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Deformation of silicon – Insights from microcompression testing at 25–500 °C

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ABSTRACT

The plastic deformation of silicon and other brittle materials near room temperature has conventionally been studied under high confining pressures, although it has been suggested that these may modify the dislocation core structure. Here, the possibility of using microcompression has been studied. Using this method the yield stress of silicon micropillars was measured for different pillar diameters and between 25 and 500 °C for a constant diameter of 2 μm. No pronounced effect of size on the yield stress was found, but the transition from failure by cracking to predominately plastic deformation was shown to be consistent with a previously proposed simple model for axial splitting. Deformed specimens were analysed by transmission electron microscopy to elucidate the operative dislocation mechanisms. This showed that at 500 °C deformation occurs by twinning and formation of partial dislocations, whereas at 100 °C it is associated with micro-cracking and only weakly dissociated dislocations.

1. Introduction

Although one might expect fracture to be of predominant interest in brittle materials, plasticity is of great importance in applications such as cutting and forming (Merchant, 1945), at high temperatures (Barsoum et al., 1997; Yamaguchi et al., 2000) and even in electronic applications, where the density, mobility and structure of dislocations can influence the efficiency and lifetime of devices (Nakamura, 1998). However, to study plastic flow cracking must be suppressed. This is usually done either by using indentation or, more elegantly, by applying a confining pressure using a solid or gaseous medium. The former is relatively straightforward, but does not allow dislocation motion on individual slip systems to be studied directly due to the complex state of strain under the indenter (Bouvier and Needleman, 2006; Gilman, 2009; Lloyd et al., 2002). Interpretation of indentation results in silicon can be further complicated by a phase transformation from the diamond cubic to the β-Sn structure under the indenter which occurs at hydrostatic pressures of approximately 12 GPa (Hu et al., 1986; Jang et al., 2005). Uniaxial compression of bulk samples is experimentally more difficult, requiring confining pressures as high as 5 GPa at room temperature in the case of silicon (Rabier et al., 2007), but allows the properties of individual slip systems to be interrogated. However, recent simulations have shown that a hydrostatic pressure can influence the dislocation activation energies in zincblende and diamond cubic materials (Pizzagalli et al., 2009). It is therefore important to be able to carry out tests without such a confining pressure. Furthermore, a method must allow testing over a range of temperatures and deformation rates and provide a specimen for the study of the resulting deformation *post facto*.

Micropillar compression is one possibility, as there appears to be a critical size below which cracking is suppressed. There are various possible explanations, including decreasing size leading to the elimination of flaws (Griffith, 1920; Gordon, 1976;

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