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THE RESPONSE OF MULTILAYER FILMS
AND MIRRORS TO INTENSE X-IRRADIATION

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Section 1

INTRODUCTION

Multilayer thin films and mirrors have become standard elements of diagnostic instrumentation employed to characterize intense x-ray sources such as those encountered in underground tests (UGT). Uncertainty exists, however, concerning the response of the dispersive or reflective elements when subjected to such intense radiation. A previous proposal, "The Response of Multilayer Films and Mirrors to Intense X Irradiation" LMSC/D944100, described a laboratory study directed toward measurement of the response of these elements. The present report describes the work performed, in the way of a preliminary study, which resolves anticipated experimental questions before embarking on the proposed study. This work was performed at the pulsed laser facility in the Applied Physics Laboratory (APL) at the Lockheed Palo Alto Research Laboratory (LPARL) under Lawrence Livermore National Laboratory (LLNL) contract F.O. 3432805.

The primary objectives of the preliminary 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 change. The experimental approach to

accomplish these objectives, which is detailed in Section 2, 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. In the case of the mirror, x rays impinged on the mirror at grazing incidence, nominally 3.4 degrees, 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 comparison of x-ray reflection from a damaged mirror to that from an undamaged mirror. The experimental configuration employed for study of the multilayer films was similar to that of the mirror studies, the exception being 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 LLNL tungsten carbide multilayer films had a d-spacing of 40 angstroms giving rise to a reflection angle of 18 degrees for 1 keV x rays. The x-ray fluence from the source was monitored using calorimeters and XRDs.

The results of the measurements are presented in Section 3. 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 and was observed at x-ray fluences of 150 mJ/cm . In the case of the multilayer film, the damage appeared as a broadening of the line profile and a decrease in the efficiency of reflection. Damage was observed to occur at x-ray fluences of 500 mJ/cm . Several auxiliary 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.

In Section 4, the results of the study are summarized and recommendations for a complete investigation are outlined. The general conclusion of the study is that the experimental approach employed is applicable for the investigation of x-ray induced damage to mirrors and multilayer films. The objectives of the study, to determine damage fluence levels and characterize the nature of the change in reflectivity due to the damage, was accomplished. With this knowledge, a more detailed and quantitative investigation is recommended. The study would include both time integrated and time dependant measurements to quantitatively determine the damage threshold. Measurements would be carried out for a variety of different mirrors and multilayer thin films and extended to pulse durations of 2-3 ns. Finally, the

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observation of the change in reflectivity would be extended to higher x-ray fluence levels.

Section 2

EXPERIMENTAL CONFIGURATION

2.1 Introduction

As a prelude to a complete study of multilayer thin film structures and x-ray mirrors a set of preliminary experiments was carried out to clarify a few technical uncertainties. The objectives of these preliminary measurements were to determine qualitatively the nature of the change produced, to find the fluence levels at which these response changes are produced, to optimize the source characteristics, and to define the best geometry for the complete studies of these elements. In the case of the mirror experiment, the 1 keV x rays from a copper target were reflected at a grazing incidence angle from a mirror into a film cassette. The geometry was such that a broad range of x-ray reflection angles were recorded on the film. The reflection angles ranged from angles less than the critical angle to angles greater than the critical angle. In this geometry, each film record contained its own normalization via an equivalent low fluence measurement. At sufficiently high fluence levels, reflection efficiency losses were observed. In the case of the multilayer thin-film structure, a similar approach was employed.

Copper x-rays were spectrally analysed, in this case through Bragg reflection, and recorded with the film cassette. Similarly, normalization was provided by a simultaneous low fluence irradiation being recorded on the same film piece. The direct comparisons between high and low intensity irradiation were found to clearly demonstrate the appearance of substantial degradation of spectral line resolution and of Bragg efficiency for sufficiently high x-ray fluence levels.

