Bridge You and Nano

Exponential Business and Technologies Company

Refractive Index of Solids Measured Using a Universal Measurement Spectrophotometer

Accurate refractive index (RI) values are essential for designing and verifying optical components, coatings, and semiconductor substrates. However, most refractometry techniques require small, transparent samples that can be mounted against a prism or placed on the prism as a liquid. This creates a gap for manufacturers who need RI measurements on readied parts and on parts that are not translucent. Traditional refractometers simply cannot measure these materials, leaving industries without a practical way to confirm optical properties on finished components. Optical performance of reflective materials, such as silicon wafers, coated optics, and specialty polymers, depends directly on their refractive index. Measuring refractive index on finished reflective parts enables manufacturers to verify material consistency, ensure coating performance, and maintain quality control without destructive sample preparation to match the specific dimensions required for typical refractometers that uses the critical angle. For coatings and layered materials, the refractive index of a non-transparent substrate influences how a coated surface reflects light, how a coating interacts with the substrate optically, and how the materials behave in optical systems.

The Cary 7000 UV-Vis-NIR Universal Measuring Accessory (UMA) enables high-precision specular reflectance measurements utilizing a high-resolution goniometer stage and a controllable linear polarizer set to *p*-polarized light, light parallel to the plane of incidence. This allows for angle-resolved specular reflectance measurements on reflective solid materials, and does not require the material to be transparent. The *p*-polarized reflectance curve exhibits a distinct reflectance minimum that can be used to determine the refractive index (*Eq. 1*) without the size or contact constraints of traditional refractometers. The minimum is called the Brewster angle (θ_B), where n_2 is the RI of the material of interest, and n_1 is the RI of the surrounding medium, which in this case is air. This minimum can be used to obtain the RI of non-transparent materials, such as a polished silicon wafer or an opaque silicone with > 90% haze. The Brewster minimum is highly sensitive, requiring a high-resolution instrument and a uniform reflective surface.

Eq. 1
$$\frac{n_2}{n_1} = tan(\theta_B)$$

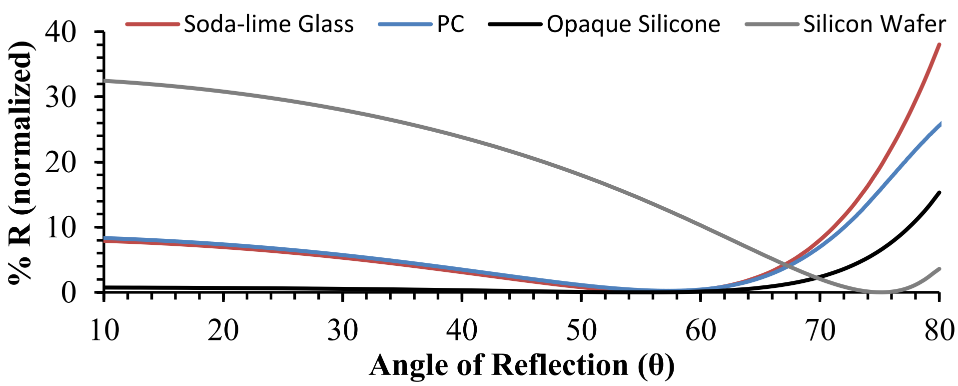

Figure 1. The reflectance of P-polarized light of four different solids: consumer soda-lime glass slide, PC, opaque medical grade silicone and silicon wafer. All samples were normalized by setting the Brewster minimum %R to 0.

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To demonstrate the versatility of the Cary 7000 UMA, four different materials, two clear and two non-transparent, were tested: polycarbonate (PC), consumer grade soda-lime glass, opaque medical-grade silicone and a silicon wafer. Figure 1 plots the reflection using 589.3 nm incident light at various angles, and Table 1 shows their measured RI values. The reflectance as a function of the incident angle was fitted using the Fresnel equation (*Eq. 2*) to mitigate uncertainty in the Brewster minimum caused by noise. R_p represents the fraction of *p*-polarized light reflected from an interface when the beam strikes at an incident angle (θ_i). The incident angle at which the reflectance is a minimum was extracted and used in *Eq. 1* to calculate the RI. 589.3 nm was chosen to mimic the sodium D-line light commonly used in many refractometers.

Eq. 2

$$R_p(\theta_i) = \left|\frac{n_2 cos\theta_i - n_1 cos\theta_t}{n_2 cos\theta_i + n_1 cos\theta_t}\right|^2$$

Eq. 3

$$\text{Where: } \theta_t = \arcsin\left(\frac{n_1}{n_2}\sin(\theta_i)\right)$$

Even for reflective or non-transparent solids, the Fresnel equation requires the internal refraction angle, θ_t (*Eq. 3*), because the electromagnetic field penetrates the surface, albeit a very small amount. During curve fitting, numerical constraints are applied to keep $\sin(\theta_t)$ within the valid boundaries of the arcsine function and ensure stable Fresnel reflectance calculations.

Table 1 RI of Four Materials at Room Temperature

Sample	**Experimental RI (589.3 nm)**	**Reference RI (589.3 nm)**	**Deviation**
Soda-lime Glass	1.520	1.523	− 0.003
Polycarbonate	1.581	1.585	− 0.004
Opaque Silicone	1.432	1.430	0.002
Silicon Wafer	3.923	3.972*	− 0.049

* RI value of pure silicon

The agreement between the experimental and reference RI values demonstrates that the system delivers reliable accuracy to the second decimal place. Conventional refractometers that measure critical angles rely on a sapphire prism that restricts the upper limit of refractive index to ~1.7. Measurements with the Cary 7000 UMA, as seen here for silicon, pushes this upper limit to 4.0. The silicon wafer's deviation from the theoretical refractive index of silicon is likely due to a contribution from the native oxide layer, which has a refractive index of 1.46.

This work shows that this automated reflectometry routine gives a fast, reliable tool for quality control and material characterization for both transparent and non-transparent materials, as well as for low and high refractive index materials. The Cary 7000 UMA gives manufacturers a practical, non-destructive method to verify optical properties, support coating development, and maintain consistent product performance.