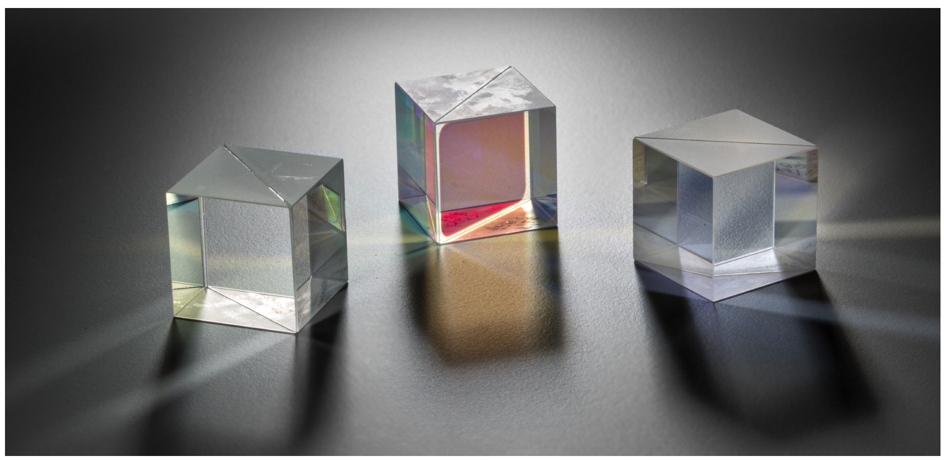
Application Note

Materials

A Faster, More Accurate Way of Characterizing Cube Beamsplitters

Using the Agilent Cary 7000 universal measurement spectrophotometer (UMS)



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Abstract

Cube beamsplitters (CBS) are critical optical components that have a wide variety of uses in consumer products, high-tech micropositioning equipment, and fiber-optic-based telecommunication systems. This application note describes *in situ*, automated and unattended, transmission, reflection, and absorptance measurements of CBS using an Agilent Cary 7000 universal measurement spectrophotometer (UMS). Spectral information obtained is shown to provide useful insight for optical engineers at the design phase, and provide QA/QC departments better control metrics during final testing; all are obtained at highly productive rates amenable to routine volume analysis demands.

Introduction

Typically, not much larger than a die (0.5 to 1 in, 12.7 to 25.4 mm), the purpose of a CBS, as the name suggests, is to split a beam of light into two distinct paths — a reflected beam and a transmitted beam (Figure 1).

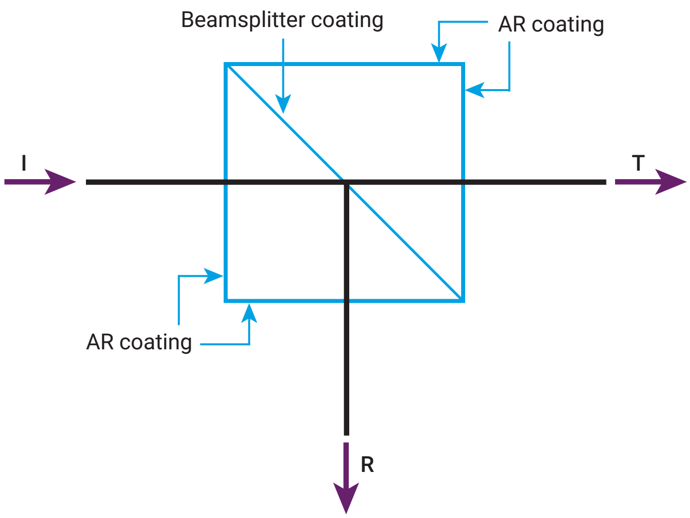

Figure 1. Plan view of a CBS showing reflection (R) and transmission (T) of the incident light (I).

The separated beam can be used to duplicate images, separate colors or polarization states, or in the case of laser applications, create compact interferometers for nano-positioning systems. In all cases, successful CBS design, implementation, and quality control rely on detailed spectral knowledge of both the transmitted and reflected beams. Dielectric (optical) coatings deposited on the central hypotenuse, and sometimes also the outside faces, determine the wavelength and polarization characteristics of the CBS. One of the measurement challenges is that the optical behavior of the internal multilayer coating is influenced by its immediate optomechanical environment, e.g., the refractive indices of the bonding agent used to combine the two halves. *In situ* measurement of the dielectric coating is imperative as an open-air characterization, performed before cementing the two prism halves together, renders different results to the completed cube assembly.

The Cary 7000 UMS permits spectral characterization of the transmitted and reflected beam on the same system without moving the sample, and hence the incident beam. The *in situ* measurement of transmission (T) and reflection (R) from identical locations on the sample permit accurate Absorptance (A = 1 – T – R) data to be calculated, providing greater insight into substrate and coating properties.

