Indium Tin Oxide

Indium Tin Oxide (ITO) coatings have found many applications in the display and optical coatings industries as a transparent conductor. Processing conditions for ITO are important because they can significantly affect film conductivity. The key is to increase conductivity while retaining transparency in the visible spectrum. The conductivity creates absorption in the infrared due to free carriers. As the free-carrier concentration increases, the absorption also increases and shifts toward short wavelengths. Due to the connection between free-carriers and optical properties (infrared absorption), spectroscopic ellipsometry offers a reliable measure of the conductivity. Jeff Hale studied the effects of annealing on ITO films with in situ SE at the University of Nebraska - Lincoln. He was able to monitor the conductivity with annealing time, as shown in Figure 1.

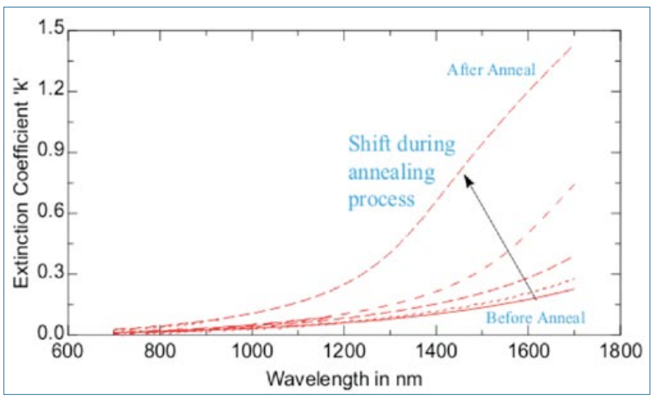

Figure 1. Change in ITO absorption (conductivity) as a function of annealing time.

To quantify the conductivity, the optical properties of the ITO film can be described with a free-carrier (Drude) absorption written in terms of resistivity and mean scattering time :

$$\varepsilon_{Drude}\left(E=\hbar\omega\right)=\frac{-\hbar^2}{\varepsilon_0\rho\left(\tau\cdot E^2+i\hbar E\right)}$$

This model allows both the film thickness and conductivity (1/ρ) to be determined. The Drude oscillator models the absorption in the NIR, however, if data is acquired below 400nm a Lorentz oscillator will also be needed to describe absorptions due to band-to-band transitions in the UV. Multiple oscillators can easily be incorporated in the new “GenOsc” layer.

Strong connection between process conditions and film properties will generally affect uniformity across a large panel. Large-area mapping systems can be used to study the spatial uniformity of a coating over entire flat panels. In addition, it is common to find variation with the film properties as a function of depth into the film. This has been studied and can generally be described with a graded optical model[1,2]. A linear gradation through the film depth is often adequate to describe the behavior of an ITO film, but more complex grading profiles are not uncommon. The optical properties from the bottom and top of an ITO film are shown in Figure 2. For further details about modeling ITO coatings, please contact a J.A. Woollam applications engineer.

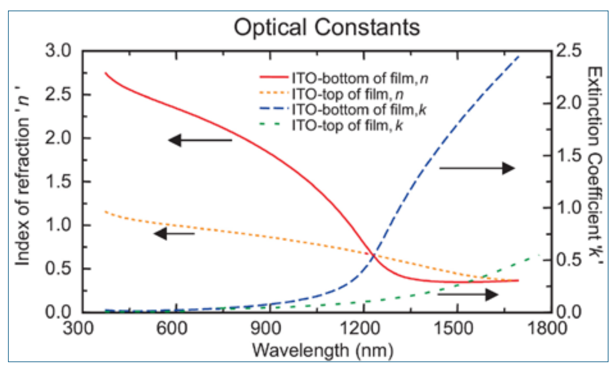

Figure 2. Optical constants (n & k) of a graded ITO film. Process conditions produce a film with different resistivity at the top and bottom of the film.

References:

1. R.A. Synowicki, “Spectroscopic ellipsometry characterization of indium tin oxide film microstructure and optical constants.” *Thin Solid Films*, **313-314**, 394, 1998.
2. J. A. Dobrowolski, L. Li, J. N. Hilfiker, “Long wavelength cutoff filters of a new type.” *Applied Optics*, **38**, (22) 4891 (1999).