LA-UR -85-3734

CONF-8410186--5

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

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1985

LA-UR--85-3734

DE86 002443

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SUBMITTED TO: National Bureau of Standards
To be published as proceedings of the Sixteenth Annual Symposium on Optical Materials for High Power Lasers at NBS, Boulder, CO, Oct ber 15-17, 1984

Los Alamos

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FORM NO 836 R4
ST NO 2629 5/81

High-Precision Damage-Resistant Multiple-Pass Ultraviolet Reflectometer

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A multiple-pass cell was reported by John White in 1942 [1]. Since then, it has been adapted for use as a high-precision reflectometer. The multiple-pass reflectometer has been studied and reported by Arnon and Baumeister [2].

Here, a reflectometer which is similar is described. It utilizes a uv laser operating at $\lambda = 351$ nm as the source and the White-cell mirrors are high-reflection dielectric coatings designed for that wavelength. Because of the low-loss reflectors used in the cell, a high number of traversals, reflections, can be achieved; $R \geq 239$. The use of dielectric mirrors also improves the damage resistance of the apparatus which is important when a uv laser beam is used.

The results of reflectance measurements performed on several ultraviolet high reflectors are also reported. These include conventional dielectric coatings as well as a hybrid coating consisting of Al_2O_3, HfO_2, and SiO_2 layers.

Key words: dielectric coatings; high reflectance; multiple-pass reflectometer; White cell.

1. Introduction

The Los Alamos optical damage laboratory has observed and defined several types of laser-induced damage to optical materials [4]. In the case of high reflection, multi-layer, dielectric coatings, damage may be defined as any change in the coating layers or at the substrate interface which causes a measurable change in reflectance at its design wavelength. Since most dielectric high reflectors have reflectances approaching unity, and a change caused by laser irradiation can be minute, a precise method for measuring high reflectance must be utilized. A multiple-pass reflectometer based on the White cell was selected because of its demonstrated precision and high accuracy. It utilizes a laser as the source for reasons described later.

2. Reflectometer

2.1. The reflectometer configuration is similar to that described by Edwards and Baumeister [3] with the exceptions of dimensions, number of traversals, and light source. Figure 1 shows the optical layout for the reflectometer described here. Although figure 1 shows both a folded and an unfolded cavity about M2, the reflectometer discussed here is only used in the folded configuration. The cell mirrors are M3, M5, M2, and M4 and have a radius of curvature of 50 cm, with the exception of M2 which is flat. All four of these mirrors are dielectrics designed for 351 nm which is the laser wavelength. They were all coated in a single run and all have the same reflectance. In practice, M3 and M5 are positioned directly above and in close proximity to M4 (figs. 2 and 3). This allows for near normal angle of incidence on M2 which is the location of the mirror under test, and alternately, the calibration mirror. M6 is positioned so that it intercepts the output laser energy and directs it toward the output detector. M1 is the injection mirror and has a radius of curvature of 25 cm which mode matches the collimated laser beam to the cell modes.

The laser used for this apparatus is a Lumonics excimer laser, Model 861, operating at 35 Hz, with a 10-ns pulse duration. As is typical with excimer lasers, the output decreases slightly with increasing age of the static fill gas so a small portion of the beam is diverted to detector B as a reference. The detectors are Laser Precision, Model RjP 734 and Model RjP 735 for A and B, respectively. The detector outputs are compared by a ratiometer, also Laser Precision, Model Rj 7200.

2.2. General Considerations

As discussed in much detail by Arnon and Baumeister, and Edwards and Baumeister, the multipass reflectometer relies on the ability to vary the number of reflections on an unknown and to achieve a high number of reflections. To this end, high-reflection dielectric coatings are utilized in this cell to not only minimize losses but also to withstand the higher energy of the laser.

There are several advantages to using a laser as the source. These include an increased signal-to-noise ratio, an increased number of traversals within the reflectometer, and relatively easy mode matching of the source to the cell. The higher energy of the laser also allows for measurements to be performed under room light conditions.

2.3. Reflectance Measurements

The key to operation of the reflectometer is to keep track of the number of reflections, or traversals, within the cell at any given time. Each traversal consists of eight reflections--one on each of mirrors M3 and M5, two on M4, and four on M2. This is true for all traversals except the last since the energy will escape one bounce on M4 and proceed to the output detector via M6. Thus, the last traversal will have only seven reflections. This reflectometer routinely utilizes up to 30 traversals (239 reflections), so keeping track of them can seem a formidable task. In reality, however, all that is necessary is to align for one traversal and from then on keep track of each additional traversal. Successive traversal can be achieved by horizontal adjustment of M3, and counted as they swing into position on the output detector.