When analyzing total losses in spectra, researchers have previously reported artifacts which may cause doubt about the quality of the data. Sources of artifact have been reported[1] to include:

- The difference in angles of incidence (AOI) at which T and R are measured
- A slight thickness nonuniformity of the film
- Absorption in a thin film acting in combination with interference effects

In this application note, data collected using the Cary 7000 UMS are presented. Both T and R have been measured without moving the sample, thereby eliminating the source of AOI variations and coating thickness nonuniformities.

Beamsplitter types

Cube beamsplitters can be categorized broadly according to the optical requirements of their end use. A basic overview will be given here to highlight the optical performance drivers behind each type.

The wavelength range covered can be broadband, covering the entire visible spectrum for example, or narrow band, accommodating a specific laser line, such as from a 632.8 HeNe laser. The wavelength range is controlled by the beamsplitter coating but the substrate material must also transmit the required wavelength range. BK7 glass is a low-cost material useful for the visible spectrum but has strong attenuation in the UV and NIR wavelengths. Fused silica has a high cost but lower optical losses and broader wavelength range, making it the preferred choice for high-power laser applications.

The bonding method used to join the two halves can be an important consideration in their end use. Optical cement produces a highly stable (mechanical) CBS but this construction is more suited to lower optical power applications. Norland Optical Adhesive 61 (NOA 61) is an example of an optical cement. It is a clear, colorless, liquid photopolymer that cures when exposed to ultraviolet light. Higher-power laser applications, on the other hand, must avoid the use of cement and turn to optical contact methods or refractive index-matched oils instead. These have higher power thresholds but must be handled and used appropriately as they are less mechanically stable.

The polarization properties of a CBS are commonly used for laser-based interferometry devices. For example, the performance of interferometric nanopositioning systems is partially determined by the requirement for a CBS with a high T_p/T_s ratio and a correspondingly high R_s/R_p ratio. The CBS measured in this application note is an example of such a polarizing beamsplitter and behaves as shown schematically in Figure 2.

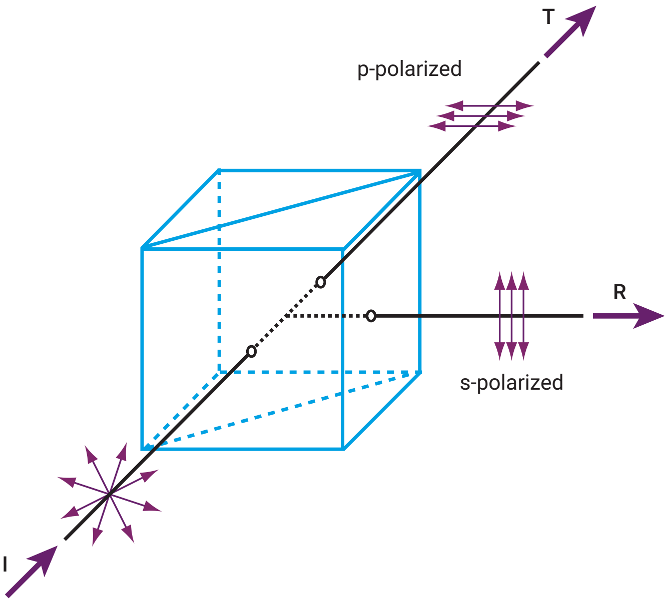

Figure 2. 3D schematic of the reflection and transmission of light incident on a polarizing CBS.

Experimental

Sample

The CBS was 25 mm cubed with a proprietary beamsplitter and antireflection coating made from titanium dioxide and silicon dioxide. The two prisms are bonded with optical adhesive.

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 allow rapid, accurate, and unattended measurements of CBS.

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 patch size variations between measurement modes (accessories) and movement of the illumination beam over the sample.

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 Cary 7000 UMS, it is now possible to measure T and R at the same sample point without moving the sample, overcoming one source of artifacts on the results. In addition, the sample can automatically be rotated 180° to permit static T and R measurements in the forward or reverse direction. In either case, T and R are measured from the same point without moving the sample.

In this study, the Cary 7000 UMS was used to acquire transmittance data for s-polarized and p-polarized incident light at 0° AOI. Reflectance data were collected at 90° to the incoming beam and transmittance data at 0° (directly) as shown in Figure 3. The sample is mounted such that the center of the cube is at the focal point of the incident beam and on the axis of rotation of both the sample and detector. The cone angle of light incident on the sample was limited by 2° vertical and horizontal apertures.

