Thin Films
Room 303C - Session TF-ThA

Photovoltaic Thin Films
Moderator: T. Klein, The University of Alabama

2:00pm **TF-ThA1 Study of Molybdenum Back Contact Layer to Achieve Adherent and Efficient CIGS2 Absorber Thin-Film Solar Cells**, *N.G. Dhere,* Florida Solar Energy Center*;* ***A.A. Kadam,*** University of Central Florida

Molybdenum is used as back contact layer in CuIn@sub 1-x@Ga@sub x@S2 (CIGS2) absorber thin film solar cells. Mo is sputter deposited using DC magnetron sputtering. Mo being refractory material develops stresses. It is essential to deposit stress-free and relatively inert Mo in order to achieve well adherent and highly efficient CIGS2 absorber thin film solar cells on stainless steel and glass substrates. Earlier studies have shown that films deposited at 300 W and 0.3 mT pressure develops compressive stress, while the films deposited at 200 W and 5 mT pressure develops tensile stress. Four experiments were carried out to achieve optimum deposition cycle to deposit stress free Mo. In first experiment two cycles of 200 W/5 mT were sandwiched between three cycles of 300 W/0.3 mT. In second experiment two cycles of compressive stress were sandwiched between three cycles of tensile stress. In third experiment two cycles each of compressive stress and tensile stress were deposited alternatively starting with compressive cycle and ending with tensile cycle. The fourth experiment was conducted in reverse order, starting with tensile and ending with compressive. All the depositions were carried out on 15 x 10 cm@super 2@ stainless steel substrates. 5 x 10 cm@super 2@ strip was cut and remaining 10 x 10 cm@super 2@ was deposited with metallic precursors copper-gallium and indium. Metallic precursors were sulfurized at 475°C for 20 minutes in a gas mixture of 4% H@sub 2@S/N@sub 2@. The presentation describes the XRD and SEM analysis to study the quality of films as a consequence of deposition cycle of Mo back contact layer. TEM analyses are also presented to study Mo/CIGS2 interface behavior. Small region of Mo films on remaining 5 x 10 cm@super 2@ strips were tested for adhesion by simple scotch tape test and remaining part was sulfurized at 475°C for 20 minutes to study the reactivity of Mo with H@sub 2@S at the operating temperature.

2:20pm **TF-ThA2 Formation of Chalcogen Containing Plasmas and Their Use in Synthesis of Photovoltaic Absorber Layers**, ***S. Kosaraju,*** Colorado School of Mines*; C.A. Wolden,* Colorado school of Mines*; R. Ingrid,* ITN Energy Systems, Inc.

The synthesis of copper chalcopyrite solar absorbers requires high temperature and excess chalcogen due to low chalcogen reactivity. This paper describes work aimed at addressing these issues through plasma processing. An inductively coupled plasma (ICP) source was used to activate both sulfur and selenium vapors into high-energy atomic and radical species. Stable ICP discharges were achieved with both sulfur and selenium vapors using argon as a carrier gas. ICP processing configurations are described for both a flowtube geometry used for metal selenization as well as for incorporation into a high vacuum co-evaporation environment. Actinometry was employed to measure the flux of chalcogen vapors from solid sources as a function of source temperature and the RF power. The potential of this approach was demonstrated by converting indium and copper/indium/gallium films to chalcopyrites using the ICP source. It is shown that indium is readily converted to In@sub 2@Se@sub 3@ using argon/selenium plasma at room temperature. Similarly, Cu/In/Ga precursor thin films on a stainless steel substrate were exposed to plasma-activated selenium at 300@super o@C. The foils were converted into ternary and quandary chalcopyrite compounds, and no crystalline binary phases (i.e. In@sub 2@Se@sub 3@, CuSe) were observed. Films were additionally characterized by scanning electron microscopy and energy dispersive spectroscopy.

2:40pm **TF-ThA3 Thin Film Photovoltaics**, ***N.G. Dhere,*** Florida Solar Energy Center **INVITED**

The world production of photovoltaic (PV) cells/modules has increased at a rate of >35%/year from 88.6 MW in 1996 to 744.8 MW in 2003 with concomitant reduction in cost. During this period U.S. fraction of PV production has dropped from 44% to 14%. Last year, U.S. production of thin-film PV modules was as follows: CdTe First Solar 2.5 MW, CuIn@sub 1-x@Ga@sub x@Se@sub 2-y@S@sub y@ (CIGS) Shell Solar 2 MW, a-Si:H UniSolar 7 MW and CIGS Global Solar 0.5 MW. Because of considerable increase in the production capacity, it is expected that the cumulative U.S. production of thin-film PV modules will double to 25 MW this year and again to 50 MW next year, thus spearheading production growth. Present PV conversion efficiencies of champion thin-film solar cells are CIGS 19.3%, CdTe 16.5% and a-Si:H 12.4%. However, those of PV modules lag considerably behind. In addition to increasing efficiency and production volume of thin-film PV modules and reducing their cost, it is also important to assure their long-term reliability. Other principle research issues in thin-film photovoltaics are discussed below. Even though the bandgaps of CdTe and CuIn@sub 1-x@Ga@sub x@S@sub 2@ (CIGS2) are near optimum for terrestrial and space applications, their open circuit voltages are considerably below theoretical attainable values. Therefore, interdiffusion, phase formation, and accumulation of impurities in the active junction region must be studied. Moreover, as CIGS film transitions from Cu-rich to In-rich composition, its microstructure must be studied. Obtaining ohmic contacts is difficult especially for CdTe because of the inherently low p-type doping level. Therefore, increasing p-type doping level is important. FSEC PV Materials Lab is participating in this effort with research and development on large area CIGS thin-film solar cells as well as by leading in testing of U.S. thin-film PV modules in the hot and humid environment as well as under high-voltage bias conditions.