To perform a reflectance measurement on an unknown, the reflectance of the cell mirrors must first be determined. To accomplish this a cell mirror is used in position M2. The output is recorded for each set of traversals from 1 to 30. The number of traversals is converted to number of reflections, (N), and the negative log of the ratio of B to A is plotted vs N. Using a linear-regression fit, a straight line is fit to the data. The average reflectance of all of the mirrors within the cell is related to the slope of this line. Since all reflectances are equal, the equation for the cell mirror reflectance is:

$$R = \log^{-1} m \quad , \tag{1}$$

where: m is the slope.

Now that the cell mirror R has been determined, M2 can be replaced by an unknown and measurements are performed in the same manner as for the cell. Now, however, there will be a change in slope caused by the different R value of the unknown.

Since the laser energy enters and exits from M2, there is always one more reflection on M2 than all three cell mirrors combined. This can be seen in a simplified layout for one traversal, figure 4. A and B are detectors. R_c represents the three cell mirrors, and R_u represents the unknown (M2).

If the extra bounce on the unknown mirror in the reflectometer is ignored there is, of course, an equal number of reflections on the cell mirrors as on the unknown. If the total number of reflections within the cell is N then the reflections on M2 = the reflections on the cell mirrors = N/2. The following equation can be generated:

$$-\log \frac{\phi_B}{\phi_A} = N \left(\frac{\log R_c}{2} + \frac{\log R_u}{2}\right) + \log k \quad , \tag{2}$$

where, ϕ_A = energy at detector A

ϕ_B = energy at detector B ,

and $K = \dfrac{\phi_{in}}{\phi_B}$.

It can be seen that this is an equation to a straight line with

$$\frac{\log R_c}{2} + \frac{\log R_u}{2} \qquad (3)$$

as the slope, (m). Minor manipulation of eq (3) and insertion into eq (1) yields the equation for the unknown reflectance value.

$$R_u = \frac{\log^{-1} 2m}{R_c} \qquad (4)$$

where: R_u = the reflectance of the unknown
and: R_c is the reflectance of the cell mirrors.

To disregard the extra reflection on the test sample causes no significant error since the number of bounces is in N in eq (2) and not in the slope.

3. Results and Conclusions

Figure 5 shows data plots and fits for several reflectors tested. Notice that reflectors with higher R's than the cell itself can be measured. The measured R for a number of reflectors available for test is shown in table 1. (The coating materials are listed for reference only and not intended to indicate general ranking of these materials.) Repeated measurements and multiple users yielded a precision for this reflectometer of ±0.0007.

Table 1. Measured Reflectance of Various Mirrors

R	COATING MATERIALS	SUBSTRATE
0.9976±0.0007	Ta_2O_5/SiO_2	F.S.
0.9948	HFO_2/SiO_2	DYN1000
0.9948	HFO_2/SiO_2	S.C. Si
0.9938	Al_2O_3/SiO_2	PC. Si
0.9938	HFO_2/SiO_2	DYN1000
0.9934	ZrO_2/SiO_2	S.C. Si
0.9933	Al_2O_3/SiO_2	PC. Si
0.9924	$10(HFO_2/SiO_2)\ 7(Al_2O_3/SiO_2)$	DYN1000
0.9906	UNAVAILABLE	--
0.9906	UNAVAILABLE	--
0.9902	Al_2O_3/SiO_2	S.C. Si
0.9898	$(ZrO_2/SiO_2)(Al_2O_3/SiO_2)$	S.C. Si
0.9875	UNAVAILABLE	--
0.9863	Al_2O_3/SiO_2	F.S.
0.9844	UNAVAILABLE	--
0.8859	Al_2O_3/SiO_2	S.C. Si
0.8498	Al_2O_3/SiO_2	S.C Si
0.8095	ALUMINUM MIRROR WITH MgF_2 O.C.	(NRC MIRROR)

The alignment necessary to achieve the number of reflections reported here was relatively easy. With care, more traversals could be obtained; however, it is easy enough now that an inexperienced operator can learn to operate it within minutes and obtain results within the reported precision.

