LA-UR -86-1378

CONF-860316--5

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TITLE EXTREME ULTRAVIOLET MULTILAYER REFLECTORS

LA-UR--86-1378

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SUBMITTED TO Proceedings for Topical Meeting on Short Wavelength Coherent Radiation, March 24-26, 1986, Monterey, CA

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FORM NO 836 R4
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EXTREME ULTRAVIOLET MULTILAYER REFLECTORS

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ABSTRACT

We have investigated the design, fabrication, and reflectance measurements of a multilayer silver/silicon reflector for use at 58.4 nm. Our results indicate that reflectors in the extreme ultraviolet do not perform as well as predicted due to the presence of surface oxides and other surface contamination layers. In addition, we have found that the correct optical constants for silver have now been published. We find also that these multilayer coatings can be utilized as reflective polarizers in the EUV with an extinction ratio of 75:1 and a throughput of 28% for the s-polarized component of the beam.

INTRODUCTION

Multilayer dielectric reflectors and simple metal coatings do not, in general, provide adequate reflectance for laser cavities or other optical requirements in the extreme ultraviolet spectrum. Various multilayer combinations of metals, semiconductors, and dielectrics are required at different wavelengths within the EUV spectrum to achieve the desired reflectance performance. In this work, we have investigated the properties of a multilayer coating of silver and silicon at 58.4 nm. One of our principal objectives has been to determine what factors limit the performance of these multilayers when utilized in the EUV.

DESIGN

The design of multilayer reflectors requires knowledge of both the refactive indexes and the extinction coefficients of the materials involved in the coating at the design wavelength. If these optical constants are not accurately known, the resulting performance of the coating design cannot be predicted. We began our design effort by ascertaining the optical constants of silver and silicon from the literature. Initially, we had no way of inferring whether these constants were the correct ones. Our initial four layer design for this coating is shown in Fig. 1. The reflectance versus thickness and angle of incidence predicted for this design are shown in Figs. 2 and 3, respectively. The predicted normal incidence reflectance from these figures is 38%.

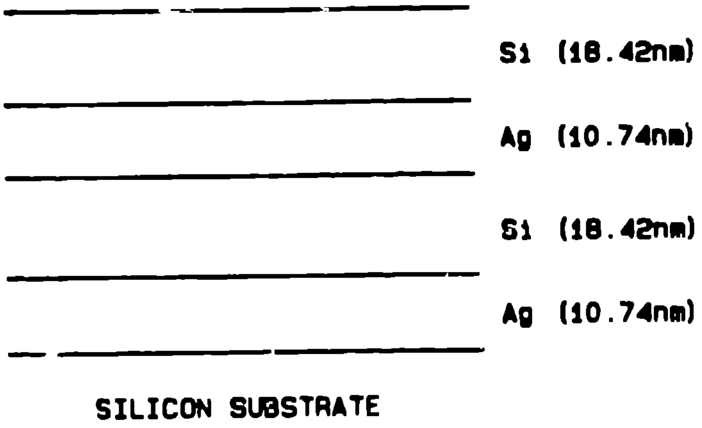

Fig. 1. A four layer reflective coating designed for use at 58.4 nm using silver and silicon on a silicon substrate.

