

Studies of Dynamic Properties of Shock Compressed fcc Crystals by In Situ Dynamic X-Ray Diffraction

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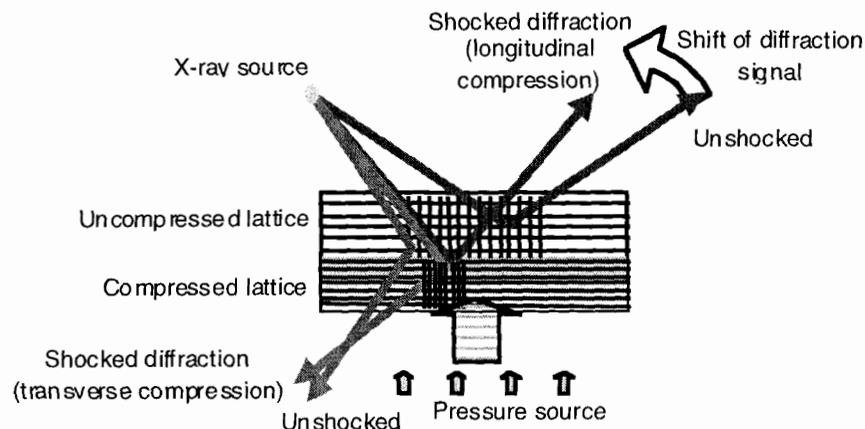
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There were 5 laser experiments conducted to date in FY-01 under the ongoing project to study the response of single crystal fcc materials under shock compression. An additional 10 laser shots are planned for August, 2001. This work has focussed on developing capability to record diffraction from multiple lattice planes during the passage of a shock through a thin foil of single crystal copper, while simultaneously performing separate shock sample recovery experiments to study the residual deformation structure in the recovered samples.

Dynamic x-ray diffraction

Time-resolved dynamic x-ray diffraction provides the capability to study the response of a lattice under shock compression directly as the shock passes through the sample. The diffraction signature provides detailed information on state of the material. Compression of the lattice spacing is observed as a shift of the Bragg angle of diffracted x-rays (Figure 1), and a broadening of the signal may be characteristic of the dislocation and stacking fault density in the material. By recording diffraction from multiple lattice planes simultaneously, this technique provides information on the state of the shocked sample. Simultaneous measurement of the lattice spacing from orthogonal lattice planes shown in Figure 1, for example, provides information on the transition from elastic to plastic deformation.

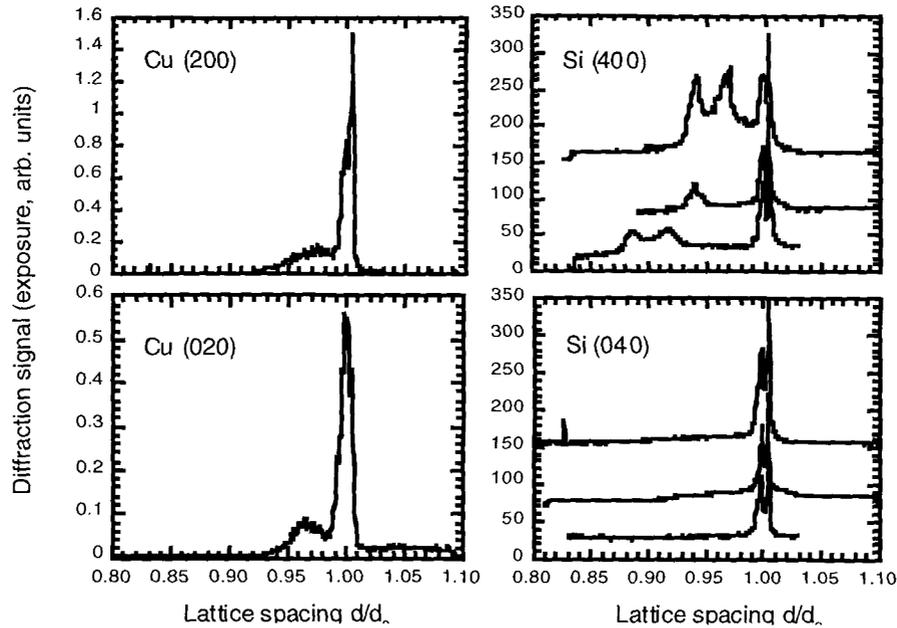
Figure 1: Configuration for simultaneous diffraction from orthogonal lattice planes parallel and perpendicular to the shock propagation direction.



