Transparent indium tin oxide films prepared by reactive thermal evaporation in the U.C. Berkeley Microlab

D. R. Queen and J. Morford

U.C. Berkeley Microfabrication Laboratory, Berkeley, CA 94720.

Transparent, conducting thin films of indium tin oxide (ITO) have been prepared by reactive thermal evaporation. Films grown from an InSn (10 wt. %) source at 175°C in 0.32 mTorr of O_2 gas have resistivity of 2.4×10^{-4} Ω cm and transparency greater than 95% over the visible spectrum.

Film Preparation

ITO films were prepared by reactive thermal evaporation from an InSn (10 wt.%) source material with a partial pressure of O_2 using the nrc thermal evaporator. The source material was evaporated from a boron nitride crucible in a tungsten heater basket to keep the source material from creeping during the deposition. Oxidation of the heated tungsten filament results a powdery residue on and around the filament. Molybdenum boats are reported to work for reactive thermal evaporation and tungsten boats should be avoided as the source material is known to creep out of the boat during deposition. Oxygen partial pressure was controlled using a piezo-electric leak valve by adjusting the supply voltage between 0V and 40V resulting in an oxygen pressure of 0.5-5mTorr. Nominal crystal thickness monitor parameters are supplied in Table 1. Substrates were heated to 175°C during deposition and were allowed to cool below 50°C before removing from the chamber.

Table 1. Process parameters for reactive thermal evaporation of ITO in the nrc thermal evaporator.

Source Material:	Indium -Sn (10 wt.%) 5N Purity ESPI Metals P/N: KNC6069	
Evaporation Source:	Boron nitride crucible (R.D. Mathis P/N: C1-BN) Tungsten Basket heater (R.D. Mathis P/N: B8A-3X.030W)	
Base pressure:	1×10^{-6} Torr	
O_2 Partial pressure:	2.5×10^{-4} Torr	
Substrate temperature:	175°C	
Filament Current:	50 A	
Deposition rate:	18 Å/min	
Nominal crystal thickness	Density:	7.1 g/cm^3
monitor settings:	Z-factor:	0.439

Results

Figure 1 shows the percent transmission of several ITO films. The percent transmission is defined as I/I_0 where I is the measured transmitted intensity of the ITO film on a glass substrate and I_0 is the transmitted intensity of light through the glass substrate. The reactive thermally evaporated film is shown in Figure 1 along with a film from Delta Technologies[1], a commercial supplier of ITO coated glass, and a film prepared by reactive thermal evaporation by the Silicon Group at the National Renewable Energy Lab (NREL).[2] These ITO films are used in the fabrication of various photovoltaic devices at NREL. Transmission measurements were made on the Sopra ellipsometer with the analyzer and polarizer arms in a horizontal configuration. Transmission spectra were acquired using the GESPACQ software.

The resistivity of the ITO film was measured to be $2.4\times10^{-4}\Omega\cdot$cm on a 200μm × 2500μm strip which is comparable to other ITO films reported in the literture.[3] The film was lithographically patterned with Shipley 1818 photoresist and etched in aqua-regia at room temperature. The etch rate of the film was found to be approximately 2nm/s.

