This application note describes how to use our omtsYs-series Thin Film Analysis (TFA) device to optically determine sheet resistance. Often sheet resistance is measured electrically with a 4-point device or magnetically using eddy current induction. An optical measurement has many advantages. First of all, the measurement is contactless and nondestructive. Also, for multiple layers of conducting material, the sheet resistance can in many cases be determined individually such as on the front and back side of a substrate. In addition to a sheet resistance determination, the TFA can simultaneously determine the film thickness and index of refraction for thin conducting oxides (TCOs) such as ITO or doped ZnO. The sheet resistance of TCO layers is an important quantity in many production processes. The TFA is available to industrial manufacturers for in-line, 24/7, process and quality control.

Example: doped ZnO (TCO)

ZnO is an ideal material for display technology and photovoltaics. First, it is transparent in the visible range of the optical spectrum. Second, when doped with aluminum and deposited on a glass substrate, the resulting layer is conductive and can be used as an electrode. By measuring and analyzing optical transmission spectra in the visible and infrared range of the electromagnetic spectrum with our in-line TFA metrology tool, it is possible to calculate the doped ZnO film thickness as well as the sheet resistance of this layer. The sheet resistance can be related to measurements taken by a conventional 4-point probe. To analyze the optical transmission measurements, it is necessary to have models for the index of refraction for the glass substrate as well as the doped ZnO layer. In general a Drude model can be used to determine the sheet resistance of conducting layers.

Physics behind the Drude Model

The classical Drude model relies on a damping constant, which does not depend on frequency. This is a good approximation in most cases. However, there are situations where the damping of the free carriers exhibits a characteristic dependence on frequency, such as in the case of scattering by charged impurities. A rather simple, but successful choice of the frequency dependence of the damping term is the following:

\[
\chi_{\text{Drude}}(\tilde{\nu}) = -\frac{\Omega_p^2}{\tilde{\nu}^2 + i\tilde{\nu}\Omega_s} \quad \text{with} \quad \Omega_p^2 = \frac{n\varepsilon_0^2}{\varepsilon_m}.
\]

- \(\Omega_s\): Plasma frequency
- \(\Omega_p\): Damping constant
- \(\tilde{\nu}\): Frequency
- \(\varepsilon_0\): Dielectric constant
- \(n\): Charge carrier density
- \(\varepsilon_m\): Effective mass
- \(\varepsilon\): Elementary charge

Fig. 1: Thin Film Analysis Device (table top version), the measuring head can be used in in-line production applications.

- Thin Film Analysis
- Sheet Resistance
- TCO/ITO
- In-line, real-time monitoring

omtsYs TFA – Thin Film Analysis Device

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Procedure (for doped ZnO on a float glass substrate)

When float glass is used as the substrate for the doped ZnO layer (see Fig. 2), a model for the substrate generally needs to be designed only once since manufacturers are consistent in their glass production. Fig. 3 shows the measured float glass transmittance and a model fit to this data.

The model and data for the float glass substrate is required so that a proper analysis of the doped ZnO layer can be ascertained. Once the TCO layer is deposited on the glass substrate, another transmission measurement is made and a new analysis (with a corresponding model for the doped ZnO layer) must be carried out.

The screenshot shown in Fig. 4 lists the components of a “dispersion” model used to describe the wavelength dependence of the index of refraction and the absorption by a doped ZnO layer. Part of this model is an “extended” Drude model (highlighted in red). This physical model is used to describe free carriers in conductive media like metals or thin conductive oxides.

The optical model for doped ZnO

This extended Drude model above predicts that the transmittance of a doped ZnO layer will decrease in the near infrared region until it levels off (see Fig. 5 in the wavelength range above 1000 nm). By applying the model to the measured data, the “plasma” frequency \( \Omega_p \), one of the parameters in the formula - can be retrieved from the model fit. The formula for \( \Omega_p \) is dependent on the density of charge carriers, \( n \). From the oscillations in the visible part of the spectrum, we can calculate the layer thickness. Given \( n \) and the film thickness, we can directly determine the sheet resistance or layer conductivity.

Summary

Here we have demonstrated an optical method (using an extended Drude model and a fit to the transmission data measured using our TFA) for the determination of the sheet resistance of doped ZnO. TFA's greatest advantage for in-line metrology systems is a contactless measurement and sheet resistance determination within seconds. An ideal application for the TFA is for process control for the industries of display technology or photovoltaics.