ABSTRACT

INVESTIGATION OF SINGLE CRYSTAL AND BI-CRYSTAL DEFORMATION IN BODY-CENTERED CUBIC TANTALUM USING INDENTATION

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To understand how polycrystalline tantalum (Ta) deforms and develops damage that can lead to fracture, it is necessary to have an understanding of the single crystal deformation as well as deformation at grain boundaries. Metallic crystals generally deform from the motion of dislocations on crystallographic planes and this motion is dependent on the orientation of the individual crystals in relation to the imposed deformation. In order to study the effects that crystal orientation and grain boundaries have on deformation, as well as quantify and characterize the dislocations involved, three primary experiments were carried out.

The first set of experiments involved single crystal microindentation, single crystal nanoindentation, and bi-crystal nanoindentation. The topographies developed were mapped using confocal microscopy for microindentations and atomic force microscopy (AFM) for nanoindentations. The single crystal indents revealed the effect crystal orientation has on topography and the bi-crystal nanoindentations reveal the effect that grain boundaries have on topography. In this work, three grain boundaries were targeted for analysis, with one indent made on each side of the grain boundary. Analysis shows that deformation across the grain boundary is dependent on the side from which deformation is approaching. The single crystal
and bi-crystal nanoindentations were coupled with crystal plasticity finite element modeling (CPFEM) simulations in order to compare the experiments with predictive models.

The second set of experiments characterized and quantified the dislocations involved in the underlying plastic deformation of single crystal and bi-crystal nanoindentations using electron channeling contrast imaging (ECCI) and cross-correlation electron backscattered diffraction (CC-EBSD). ECCI directly images and characterizes dislocations using contrast analysis. On the other hand, CC-EBSD calculates the geometrically necessary dislocation (GND) density from the subtle shifts in the EBSD patterns. CC-EBSD can also split the GND density onto the specific slip systems. The effectiveness of these two techniques to quantify and characterize dislocations were compared and the advantages and disadvantages of both outlined.

In the third experiment, the sub-surface deformation of a single crystal wedge indentation was analyzed using ECCI and EBSD. The wedge indentation was specifically aligned to the crystal orientation so that when the sample was cut in half, all deformation was manifested as plane-strain in the analyzed surface plane. ECCI and EBSD were carried out on a small area underneath the area where the indenter tip was in contact with the sample. Backscattered electron (BSE) imaging and EBSD mapping reveal thin needle like bands that resemble that of twinning. The crystal orientation alternates between thin bands of rotated crystal orientation and thick bands of the original crystal orientation. ECCI shows high dislocation densities within the bands and at the boundaries between bands. Due to the fact that the alternating banding leaves no residual lattice curvature, it is concluded that all dislocations within a given band are statistically stored dislocations (SSDs).

This work reveals that the surface topography and the dislocation distributions that result from indentation reflect the symmetry of the indented crystal orientation. Also, deformation at
grain boundaries is dependent on the direction from which deformation is approaching. Even further, this work shows that the combination of indentation, AFM, ECCI, and CC-EBSD is a great method for investigating deformation but the limitations of each of these tools need to be understood in order to be fully utilized.