalline CdS/CdTe photovoltaic (PV) devices, the presence of Cu within the back contact is linked to both significant improvements in device performance as well as potential long-term device instability. There have been several studies of Cu distributions in devices performed using secondary ion mass spectrometry (SIMS), and in most depth profiles the Cu appears to segregate to the CdS layer in the device. Taken with the knowledge that grain sizes in the CdS are smaller, this has suggested that Cu is distributed primarily along grain boundaries. However, artifacts in the SIMS measurements may distort the profile and lead to erroneous conclusions if differences in sputter rate and corrections for ion yield are not made. In this study we use ion implanted standards of Cu into CdTe and CdS to quantify the levels of Cu in CdTe/CdS devices before, and after, one of three different back contact processes are applied. Our results show that while Cu does increase in the CdS layer of the device, the level prior to contacting is usually lower than in the CdTe. We also show that the CdCl@sub2@ process typically performed prior to application of the back contact can introduce signicant levels of Cu into the device. Device characteristics are also compared with the SIMS diffusion profiles.

3:40pm **TF2-WeA6 Electron Cyclotron Resonance Plasma Sputtering Deposition of Highly Textured LiNbO@sub 3@ Thin Films on Si Substrates and Their Electro-Optic Properties**, ***H. Akazawa,*** *S. Masaru,* NTT Microsystem Integration Laboratories, Japan

*Electron cyclotron resonance plasma sputtering provides high-quality thin film growth in the spontaneously generated electric field as well as the plasma stream, which carries kinetic energies of 10-30 eV. This technique has been used to grow textured LiNbO@sub 3@ (LN) thin films on Si substrates with a LiNbO@sub 3@ target. Smooth, crack-free films more than 1.2 µmm thick, were obtained. The x-ray diffraction pattern of films grown under optimized conditions revealed a single LiNbO@sub 3@ phase with its direction preferentially oriented along the substrate normal. The LiNb@sub 3@O@sub 8@ phase developed under excess O@sub 2@ gas ambient because of the enhanced re-evaporation of Li@sub 2@O molecules. ICP atomic emission spectroscopy confirmed that the composition is mainly affected by the oxygen partial pressure, but little affected by the growth temperature. Cross-sectional TEM images revealed columnar grains extending from the interface, and the volume fraction of the c-axis oriented domains was about 30%. Double inter-layers, 3-5 nm thick, (possibly a-SiO@sub 2@ and a-LN) were seen between the crystalline LN film and the Si substrate. The refractive index of the LN film was similar to the value of bulk crystal, indicating that the film was densely packed. The current-voltage characteristic was reversible up to the electric coercive force of bulk LN without destroying the insulating property, and the resistance was of the order of 10@super -11@ @ohm@cm below the applied voltage of 2 eV. The electro-optic effect was investigated by spectroscopic ellipsometry. We could detect a @delta@n value in the 10@super -4@ range, which corresponds to 30-20% of the Pockels constant of bulk crystal.

4:00pm **TF2-WeA7 Infrared Electroluminescent Zinc Sulfide: Rare Earth Doped Thin Film Devices**, ***A.S. Kale,*** *W. Glass, N. Shepherd, M.R. Davidson, P.H. Holloway,* University of Florida

ZnS doped rare earth fluoride thin films have been fabricated by RF magnetron sputtering in the conventional metal-insulator-semiconductor-metal electroluminescence (EL) configuration as a novel source for IR radiation. These ACTFEL (alternating current thin film electroluminescent) devices have promise for applications in fiber optic communication and industrial gas sensors as well as consumer electronic devices. ZnS thin films, typically 1µm thick, doped with ErF@sub 3@ and NdF@sub 3@ have been studied for their IR versus visible emissions. Electroluminescence has been investigated after different annealing temperatures (as deposited to 475°C) at a fixed time (60min) to study the influence of annealing on the IR brightness. An extremely sharp temperature dependence has been found in the IR emission, where anneals at 425°C sharply increase the emission intensity, while temperatures 25°C higher or lower result in sharply attenuated emission. The origin of this effect will be discussed. Emission spectra and efficiency from 0.35 to 1.55µm will be reported. For Er doped films, there is no shift in 4f-4f emission wavelengths versus annealing temperature, but shifts of up to 10 nm are seen for Nd doped ZnS thin films. This shift in wavelengths in Nd has been attributed to crystal field effects on the mixed 5d-4f as well as the 4f-4f transitions. Room as well as low temperature time resolved decay measurements are presented to compare the nature of specific energy transitions and energy transfer mechanisms as function of device temperature.

