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Evaluation on Tensile Property of Single Crystalline Gold Nanorod with Single Slip Orientation

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Abstract

We investigate the tensile properties of a single crystal gold nanorod with a square cross-section of 190 nm x 190 nm. A gold nanorod, which has a single slip orientation, is mounted on a lozenge-shaped silicon frame and is pulled by a compressive load on the top face of the frame. Although the applied load increases linearly in the early stage of deformation, it drops suddenly at a certain displacement. *In-situ* TEM observations indicate that the rapid drop is due to crystallographic slip generation within the nanorod. The critical resolved shear stress on the active slip system at yielding is evaluated to be 325.8 MPa, which is about 600 times larger than that of the bulk counterpart. After necking, which occurs regardless of the crystal structure, the nanorod is fractured.

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Keywords: Tensile test, Nanorod, Single crystal, Mechanical property, Gold

1. Introduction

The mechanical properties of submicron- or nanometer-scale materials are of practical importance because they are used in interconnections above semiconductor layers in ultra-large-scale integrated circuits. It is widely known that the mechanical properties of submicron- and nanometer-scale materials are different from those of the bulk due to the small volumes of the former. Although bending and nanoindentation experiments have examined the size

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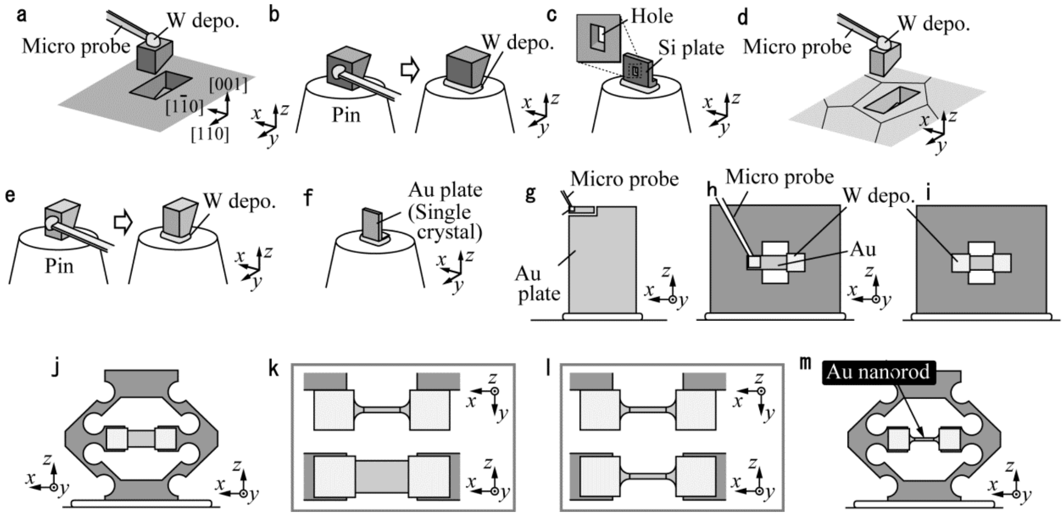

Fig. 1. Schematic illustration of the specimen preparation procedure.

effects in plasticity (McElhaney et al., 1998), these are due to the presence of severe strain gradients. Micro- or nano-scale pillar compression experiments (Dimiduk et al., 2005, Uchic et al., 2005) where the strain gradients are minimal have also been carried out; however, this method cannot yield fracture properties. Consequently, tensile experiments are desired, because of the uniform stress distribution as well as the ability to obtain fracture behavior at large strains.

In this work, a tensile test are carried out for a gold (Au) single crystal nanorod with single slip orientation, and the tensile deformation and fracture properties are investigated.

2. Experimental

2.1. Material and specimen

After annealing a polycrystalline gold (Au) plate (purity: 99.95%, average grain size: 220 μm) in vacuum (4.0×10^{-4} Pa) at 973 K for 24 h to remove residual strain, the crystal orientation and shape of each grain on the surface are analyzed by electron backscatter diffraction (EBSD). A single crystal nanorod is then carved out of one grain on the plate using a focused ion beam (FIB) processing system (Hitachi, FB-2200; accelerating voltage: 40 kV). The following process is used:

(1) A block (20 μm × 20 μm × 15 μm) is carved out of a silicon (Si) substrate with a (001) surface (Fig. 1(a)). The block is mounted on the flat top of an Au wire using tungsten (W) deposition (Fig. 1(b)).
(2) The block is processed to plate form with dimensions of 15 μm (height) × 14 μm (width) × 1.5 μm (thickness), and a rectangular hole is made in the middle position (Fig. 1(c)).
(3) A 25 μm × 15 μm × 15 μm block is carved out of one grain in the Au plate (Fig. 1(d)). The block is mounted on the flat top of a different Au wire (Fig. 1(e)) and is formed into a plate with dimensions of 25 μm (height) × 12 μm (width) × 1.0 μm (thickness) (Fig. 1(f)).
(4) A bar of 4 μm (length) × 1 μm (height) is cut out of the Au plate (Fig. 1(g)). The ends of the bar are fixed on the middle position of the Si plate using W deposition (Fig. 1(h), (i)).
(5) After the Si plate is processed into a lozenge frame (Fig. 1(j)), the Au bar is processed into rod form with a square cross-section with nanometer-scale (Fig. 1(k)-(m)). The accelerating voltage and beam current used in this fabrication are 40 kV and 30 pA for the crude processing, and 30 kV and 4 pA for the finishing processing. The rod surface is flattened by a beam parallel to the surface in order to avoid the introduction of thick surface damaged layer by FIB as much as possible.
(6) Argon (Ar) ion milling processing (LINDA, GENTLE MILL) with an accelerating voltage of 0.2 kV is