2.2 Experimental Configuration for the Nickel 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. Q-switched laser pulses of 20 to 25 ns duration were focussed onto the target to a focal spot diameter of the order of 100 μ m. The resulting x-ray pulses ranged from 15 to 20 ns in duration. The spectral content included x-rays of 980 keV energy (a doublet), several very intense lines in the 1.1 to 1.3 keV spectral range and an intense lower energy component in the 200 eV to 500 eV range. The mirror experiments, by appropriate filtering, made use primarily of the 1 keV range x rays.

The general experimental configuration is shown schematically in Figure 2.2-1. The laser beam is directed into a 12 inch diameter vacuum chamber containing x-ray source monitor detectors and the element to be tested. Vertical and horizl plan views of the source-mirror-film cassette configuration are shown in Figures 2.2-2 and 2.2-3. 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 an angles about 3.4 degrees. The film plane was at a distance of 10.8 cm from the irradiation zone. An aperture plate with a .318 cm high by .476 cm wide aperture was mounted at a distance of 1.0 cm from the target spot. A beryllium foil filter at 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, a split field geometry. 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 cm. The film cassette had a piece of beryllium foil covering the left field to provide identical absorption thicknesses in both halves of the split field. Accordingly any observable differences would be attributable to mirror reflection efficiency changes. For

FIGURE 2.2-1

GENERAL HORIZONTAL PLAN VIEW OF EXPERIMENTAL ARRANGEMENT USED IN THESE EXPERIMENTS

FIGURE 2.2-2

VERTICAL SECTION VIEW THROUGH THE MIDPLANE OF THE TARGET-MIRROR-CASSETTE SYSTEM

FIGURE 2.2-3

HORIZONTAL PLAN VIEW OF THE MIRROR SUPPORT ASSEMBLY SHOWING
FILTER LOCATIONS FOR THE SPLIT FIELD ARRANGEMENT

these experiments a piece of Kimfol (270 g/cm polycarbonate foil) was placed over the whole front most aperture to provide a debris shield and to remove most of the contribution from x-ray spectral components below the 980 keV doublet. The beryllium filter in front of the mirror was replaced after each shot. The Kimfol covered the front of the aperture. The split field beryllium filter was mounted on a moveable rod which was advanced after each shot to bring in an unused portion of the foil.

In addition monitors of x-ray production and laser pulse characteristics were deployed in these experiments to provide x-ray yield and general performance information. An XRD, filtered so as to be sensitive only to the 1 keV range of x-ray energies, provided a time profile of the x-ray pulses. A filtered calorimeter measured the integrated yield of x rays in a pulse. A photodiode with an Si photocathode was employed to monitor the temporal characteristic of the laser beam and to measure the laser pulse energy. The latter was provided by normalization of the Si photodiode response with simultaneous laser calorimeter measurements. All monitor signals were recorded using a computer based data acquisition system. Signal digitization was provided by Tektronix 7912 oscilloscopes for the XRD and Si signals and by a second slow digitizer

for the calorimeter signal. The film used in the experiment was Kodak RAR 2497. Film processing entailed development for 6 minutes at 67 degrees F in full strength Kodak D19 followed by 15-30 seconds immersion in Kodak Indicator Stop Bath and, finally, dipping two minutes in Kodak Rapid Fix. The film records were scanned by a computer based microdensitometer system which provided disc recording of the digitized scan data and hard copy graphs of the densitometer scans.

2.3 Experimental Configuration for The Tungsten Carbide-Carbon Multilayer Structures

The general description of the experimental arrangement and procedure for the multilayer experiments was the same as that for the mirror experiments described in Sec 2.2. For Bragg reflection of the .980 keV copper doublet from the multilayer structure, the angle of reflection was 18.4 degrees as determined by a 2d spacing of 3.92 nm. The first experiments in this series used an arrangement of the split-field-filter very similar to the mirror experiments. The film cassette split-field-filter was repositioned to 6 mm behind the multilayer sample. A horizontal plan view of the modified experimental arrangement is shown in Fig 2.3-1. The only other change was substitution of a 115 g/cm

stretched polypropylene foil for the Kimfol debris shield
This foil transmitted more of the low energy x rays thus
enhancing the sample heating. Data recording, film
processing, and film scanning were as described for the
experiments of Sec. 2.2.

