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Bragg diffraction using a 100ps 17.5 keV x-ray backlighter and the Bragg Diffraction Imager*

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A new diagnostic for measuring Bragg diffraction from a laser-driven crystal using a 100ps 17.5 kV x-ray backlighter source is designed and tested successfully at the Omega EP laser facility on static Mo and Ta single crystal samples using a Mo Ka backlighter. The Bragg Diffraction Imager (BDI) consists of a heavily shielded enclosure and a precisely positioned beam block, attached to the main enclosure by an Aluminum arm. Image plate is used as the x-ray detector. The diffraction lines from Mo and Ta <222> planes are clearly detected with a high signal-to-noise using the 17.5 keV and 19.6 keV characteristic lines generated by a petawatt-driven Mo foil. This technique will be applied to shock- and ramp-loaded single crystals on the Omega EP laser.

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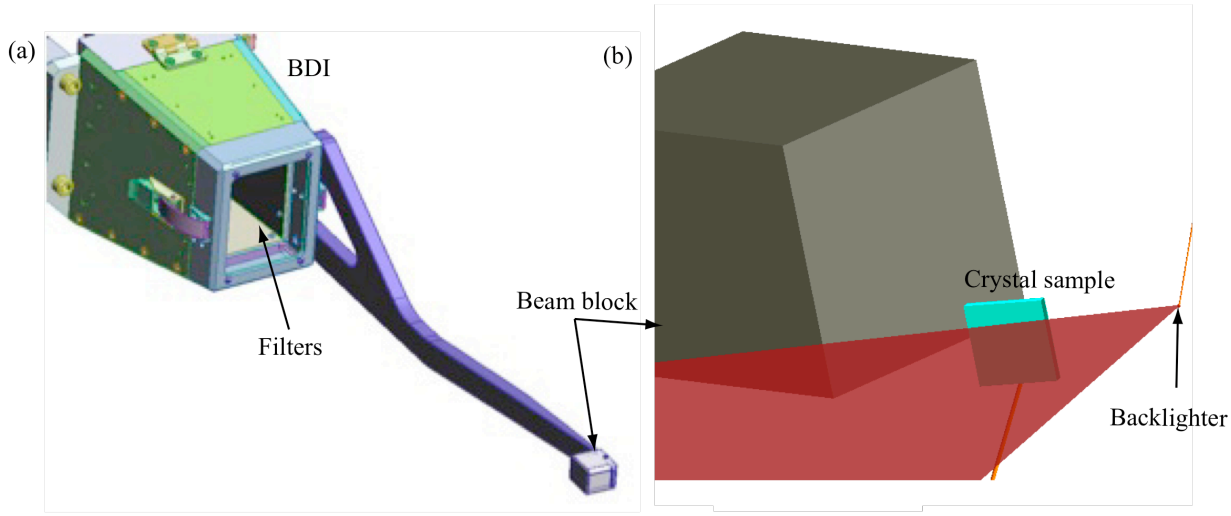

Figure 1 (a) Schematic drawing of the Bragg Diffraction Imager (BDI) showing the heavymet enclosure and attached Al arm that precisely holds a beam block (b) close-up view of the diffraction geometry showing positions of x-ray backlighter and crystal relative to the BDI beam block.

Introduction

Pulsed x-ray diffraction of shock- and ramp-compressed materials is an exciting new technique that can give insight into the dynamic behavior of materials at ultra-high pressure not achievable by any other means to date. X-ray diffraction can be used to determine not only the phase and compression of the lattice at high pressure, but by probing the lattice compression on a timescale equal to the 3D relaxation time of the material, information about dislocation mechanics, including dislocation multiplication rate and velocity, can also be derived [1].

Both Bragg, or reflection, and Laue, or transmission, diffraction have been developed for shock-loaded low-Z crystalline structures such as Cu, Fe, and Si using nano-second scale low-energy implosion and He-α x-ray backlighters [2-6]. However, higher-Z materials require higher x-ray probe energies to penetrate the samples, such as in Laue, or probe deep enough into the target, as in the case of Bragg diffraction. Petawatt laser-generated Kα x-ray backlighters have been developed for use in high-energy radiography of dense targets and other HED applications requiring picosecond-scale burst of hard x-rays [7]. While short pulse lasers are very efficient at producing high-energy x-rays, the characteristic x-rays produced in these thin foil targets are superimposed on a broad bremsstrahlung background and can easily saturate a detector if careful diagnostic shielding and experimental geometry are not implemented.

A new diagnostic has been designed to measure Bragg diffraction from laser-driven crystal targets using characteristic x-rays from a short-pulse laser backlighter on the Omega EP laser. The Bragg Diffraction Imager, or BDI, is a TIM-mounted instrument consisting of a heavily shielded enclosure made from 3/8” thick Heavymet (W-Fe-Ni alloy) and a precisely positioned beam bock, attached to the main enclosure by an Aluminum arm. The beam block is made of 1” thick, Al-coated Heavymet and serves to block the x-rays directly from the petawatt backlight, while allowing the diffraction x-rays from the crystal to pass to the enclosure. A schematic of the BDI is shown in Fig. 1a. Image plates are used as the x-ray detector and are loaded through the top of the diagnostic in an Aluminum, light-tight cartridge. The front of the enclosure can be fitted with various filters to maximize the diffraction signal-to-noise.

