BAPVC Annual Project Report

Project Title: Ideal transparent conductors for full spectrum photovoltaics

PI: Wladek Walukiewicz
E-mail: w_walukiewicz@lbl.gov

Summary:

The group has developed high quality Cadmium Oxide (CdO) based transparent conductors (TCO) thin films with excellent electrical and optical properties using radio frequency magnetron sputtering method. They demonstrated a significant improvement in the photon flux transmitted through CdO:In compared with commercial Fluorine doped Tin oxide (FTO) for PV technologies relying on the infrared part of the solar spectrum. They developed a low resistance ohmic contact between CdO and p-Si. The group has also discovered and optimized properties of CdNiO alloys for environmental protection of CdO TCOs.

Key Accomplishments:

Previously the group has developed a method to grow a high quality n-type Cadmium Oxide-based TCO thin films with excellent electrical and optical properties. In the past year, the group's research was focused on three areas:

(i) Evaluation of the advantages of CdO compared with standard, commercial TCOs;
(ii) Development of low resistance contacts to Si PVs;
(iii) Development of CdNiO protective layers;

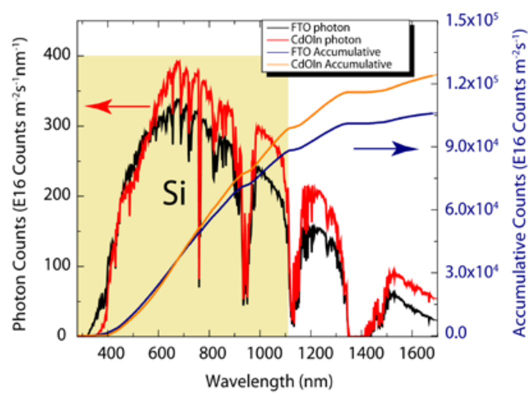

Fig. 1 Photon transmittance and accumulative photon count of commercial FTO and CdO:In films. Significant improvement in transmission of NIR photons (> λ=1130 nm) with CdO:In. More gain for longer wavelength absorbers.

(i) Fig. 1 shows the photon transmittance and accumulative photon count for solar spectrum passing through CdO:In and commercially available FTO of the same sheet resistance. A significant improvement in the transmission of NIR photons in CdO:In fully compensates for the small deficiency in UV transparency of this TCO. An accumulative photon count shows an advantage of the CdO based TCO for absorbers with λ_g>800 nm (E_g<1.6 eV). The superior NIR transparency demonstrates the feasibility of using CdO TCO in Si PV technology with λ_g=1130 nm.

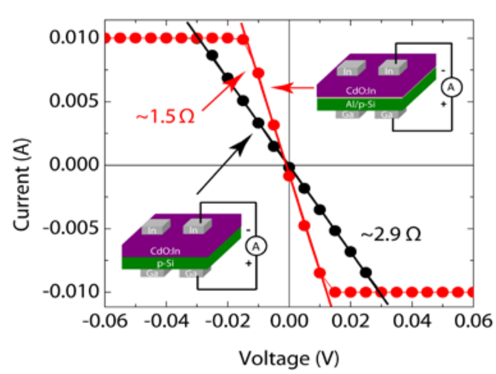

Fig. 2 Current-voltage curve of CdO:In/p-Si. Resistance of optimized p-Si/CdO:In interface does not contribute to the total series resistance.

(ii) Applications of CdO TCO to Si PV technology require low resistance ohmic contacts between CdO TCO and Si. The group has developed a method to grow CdO:In films on p-type Si with very low contact resistance. Fig. 2 shows the current-voltage curve of CdO:In/p-Si heterostructure. The resistance of optimized p-Si/CdO:In interface does not contribute to the total series resistance of a standard Si solar cell. The contact resistance is further reduced by Al diffusion from Al interlayer at the interface.

(iii) An environmental stability is an important consideration for applications of CdO TCO.

The group has found that the decomposition of CdO-based TCOs under highly corrosive conditions is significantly reduced by alloying CdO with NiO. Fig. 3 displays the conductivity as a function of Cd content in the $Ni_xCd_{1-x}O$ films. The films exposed to a negative bias in an electrolyte become more conductive and less transparent (colored) due to loss of oxygen and material decomposition. The alloying of CdO with NiO reduces the decomposition. Coloration effect is decreasing with increasing Ni content and becomes negligible for Ni content larger than ~25%. The coloration effect has been attributed to the presence of the surface electron accumulation layer as the films show much larger stability for the positive bias (bleaching) conditions.

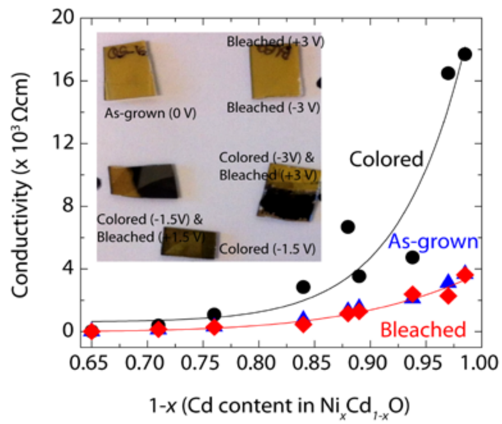

Fig. 3 Conductivity as a function of Cd content in the as-grown, colored, and bleached $Ni_xCd_{1-x}O$ films. Alloying of CdO with NiO reduces the decomposition. CdNiO with more than 25% Ni can be used as a protective coating.

Future Work:

The main focus of the group's future effort will be implementation of CdO-based TCOs for Si PVs technology. The performance of p/n and n/p Si solar cells with CdO-based transparent contacts will be compared with standard Si PVs using Ag grid. This work will be done in collaboration with Australian National University and a commercial Si PV company that have already provided Si p/n and n/p structures for CdO deposition to be compared with reference cells fabricated using standard Ag grid technology. The objective of this work will be to fabricate Si PVs with CdO contacts that are within 10% (relative) efficiency of the reference devices.

The detailed tasks are as follows:

1. Fabrication of n/p+ and p/n+ Si solar cells with CdO:In contacts (in collaboration with ANU and industrial partner).
2. Optimization of the CdO:In deposition conditions for low carrier recombination at Si/CdO:In interface.
3. Evaluation of CdO:In for use as anti-reflective coating on Si cells.
4. Comparison of the performance of Si cells with CdO:In TCO and with standard Ag grid.
5. Study of the effects of CdNiO protective layer on the cell performance.