The reflectometer will probably prove most useful in a range from about 0.9990 down to 0.8000. From figure 5 it can be seen that for a reflector of 0.8498 the attenuation was so high that only 23 reflections were possible. The laser energy could have been increased but mirror damage would have been possible. The cell mirrors have damage thresholds much below state of the art so this could be improved with better coatings.

4. References

[1] White, John U. Long optical paths of large aperture. J. Opt. Soc. Am. Vol 32, No. 285; 1942.

[2] Arnon, O.; Baumeister, P. Versatile high-precision multiple-pass reflectometer. Appl. Opt. Vol. 17, No. 18; 1978.

[3] Edwards, David F.; Baumeister, Philip. High-precision multipass reflectometer, SPIE Vol. 288, Los Alamos Conf. on Opt.; 1981.

[4] Foltyn, S. R.; Jolin, John. Catastrophic versus microscopic damage: applicability of laboratory measurements to real systems, Nat. Bur. Stand., Boulder Damage Symposium; 1983. (To be published)

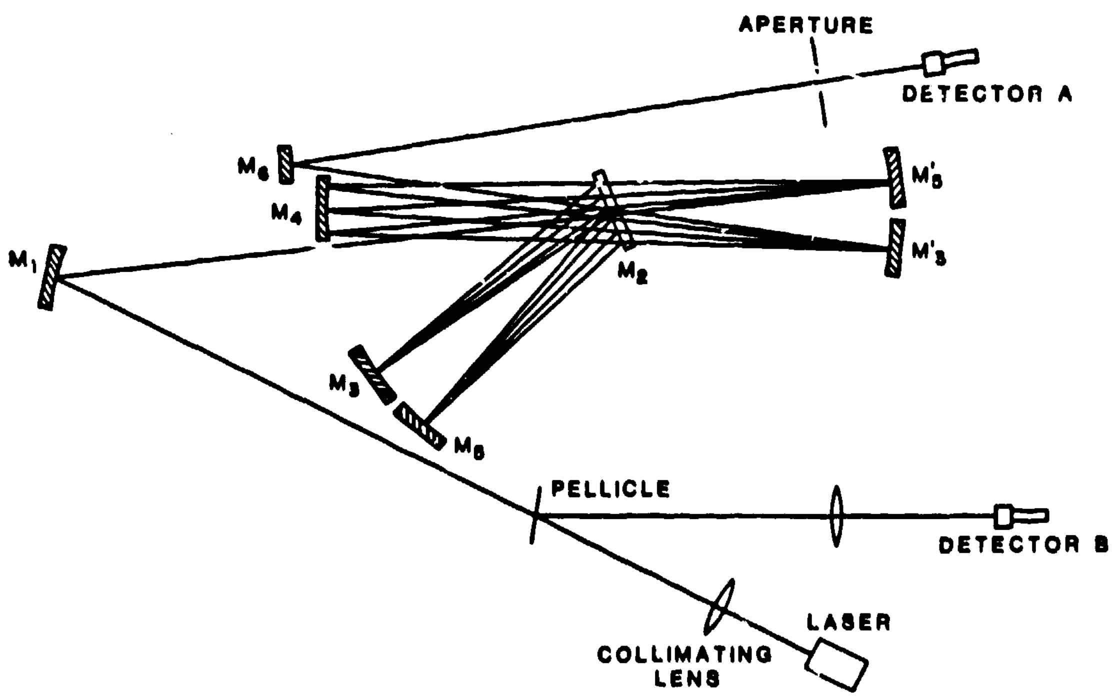

Figure 1. Reflectometer optical layout. Here, 15 reflections (2 traversals), is illustrated. This reflectometer utilizes only the folded cavity as represented by M_4, M_2, M_3, and M_5. M_2 is the position of the unknown.

