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PULSED X-RAY INDUCED DAMAGE TO
METAL AND MULTILAYER MIRRORS

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FIGURE

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PULSED X-RAY INDUCED DAMAGE TO METAL AND MULTILAYER MIRRORS

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ABSTRACT

The effect of intense pulses of laser-produced x rays upon the reflective and diffractive properties of metal mirrors and multilayered mirrors (artificial crystals) have been investigated. Laser pulses from a Nd-glass pulsed laser system of 25 ns pulse width and 50 J energy were focused onto a copper target to generate the required x-ray pulses. A polished planar sample of nickel was used to reflect the 1.0 to 1.3-keV x rays onto photographic film. The x-ray flux onto the mirror (at grazing incidence angles near 3.5°) was split into two adjacent fields with a beryllium filter over one field and with an equal thickness beryllium filter placed over the film holder covering the adjacent field. Thin pieces of Kimfol were used as debris shields ahead of the mirror sample. This technique provided an insitu normalization since both a low intensity and a high intensity irradiation can be simultaneously achieved on adjacent portions of the sample. A similar technique was used to study reflection by a multilayer sample of carbon-tungsten carbide layering and $19.6\text{\AA}$ spacing. Experimental details and the results obtained are presented.

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I. INTRODUCTION

Multilayer thin films and mirrors have become standard elements of diagnostic instrumentation employed to characterize intense x-ray sources. Uncertainty exists, however, concerning the response of the dispersive or reflective elements when subjected to radiation sufficiently intense to produce damage. The primary objectives of this study were to determine 1) the fluence levels at which the response of mirrors and multilayer films change and 2) the qualitative nature of the changes. The experimental approach to accomplish these objectives, entailed using the APL pulsed laser to create an intense burst of x rays of 20 ns duration. The element under study was positioned close to the x-ray source. For the metallic mirror, x rays impinged on the mirror at grazing incidence, and were reflected onto a film pack located behind the mirror. Debris and attenuation foils were interposed between the source and the nickel mirror. A split-field geometry for the attenuation foils was employed so that adjacent portions of the mirror were exposed to different x-ray fluences. This allowed direct comparison of x-ray reflection from a damaged mirror to that from an undamaged mirror. The configuration employed for the multilayer films was similar to that of the mirror studies, except that the x-ray angle of incidence was set so that x rays in the spectral energy range of 1-keV were Bragg reflected onto the film. The x-ray fluence from the source was monitored using calorimeters and XRD's.

A change in the reflectivity was observed for both the mirror and the multilayer film. In the case of the mirror, the change in reflectivity appeared as a decrease in the efficiency. In the case of the multilayer film, the damage appeared as a broadening of the line profile and as a decrease in the reflection efficiency. Several auxillary measurements were performed to substantiate the observed effects. These included reducing the x-ray fluence to observe a null effect and using a variety of filtering and debris foils to check background effects.

II. Experimental Procedure

A. Metallic Mirrors

Intense x-ray pulses were produced by irradiation of a planar copper target with focussed laser light from the APL pulsed Nd-glass laser. The resulting x-ray pulses ranged from 15 to 20 ns in duration. The spectral content included x rays of 0.980-keV (a doublet), several very intense lines in the 1.1 to 1.3-keV range, and an intense lower energy component in the 0.200-keV to 0.500-keV range. The metallic mirror experiments, by appropriate filtering, made use primarily of the 1 - 1.3-keV range of x-ray energies.

The laser beam was directed into a 12 inch diameter vacuum chamber containing x-ray source monitors and the element to be tested. The vertical and horizontal plan views of the source-mirror-film cassette configuration are shown in Figure 1. The mirror sample was positioned at a nominal distance of 1.5-cm from the source. The x rays were incident on the mirror at angles of about 3.4 degrees. The film plane was at a distance of 10.8-cm from the reflection zone. An aperture plate with a 0.318 cm high by 0.476-cm wide opening was mounted at a distance of 1.0-cm from the target spot. A beryllium foil, positioned 1 cm from the x-ray source, covered the right half of the radiation field. This produced a reduced x-ray intensity in half of the field. The unattenuated radiation irradiated the mirror in the left field. A baffle was used to prevent the direct x-ray beam from reaching the film cassette and to provide shielding against scattered radiation. It was positioned 0.5 cm behind the aperture plate with a typical separation from the mirror surface of 0.64 mm. The film cassette contained a beryllium foil covering the left field to provide identical absorption thicknesses in both halves of the split field. Accordingly, any observable differences should be attributable to mirror reflection efficiency changes. For these experiments a piece of Kimfol ($270 \mu\text{g}/\text{cm}^2$ polycarbonate foil) was placed over the entire front aperture to provide a debris shield and to remove most of the contribution from x rays below 0.900-keV. The beryllium filter in front of the mirror was replaced after

a.

b.

each shot.

Monitors of x-ray production and of laser pulse characteristics were employed to provide x-ray yield information. An XRD, filtered to be sensitive only to the 1-keV range of x-ray energies, provided a time profile of the x-ray pulse. A filtered calorimeter was employed to measure the integrated yield of x rays. All monitor signals were recorded using a computer based data acquisition system. The film used in the experiment was Kodak RAR 2497.

B. Carbon-Tungsten Carbide Multilayer Structures

The general description of the experimental arrangement and procedure for the multilayer experiments was the same as that for the mirror experiments. For Bragg reflection of the 0.980-keV copper doublet from the multilayer structure, the angle of reflection was 18.4 degrees as determined by the 2d spacing of 3.92 nm. In the final configuration used for these measurements the position of the film cassette split-field filter was 6 mm behind the multilayer sample. The only other change was substitution of a 215 $\mu\text{g}/\text{cm}^2$ stretched polypropylene foil for the Kimfol debris shield. This foil transmitted more of the low energy x rays, thus enhancing the sample heating.