Section 3

RESULTS OF THE PRELIMINARY EXPERIMENTS

3.1 Time Integrated Effects In Nickel Mirrors

The mirror experiments involved optimization of the laser conditions, optimization of the experimental geometry, and observation of mirror damage. The variables explored included 1) laser power level, 2) laser beam focussing, 3, beryllium filter thicknesses, and 4, shielding placement. The final configuration employed 0.001" beryllium foils for the split-field-filters and a 0.005 beryllium foil for the film cassette light shield. A Kimbol film 27" ground covered the entrance aperture to the mirror sample. Shots 25912 and 25935 with laser fluences of 120 and 500 respectively, were chosen for detailed analysis. For the lower level shot no change in reflectivity was observed. Figure 3.1-1 and 3.1-2 show densitometer scans of the left and right sides, respectively, of the film record for the low intensity shot. In the case of the higher energy shot a substantial difference between the left and right sides was observed. Figure 3.1-3 and 3.1-4 show the corresponding densitometer scans for the high intensity shot. It should be noted that the optical density on the film was similar for both high and low shots even though the x-ray fluence differed by a factor of four. This was accomplished by

FIGURE 2.3-1

HORIZONTAL PLAN VIEW OF THE MULTILAYER SAMPLE SUPPORT FIXTURE

FIGURE 3.1-1

DENSITOMETER SCAN FOR SHOT #25912 (LEFT SIDE)

FIGURE 3.1-2

DENSITOMETER SCAN FOR SHOT #25912 (RIGHT SIDE)

FIGURE 3.1-3

DENSITOMETER SCAN FOR SHOT #25935 (LEFT SIDE)

FIGURE 3.1-4

DENSITOMETER SCAN FOR SHOT #25935 (RIGHT SIDE)

placing an additional 0.0005" beryllium foil on the film cassette for the higher level shot.

A densitometer scan across the two halves of the split field is shown in Figure 3.1-5. 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 on the left side which was the more intensely irradiated zone 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 a 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-ray group through the 0.001 inch beryllium film cassette filter (a factor of about 15). Each film record contains steps covering a wide range of initial film densities -- one for each transverse scan such as shown in Fig. 3.1-5. A density versus relative exposure plot can be constructed by a simple iterative

FIGURE 3.1-5

TYPICAL DENSITOMETER SCAN ACROSS FILM (SHOT 25935)

FIGURE 3.1-6
CALIBRATION CURVE FOR KODAK TYPE RAR 2497 FILM

process to obtain a smooth curve. Figure 3.1-6 presents such a curve for the data of laser shot 25935. Similar scans for which a split field filters of 0.0005" was employed give results in agreement with the 0.001" split field filter case. With this curve, the ratio of reflectivities of 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 Fig. 3.1-7 as a function of reflection angle and corresponding high field x-ray fluence. Reflection at large angles occurs at positions on the mirror which are closest to the source, and thus have a higher fluence. As is apparent from the figure, damage in the form of decreased reflection efficiency begins to occur at fluence levels of about 0.15 J/cm. The efficiency drops rapidly with increased fluence. A similar analysis for the low fluence shot showed no difference between the left and right reflectivity. The high fluence shot was five times more intense than the low fluence shot.

3.2 Time-Integrated Effects in Tungsten Carbide Multilayer Structure

The first shots in this series exhibited no apparent damage effects. The x-ray source to target distance was then

FIGURE 3.1-7

REFLECTIVITY OF THE L.H.S. NORMALIZED BY THAT OF THE R.H.S. (OR UNDAMAGED SIDE)

