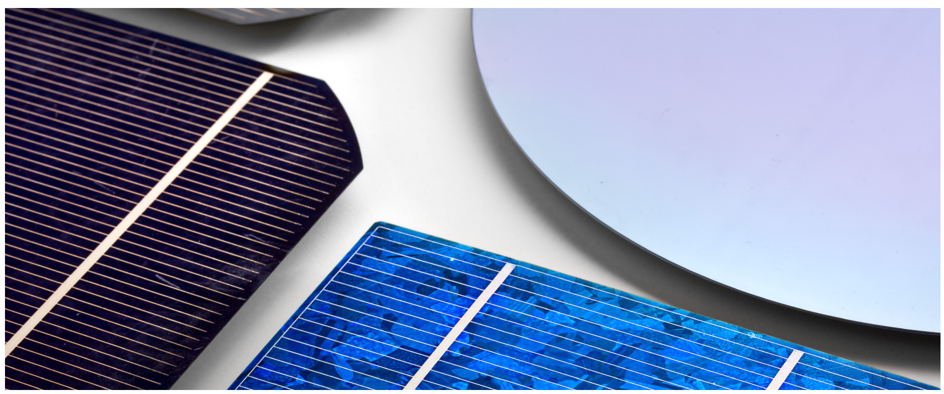
Application Note

Materials

Investigating the Angular Dependence of Absolute Specular Reflection

Using the Agilent Cary 7000 universal measurement spectrophotometer (UMS)



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Introduction

When characterizing an optical sample it is common to measure reflection or transmission properties at a single angle of incidence (AOI). However, for a more complete characterization of the sample, it is desirable to measure reflection and/or transmission at multiple AOI's as this can provide a much deeper insight into the sample's optical properties.

This application note illustrates how the Agilent Cary 7000 universal measurement spectrophotometer (UMS) can provide rapid and automated absolute specular reflection measurements at multiple AOIs. The value of using three-dimensional (3D) plots and two-dimensional (2D) contour plots to visualize the data is also demonstrated.

Experimental

Sample

The sample was a large silicon wafer measuring 200 mm in diameter and 0.80 mm in thickness. A proprietary optical coating had been applied to the front surface after polishing. A summary of the sample and collect conditions is given in Table 1.

Instrumentation

The data were collected using the Cary 7000 UMS, which is a highly automated variable-angle absolute specular reflectance and transmittance system. With the Cary 7000 UMS, operators have independent motorized control over the angle of incidence onto the sample and the position of the detector, which can be freely rotated in an arc around the sample. The independent control of sample rotation and detector position allows rapid, accurate, and unattended measurements.

Traditionally, reflectance and transmittance measurements have been performed using spectrophotometers fitted with different accessory attachments. In practice, this can lead to different areas of the sample being tested due to illumination beam geometry variations between measurement modes (accessories) and movement of the illumination beam over the sample.

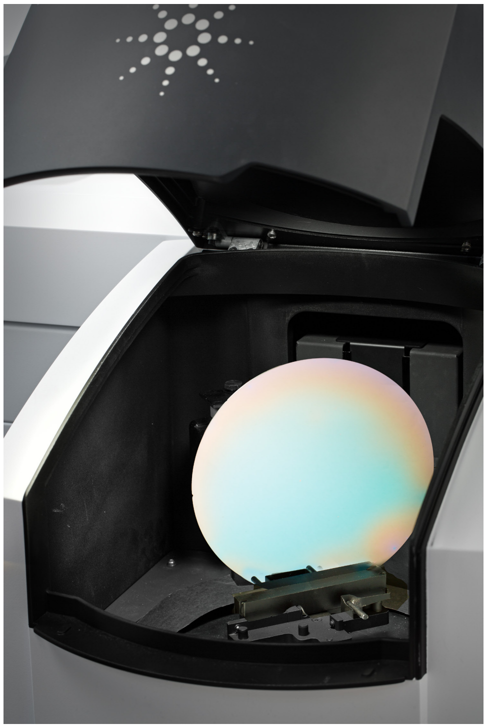

Figure 1. Agilent Cary 7000 UMS with a 200 mm diameter silicon wafer sample mounted in the measurement chamber.

If the deposition process produces a film with a nonuniform thickness, it is reasonable to expect that reflectance and transmittance measurements would be affected.

With the development of the Agilent Cary 7000 UMS, it is now possible to measure T and R at the same sample point, without moving the sample, thus overcoming one source of artifacts on the results.

Measurements

Specular reflection measurements were made with AOIs from 6° to 86° in 1° increments. The polarization of the light incident on the sample was controlled with an automated rotatable wire grid polarizer. Reflection with both s- and p-polarization was measured.

The collect conditions were set up using the Cary WinUV software method editor. Only two baselines are required at the start of the full data collection sequence, one for s- and one for p-polarization. These baselines were used for all angles, and the software applied the appropriate baseline to the individual collected spectra. In contrast, other systems require a unique baseline for each polarization at each angle, which dramatically increases the total time of collect. Once the two baselines had been collected, the system was left unattended to collect the entire data set.

As has already been noted, the silicon wafer was particularly large at 200 mm diameter. The Cary 7000 UMS is designed to accommodate samples as large as 275 mm in diameter enabling very high grazing angles of incidence to be measured. With the largest possible samples, angles close to 90° can be measured without the incident light "falling off" the sample.

Table 1. Agilent Cary 7000 UMS collect conditions.