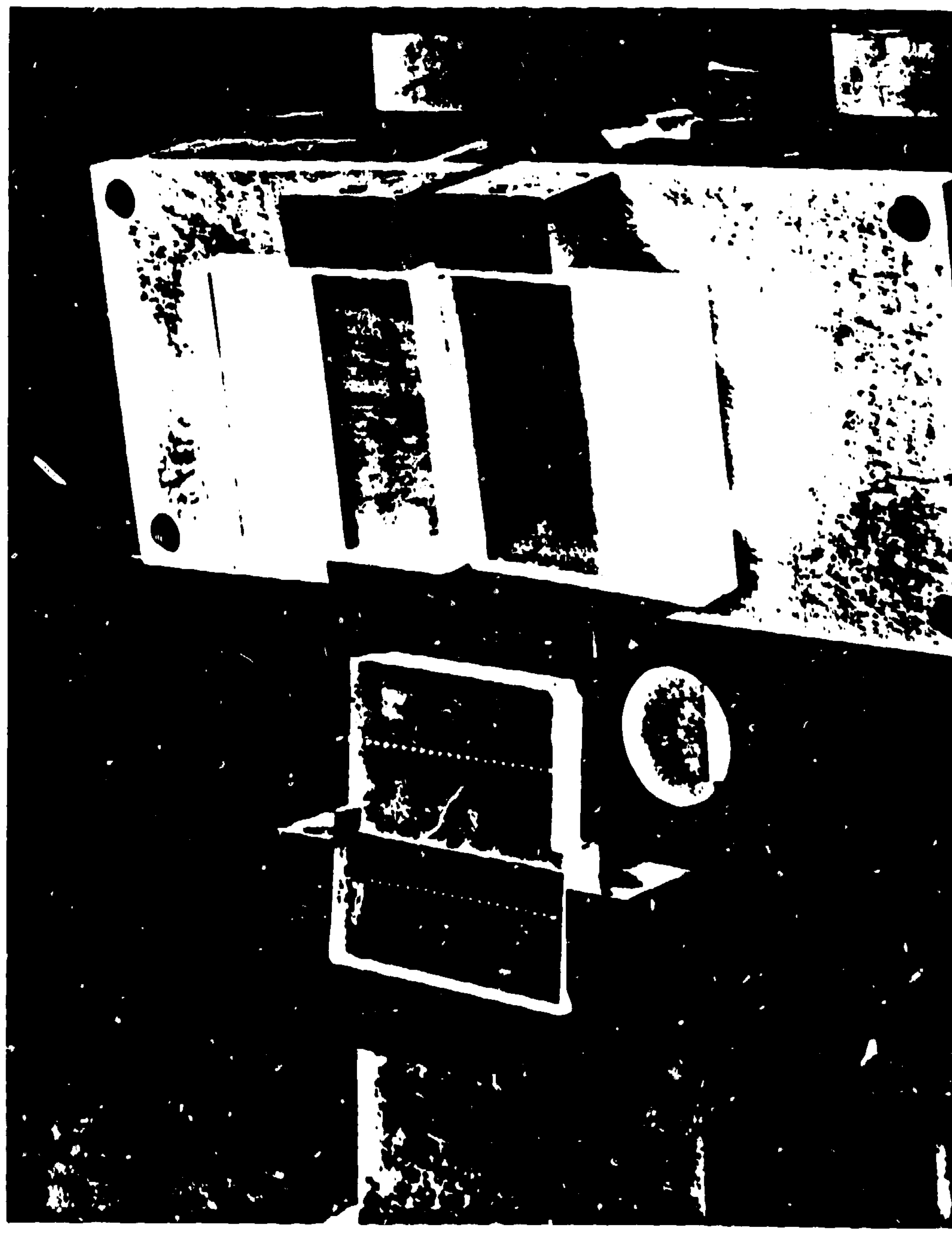

Figure 2. M_3, M_5 (top), and M_4 (bottom) are shown. The separation of the irradiated areas in the vertical direction limits the angle of incidence at which one can test. Here, it is 7 degrees.

