Single Photon Energy Dispersive X-ray Diffraction (SPEDX)

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Introduction

Advances in high power lasers are enabling us to drive solid matter to increasingly extreme states, reaching pressures unattainable by static compression [1-3]. Generating these states of matter allows us to probe the conditions within planetary interiors and to study the initial stages of an inertial confinement fusion implosion.

Laser-driven shock or quasi-isentropic compression not only generates extreme conditions in the sample but also an extreme environment and challenge for diagnostics. At the NIF, the large energy deposition coupled with the significant fraction of unconverted light creates difficulties with preserving diagnostics positioned close to the target, and any data with them. Using more distant detectors is one way of mitigating this problem and a new diagnostic technique is being developed which will allow in-situ x-ray diffraction measurements at these laser facilities.

Single Photon Energy Dispersive X-ray diffraction (SPEDX) is a novel method of performing in-situ x-ray diffraction. The technique utilises a CCD camera operated in single photon mode to detect photons diffracting from a polycrystalline target [4]. A white light x-ray source is used to generate x-rays which are collimated onto a metal foil target. Photons generated via noise processes will be randomly spatially distributed whilst those that are diffracted will have a correlation between energy and scattering angle; therefore the use of multiple cameras can aid the identification of diffraction peaks for a single shot.

In this report we present data from the first experiment to study driven targets using SPEDX with the Vulcan laser in Target Area West. The experiment also used multi-target mounts and remote alignment to significantly increase the shot rate by reducing the need to regularly cycle the chamber.

Experimental Setup

The experiment was performed in VULCAN's TAW, with the experimental setup sketched in Fig. 1. Beams 1-6 delivered up to 600 J of frequency doubled 532 nm laser light to the backlighter target in 1-2.5 ns. The beams were defocused to a spot size ~100 μm and generating intensities of ~10^{14} Wcm^{-2}.

Mixed metal backlighters were used, produced by the target fabrication group at the CLF, to generate a quasi-white light source between 3-9 keV [6]. The backlighter was optimized during the experiment to be bright at 4 keV.

The x-rays were collimated using a molybdenum collimator to limit the x-ray spot size to ~0.5 mm^2. The use of a collimator ensures that the x-ray spot is smaller than the drive spot to minimize the amount of diffraction from undriven material. Lead shielding was also used to minimize the number of stray photons from the backlighter being recorded on the CCD.

Additionally the compressor was bypassed in order to use beams 7 and 8 to deliver 10 – 80 J over 3 – 8 ns to shock compress metal foil samples. Random phase plates were used to provide uniform drive intensity over the drive spot. This achieves an intensity of up to 10^{12} Wcm^{-2} and a drive pressure of up to 1 Mbar [5].

The sample materials were 30 μm polycrystalline metal foils of Ta, Cu and Fe coated with 10 μm of CH plastic and an Al flash layer ~5 nm thick.

Two Princeton MTE x-ray CCD cameras were used during the experiment to collect x-rays at different Bragg angles and were placed 50-70 cm away from the target. The cameras were operated at -30 °C and water-cooled via an external chiller in order to minimize the number of dark counts recorded by the CCDs. The cameras were also shielded using thick aluminium tubes to narrow their field of view such that only photons from the sample were collected.

The use of two cameras at different angles allows for determination of the strain state of the compressed material along two different reciprocal lattice directions. This allows the transverse and longitudinal strain in the material to then be inferred.

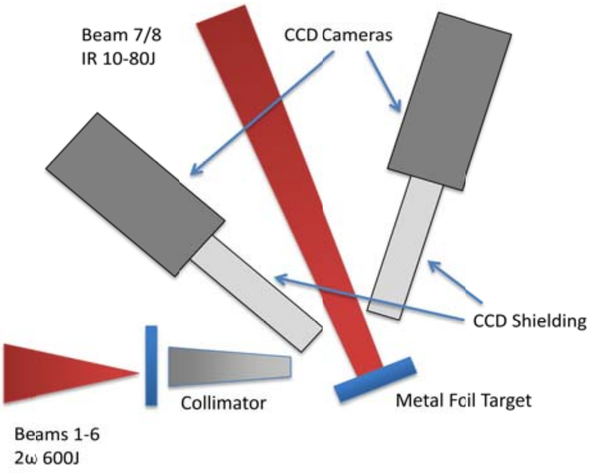

Figure 1: Diagram of experimental setup

The two sets of beams were co-timed during setup to within 0.5 ns of each other using a fast diode. A range of delays between the drive and backlighter beams was used in order to probe the target material at different stages of its compression.

Mounting the targets on pinwheels allowed for multiple shots to be taken in succession without the need for replacing targets every shot and cycling the target chamber vacuum therefore providing a significant increase in shot rate. Due to being the only Vulcan users during the experiment it was also possible to interleave upper and lower beams to further increase the shot rate up to a maximum once every 10 minutes. A diagram of the experimental setup is shown in Figs. 1&2.

