Multi-Angle Spectroscopic Ellipsometry Analysis of a Mirror Sample : Determination of Optical Properties at Low Incident Angles

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Abstract

This note presents the use of the UVISEL Plus spectroscopic ellipsometer for precise optical characterization of a mirror sample with a protective coating. By measuring at multiple incident angles (45° and 70°) and using classical dispersion functions, accurate optical constants and thickness were determined. The Bound Multimodel approach improved parameter correlation and allowed extrapolation to lower angle of incidence (10°), confirming high reflectance above 0.95 over a wide spectral range.

Background and Challenges

Ellipsometry is a powerful, non-destructive optical technique widely used to characterize thin films and coated surfaces. By analyzing the change in polarization upon reflection, it provides detailed information on film thickness and optical constants over a broad spectral range. The UVISEL Plus spectroscopic ellipsometer, equipped with advanced phase modulation and double monochromator technology, offers high accuracy and excellent sensitivity, making it well-suited for complex optical analyses.

In this study, a mirror sample with a protective coating was analyzed to extract precise optical parameters and validate coating performance.

Objective

The goal was to determine optical constants and thickness of a mirror sample using UVISEL Plus, and predict optical behavior at 10° incidence using validated models

Figure 1: UVISEL Plus spectroscopic ellipsometer equipped with advanced phase modulation and double monochromator system (source: HORIBA)

Experimental Setup & Measurement Procedure

Measurements were performed using the UVISEL Plus spectroscopic ellipsometer (Figure 1), which features advanced phase modulation for maximum accuracy and speed. The system also features a high-stability 150 W Xenon light source, a double monochromator for low stray light in the FUV-Vis range, and a high-resolution NIR monochromator. The objective was to characterize a mirror sample by analyzing its optical response to polarized light at incident angles of 45° and 70°. Additional modeling was performed to extrapolate data at lower angles. A single mirror sample with a protective coating was analyzed. Due to confidentiality, no further details on structure, deposition, or supplier are disclosed.

Key measurements included ellipsometric parameters (Is and Ic, see inset) over wide wavelength range of 190-2100 nm. A multilayer optical model was defined to represent the sample structure. Unknown properties, such as layer thicknesses and optical constants (n, k), were introduced as fit parameters. The software automatically adjusted these parameters to minimize the difference between experimental and simulated curves, achieving a best-fit solution. Once validated, the final model enabled accurate optical characterization and allowed extrapolation to additional angles of interest (10°). The mirror sample was measured with a HORIBA UVISEL Plus spectroscopic ellipsometer. Measurements were performed at 45° and 70° incidence over the selected spectral range.

Ellipsometry is a technique that measures how the polarization of light changes after it reflects from the surface. When light reflects, it can be separated into two components: p-polarized light (parallel to the surface) and s-polarized light (perpendicular to the surface). The change in their relative behavior is described by two angles, Ψ (psi) and Δ (delta). Ψ represents the ratio of the amplitudes of the reflected p and s components, while Δ represents the phase shift. Mathematically, this relation is written as

$$\rho = \frac{r_p}{r_s} = tan\ (\Psi) e^{i\Delta}$$

where r_ρ and r_s are the Fresnel reflection coefficients for p and s polarizations. The angle Ψ ranges from 0° to 90°, and Δ ranges from 0° to 360°. From Ψ and Δ , we can also define two useful quantities,

$$I_s = sin\ (2\Psi)\ \ sin\ (\Delta),\ \ I_c = sin\ (2\Psi)\ cos\ (\Delta)$$

which are often used in ellipsometric analysis. In simple terms, ellipsometry tracks how strong each polarization is (through Ψ) and how much one is delayed compared to the other (through Δ). These values provide information about material properties such as thickness and refractive index, all without physically touching the sample.

Data Analysis and Modeling

In this study, the optical model was constructed using a multilayer approach to describe the sample structure. Each layer was characterized by its optical constants and thickness, with the top coating layer modeled using classical dispersion functions to accurately determine its spectral behavior. The unknown parameters were adjusted through fitting to achieve the best match with the experimental ellipsometric data (Is and Ic), allowing a reliable description of the overall optical response. Data analysis and model fitting were performed using DeltaPsi2 software, which provides advanced multilayer modeling and dispersion analysis capabilities.