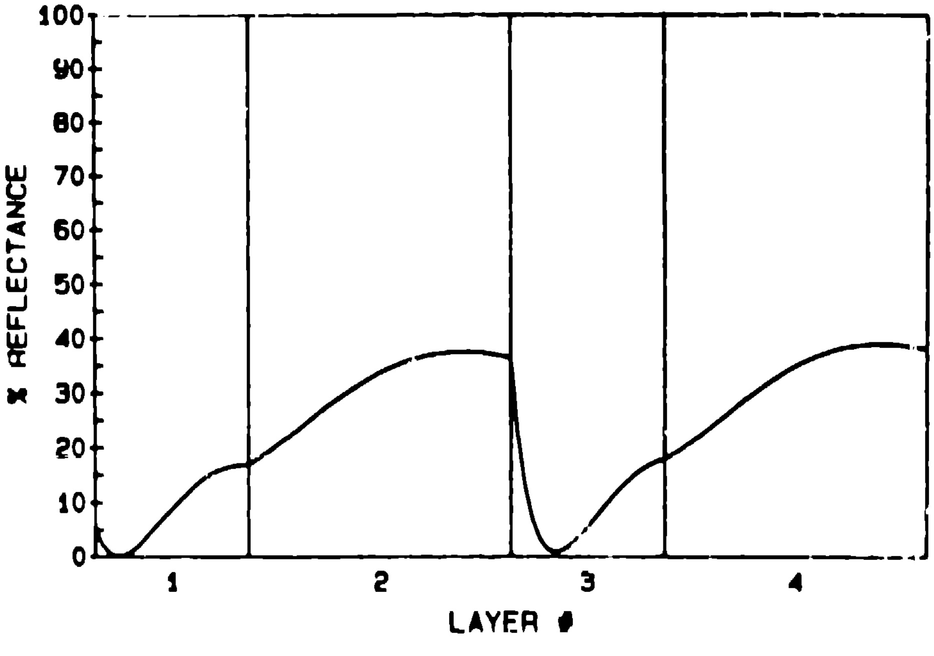

Fig. 2. The reflectance versus thickness for the four layer silver/silicon multilayer coating.

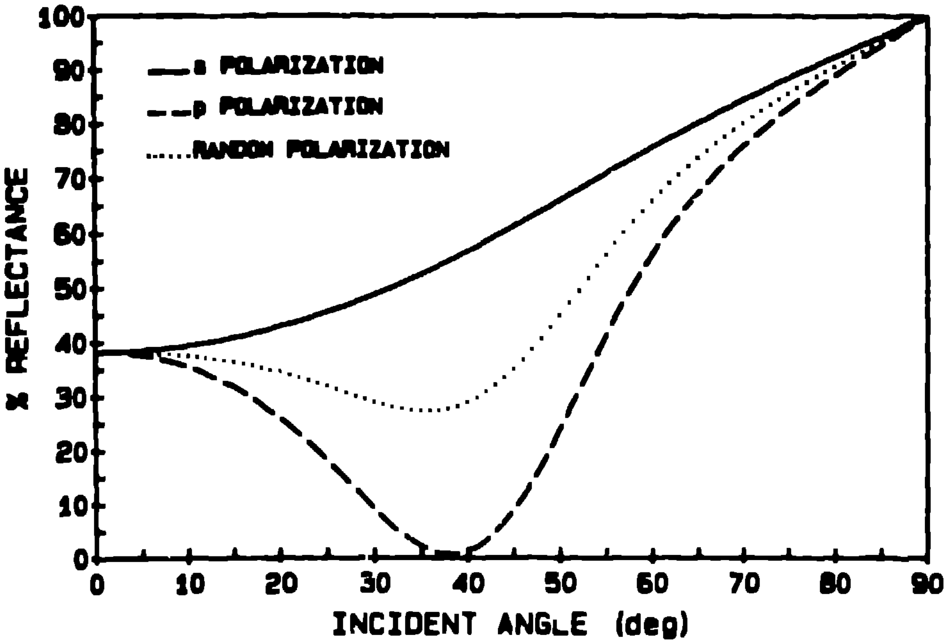

Fig. 3. The reflectance versus angle of incidence predicted for the four layer silver/silicon multilayer coating.

FABRICATION

We fabricated our silver/silicon multilayer coatings using DC magnetron sputtering in a high vacuum chamber illustrated in Fig. 4. The chamber was evacuated to a base pressure of 1.4×10^{-6} Torr. The deposition rates of the silver and silicon were 3.6 and 6.1 Angstroms/sec, respectively. The ambient Argon pressure during deposition was 40 mtorr. The silicon substrates were alternately rotated beneath the magnetron gun with the silver target and the gun with the silicon target. The two halves of the chamber were completely shielded to prevent cross contamination of the two materials during deposition. Shutters on the guns and quartz crystal monitors were used to control the layer thicknesses after several calibration runs.