III. RESULTS AND DISCUSSION

A. Time Integrated Effects In Nickel Mirrors

The mirror experiments required optimization of both laser conditions and experimental geometry. The final configuration employed 0.0025-cm beryllium foils for the split-field filters and a 0.0013-cm beryllium foil for the film cassette light shield. A Kimfol film ($270 \mu\text{g}/\text{cm}^2$) covered the entrance aperture to the mirror sample. Shots 23912 and 25966 with laser fluences of 12 J and 50 J, respectively, were chosen for detailed analysis. For the lower level shot no change in reflectivity was observed.

A densitometer scan across the two halves of the split field for the higher energy shot is shown in Figure 2. The scan is along a line corresponding to one angle of reflection

over both the right and left sides of the split field. The densitometer scan clearly shows a significant reduction in reflection efficiency for the more intensely irradiated left side of the mirror. The structure in the center of the scan, a reduction in intensity just left of center with a sharp rise at midpoint, is due to the finite size of the source. The reduced film exposure is due to the portion of the source which was behind both split-field filter foils. The enhanced exposure is a result of part of the source extending beyond the 1st split-field filter. The discontinuity in x-ray exposure at the midpoint, due to the split-field filter at the film cassette, was used to construct a curve of optical density versus relative x-ray fluence. This is possible because the jump corresponds to the known transmission of the 1-keV x rays through the 0.0025-cm beryllium film cassette filter. Each film record contains steps covering a wide range of initial film densities - one for each transverse scan such as shown in Figure 2. A density versus relative exposure plot can be constructed by a simple iterative process to obtain a smooth curve. With this calibration curve the ratio of reflectivities in the two halves of the split-field can be determined.

A plot of the ratio of reflection from the left and right sides for the high fluence shot is shown in Figure 3 as a function of reflection angle and corresponding x-ray fluence for the more intensely irradiated zone. As is apparent from the figure, damage in the form of decreased reflection efficiency begins to occur at fluence levels of 0.15 J/cm^2 . The efficiency drops rapidly with increased fluence. A similar analysis that of the low fluence shot showed no difference between the left and right reflectivity. The x-ray fluence for the high fluence shot was five times that of the low fluence shot.

B. Time-Integrated Effects in Carbon-Tungsten Carbide Multilayer Mirrors

Except for the different placement of the film cassette filter the experimental configuration used was basically the same as shown in Figure 1. The split field filters were 0.0013-cm beryllium while the film-cassette light shield was 0.0025-cm beryllium. The debris shield was $115 \text{ } \mu\text{g/cm}^2$ stretched polypropylene film instead of Kimfol. The left

hand spectra, corresponding to the side receiving the greater fluence, were degraded in resolution and amplitude compared to the right hand spectra. A significant difference in the appearance of the spectra was readily produced as is clearly shown for instance, for shot 26083 (Figure 4). In this case the 0.980-keV doublet is reduced in intensity by a factor of 2 and also broadened in the left field as compared to the right field. The total beam fluence at the nominal 18.4 degrees Bragg reflection position was $.46 \text{ J/cm}^2$.

C. Fluence Level Measurements

The primary calorimeter measurement for shot 23935 of the mirror reflectivity series, corresponds to a fluence of $.233 \text{ J/cm}^2$ at 1.5 cm from the source. The angular positions of the calorimeter and mirror relative to the target normal were different necessitating a separate series of calorimeter measurements to determine the relevant x-ray anisotropy correction. The anisotropy ratio was separately determined by using two identical calorimeters, the original one in its normal position and another calorimeter placed at the angle of the mirror assembly. The anisotropy ratio was determined to be 0.68 averaged over a number of shots. The corrected fluence at the mirror was 0.160 J/cm^2 at 1.5 cm from the source. The corrected fluence levels at the multilayer sample are $.116 \text{ J/cm}^2$ (1-keV group), $.340 \text{ J/cm}^2$ (soft component), and $.46 \text{ J/cm}^2$ total.

D. Summary

In the present study the fluence levels at which component degradation occurs have been determined and the nature of the change in reflectivity resulting from x-ray induced damage has been characterized. For the case of the nickel mirror, damage occurred at x-ray fluence levels of $\sim .150 \text{ J/cm}^2$ and above. The result of the damage was a decrease in the reflectivity of the mirror. For the case of the multilayer thin film structure, damage was observed at an x-ray fluence level of $.46 \text{ J/cm}^2$. The damage appeared as a broadening of the line width of the Bragg reflection and a decrease in the reflection efficiency.

LIST OF FIGURE CAPTIONS

Figure 1. Schematic views of the x-ray source - irradiation sample film-cassette geometry:

1a. shows a horizontal plan view of the arrangement while 1b. shows a vertical section view through the midplane of the x-ray irradiation field.

Figure 2. A densitometer scan across the film for a high fluence shot (#25935). The difference in reflectivity for the two x-ray exposure levels is quite evident.

Figure 3. The ratio of reflectivity for the left-hand sides and right-hand sides of the split-field irradiation versus reflection angle and corresponding local fluence level at the sample.

Figure 4. The Bragg reflection spectra for the left-hand and right-hand sides of the split-field zones for the carbon-tungsten carbide multilayer sample ($2d = 3.92$ nm). The LHS (high intensity side) clearly shows a reduced amplitude ($\sim \times 2$) for the .980-keV Cu doublet compared to that of the RHS.