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Size dependent mechanical behaviour of tantalum

D. Kaufmann [a], R. Mönig [a,*], C.A. Volkert [b], O. Kraft [a]

[a] Karlsruhe Institute of Technology, Institute for Materials Research II (IMF II), Postfach 3640, 76021 Karlsruhe, Germany
[b] Georg-August-University Göttingen, Institut for Materials Physics, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

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ABSTRACT

The size dependence of deformation of Ta was studied using compression tests of focused ion beam (FIB) machined microcolumns. Columns with diameters between 0.5 and 8 μm with ⟨1 1 1⟩ and ⟨1 0 0⟩ orientations along the column axis were tested. By comparing results of bcc Ta columns with results from previous experiments on fcc metals it was found that Ta shows significantly higher normalized yield stresses in combination with a weaker sample size dependence. The differences between bcc and fcc metals can be attributed to the different dislocation behaviour of bcc metals, especially to the lower mobility of screw dislocations.

1. Introduction

Tantalum is used in many technological applications. For example it is used in electrical resistors and capacitors or as base material for medical implants. Various experimental (Hoge and Mukherjee, 1977; Khan and Liang, 1999; Maudlin et al., 2003) and recent theoretical investigations (Voyiadjis and Abed, 2005; Plunkett et al., 2007; Kuchnicki et al., 2008) on the mechanical behaviour of the bulk metal can be found in the literature. For the mechanical behaviour of small scaled tantalum only limited knowledge exists. Although nanoindentation experiments on nanocrystalline (Wang et al., 2005, 2006) and on single crystalline Ta (Biener et al., 2007) have been performed, no microcompression data of small single crystalline Ta samples are available.

This work was motivated by the continuing demand for miniaturization which leads to smaller and smaller components in microfabricated devices. Shrinking the size of components down to the micrometer range or below is not only a complicated technological task, but also requires attention to materials. On this size scale, strong deviations from the well known mechanical behaviour of bulk materials are expected (Kraft et al., 2010). In the past, many studies on the size dependent behaviour of fcc metals have been reported which show that the yield strength increases significantly when sample dimensions are reduced into the sub-micrometer range (Uchic et al., 2004; Yu and Spaepen, 2004; Greer et al., 2005; Volkert and Lilleodden, 2006; Nix et al., 2007). So far size effects in bcc systems and in particular on tantalum have only received little attention. Glide systems and dislocation mobilities of bulk bcc metals are different from those of fcc systems. Therefore differences in the size dependent behaviour between fcc and bcc may be expected on the micron scale. Recent investigations on molybdenum (Brinckmann et al., 2008; Schneider et al., 2009a) show that there is a mechanical size effect in bcc metals leading to higher strengths as the samples become smaller. The observed behaviour has been phenomenologically described by using an exponential relation between column diameter and strength:

* Corresponding author. Tel.: +49 (0) 7247 82 2487.
E-mail address: Reiner.Moenig@kit.edu (R. Mönig).

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