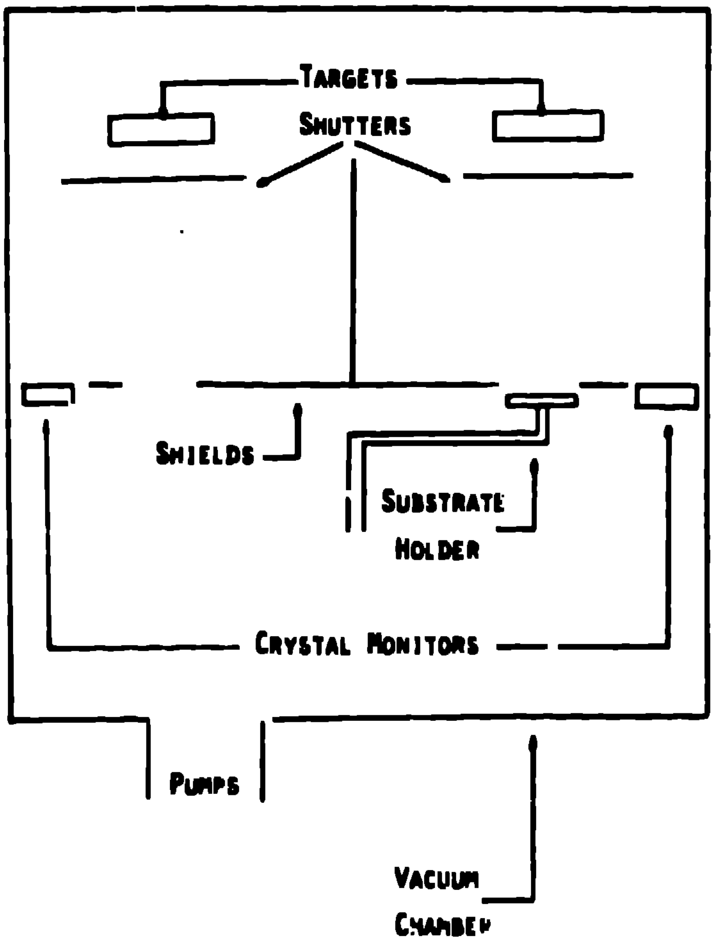

Fig. 4. Schematic diagram of the high vacuum chamber utilizing for DC magnetron sputtering the silver/silicon multilayer coating.

REFLECTANCE MEASUREMENTS

Reflectance versus angle of incidence measurements at 58.4 nm were performed at the University of Colorado on our silver/silicon multilayer. The experimental apparatus used to make these reflectance measurements is illustrated in Fig. 5. A hollow cathode gas-discharge source is incident on a McPherson Model 247 grazing incidence monochrometer fitted with a 300 groove/mm concave reflection grating and scanning entrance slit. The desired 58.4 nm line of Helium is transmitted by the monochrometer to the sample with a resolution of .2 nm and angular divergence of 7 arcmin. The results of these measurements are compared to our original design calculation in Fig. 6.