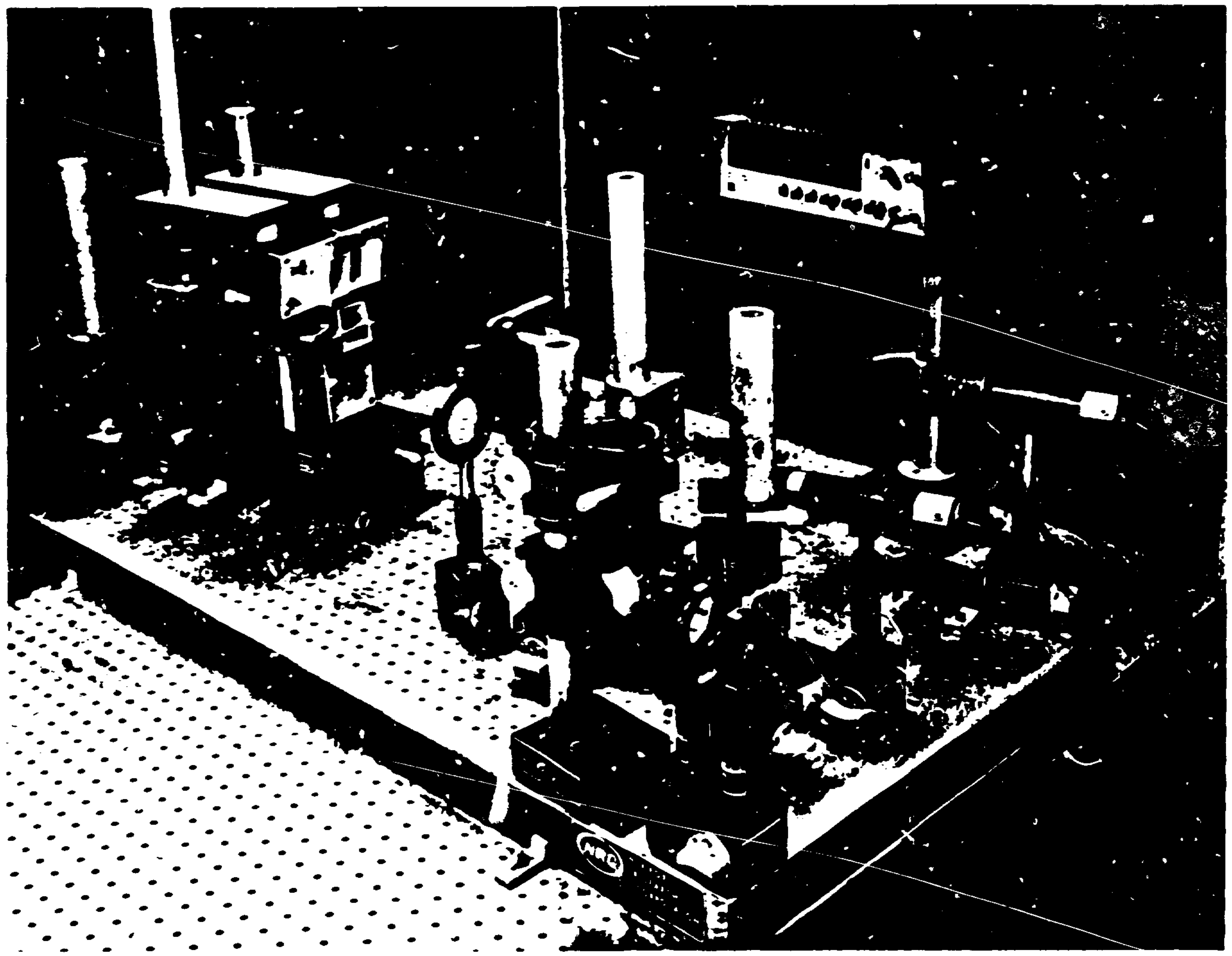

Figure 3. Overall layout of the multiple-pass reflectometer.

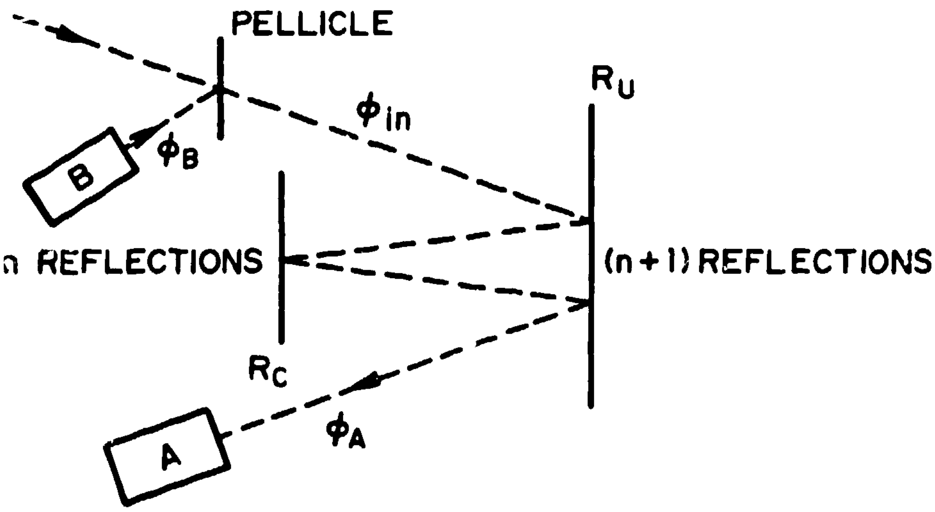

Figure 4. Simplified schematic for a reflectometer. R_c represents the cell mirrors; R_u represents the unknown reflector. n can assume values of 3,7,11,...for the reflectometer described.

