A Fresh Look at Multi-Sample Analysis

In this article, we focus on Multi-Sample Analysis (MSA) with the hope to uncover its mysteries. Along the way, we will reveal new applications that do not require "multiple" samples.

Traditional Multi-Sample Analysis

MSA was first demonstrated with spectroscopic ellipsometry data in the early 1990s[1]. It works by combining information from different light path-lengths through films of different thicknesses. More recently, we demonstrated that MSA can also work with films of the same thickness[2]. In this special case, each sample must have a different overall structure. For example, the same coating is deposited on silicon and above a thick dielectric coating on silicon. Light interacting with the common absorbing layer has been modified by its surroundings (sample structure) and thus is able to provide new information.

Example – PEDOT:PSS Films

Thin polymer films are finding their way into light-emitting diodes, solar cells, and plastic electronics. Conjugated polymers such as PEDOT:PSS are very interesting due to their conductive properties. Many blends of PEDOT:PSS exhibit anisotropy due to their orientation, which has been likened to a stack of pancakes[3]. The optical properties of PEDOT have been shown to exhibit uniaxial anisotropy with metallic and dielectric behavior in the ordinary and extraordinary directions, respectively[4].

In this example, we investigate a series of PEDOT:PSS films spin-coated onto glass substrates. Layers of different thickness provide different sensitivity to the film optical properties, especially if the layers are absorbing. Three samples were simultaneously analyzed, as shown in Figure 1. The optical constants for all films are assumed identical – which greatly reduces the number of fit parameters.

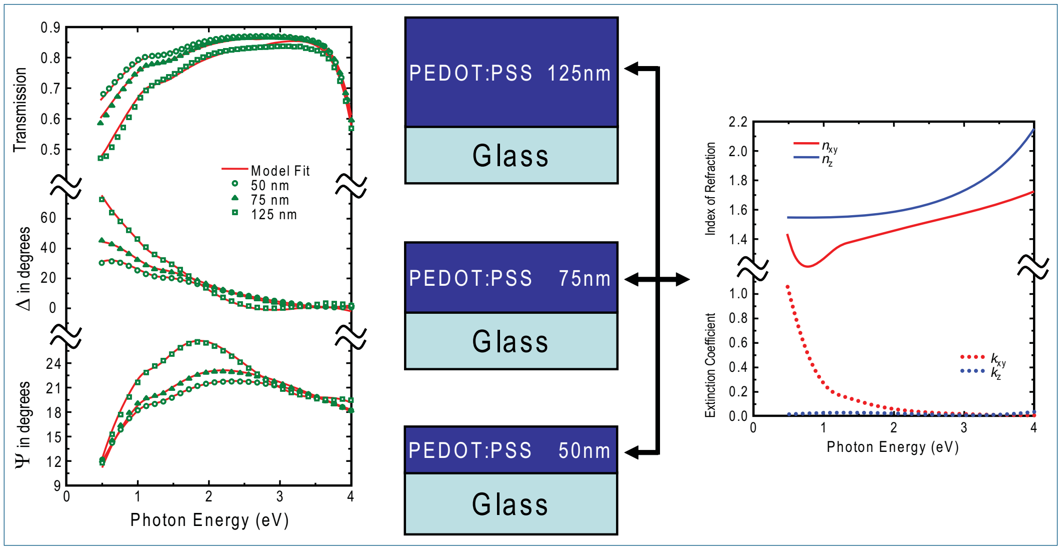


Figure 1. Experimental data from 3 different samples of PEDOT:PSS are simultaneously analyzed with the MSA method. This results in a single consistent set of anisotropic optical constants.

The final fit results in Figure 1 show data from each thickness on the same graph. Notice all three samples fit well, including both SE data and Transmission intensity. The final optical constants are also shown in Figure 1.