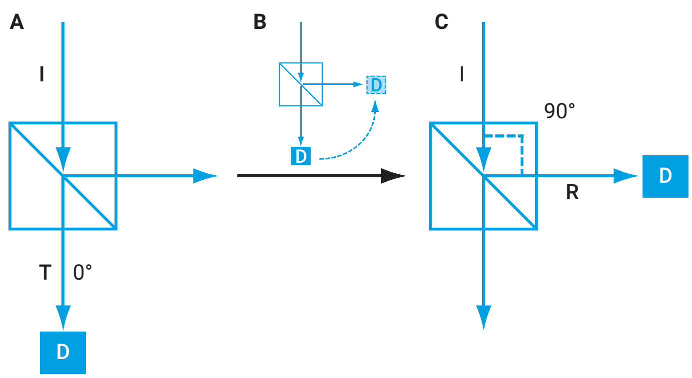

Figure 3. (A) CBS sample and detector (D) orientation for transmission measurement. (B) The detector is rotated around the sample in the plane of incidence so that for reflection measurements (C), the detector is at 90° to the incident beam and sample. **Note:** The sample does not move.

Spectra were measured over 500 to 720 nm with a data interval of 1 nm, a spectral bandwidth of 5 nm, and a 0.5-second spectral averaging time.

Results and discussion

The CBS is designed for use with a helium neon laser, which emits at 632.8 nm. At that wavelength the CBS would ideally transmit 100% p-polarized light and reflect 100% s-polarized light. In reality, the desired transmittance and reflectance of polarized light will not be perfect so it is important to be able to measure the true performance of the CBS.

Figure 4A shows s-polarization transmittance and reflectance spectra measured using the Cary 7000 UMS system. By zooming in on each of the spectra around 633 nm (see Figures 4B and 4C), the transmission and reflection values at 633 nm can be seen. The transmission of s-polarized light at 633 nm is 0.04% T, which is within the specification for the CBS of <0.2% T. The p-polarized spectra are shown in Figure 5. The transmission of p-polarized light at 633 nm is 98.19 %T, which is within the specification of >98% T.

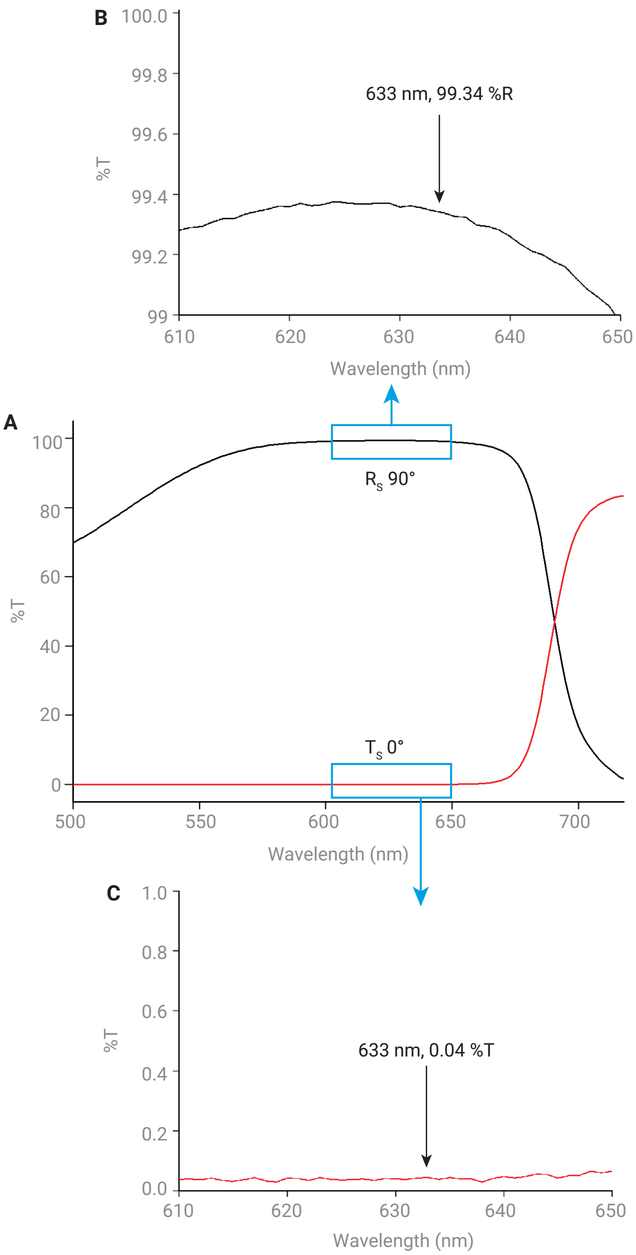

Figure 4. (A) Transmission and reflection spectra for s-polarized light measured on a CBS sample in an Agilent Cary 7000 UMS. (B) Reflection spectrum zoomed in around 633 nm. (C) Transmission spectrum zoomed in around 633 nm.

