MESOSCALE PLASTIC DEFORMATION IN THE SHOCK RECOVERED METALS FROM WHITE BEAM DIFFRACTION

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ABSTRACT During uniaxial compression by strong shock waves, metals undergo a transition from elastic compression to plastic compression. The nature of this plastic compression has been of considerable interest since the time of C.S. Smith. However, a detailed understanding has been inhibited by the need to examine soft recovered samples. White microbeam X-ray diffraction offers the prospect of quantifying the shock induced anisotropic plastic state in materials. The disorder created at the shock front leads to significant scattering surrounding the Bragg peaks. Analysis of these scattering results gives a measure of dislocation density and local lattice rotation. We have measured polychromatic X-ray microdiffraction from shock recovered samples of Cu single crystals at the Advanced Photon Source. The density and organization of dislocations will be presented as well as comparison to SEM and OIM on the same samples.

INTRODUCTION: Copper has been the object of numerous shock experiments. Recently developed in-situ time resolved x-ray diffraction relates in-situ pseudo Kossel line broadening with dislocation density during the shock experiments [Loveridge-Smith 2001, Kalantar 2003,]. After shock structure in the Cu single crystal studied by TEM reveals severe deformation and twinning in the (200) shock compressed Cu single crystals [Meyers 2003]. We complement these results with white (polychromatic) X-ray microbeam study of the after shock dislocation microstructure in the (200) Cu single crystal.

PROCEDURES, RESULTS AND DISCUSSION: Residual plastic deformation of Cu single crystals was studied by 3D polychromatic X-ray microdiffraction (PXM). PXM is sensitive to the density and organization of the dislocations, which occurs at several structural levels. Small size of the beam (0.5 μm) and depth dependent analysis of Laue intensity gives possibility to obtain 3D spatially resolved information about the dislocation structure organization nondestructively (in contrast to TEM). The sketch of the shocked single crystal and the geometry of initial and diffracted white beam radiation

and the microbeam geometry are shown in the Figs.1 a, b. Cu single crystal (001) with initial dimensions: diameter 3 mm and thickness 1 mm was analyzed from both the back side and the crater (Fig 1a).

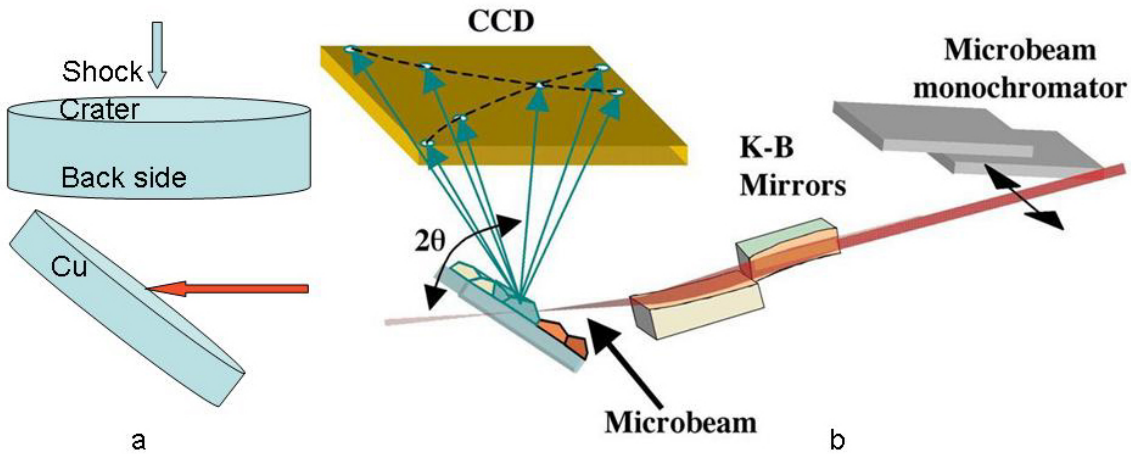

Fig.1 Sketch of the sample orientation during shock experiment and orientation of the Cu single crystals relative to microbeam (a); polychromatic microbeam geometry (b).