Anisotropic Samples

MSA analysis does not always require multiple samples, as the name implies. It can also apply to the same sample when different orientations provide new information. For anisotropic substrates, the optical axis can be oriented in multiple directions relative to the ellipsometer measurement beam (plane of incidence) to provide new information. Figure 2 shows experimental SE data for a SiC substrate with in-plane 4H hexagonal crystal structure. Multiple data sets from the same sample but with different orientations of the optical axis provide very different results. This difference is very noticeable between measurements shown with the optical axis parallel and perpendicular to the plane of incidence. Using the MSA approach, both orientations are analyzed simultaneously to determine the ordinary and extraordinary dielectric functions, as shown in Figure 2.

Mapping Data

The latest application of MSA also involves a single sample. In this case, new information comes from measuring different locations across a non-uniform coating that is mapped with spectroscopic ellipsometry. Data from multiple points are analyzed simultaneously to help develop a consistent model that accounts for

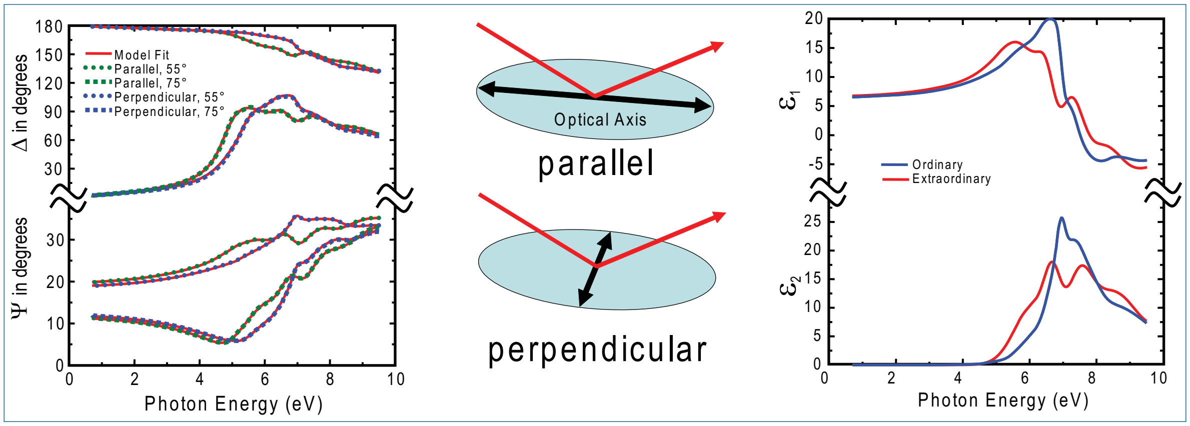
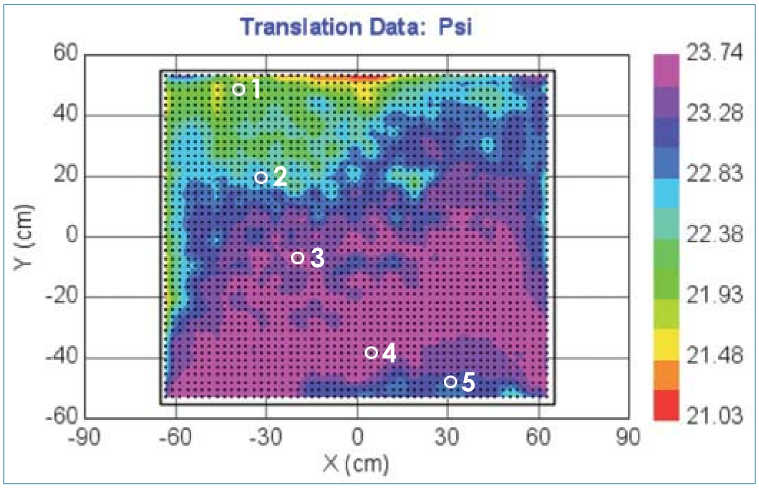


Figure 2. MSA approach applied to multiple measurements of the same anisotropic sample. Each measurement is aligned with different orientation to the optical axis. This provides the additional information needed to determine both ordinary and extraordinary dielectric function for the hexagonal SiC substrate.