During the course of this project, a target configuration was developed for simultaneous measurements of the lattice deformation both parallel and perpendicular to the shock propagation direction. In these experiments, the single crystal samples of Cu were shocked by direct laser irradiation on the thin Cu foil or on a CH ablator coated

onto the Cu foil. Both time-resolved and time-integrated Bragg diffraction data was recorded from the orthogonal lattice planes. Example lineouts of the time-integrated data from shocked Cu is shown in Figure 2. These lineouts show diffraction from both the uncompressed lattice (before the shock drive is turned on) and compressed lattice (during shock loading). These are contrasted with previous results from shocked Si where the lattice responded purely elastically with no deformation perpendicular to the direction of the shock propagation.

Figure 2: Lineouts of the diffraction signals from shocked Cu (left) and shocked Si (right). The top lineouts show compression along the shock direction, and the lower lineouts show compression perpendicular to the shock direction. (See Loveridge-Smith, *et al*, PRL, 2001)



During FY-01, we recorded diffraction from the (200) and (020) lattice planes of Cu using a V x-ray source (2.38 Å), which is well matched for these simultaneous measurements of the Cu lattice with a 42° Bragg angle. In addition, we tested a modified target using a Cu x-ray source (1.4 Å) to record the (400) lattice planes of Cu. This will then be used with a mixed x-ray source (Sc and Cu at XX and 1.4 Å) to simultaneously record x-rays diffracted from the parallel (200) and (400) lattice planes on upcoming experiments in August, 2001.

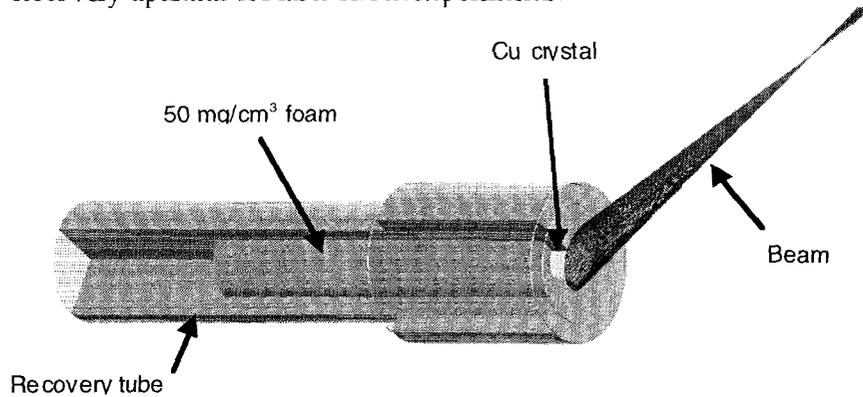
To further extend the technique, plan to field a large solid angle film holder on these diffraction experiments. This is a static film-based detector that will record x-rays diffracted from many different lattice planes, covering a π -steradian solid angle, fully one fourth of the target chamber. This diagnostic will be tested on NLUF diffraction experiments in August, 2001.

Shocked sample recovery

Following shock compression, there is a release wave when the laser turns off. This further processes the samples. In order to study the detailed response due to shock loading, we have demonstrated recovery of shocked single crystal samples of Cu for post-shock micro-structural analysis. Single crystal Cu disks are placed within the tip of a recovery tube filled with a low density aerogel foam foam (Figure 3). Direct laser irradiation generates a high pressure shock that propagates into the sample. It is a