Results and Discussion

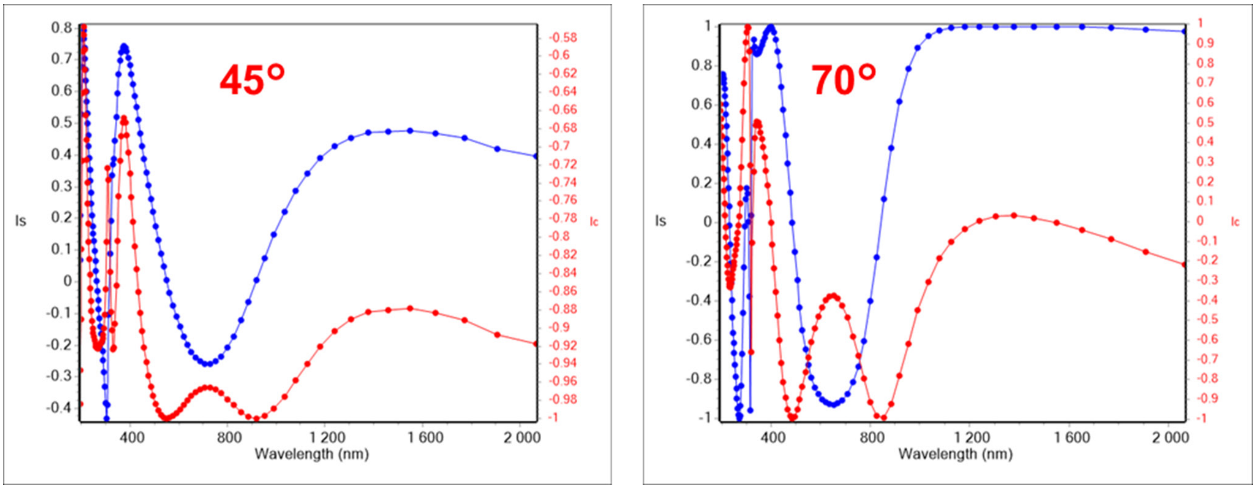
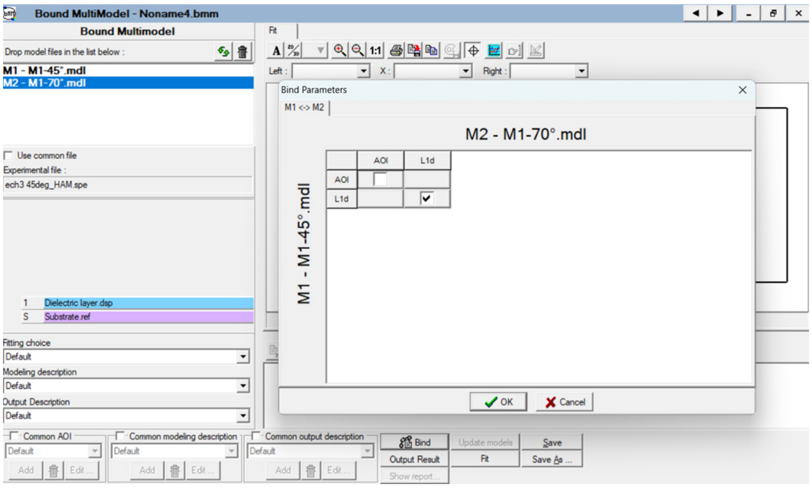


Figure 2: Measured Is and Ic spectra at 45° and 70° incidence angles

The graphs presented in Figure 2 show the measured ellipsometric parameters Is and Ic for the same sample at two incident angles: 45° and 70°. By combining data from both angles, as shown in Figure 2, it is possible to improve model reliability and minimize parameter correlation, enabling robust determination of thickness and optical constants.



M1 - M1-45°.mdl
M2 - M1-70°.mdl

☐ Use common file
Experimental file : ech3 45deg_HAM.spe

1 Dielectric layer.dsp
S Substrate.ref

Fitting choice: Default
Modeling description: Default
Output Description: Default

☐ Common AOI: Default
☐ Common modeling description: Default
☐ Common output description: Default

Bind Parameters — M2 - M1-70°.mdl (columns) / M1 - M1-45°.mdl (rows)

	AOI	L1d
AOI	☐	
L1d		☑

Figure 3: Bound Multimodel interface example showing linked parameters between models at different angles

The figure above (Figure 3) illustrates how to set up the Bound Multimodel within DeltaPsi2. This advanced feature allows fitting multiple models simultaneously and, importantly, enables binding shared parameters between them. Beyond simply combining data from different incident angles, the Bound Multimodel can also integrate models from other measurement configurations, such as transmission or reflectance. By linking common parameters, such as layer thickness or refractive index, this approach supports global fitting across complementary data sets, improving overall accuracy and ensuring consistent and robust parameter extraction.