Parameter	Value
AOI	6° to 86° in 1.0° intervals
Wavelength Range	2,500 to 250 nm
Data Interval	UV-Vis 1.0 nm, NIR 4.0 nm
Spectral Bandwidth	UV-Vis 4.0 nm, NIR 4.0 nm
Signal Averaging Time	0.26 sec
Polarization	s and p
Incident Beam Aperture	3° × 3° (vertical × horizontal)

Results and discussion

Specular reflectance

Figure 2 shows the absolute specular reflection spectra with angles of incidence ranging from 6° to 86° in 1° increments for s-polarized light. A similar plot was generated for p-polarized light as well (not shown in this document).

Analyzing such a large number of spectra can be a significant challenge. Figures 3 and 4 show 2D contour plots and 3D plots generated using Scilab software[1], respectively, for the same data set. It can be seen that the reflective properties, in terms of the positions of minima and the associated %R values, are highly dependent on AOI.

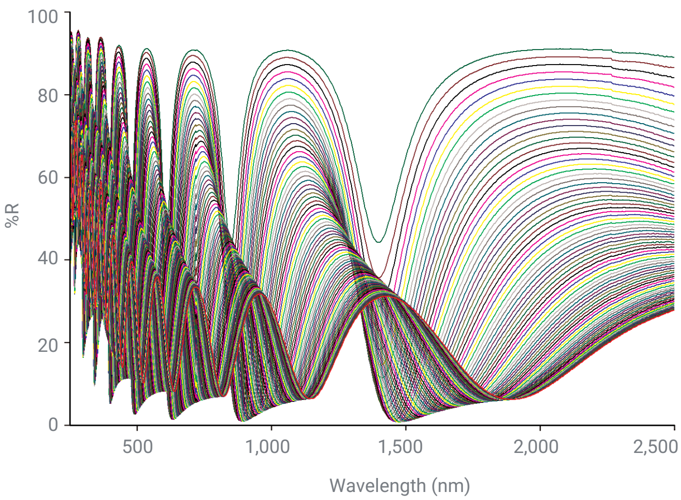

Figure 2. Absolute specular reflectance of s-polarized light from the silicon wafer from 6° AOI to 86° AOI at 1° intervals.

For example, in the infrared region, at near normal AOI, there is a broad minimum centered at approximately 1,900 nm. At much higher angles of incidence, at approximately 70°, the minimum is centered at approximately 1,400 nm. In addition, the minimum is narrower and reaches a %R value that is much closer to zero.

Depending on the intended end use of reflective coatings and the associated performance requirements in terms of AOI, spectral region, and %R, these types of observations can be fed back into coating design. Measuring the coating at one AOI only, as is common, gives no indication of this strong angular dependence.

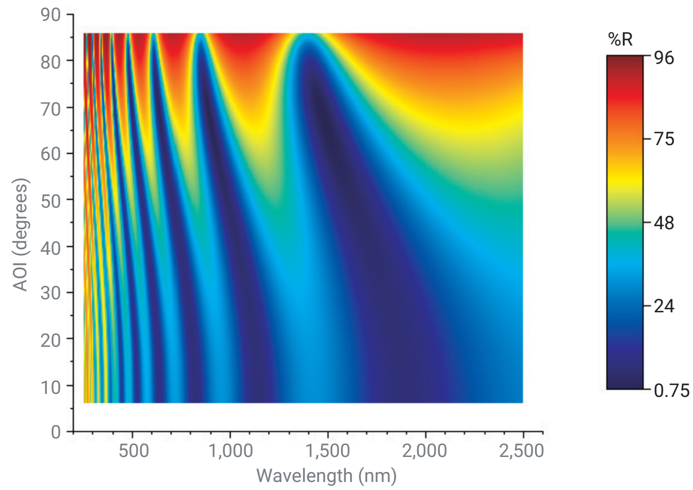

Figure 3. 2D contour plot of the same data displayed in Figure 2.

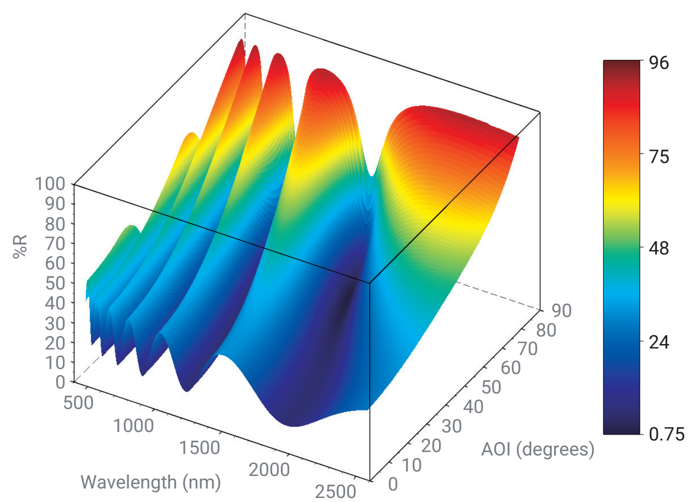

Figure 4. 3D plot of the same data displayed in Figure 2.

Conclusion

It has been demonstrated that the Agilent Cary 7000 UMS can be used to automatically collect high quality spectra for a large, coated sample at a wide range of AOIs, in both s- and p-polarization. The measurement is made under complete software control and, once the sample is mounted, data collection is entirely unattended. The complete characterization of this sample over a wide wavelength range, AOI and polarization allowed greater insight into the angular dependence of the optical coating.

Furthermore, using 3D and 2D contour plots to visualize the large data sets provides a more thorough understanding of the properties of an optical coating. This valuable information can be used to aid coating design and optimization.

References

1. Scilab is free open source software available at https://www.scilab.org

www.agilent.com/chem/cary7000ums

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