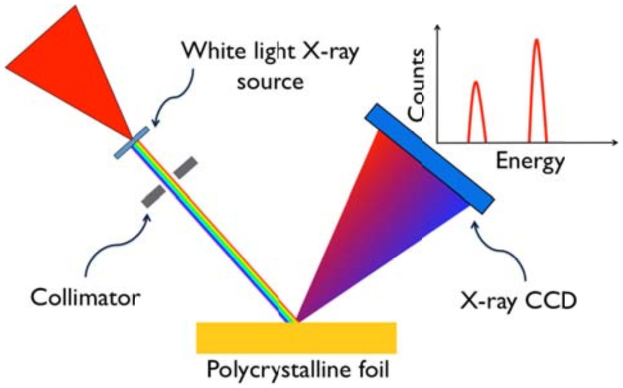

Figure 2: Schematic diagram of a SPEDX experiment.

A 100 μm filter of PETP plastic was placed at the end of the shielding tubes to reduce the number of low-energy x-rays collected from drive noise that can lead to the CCD no longer being in the single-photon regime.

Results

Figure 3 shows a representative example of the spectrum measured by the CCD cameras from an undriven target. The response of the CCD is linear over a large energy range enabling multiple diffraction peaks to be identified which allows for the determination of both structure and unit cell size. The (011) diffraction peak at ~4 keV is brightest due to the backlighter spectrum being brightest at that energy.

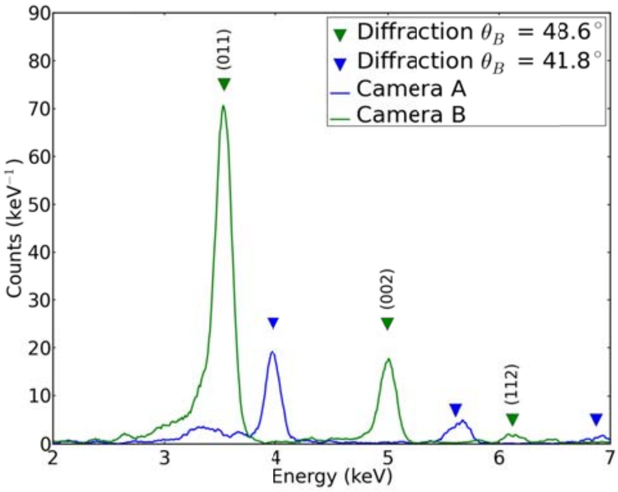

Figure 3: Spectra measured of static tantalum from two CCD cameras at indicated Bragg angles.

The diffraction pattern from a driven Tantalum target is shown in Fig. 4. Both cameras measure a change in peak position indicating diffraction from compressed material. Cameras A and B measure compressive strains of 2.7 and 1.5 percent respectively, indicating a pressure of ~20 GPa. The different compressive strains measured on the two cameras indicate that the Tantalum is in a non-hydrostatic condition and exhibits some degree of residual strength.

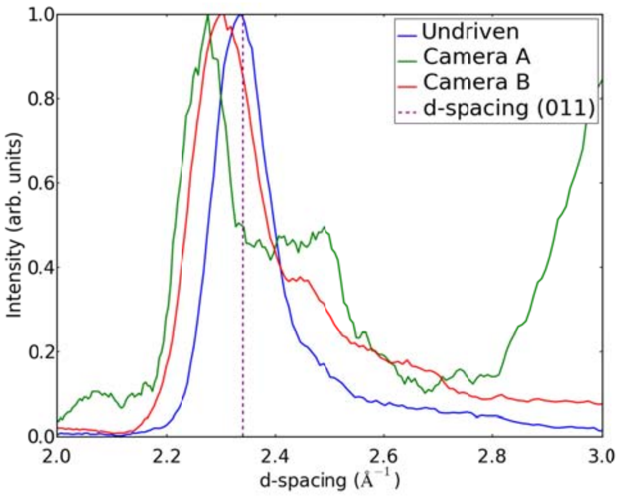

Figure 4: Diffraction pattern of shock compressed Tantalum indicating compression of the (011) lattice plane.

The counts measured at larger d-spacings, particularly on the second camera, indicate that background noise is not being effectively filtered.

For shots where the camera is not saturated with drive noise the diffraction peaks are reliably observed. By performing the experiment with a backlighter that is brighter at higher energies; smaller scattering angles could be utilised and therefore higher order diffraction planes would be of more use. This would then allow for more aggressive filtering of drive noise and therefore enable the use of higher drive intensities due to the drive noise scaling with the square of the drive intensity.

Conclusions

Single Photon Energy Dispersive X-ray diffraction (SPEDX) has been performed for the first time using driven targets using the Vulcan laser in Target Area West. Diffraction signal was consistently observed although saturation of the CCDs by drive noise was an issue at large drive intensities. Using a backlighter at higher energies in order to observe higher order diffraction peaks would be of benefit.

Acknowledgements

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