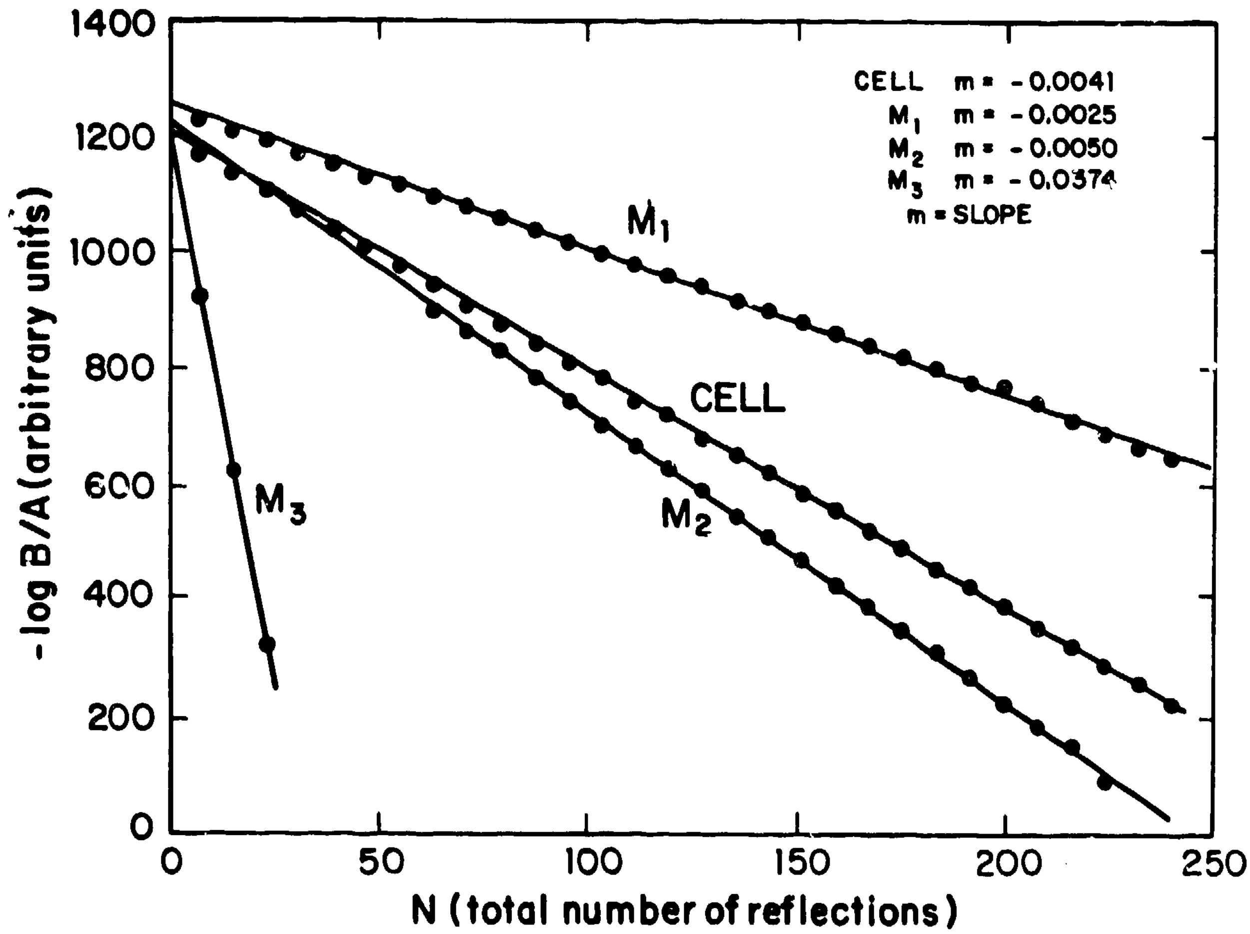

Figure 5. Data plot for several reflectors and the cell, itself, are shown. The reflectances are: M_3 = 0.8484, M_2 = 0.9863, M_1 = 0.9976, and the cell mirror = 0.9906.