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Gripless nanotension test for determination of nano-scale properties

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ABSTRACT

This paper proposes a novel material testing method, gripless nanotension technique (GNT), to assess the basic mechanical properties of nano-scale structures in top-down processes. The GNT exhibits prominent advantages over conventional methods, i.e., use of a nanoindenter as a reliable and simple testing device, high-quality nano-scale metallic specimen with negligible residual stress, and tensile testing possible in the through-thickness direction. Using the proposed method, nano-scale polycrystalline specimens obtained from a nickel film were tested. Through the experiment, well-defined values of material properties with extraordinary phenomenal findings, i.e., strikingly reduced elastic modulus, yield strength and tensile strength of much higher values could be reliably observed and determined at the nano-scale.

1. Introduction

Nano/micro-scale devices and systems are used in numerous mechanical, optical, and electrical applications. For a cost-effective and robust design of these devices, the mechanical properties of the materials are indispensable.

Diverse nano-scale materials are fabricated using top-down processes which are generally based on thin film deposition and patterning. These processes have been implemented under characteristic conditions of temperature, pressure, and mechanism of deposition. They all lead to internal material structures (grain sizes, pores, dislocation patterns, etc.), which are very different from those of bulk macro-materials. In nano/micro-scale, however, it is necessary to measure a property with a specimen of the same scale as that of the considered geometrical structure because mechanical properties are usually dependent on the external size of the structure (Brenner, 1956, 1957; Espinosa et al., 2004, 2005, 2006; Fredriksson and Gudmundson, 2005; Kiener et al., 2008; Nix and Gao, 1998; Uchic et al., 2004). For instance, the yield strength greatly increases when the specimen diameter decreases, a phenomenon known as the size-scale effect. This effect has been observed and verified experimentally through micro-tensile testing for a variety of single crystal metallic whiskers in the 1950s (Brenner, 1956, 1957). Recently, new methodologies of micro/nano-compression and tension tests were exploited to show that the size-scale effect is very drastic for specimen sizes under several tens of micrometers (Kiener et al., 2008; Uchic et al., 2004). It was demonstrated that polycrystalline structures have different mechanical properties depending on the film thickness as well as the grain size (Espinosa et al., 2004, 2005, 2006). Khan et al. (2006) also showed from nanocrystalline aluminum powder that the reduction in grain size resulted in several-fold increase in hardness and strength.

Various nano/micro-testing methods have been developed to understand the dependence of the properties on the external specimen size and internal material structures (grain sizes, pores, dislocation patterns, etc.) (Haque and Saif, 2002a,b; Oliver and Pharr, 1992; Schenk et al., 1990; Sharpe et al., 1997b; Stoykovich et al., 2008; Tsuchiya et al., 1998). Among

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