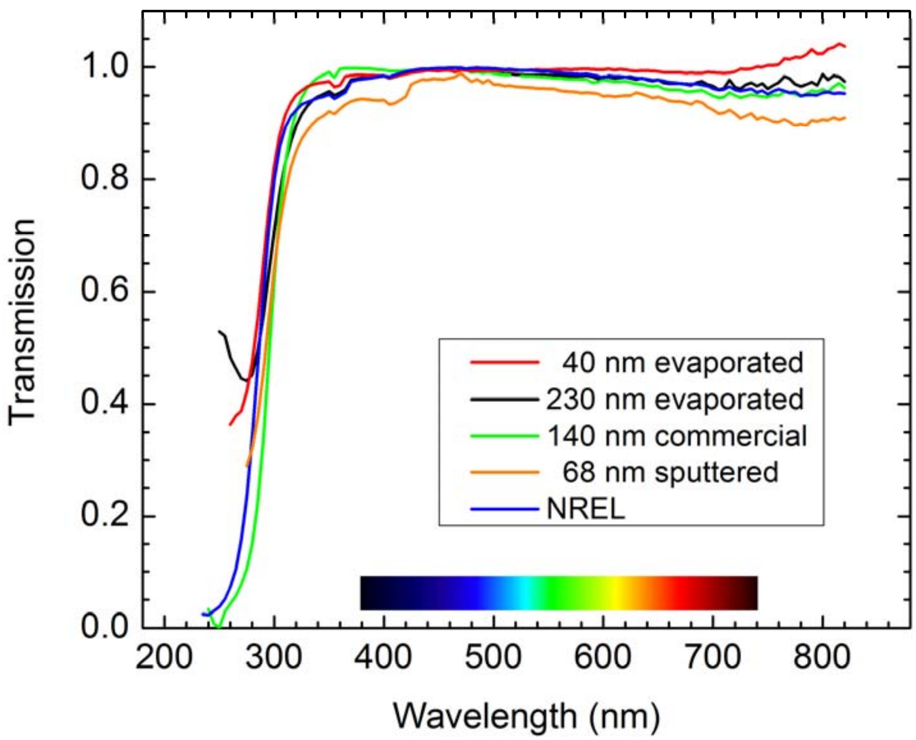

Figure 1. Optical Transmission (I/I_0) of several ITO films as measured using the Sopra ellipsometer. The visible spectrum is shown as a reference. The 40nm and 230nm films were prepared by reactive thermal evaporation in the NRC. The 140nm film was supplied by Delta Technologies and the NREL film was prepared by reactive thermal evaporation by the Silicon Group at the National Renewable Energy Lab. The sputtered film was prepared by DC magnetron sputtering from an ITO sputter target as described in the text.

A comparison ITO film was prepared by DC magnetron sputter deposition[4] in the edwards sputterer with the following deposition conditions:

Base Pressure:	8×10^{-5} Torr
Ar Pressure:	2.2×10^{-3} Torr
Power:	45W
Deposition Rate:	3nm/min
Substrate Temperature:	Room Temperature
Target:	ITO sputter target (3”×0.250”) Kurt J. Lesker P/N: EJTITOX403A4

The 68nm sputtered film was found to have a resistivity of 3.8×10^{-3} Ω·cm and 94% transmission over the visible spectrum.

Discussion

The film deposition rate was found to decrease with increasing the O_2 partial pressure. This decrease is presumably due to the low vapor pressure of the oxide that forms on the surface of the source at these high O_2 pressures. Additionally, the stoichiometry of the source material must be considered during deposition evaporation. Jan and Lee[5] report that the higher vapor pressure of In leads to a Sn rich source that changes the vapor concentration of In and Sn during the evaporation. They recommend that only a small portion of the sample be vaporized during the deposition to maintain keep the stoichiometry of the source relatively unchanged. The dependence of film quality on substrate temperature was not explored in this work.

Conclusion

Low resistivity, high transparency thin films of ITO have been successfully prepared by reactive thermal evaporation in the nrc thermal evaporator. Film transparency was found to be greater than 95% across the visible spectrum. The resistivity of these ITO films was 2.4×10^{-4}Ω·cm which is comparable to high quality films reported in the literature. X-ray diffraction and Hall measurements can be used to further characterize these films and refine deposition parameters.

---

[1] Delta Technologies, Limited. 13960 North 47th St. Stillwater, MN 55082.

[2] National Renewable Energy Laboratory, 1617 Cole Blvd. Golden, CO 80401-3393

[3] R.B.H. Tahar, T. Ban, Y. Ohya, and Y. Takahashi, “Tin doped indium oxide thin films: electrical properties,” J Appl. Phys. **83**, 2631 (1998).

[4] F. Kurdesau, G. Khripunov, A.F. da Cunha, M. Kaelin, and A.N. Tiwari, “Comparative study of ITO layers deposited by DC and RF magnetron sputtering at room temperature,” J Non-Cryst. Solids **352** 1466 (2006).

[5] S.W. Jan and S.C. Lee, “Preparation and Characterization of Indium Tin-Oxide deposited by Direct Thermal Evaporation of Metal Indium and Tin,” J Electrochem. Soc. **134**, 2056 (1987).