4:40pm **TF2-WeA9 Dual-Color UV/IR Photodiodes Based on AlGaN Grown on Si and SOS for Advanced Fire/Flame Detectors**, ***D. Starikov,*** *C. Boney, N. Medelci, R. Pillai, A. Bensaoula,* University of Houston

Rugged and reliable fire/flame detector arrays can be developed through integration of mature Si-based photodetectors with the newer UV wide band gap semiconductor photodetector technology. A GaN/InGaN/GaN double heterostructure grown on Si is photosensitive in the range from near UV to near IR. The UV range provided by the nitride layers (235-365 nm) is extended into visible and IR regions (365-1100 nm) by a Si p-n junction formed during the growth of the AlN buffer on the Si substrate.

Schottky barrier photodiodes based on AlGaN layers grown on Si (detector 1) and sapphire (detector 2) can further extend the UV range of the above described structure and will be the focus of this paper. The AlGaN structures were grown using RFMBE and were processed by Cl-based reactive ion etching in order to expose each layer in the multilayer structure, deposit ohmic and Schottky barrier contacts, and investigate the electrical and photovoltaic properties of each interface. The results from detector 1 indicate high responsivity in short UV wavelengths down to 275nm, confirming the 35% Al concentration as determined by independent transmittance measurements, and in 550nm and longer range. Measurements from the detector 2 show a response limited to the UV range with a cutoff of between 290nm and 300nm indicative of an aver age Al content of ~25%. The above results are currently being implemented in the development of UV/IR sensitive tandem structures fabricated on silicon-on-sapphire (SOS) substrates. Results on the SOS-based photodetector fabrication, testing, as well as optimization of the UV to IR ratio by modeling of the component pixel structure will be presented.

5:00pm **TF2-WeA10 Gadolinium Doped Yttrium Oxide Thin Films Deposited by Radio-frequency Magnetron Sputtering; Film Quality and Cathodoluminescence Properties***, **J.D. Fowlkes**, P.D. Rack, Y. Deng,* The University of Tennessee, Knoxville*; J.M. Fitz-Gerald, R.K. Bansal,* The University of Virginia

Miniaturized ultraviolet (250 - 350 nm) emitting solid - state sources are required as components for proposed device structures such as non-line-of-sight communication transceivers and receivers and bioparticle detection units. Rare - earth doped, yttrium oxide thin films emit ultraviolet light over this proposed frequency range. Yttrium oxide thin films were deposited by radio - frequency magnetron sputtering in a reactive oxygen atmosphere. The films were deposited on Si (001) substrates and were polycrystalline with a preferred (222) pole orientation along the substrate normal that became more prominent at high temperature. In addition to texture, crystal size and crystal quality were determined, using x-ray diffraction, for a host of sputtering conditions. Yttrium oxide was doped with gadolinium which emits in the ultraviolet via an interband 4f-4f transition. The films emit at 314 - 315 nm with optimum intensity at ~ 10 at% Gd. Correlations have been made between thin film orientation, crystallite size, residual stress, and cathodoluminescence (CL) studies. CL excitation was optimized per sample by proper voltage, current, and temperature selection. In addition, CL data will be presented that reflects the characteristics of the Gd optical transition. Specific information regarding the phonon assisted transition and thermal and concentration quenching will be discussed.

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