The x-ray synchrotron measurements allow for true 3D mapping of the crystalline phase, orientation and plastic deformation with 1 μm spatial resolution. A region of interest is identified using an optical microscope and the polychromatic x-ray beam is then focused onto the sample. Details on the experimental setup and data collection can be found elsewhere [Larson 2002]. Data were collected using microbeam Laue diffraction on the 34ID beamline at the Advanced Photon Source. Dimensions of the beam were 0.5 by 0.5 microns with a penetration depth of ~ 50 microns.

A two-dimensional map of PXM intensity was collected from different locations at the back and front sides of the Cu single crystal with the step size of 1 μm in both directions. Typical Laue patterns from the back and front sides of the shocked Cu crystal are shown in Fig. 2. One of the Laue pattern (Fig. 2 a) is indexed for convenience. Residual plastic deformation is observed at both sides of the crystal. However deformation at the crater is much more severe. Formation of geometrically necessary dislocations (GNDs) and geometrically necessary boundaries (GNBs) is observed.
As was shown previously GNDs and GNBs cause streaking and splitting of the Laue spots [Barabash 2003]. The direction of the streak is related to the orientation of the primary slip system in the probed region and to the local lattice rotations.
Severe plastic deformation in the crater is accompanied by the formation of the large number of twins. Twinning causes splitting of all Laue spots and appearance of “two” overlapping disoriented diffraction patterns (Figs. 2 d, e). This is in agreement with TEM results described by [Meyers 2003]. The density and organization of dislocations is presented as a function of depth under the shock front as well as comparison to SEM on

the same samples. These experimental findings are consistent with recent MD simulations.

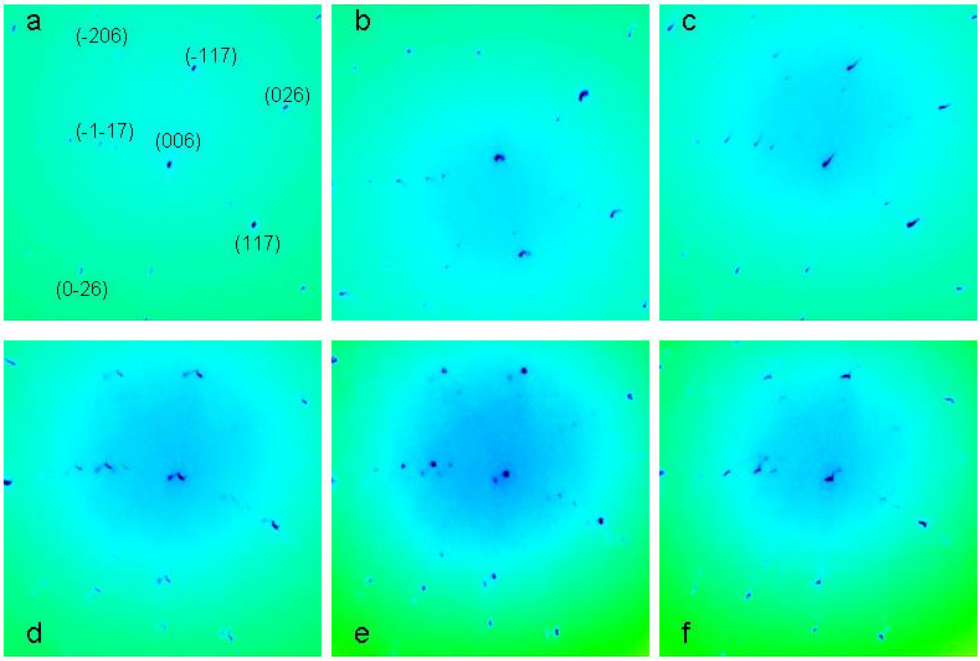

Fig. 2 Laue images obtained from the (001) Cu shocked single crystal: The back side of crystal (a - c) and the crater at the front side of the crystal (d – f).

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