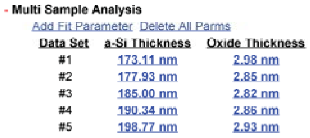
variation across the sample. With CompleteEASE software, multiple points from a map can conveniently be analyzed with the MSA approach. Figure 3 shows a measurement from an amorphous silicon film mapped with our AccuMap-SE system (see Page 6). Five points were selected across the panel (circled in figure), with the corresponding Psi and Delta from each point graphed for easy comparison. A single model is used within the MSA approach to fit all 5 data sets simultaneously. A single Cody-Lorentz oscillator describes the optical constants for all locations, while the variation from location-to-location are matched by fitting different film thicknesses. Once developed, the model can be implemented into automatic recipes for future use.

Conclusion

While the multi-sample analysis technique has been around for over two decades, its power and flexibility are often overlooked. We reviewed the traditional application of MSA, where multiple samples are analyzed with different thicknesses. We also introduced a few applications that use MSA on the same sample, where different orientations or locations are measured. For more information on the MSA approach, please contact our Applications Engineers at: measurements@jawoollam.com.



Layer # 2 = SiO2 Oxide Thickness = 2.93 nm (MSA fit)
Layer # 1 = a-si_CL-1 a-Si Thickness = 198.77 nm (MSA fit)
Add Oscillator Show Dialog
Einf = 1.000
1: Type = Cody-Lorentz Amp. = 114.121 (fit)
Br = 2.580 (fit) Eo = 3.595 (fit) Egap = 1.646 (fit)
Ep = 1.732 (fit) Et = 0.114 (fit) Eu = 0.500 Common Eg = OFF
Substrate = float top-side nk



- Multi Sample Analysis

Add Fit Parameter Delete All Parms

Data Set	a-Si Thickness	Oxide Thickness
#1	173.11 nm	2.98 nm
#2	177.93 nm	2.85 nm
#3	185.00 nm	2.82 nm
#4	190.34 nm	2.86 nm
#5	198.77 nm	2.93 nm

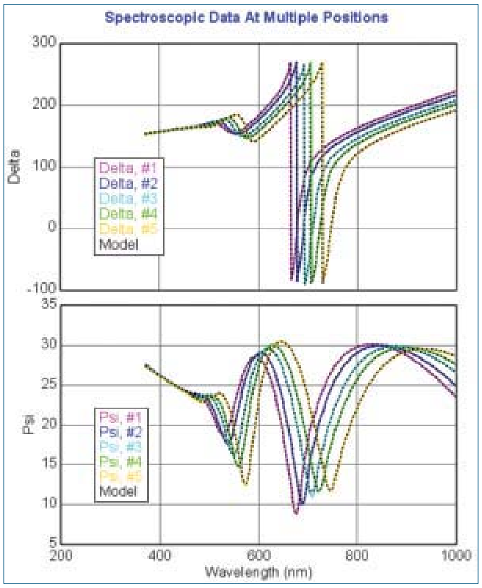


Figure 3. Data mapped from an amorphous silicon film are analyzed with the MSA approach in CompleteEASE to develop a single model to match the variation across this large panel.

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[1] W.A. McGahan, B. Johs, and J.A. Woollam, "Techniques for ellipsometric measurement of the thickness and optical constants of thin absorbing films", *Thin Solid Films*, **234** (1993) 443.

[2] J.N. Hilfiker et al. "Survey of methods to characterize thin absorbing films with Spectroscopic Ellipsometry", *Thin Solid Films*, **516** 20 (2008) 7979.

[3] A.M. Nardes et al. "Microscopic Understanding of the Anisotropic Conductivity of PEDOT:PSS Thin Films", *Adv. Mater*. **19** (2007) 1196.

[4] L.A.A. Pettersson et al. "Spectroscopic ellipsometry studies of the optical properties of doped poly(3,4-ethylenedioxythiophene): an anisotropic metal", *Thin Solid Films* **313-314** (1998) 356.