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Mechanical Properties of Electrodeposited Gold for MEMS Device

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Abstract

Mechanical properties of electrodeposited gold materials for MEMS device were evaluated by a micro-compression test. The gold electroplating method is considered as a key technology for post-CMOS fabrication process. The micro-compression specimens were 15×15×30 μm^3 micro-pillars fabricated by focused ion beam. The gold micro-pillars showed a high compressive strength of 600 MPa. The high strength was suggested to be mainly caused by size of the gold grains, which was found to be about 14.7 nm.

1. Introduction

Gold has high chemical stability, corrosion resistance, electrical conductivity and density. Because of these properties, gold is often used in the electronic industry. Gold has also been studied as a structure material for micro-electro-mechanical systems (MEMS) devices. Yamane et al. suggested MEMS accelerometers made of gold, a high density (it is 19.30 g•cm^{-3}) material, could give a much higher sensitivity than that of silicon [1-3]. The MEMS accelerometer has been fabricated by gold electroplating that is compatible with post-CMOS process; the fabrication process could enable us to achieve CMOS-MEMS integration, which would further reduce device size and parasitic elements. Electroplating is a film deposition technique which offers a number of advantages, such as near-room-temperature operating temperature, low-energy requirements, rapid deposition rates, capability to handle complex geometries, low cost and simple scale-up with easily maintained equipment. Thus, electroplating is a good candidate in fabrication of micro-components used in MEMS [4].

When size of the materials is reduced to micro-scale, increase in flow stress is observed with continuous reduction in size of the material. This phenomenon is called size effect. Observation of size effect indicates differences in mechanism of deformation when comparing with the bulk materials. Thus, clarifying micro-mechanical properties, such as young's modulus and yield strength, of the gold materials is important for the applications in MEMS. However, there is very limited information on micro-mechanical properties of gold materials.

In previous studies, our group has proposed methods to conduct micro-bending [5], micro-compression [6], and micro-tensile tests [7,8] of electrodeposited materials. In this study, micro-mechanical properties of commercially available electrodeposited pure gold films were evaluated by the micro-compression test.

2. Experiment methods

The gold film was electrodeposited on a Pt substrate. Thickness of the gold film is about 40 μm. For the micro-compression test, three micro-pillars were fabricated by focused ion beam (FIB). Dimensions of the pillars were 20×20×40 μm^3, 15×15×30 μm^3, and 10×10×20 μm^3 with a square cross-section and parallel to the Pt/Au interface as shown in Fig. 1. The compression test was conducted using a test machine designed for micro sized specimen [5] with flat-ended diamond indenter at a constant displacement of 0.05 μm/s using a piezo-electric actuator.

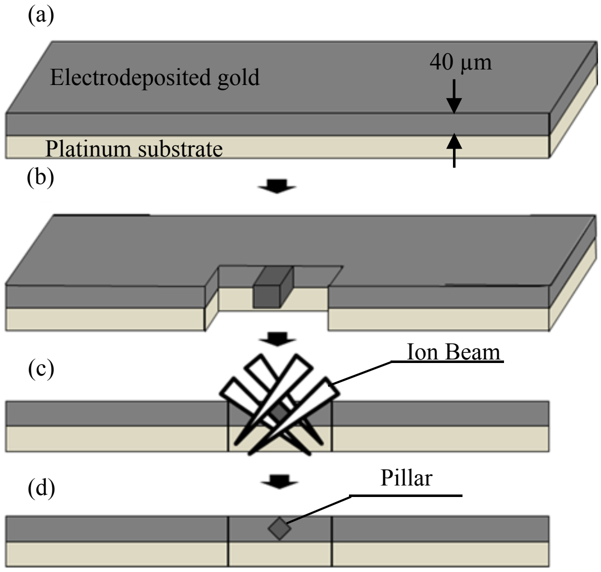

Fig. 1 Schematic images showing flow of the pillar fabrication. (a) Electrodeposited gold. (b) Fabrication of the pillar from edge of the specimen. (c) Size reduction of the pillar. (d) Finishing with a low intensity beam at a tilt angle of ±2

3. Results and discussion

The deformation behavior was observed from SEM images shown in Fig. 2. Generally, pillars deform into barrel shape after compression tests. However, this behavior was not observed in this study. Fig. 3 shows engineering stress-strain curve of the (10×10×20 μm^3 micro-pillar. The micro-pillar showed a high compressive strength of 600 MPa. This strength is much higher than that of bulk gold materials.