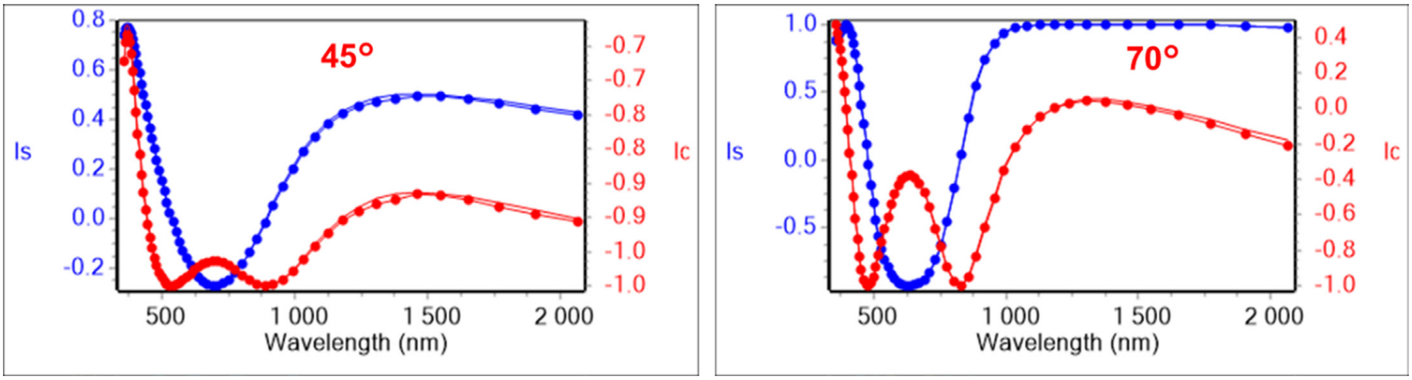


Figure 4: Comparison of measured and fitted Is and Ic spectra at 45° and 70° incidence

The figures in Figure 4 illustrate the fitting results for the sample at 45° and 70°. In each plot, solid lines represent the fit, while the dotted lines correspond to experimental data. A strong agreement is observed, confirming the reliability of the optical model and dispersion parameters.

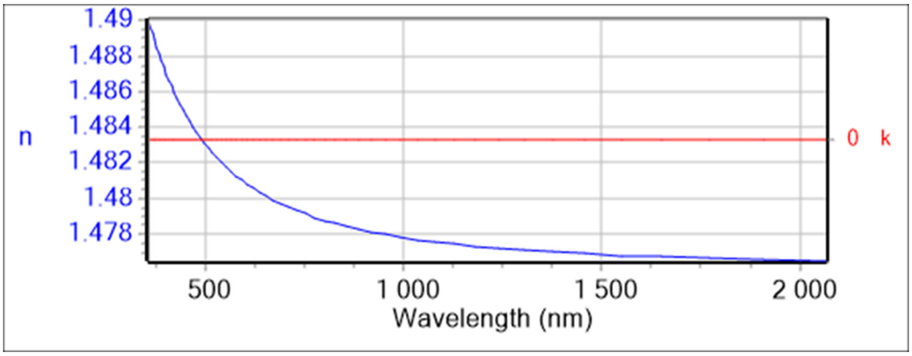


Figure 5: Refractive index dispersion curve of the coating layer

The curve in Figure 5 illustrates the refractive index (n) profile of the coating layer as a function of wavelength. The extinction coefficient (k) remains zero across the spectral range, confirming the transparent nature of the layer. Using a Bound Multimodel analysis at both incident angles, the refractive index was determined, with a corresponding thickness on the order of 1600 Å. These results confirm the model accuracy and the expected optical behavior of the coating from the visible to near-infrared region.

With all necessary data obtained, it was possible to simulate both the reflectance (R) and ellipsometric response ($\Psi$and Δ) at a 10° incidence angle using post-model calculations (Figure 6). The calculated absolute reflectance values range from 0.951 to 0.976, consistently above 0.95 for wavelengths longer than 500 nm.

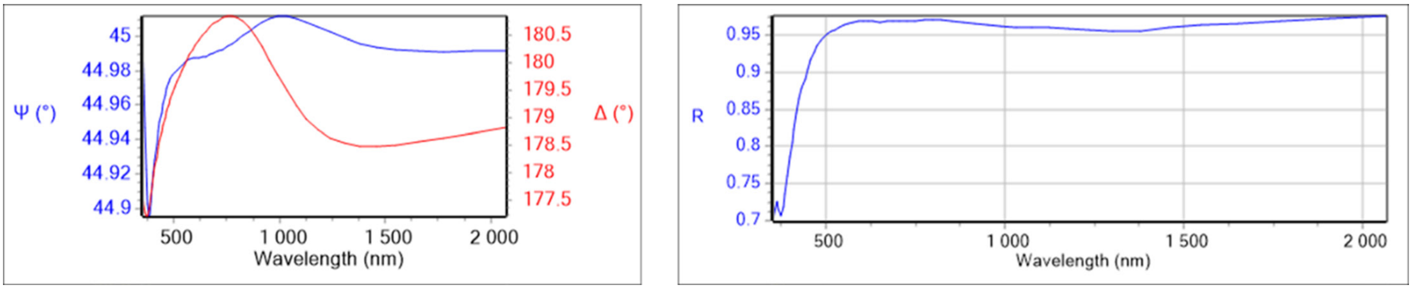


Figure 6: (Left) Simulated ellipsometric response (Ψ, Δ) at 10°; (Right) Reflectance (R) spectrum derived using Bound Multimodel extrapolation

Conclusion

UVISEL Plus and the Bound Multimodel approach enabled precise characterization and reliable extrapolation of a mirror coating. High accuracy, sensitivity, and robust modeling confirm its suitability for advanced optical coatings.

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