3:20pm **TF-ThA5 Reaction Kinetics of Cu with the CdTe(111)-B Surface**, ***G. Teeter,*** *C.L. Perkins, T. Gessert,* National Renewable Energy Laboratory*; C. Corwine,* Colorado State University*; S. Asher,* National Renewable Energy Laboratory

Copper is frequently incorporated at the back contacts of CdTe-based thin film photovoltaic devices, where it is believed to dope the CdTe p-type and aid in the formation of a pseudo-ohmic contact. In the present study, the reaction kinetics of Cu thin films (0-30 Å) with the CdTe(111)-B surface have been measured via mass spectrometry in ultrahigh vacuum. Cu was deposited on the clean surface, and upon annealing it was observed that atomic Cd desorbs from the surface in proportion to the amount of deposited Cu. Temperature programmed desorption (TPD) measurements reveal zero order reaction kinetics for the Cu/CdTe(111)-B system. In addition, surface composition maps generated by scanning Auger Electron Spectroscopy (AES) show that a metastable copper telluride phase forms at the surface under certain conditions.

3:40pm **TF-ThA6 Transparent and Semi-Transparent Conducting Film Deposition by Reactive-Environment, Hollow Cathode Sputtering**, *A.E. Delahoy,* ***S.Y. Guo,*** Energy Photovoltaics, Inc.

Highly transparent and conductive In@sub 2@O@sub 3@ and ZnO films containing different doping elements such as Mo, Zr, Nb, Ta, W (for In@sub 2@O@sub 3@) and Al, B (for ZnO) have been prepared by the reactive-environment, hollow cathode sputtering method.@footnote 1@ The use of Nb and W as effective dopants is reported for the first time. Metallic targets were used exclusively, and the dopant concentration was easily controlled using a second sputtering power supply. As a result of the cathode and gas flow geometry, the sputtering is conducted in metal mode, and the target and doping materials are free from oxidation during the deposition process. Film resistivities achieved with the various dopants will be reported. For In@sub 2@O@sub 3@:Mo, a resistivity of 1.6x 10@super -4@ @ohm@-cm and a mobility of 80 cm@super 2@/Vs were achieved for Mo concentrations in the range 0.5-5.0% as measured by ICP. XPS analysis indicates Mo with a +6 valence state. The dependences of film resistivity on substrate temperature during preparation and film temperature during measurement will be presented and discussed. Different dominant scattering mechanisms can be seen in different films. Reasonably transparent films of CuAlO@sub 2@ will be reported. And remarkably, semi-transparent films of InN having sheet resistances of 12 @ohm@/square have also been prepared. A scaled-up linear cathode 50 cm in length is under construction, and we expect to report results for ZnO:B deposited using this source. @FootnoteText@ @footnote 1@A. E. Delahoy, S. Y. Guo, C. Paduraru, and A. Belkind, J. Vac. Sci. Technol. A 22 Jul/Aug 2004.

4:00pm **TF-ThA7 High Efficiency CIGS Thin Film Solar Cells**, ***K. Ramanathan,*** National Center for Photovoltaics **INVITED**

This paper will present the current staus of solar cells fabricated from CuInGaSe@2@(CIGS) polycrystalline thin films. CIGS thin film solar cells are considered as an excellent option for power generation at low cost. The technology has matured to the point of commercial production. We will highlight the special properties of CIGS materials and the 3-stage growth process developed at NREL. We have achieved a world-record solar cell efficiency of 19.3% at NREL. As the device efficiencies have increased and the confidence in the repeatability has grown, more attention is given to

basic science of junction formation, surface properties of absorber films, and electronic properties of interfaces. We shall review our work in this area and also our collaborations with our industrial partners.

4:40pm **TF-ThA9 High Stability a-Si:H Films Deposited using Cluster-Suppressed Triode Plasma CVD**, ***K. Koga***, *N. Kaguchi, M. Shiratani, Y. Watanabe,* Kyushu University, Japan

Reduction of a total volume of amorphous silicon particles below 10 nm in size (clusters) incorporated into a-Si:H films is the key to suppression of light-induced degradation of the films, since the films containing the less volume of clusters show the higher stability.@footnote 1@ In order to realize such reduction, we have deduced a sticking probability s of clusters to a stainless steel mesh from an experiment for which gas containing clusters has been passed through a series of eight meshes. Most clusters are trapped with the first two meshes, indicating s~1. Based on the result, we have employed a cluster-suppressed plasma CVD reactor@footnote 2@ together with a triode discharge for which clusters are trapped with a mesh placed at 18 mm above a substrate. The light-induced degradation of the film qualities has been evaluated using a n@super +@Si/a-Si:H(1µm thick)/Ni Schottky solar cell. The initial and stabilized fill factor FF of the Schottky cell is 0.60 and 0.56, respectively. The degradation ratio of 6.7% is significantly low compared to the ratio of 17% for device quality films deposited using a conventional diode discharge. The stabilized FF= 0.56 surpasses the initial FF= 0.53 for the diode discharge. We will also present experimental results obtained using an "improved version" of the cluster-suppressed triode plasma CVD reactor. @FootnoteText@ @footnote 1@K. Koga, N. Kaguchi, M. Shiratani and Y. Watanabe, J. Vac. Sci. Technol. A 22, (2004) to be published.@footnote 2@M. Shiratani, K. Koga, M. Kai, and Y. Watanabe, Thin Solid Films 427, 1(2003).

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