decreased from 15 mm to 12 mm which increased the fluence by a factor of 1.5. No apparent effect was observed. Subsequently, the Kimfol debris shield was replaced with a 115 g/cm stretched polypropylene film. With this change significant differences were observed in the split-field spectra. The left side spectra, corresponding to the side receiving greater fluence, were degraded in resolution and amplitude compared to the right side spectra. For these shots the experimental configuration used was that of Fig. 2.3-1 with 0.0005" beryllium split field filter and a 0.001" beryllium film cassette light shield. Figures 3.2-1, 3.2-2, and 3.2-3 show densitometer scans for the left and right spectra superimposed on each figure for three of the shots in this series of experiments. The first shot, 26081 (Fig. 3.2-1) employed a Kimfol debris shield. No significant difference in the two spectra is apparent. Figure 3.2-2 shows the corresponding scans for shot 26052 in which the thinner polypropylene debris shield was used. A significant difference in the appearance of the spectra is now apparent. The copper doublet at 0.980 keV is reduced in amplitude by about a factor of 3 and substantially broadened. Similarly for shot 26083 (Fig. 3.2-3) the 0.980 keV doublet is reduced by about 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 for shots 26052 and 26083 are 500

FIGURE 3.2-1

DENSITOMETER SCANS FOR BOTH HALVES OF FILM FOR SHOT #26051

FIGURE 3.2-2

DENSITOMETER SCANS FOR BOTH HALVES OF FILM FOR SHOT #26052

FIGURE 3.2-3

DENSITOMETER SCANS FOR BOTH HALVES OF FILM FOR SHOT #26083

mJ/cm and 455 mJ respectively.

3.3 Fluence Levels Measurements

The primary calorimeter measurement for shot 23935 of the mirror reflectivity series corresponds to a fluence of 233 mJ/cm at 1.5 cm distance. The angular positions of the calorimeter and mirror relative to the target normal were different however and a separate series of calorimeter measurements were necessary to determine the relevant x-ray anisotropy conversion. The anisotropy ratio was 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 comparable to that of 25935. The final value for fluence at the mirror was 0.160 J/cm at 1.5 from the source. The primary calorimeter measurement for shot 26052 of the multilayer series corresponds to 560 mJ/cm. The yield of 1 keV x rays correspond to approximately 1/3 of this or 187 mJ/cm and the low energy group provides approximately 2/3 or 373 mJ/cm. The angular distribution corrections thus reduces the number by the factor .68 for the 1 keV x ray while the estimated yield is approximately unchanged for the soft component. The final fluence estimates at the multilayer sample are then: 127 mJ/cm (1 keV group), 373 mJ/cm (soft component),

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and 500 mJ/cm total. The corresponding levels for shot 26083 are 116 mJ/cm, 340 mJ/cm, and 455 mJ/cm. The various fluence levels are summarized in Table 3-1.

FLUENCE LEVELS IN MIRROR AND MULTILAYER EXPERIMENTS

Multilayer Experiments:

Fluence levels for shot 26052

127 mJ/cm , 1 keV x-ray group

373 mJ/cm , soft component

500 mJ/cm , total

Fluence levels for shot 26053

116 mJ/cm , 1 keV x-ray group

340 mJ/cm , soft component

455 mJ/cm , total

Section 4

SUMMARY AND RECOMMENDATIONS

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 150 mJ/cm. 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 x-ray fluence levels of 500 mJ/cm. The damage appeared as a broadening of the line width of the Bragg reflected x-rays and as a decrease in the reflection efficiency. In summary, the results of the present study show that there is sufficient x-ray fluence to damage mirrors and multilayer thin film structures and that the experimental configuration employed for the measurements is quite satisfactory for observation of x-ray induced damage to components of interest.

With the results of the present study as a basis, a more detailed and quantitative study is recommended. The diagnostic measurements could be extended to include both time-dependent as well as time-integrated information. The time dependant measurements could be undertaken using the APL streak-and-framing camera and the LLNL x-ray streak

camera. The time regime of interest could be broadened to include pulse widths from 2 to 20 ns. This pulse range is well within the capabilities of the APL pulsed laser facility. The choice of mirror material could be extended to include carbon mirrors. With the facility upgrades presently underway at APL, x-ray fluence levels of 1.5 to 2.0 J/cm at the component will be possible which is expected to be sufficient to produce damage to carbon mirrors. These changes and additions would then allow a quantitative study of the x-ray induced damage to mirror and multilayer thin-film structures to be carried out.