MASTER

TITLE:

HIGH-PRECISION MULTIPASS REFLECTOMETER

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SUBMITTED TO:

1981 LASL CONFERENCE ON OPTICS
April 1981 Santa Fe, NM

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ABSTRACT

The multipass reflectometer has been shown to be a convenient and precise instrument for the measurement of spectral reflectances in excess of 0.99. This report gives a brief sketch of the initial setup of the reflectometer, its operation, optimization of parameters, and some limitations to the expected precision. The instrumental precision is set by the uncertainty in the computer fit of a straight line to the measured data. Systematic errors due to nonuniform photosurfaces and the effects of astigmatism have been minimized. We have used this reflectometer to measure the absolute reflectance of evaporated aluminum films in the uv and visible regions. It has also been used to measure the low-level insertion losses of laser window materials for this same spectral region.

INTRODUCTION

Arnon and Baumeister¹ have used a modified White cell² as a multipass reflectometer to measure spectral reflectances in excess of 0.99. In general, such measurements are made with much difficulty depending on the precision required. With the multipass reflectometer described here, precision of a few places in 10^{-4} are routinely obtained. Given in this report is a summary of the setup, operation, optimization of parameters and some limitations to the expected precision of this instrument.³

The modified White cell is shown schematically in Fig. 1. The mirrors are of the same radius of curvature and are separated by this radius. For this separation an image in the plane of the field mirror, M_2 , will be reimaged in this place by one of the field mirrors. This reimaging has been explained elsewhere.² Once the mirrors have been properly aligned the successive images on the field mirror will be in parallel rows and of the same height. We have obtained as many as 45 images using the green line of a mercury spectral lamp. For most applications this is more than is necessary.

ABSOLUTE REFLECTANCE

The absolute reflectance of a sample mirror can be determined, using a "sample-out - sample-in" measurement. For the "sample-out" configuration of Fig. 2, we denote the absolute reflectance of each mirror M_i as R_i . Taking the entrance flux as ϕ_0 and the exit flux for n reflectometer traversals as $\phi(n)$, we have from Arnon and Baumeister (AB)

$$\phi(n) = \phi_0 R_1 R_2 R_3 R_2 R_1 \cdot \cdot \cdot R_3 \quad , \quad (1)$$

FIELD MIRROR
 M_2

OBJECTIVE MIRRORS
 M_1 & M_3

Fig. 1.

Fig. 2.

where R_3 is the last reflection before exit. Calling $\bar{R} = (R_2 R_1 R_2 R_3)^{1/4}$ the average reflectance, then

$$\Phi(n) = \Phi_0 \frac{1}{R_2} (\bar{R})^{4n} = \Phi_0 \frac{1}{R_2} \bar{R}^N, \quad (2)$$

where $N = 4n$, is the total number of reflections in the reflectometer.

Taking the logarithm of Eq. (2),

$$\text{Log } \Phi(N) = N \text{ Log } \bar{R} + \log (\Phi_0/R_2), \quad (3)$$

A semilog plot of $\Phi(N)$ versus N will be a straight line with slope $\bar{R}$. By this method we obtain a precise measurement of the average reflectance $\bar{R}$. Figure 3 is an example of such a plot for the reflectometer aluminized mirrors and a wavelength of 546.1 nm. The linear dependence extends over four orders and represents up to 87 reflections. From the slope the reflectance is $\bar{R} = 0.9095 \pm 0.0002$ with the precision determined by the uncertainty of the computer fit of the straight line to the data points. The residuals of the measured and calculated values are randomly distributed about zero indicating a small systematic error.

AB have folded the reflectometer about their sample, M_4 , as shown in Fig. 2. This arrangement permits the measurement of the absolute reflectance of M_4 . Realization that this folded system can be used is a major advantage of this reflectometer. Various samples can be measured without the necessity of stripping and recoating one of the reflectometer surfaces. For this "sample-in" configuration the output flux will be

$$\text{Log } \tilde{\Phi}(N) = N \text{ Log } (\bar{R}R_4) + \log (\Phi_0/R_2), \quad (4)$$

AP-1-VG-6748

where R_4 is the absolute reflectance of the sample. From the slope of the semilog plot of Eq. (4) and the value of $\bar{R}$ from Eq. (3) we thus obtain R_4 . Using this technique AB have measured spectral reflectance values as large as 0.9996 ± 0.0002 at 520 nm for a multilayer dielectric reflector. We have used this technique to measure the absolute reflectance for several aluminum films in the uv-visible region ($200 < \lambda < 550$ nm). The results are reported elsewhere in this proceedings. We have also used a variation of this multi-pass system to measure the low-level insertion losses of uv-vis laser windows. These results are reported in this proceedings also.

The overall precision of the measurement is determined by a number of factors. Stable monochromatic source and stable uniform photomultiplier tubes are essential. Systematic errors due to astigmatism can be minimized by careful design and alignment. Detector signal-to-noise usually sets the upper limit to the number of reflections. It has been our experience that each of the limitations can be minimized with proper care. Figure 2 is evidence to the success of our efforts.

Fig. 3.

REFERENCES

1. O. Arnon and P. Baumeister, Appl. Opt. 17, 2913 (1978).
2. J. W. White, J. Opt. Soc. Am. 32, 285 (1942).
3. The unabridged version of this paper has been submitted for publication in Applied Optics under the title, "The Multiple-Pass Reflectometer." The reader is referred to this paper for details.

FIGURE CAPTIONS

- Figure 1. Schematic drawing of the modified White cell used as a multipass reflectometer. The mirrors have the same radius of curvature and can be made from a pair of nonexpensive commercial spherical mirrors.
- Figure 2. The multipass reflectometer showing a number of internal reflections. The images on the field mirror, M_2 , will correspond to $2n + 1$ reflections within the reflectometer. Folding the reflectometer about the sample surface, M_4 , permits the measurement of absolute reflectance by the "sample-out - sample-in" technique.
- Figure 3. Experimental data showing the linear dependence for 87 reflections within the reflectometer. The residuals are randomly distributed about zero indicating the small systematic error of the instrument.