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FINAL REPORT (Subcontract No. 2695501)

SYNTHETIC MULTILAYER X-RAY DISPERSION ELEMENTS FOR
200 Å (62 eV) TO 0.62 Å (20 keV) RADIATION

November 1983

✓ SU-DMS-84-R-1

Prepared for: Lawrence Livermore National Laboratory
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This final report concerns research performed at Stanford University on a program sponsored by the Department of Energy through Lawrence Livermore National Laboratory and the Regents of the University of California (Subcontract No. 2695501) entitled "Synthetic Multilayer X-ray Dispersion Elements for 200 Å (62 eV) to 0.62 Å (20 keV) Radiation." The thrust of the research was to investigate the synthesis process parameter dependence of the nature of the interfaces between constituent adjacent layers, the uniformity of layers, and the reflectivity for light of wavelengths 0.62 Å to 200 Å of synthetic multilayer crystals.

Additionally, device development was to be undertaken with emphasis on spectrum analyzing dispersion elements, high energy Kirkpatrick-Baez X-ray microscope mirrors, multi-keV (1 to 5 keV) X-ray applications, X-ray beam splitters and synthetic multilayers fabricated from adjoining elements in the periodic table.

The results of this research performed here at Stanford and in other laboratories including Lawrence Livermore National Laboratory, the Naval Research Laboratory (Washington, D.C.), and the Stanford Synchrotron Radiation Laboratory have been summarized in three papers submitted for publication and in a presentation at a meeting of the American Physical Society. These three papers and the abstract of the presentation are included here as the body of the report.* The papers are:

1. * Troy W. Barbee, Jr. and James H. Underwood, "Solid Fabry-Perot Etalons for X-Rays" accepted for publication in Optics Communications.
2. * Troy W. Barbee Jr., William K. Warburton and James H. Underwood, "Determination of the X-ray Anomalous Dispersion of Titanium/Carbon Layered Synthetic Microstructure" submitted for publication.

* Abstracts and preprints removed.
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3. * N.G. Loter, J.V. Gilfrich, D.J. Nagel and T.W. Barbee, Jr., "Multilayer X-Ray Reflectors for Plasma Diagnostics and Compact Plasmas for Multilayer Characterization" submitted for publication.

The presentation was made at the 25th Annual Meeting of the Division of Plasma Physics of the American Physical Society in Los Angeles, CA. November 7-11, 1983. It is: R.H. Price, T.W. Barbee, Jr., M. Gerassimenko, W.M. Cook, W.M. Ploeger, M.W. Kobierecki, and W.B. Laird, * "A Kirkpatrick-Baez X-ray Microscope (KBXRMS) with W/C Multilayer Reflecting Coatings." Included following this abstract is a description of the design of multilayers (W/C) for application as Kirkpatrick-Baez microscope mirrors.

DESIGN OF MULTILAYERS FOR OPTICS
OPERATING AT FIXED ANGLE
AND ENERGY NEAR GRAZING INCIDENCE

Although the design of multilayers for dispersion element applications is routine due to the flexibility typical of x-ray spectrographs, design for application to fixed angle-fixed wavelength optics operating at grazing incidence requires detailed knowledge of the optical constants of the multilayer constituents and the relative thicknesses of the constituent layers. The two mirrors fabricated for application in a Kirkpatrick-Baez microscope designed to operate at angles of incidence of 1.946 deg and 2.054 deg with 4.727 keV radiation present an excellent example of the importance of this consideration.

These two mirrors were synthesized onto quartz glass substrates mechanically polished to a roughness $< 6 \text{ \AA}$ and a cylindrical radius of 16.45 m. The multilayer structures consisted of 50 layer pairs of tungsten/carbon having a thickness ratio $t_w/t_c \cong 0.61$. Carbon was the top layer and provides a protective passive coating stabilizing this structure relative to ambient environmental contamination.

The subtlety in the design results from refraction of the incident light by the multilayer coating so that Bragg reflection occurs at angles substantially higher than expected. Bragg's equation neglecting refraction effects is :

$$n_B \lambda = 2d \sin \theta \quad (1)$$

where λ is the wavelength of the incident light, d is the period of the diffracting structure, and θ the Bragg angle. N_B is the order of the reflection which is equal to one in this case. For angles of incidence of 1.946 deg. and 2.054 deg the values of d predicted by Eq. (1) for 4.727 keV light are 38.62 Å and 36.59 Å respectively. These values of d are incorrect as they are uncorrected for refraction effects.

Bragg's equation (Eq. (1)) may be written in corrected form as:

$$n\lambda = 2d_0 \sin \theta_m \left[1 - \frac{\delta}{\sin^2 \theta_m} \right] \quad (2)$$

where d_0 is the period of the multilayer, θ_m is the measured Bragg angle, and δ the real part of the complex index of refraction. The index of refraction, n , is given as

$$n = 1 - \delta - i\beta \quad (3)$$

where δ is the real part associated with scattering and β , the imaginary part, is associated with absorption. Although δ , the parameter of importance can be calculated from first principles it may also be determined by experiment.

At very low angles of incidence X-rays are specularly reflected. Above a critical angle, θ_c , the X-rays are no longer specularly reflected. The critical angle, θ_c , is related to δ by

$$\delta = \frac{\theta_c^2}{2} \quad (4)$$

Measurement of θ_c therefore results in the determination of δ . Such an experiment was performed at SSRc with 4.955 keV ($\lambda = 2.501 \text{ \AA}$) radiation on a tungsten/carbon synthetic multilayer ($t_w/t_c = 0.6$). The measured value of $\delta(\lambda = 2.501 \text{ \AA})$ is 5.67×10^{-5} . The value of $\delta(\lambda = 2.623 \text{ \AA})$ can be determined from the value at $\lambda = 2.501 \text{ \AA}$ since in regions away from absorption edges δ is proportional to λ^2 ; the value of $\delta(2.623 \text{ \AA})$ is 6.24×10^{-5} . This results in a correction of the synthetic multilayer spacing require for diffraction of $2.623 \text{ \AA}$ light at Bragg angles of 1.946 deg and 2.054 deg as shown in Table 1. This correction represents a change in the multilayer period which is twice the bandpass of multilayers so that if it were not made, the Kirkpatrick-Baez microscope would not operate at the design wavelength ($\lambda = 1.623 \text{ \AA}$).

TABLE 1

THE DESIGN BRAGG ANGLE (θ), THE UNCORRECTED SYNTHETIC MULTILAYER PERIOD (d), THE REFRACTION CORRECTED SYNTHETIC MULTILAYER PERIOD (d_0) AND THE ACHIEVED SYNTHETIC MULTILAYER PERIODS ($d_{1,2}$) FOR MIRROR BLANKS KB1 AND KB2 ARE GIVEN.

	$\theta(\text{deg})$	$d(\text{\AA})$	$d_0(\text{\AA})$	$d_{1,2}(\text{\AA})$
KB1	2.054	36.59	38.46	38.41
KB2	1.946	38.62	40.83	40.3