EXPERIMENTAL APPARATUS FOR 58.4nm MEASUREMENTS

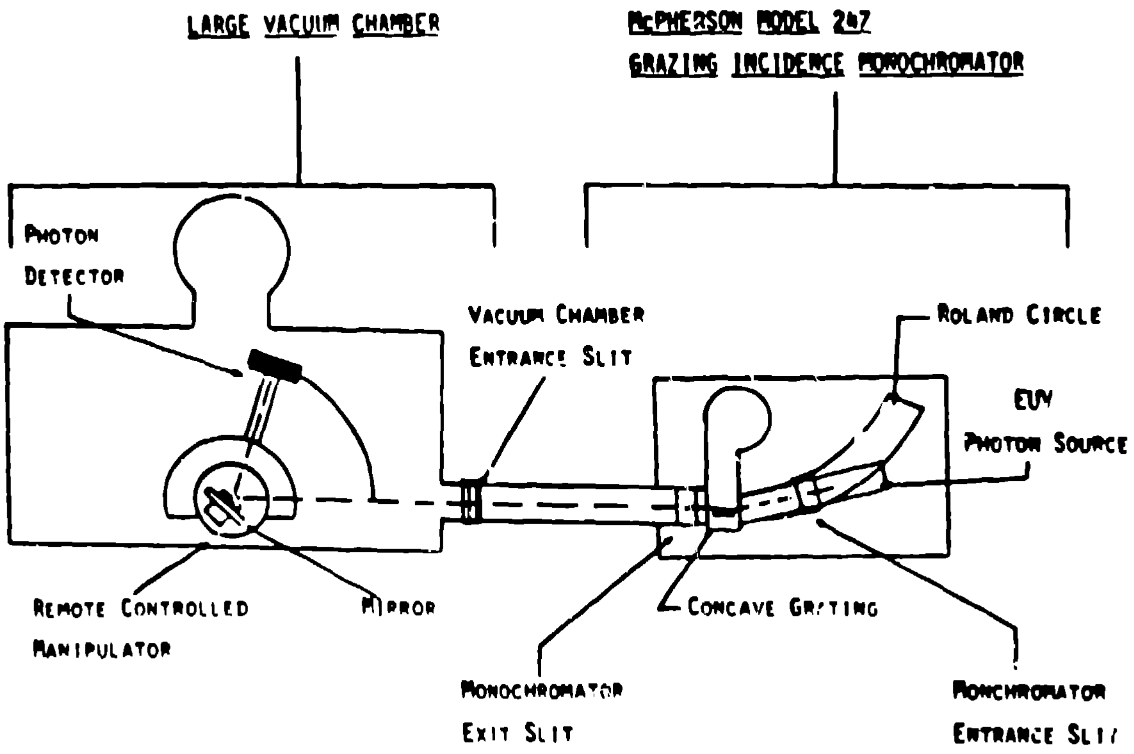

Fig. 5. Experimental apparatus used in reflectance measurements at 58.4 nm.

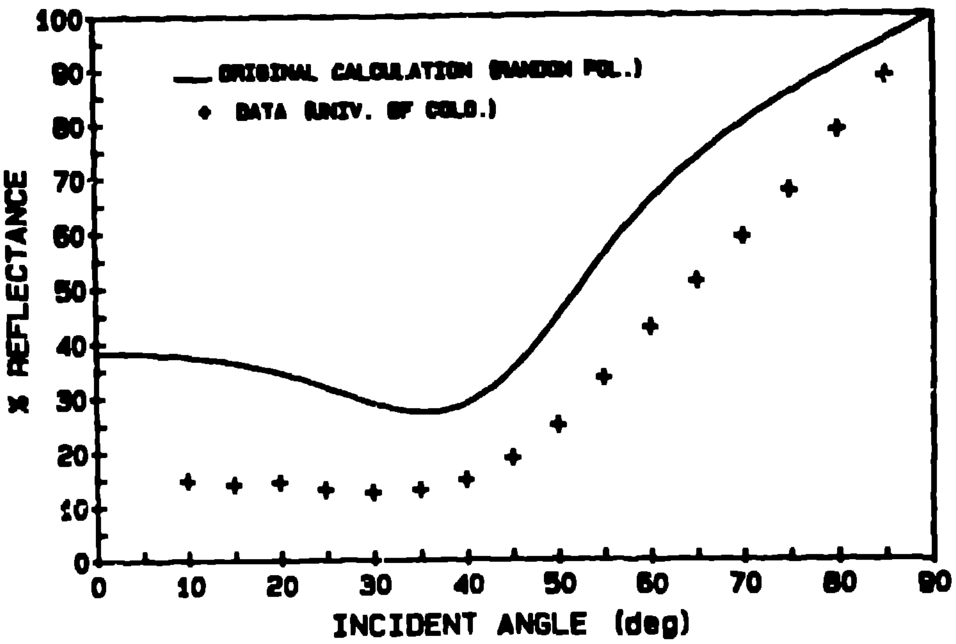

Fig. 6. A comparison of our original design calculation of the reflectance versus angle of incidence with the measured values.