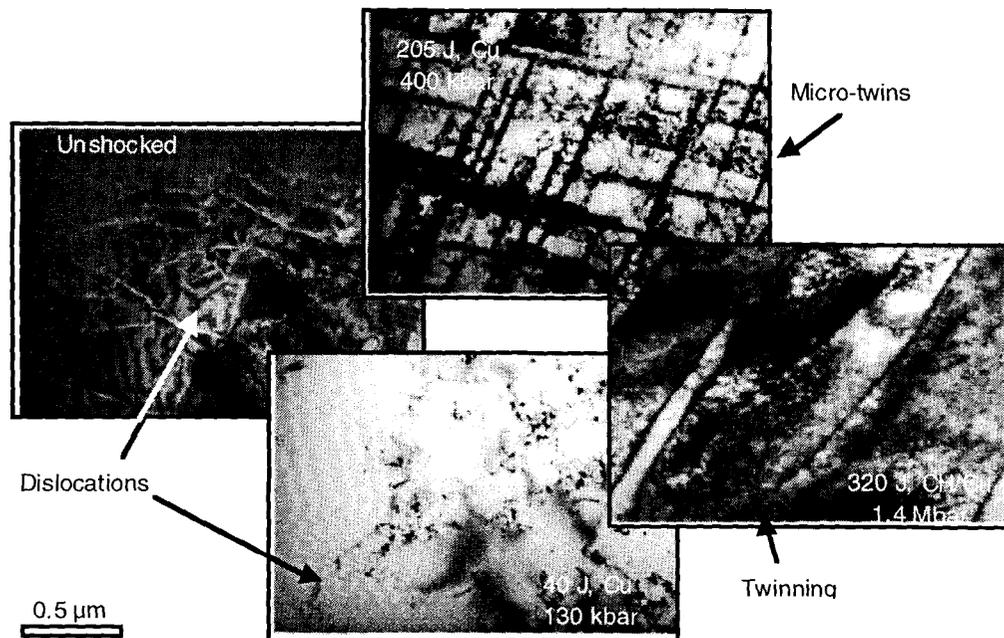
decaying wave that breaks out the free surface of the sample, in some cases causing incipient spall due to void formation and coalescence.

Figure 3: Recovery apparatus for laser shock experiments.



We have shocked a series of single crystal samples of Cu and recovered them for micro-structural analysis. Transmission electron microscopy (TEM) was used by Prof. Meyers at UCSD to investigate the residual deformation structure due to shock loading at a range of pressures. Images of the residual structure are shown in Figure 4. At the lowest shock pressure, an increased density of dislocations is observed. At higher pressure, there is a relaxation to a cell structure with distinct regions of micro-twinning, and at the highest pressures, large twin regions are formed as the temperature behind the shock is high enough to allow thermal recovery and evolution of the micro-structure after the passage of the shock. These samples were (100) Cu, which has 8 slip systems. Experiments conducted during FY-01 were also done with (134) Cu, which has fewer slip systems. Results from these tests are being analyzed, and follow-up experiments are planned during the final series of experiments in FY-01 in August.

Figure 4: TEM analysis of shocked single crystal Cu samples recovered on OMEGA.



Future plans

The goal of these experiments is to develop an understanding of the fcc lattice response due to shock loading. In order to obtain a full data set, we are working to conduct multiple simultaneous experiments using the OMEGA laser facility. Specifically, with 60 beams and 6 diagnostic ports available, we have developed a configuration to use different beams to shock load three separate samples (Figure 5):

1. Dynamic x-ray diffraction measurements of the lattice response during and after shock loading.
2. VISAR wave profile measurement.
3. Recovery and post-shock micro-structural analysis.

The combination of these techniques provides information to correlate the dynamic diffraction data with the actual shock wave profile, and the real-time lattice response with the residual deformation structure following recovery.

During the remainder of FY-01, we will test the configuration for multiple experiments, and we will evaluate the large solid angle film collection. During FY-02, we plan to perform a series of experiments to record the response of multiple lattice planes of Cu at a range of drive pressures. We will also record VISAR wave profiles and recover shocked samples. This will be extended to another material such as Ta, where the Peierl's barrier is intermediate between that of Si (which showed uniaxial compression) and Cu (which showed a 3D plastic deformation under compression).

Figure 5: Target chamber configuration for multiple simultaneous experiments: diffraction, VISAR, recovery.