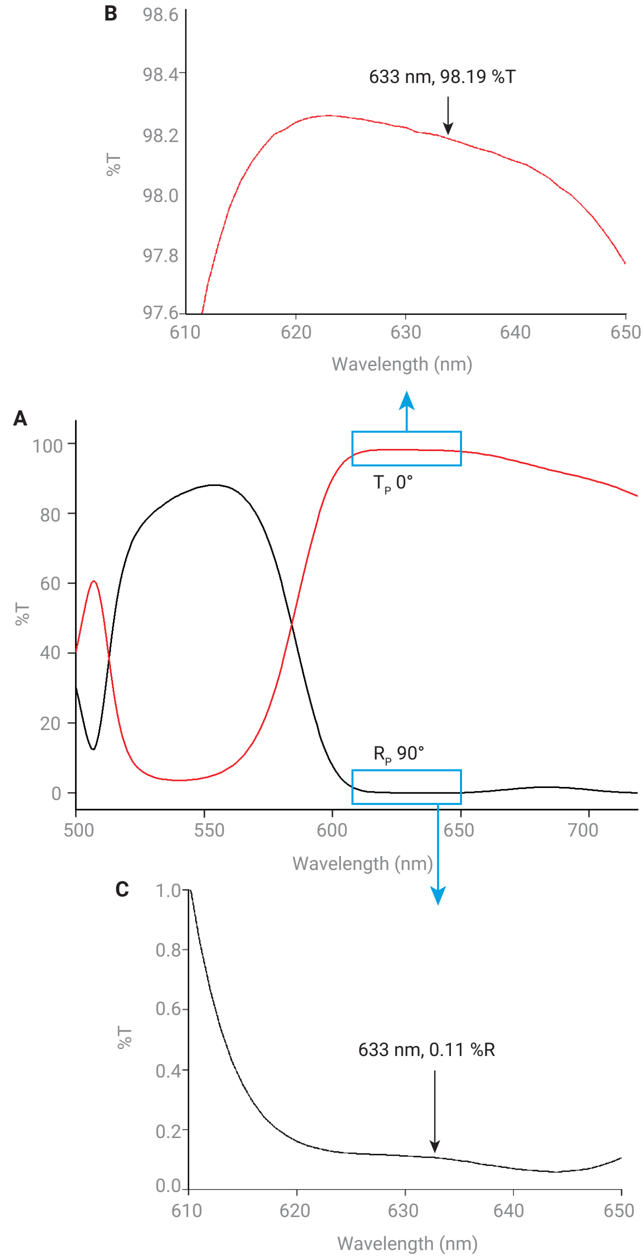

Figure 5. (A) Transmission and reflection spectra for p-polarized light measured on a CBS sample in an Agilent Cary 7000 UMS. (B) Transmission spectrum zoomed in around 633 nm. (C) Reflection spectrum zoomed in around 633 nm.

Since transmission and reflection have been measured without moving the sample, self-consistent spectral data have been collected, which are useful for determining total losses (e.g., retroreflection, internal absorption, or scattering). Absorptance (A) where A = 1 – T – R, for s- and p-polarized light are shown in Figure 6, which displays the spectral profile of light associated with these losses.

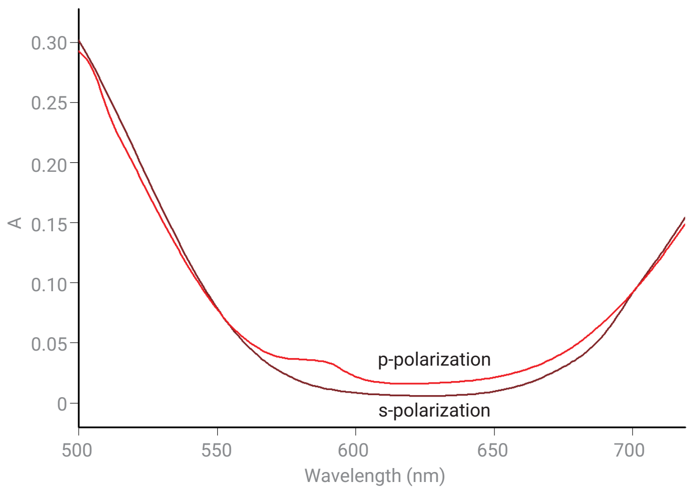

Figure 6. Absorptance spectra for s- and p-polarization

Conclusion

The Agilent Cary 7000 UMS has been shown to be a valuable tool for the characterization of cube beamsplitters. The system allows independent and automated control of the sample rotation and the detector position. The unique ability to measure T and R components without having to move the sample, keeping the incident light on the sample unchanged, has also provided detailed spectral information on the absorptance of the beamsplitter.

The Cary 7000 UMS is ideal for QA/QC environments because it offers convenience, ease-of-use, and completely unattended data collection.

Reference

1. Amotchkina, T. V. *et al.* Oscillations in Spectral Behavior of Total Losses (1 – R – T) in Thin Dielectric Films. *Optics Express* **2012**, *20(14)*, 16129–16144.

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