NEW MODEL REQUIRED

The significantly lower reflectance values measured for this coating required that we remodel the coating with surface contamination layers of silicon oxide and carbon (illustrated in Fig. 7) as well as reviewing the optical constants of the materials. We found optical constants for silver in reference 1 that better described our data when used in conjunction with the new model. An excellent fit to the measured reflectance versus angle of incidence data was obtained with the new model as indicated in Fig. 8. This fit was obtained by varying only the thicknesses of the two surface contamination layer thicknesses. The optical constants for silicon dioxide and carbon were obtained from references 1 and 2 respectively. The values obtained for the thicknesses of these two layers were 1.2 nm for the silicon oxide and 1.1 nm for the carbon. These results are in agreement with previous surface science experience in terms of the type and thickness of surface contamination on silicon.

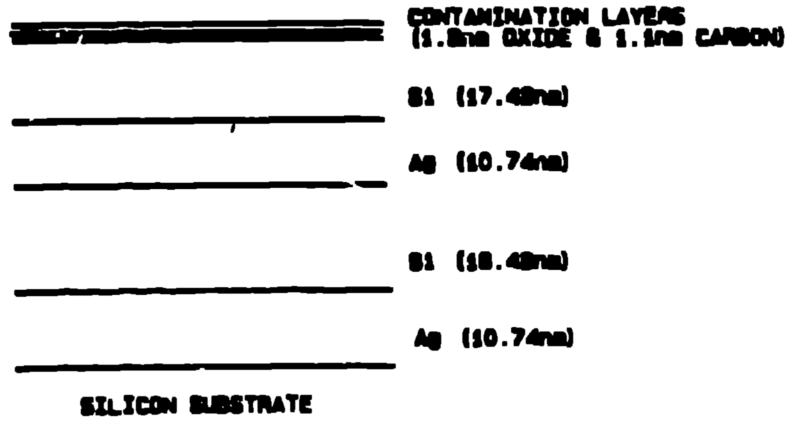

Fig. 7. New model of our silver/silicon multilayer coating incorporating surface contamination layers of silicon oxide and carbon.

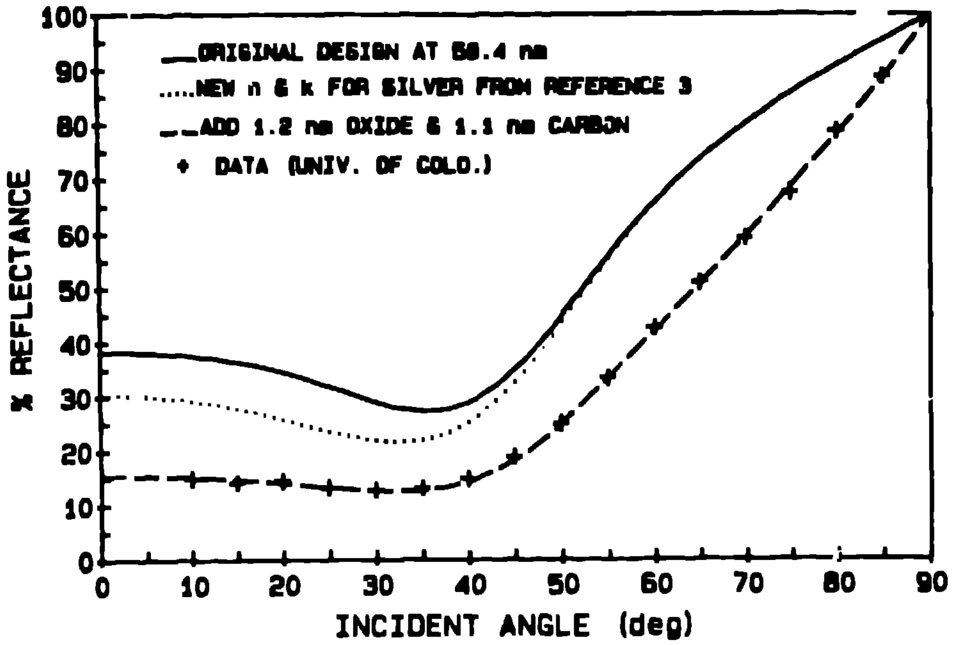

Fig. 8. Comparison of calculations from new model and measured reflectance versus angle of incidence data at 58.4 nm.