Experimental Setup

Figure 1b shows the experimental setup used to test the BDI diagnostic on the Omega EP laser. The petawatt backlighter was a 12μm thick, 250μm diameter Mo disk

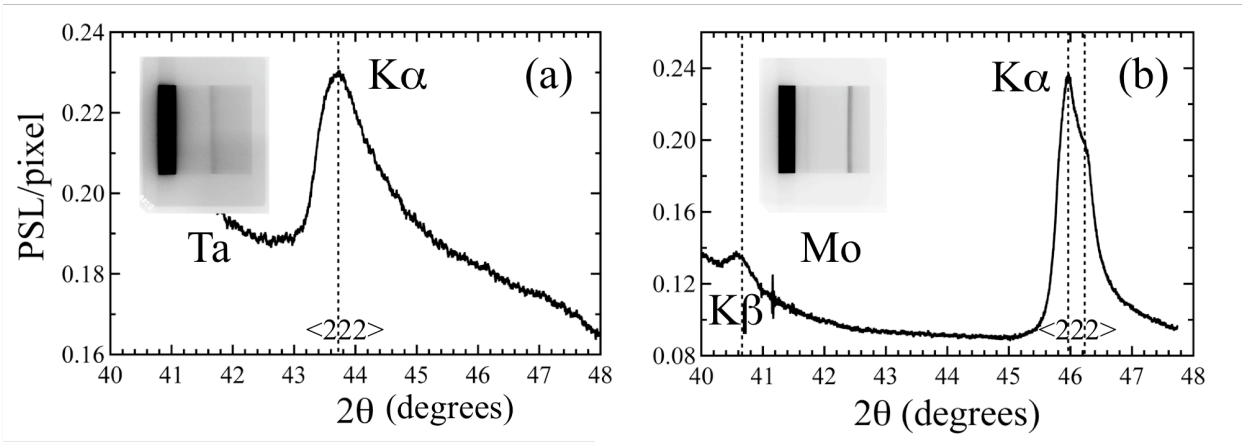

Figure 2 . (a) Ta and (b) Mo diffration from (111) oriented single crystals taken at Omega EP using the BDI diagnostic. Bragg diffraction from <222> planes from the 17.478 keV Mo Kα line is visible in both images while the Kβ line is also visible in the Mo diffraction.

and was placed at target chamber center. The backlighter was irradiated using the Omega EP backlighter petawatt beam (beam 2) at the maximum available energy (1000 J), with a pulse length of 100ps and a nominal spot diameter of 200μm, giving a nominal on-target intensity of $3.2\text{x}10^{16}\text{W/cm}^2$ This laser setting was chosen from previous experiments on Omega EP to provide a high Kα/bremsstrahlung ratio. The crystal sample was placed at a radius of 12mm from the backlighter and angled such that the 17.478 keV Kα x-rays satisfy the Bragg condition for <222> lattice planes at the center of the crystal and the diffracted x-rays strike the center of the IP detector. Two different Z single crystals were tested, Mo and Ta, and both polished so that the (111) planes were parallel to the crystal surfaces. The crystals were supplied polished to +/-1° from Accumet Materials.

Crystals were aligned in the Omega EP chamber by rotating them edge-on in the target viewing system and then rotating about the positioner axis a calculated amount based on metrology data. The Bragg angles, or θ_B, for the two crystals can be calculated using the Bragg diffraction equation $n\lambda = 2d\sin(\theta_B)$, were λ is the x-ray wavelength, n is the diffraction order, d is the spacing between <222> planes, and θ_B is the angle between the x-rays and the <222> plane normal. For 17.478 Mo Ka photons θ_B is 21.85 and 22.98 for Mo and Ta <222>, respectively. For both crystals, the BDI was filtered using a graded-Z stack of (starting at the front) 100μm Al, 12.5μm Mo, 100μm Al, and 200μm Mylar to act as a Mo Kα edge filter and to also filter out any low-energy fluorescence from the crystal target due to high-energy x-rays and electrons from the backlighter.

Results

Results from the undriven short-pulse diffraction experiments on Ta and Mo are shown in Fig. 2a and 2b respectively. Ta (111) was tested first and shows a broad diffraction line slightly off-center of the detector corresponding to a ~1.5 degree error in angular alignment of the crystal. This line corresponds to <222> diffraction from the Mo Kα x-rays. The left side of the image shows x-rays directly from the backlighter that were not blocked by the Heavymet beam block. This signal is bright enough to saturate the image in this region.

Figure 2b shows the results from Mo (111). A similar result is obtained. A strong diffraction feature corresponding to Mo <222> from 17.478 keV Mo x-rays appears roughly centered on the detector along with some portion of the x-rays directly from the backlighter. However, in this case both the $K\alpha_1$ and $K\alpha_2$ lines are resolved. In addition, the <222> diffraction from the 19 keV Mo Kβ

line is also observed closer to the straight-through signal. The background signal level is also lower than that obtained on the Ta single crystal shown in Fig. 2a by a factor of 2. This is most likely due to the addition of a 250mm Mylar filter directly in contact with the image plate during the Mo diffraction shot. A low energy (<3 keV) background was observed on similar experiments on the Titan laser, however the source of this background signal is yet to be determined.

Discussion and Conclusion

Lineouts of the diffraction images are also shown in Fig 2a and 2b for Ta and Mo, respectively. The abscissa for both graphs have been converted into the x-ray deflection, 2θ [degrees], at the crystal plane. The width of the Kα diffraction peaks are ~0.2° and 0.4° for Mo and Ta, respectively, and are much larger than the typical rocking curve of a perfect crystal which is on the order of a few milli-degrees. Source broadening from the ~200μm diameter x-ray backlighter is a maximum of ~30 mili-degrees. The remaining broadening of the diffraction lines is likely due to the defect density at the surface of the crystal from polishing. Indeed, subsequent shots using the same experimental setup showed varying degrees of line broadening consistent with a varying degree of damage from polishing. With proper preparation of the surface of crystals in future experiments, this line broadening can be used to derive a measure of the material defect density during shock- or ramp-compression.

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