Thickness Measurement of Thin Film Semiconductors and Electronic Materials Using X-Ray Reflectivity

Thin film electronic materials such as semiconductors, insulators, and conductive coatings are crucial to modern technology. The properties of these thin films can be tailored in numerous ways. One way of modifying the properties of thin films is through varying film thickness. Varying film thickness is a powerful tool that allows for the targeting of very specific properties. For example, changing the thickness of a semiconductor thin film allows for modification of the band structure and the targeting of quantum size effects. Quantum size effects are achievable by using film thicknesses close to the de Broglie wavelength of metallic electrons (~10 nm). This necessitates precise measurements of film thickness. A common method of measuring the thickness of nanoscale thin films is through the use of x-ray reflectivity (XRR).

XRR is a versatile technique capable of measuring not just film thickness, but also density and surface/interface roughness. It can be applied to not just simple, single-layered films, but also complex, multi-layer structures. XRR functions through the use of low-angle x-ray reflection. The x-ray beam starts as being fully reflected from the surface at the critical angle and then rapidly increases its penetration depth as the angle is increased past the critical angle. As the penetration depth passes an interface—including the film-air interface—part of the beam is reflected. When reflections occur at two or more interfaces, the interference between these partially reflected X-rays creates a reflectometry pattern. This wavelike pattern can be decomposed using a Fourier transform to isolate the components of the signal. Each component of the interference pattern corresponds to an interface, analysis of it allowing the determination of the thickness, density, and roughness of each involved layer.

Ebatco is equipped with a Rigaku SmartLab X-ray Diffractometer which is capable of conducting XRR measurements for the determination of thin film thickness. For the purpose of illustrating this capacity, three thin films have been analyzed: gold, indium tin oxide (ITO), and silicon nitride. The thin films were on substrates of glass, glass, and silicon, respectively. The specified thickness values for each of the films were 10 nm (gold), 65 nm (ITO), and 100 nm (silicon nitride). ITO is a transparent conducting oxide commonly used in optoelectronic devices, such as solar cells, as a high-bandgap semiconductor. Gold and silicon nitride thin films are often used in circuit boards as a conductive material and as an insulator, respectively.

Table 1 XRR Measurement Results for Each Thin Film on Substrate Sample

Film	10 nm Gold			65 nm ITO			100 nm Si_3N_4		
Layer	Gold	Ti adhesion layer	Glass substrate	ITO	ITO-Glass Interface	Glass substrate	Si_3N_4	Si_3N_4-Si Interface	Si substrate
Thickness (nm)	10.5	3.3	N/A	63.9	2.9	N/A	98.8	4.0	N/A
Density (g/cm^3)	19.07	3.70	2.21	7.59	5.07	2.21	3.32	2.97	2.33
Roughness (nm)	0.6	0.6	0.4	1.9	0.2	1.4	0.9	0.4	2.0

As an example, Figure 1 shows the XRR measurement and analysis results of the gold film on a titanium adhesion layer on a glass substrate. Table 1 presents the numerical values of film thickness, density, and surface roughness determined via XRR analysis for all three thin film on substrate samples. As shown by Table 1, the values found by XRR show very good agreement with the specifications of each film, as the determined thicknesses for the gold, ITO, and Si_3N_4 films were 10.5 nm, 63.9 nm, and 98.8 nm, respectively.

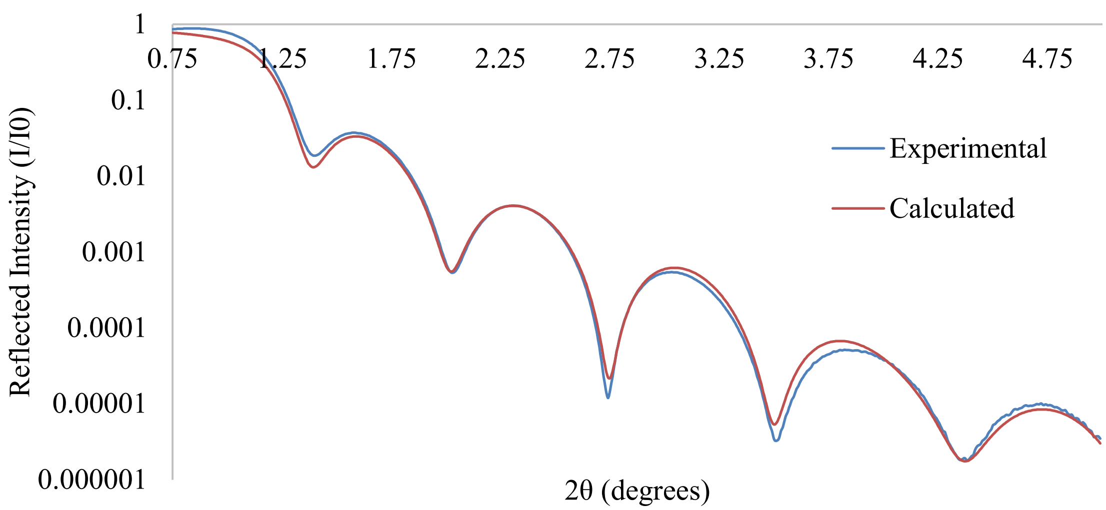

Figure 1. XRR scan of the 10 nm gold thin film on a titanium adhesion layer on a glass substrate.

The above findings highlight XRR's efficacy as a potent and precise means for thin film characterization. The inclusion of XRR analysis in R&D efforts allows for the better understanding of the properties of synthesized thin films, aiding in the development of new semiconductors and other electronic materials.

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