We wondered why such thin surface layers should have such a profound effect on the reflectance of our multilayer coating. The answer is a combination of two factors. The first factor is that the optical constants of these materials indicate that the layers are highly absorbing at this wavelength (58.4 nm). The second factor is that these surface layers occur very near the anti-node of the standing wave electric field set up by the incident and reflected

EUV beams as shown in Fig. 9. This combination causes the surface contamination layers to exhibit a maximum absorption of the beam, and therefore, a maximum reduction in the reflectance of the coating.

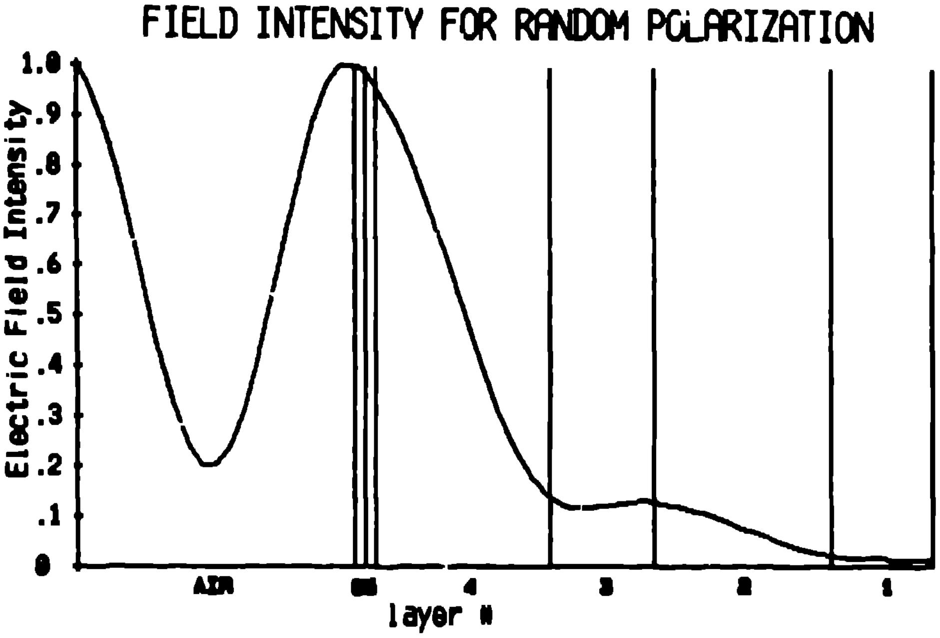

Fig. 9. This plot of the standing wave electric field intensity in the multilayer at normal incidence indicates that the surface contamination layers are very close to an anti-node (peak) in this distribution.

EUV POLARIZER

Although the normal incidence reflectance of the silver/silicon multilayer was disappointing as mentioned in the previous paragraphs, we discovered that the calculated performance of the multilayer as a reflective polarizer was not seriously degraded. The performance of the multilayer as a polarizer from our original calculation as well as the actual performance are indicated in Table I.

TABLE I. Polarizer Characteristics of Multilayer Coating

Quantity Calculated	Original Design (30 deg.)	New Model (39 deg.)
s-Reflectance	54.92%	27.58%
p-Reflectance	00.64%	00.37%
Rs / Rp	86:1	75:1

Although the s-polarized reflectance of the coating decreased by a factor of two from the original calculation, the extinction ratio remained about the same because the p-polarized reflectance also decreased by approximately a factor of two.

CONCLUSIONS

We have found optical constants that agree well with the reflectance measurements of our multilayer coating of silver/silicon, including those of the surface contamination layers. Surface contamination layers are very important in the EUV and must be modeled to achieve satisfactory agreement between theory and experiment. We also conclude that multilayer coatings can be utilized as reflective polarizers in the EUV.

REFERENCES

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2. H. J. Hagemann, W. Gudat, and C. Kunz, DESY SR-74/7 (1974).