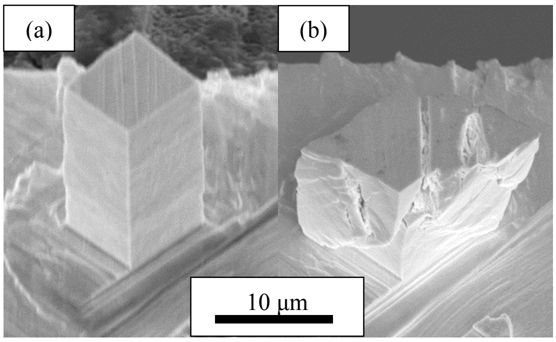

Fig. 2 SEM images of the (a) as-fabricated and (b) deformed pillar ($10{\times}10{\times}20\ \mu m^3$).

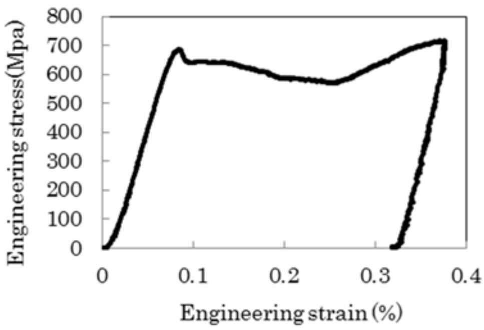

Fig. 3 Engineering stress-engineering strain curve from compression of the micro-pillar ($10{\times}10{\times}20\ \mu m^3$).

The mechanical properties could be greatly affected by the grain size. Fig. 4 shows scanning ion microscopy (SIM) image of the as-fabricated pillar. Generally, grain boundaries could be identified form SIM images. Top surface of the pillar showed the columnar grain feature, which is often observed in electrodeposited materials. From the image, size of the columnar grains was in micro-scale.

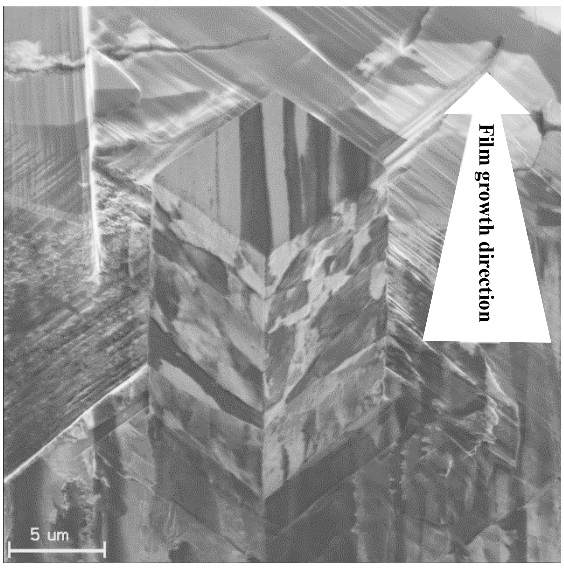

Fig. 4 SIM image of the as-fabricated pillar ($10{\times}10{\times}20\ \mu m^3$).

However, gold micro-pillar with grain size in micro-scale should not give the high strength observed, and resolution of the SIM is not high enough to identify grain size in nano-scale. Therefore, x-ray diffraction and Scherrer equation were applied to estimate grain size of the gold films. Scherrer equation is given in the following:

$$g=\frac{\lambda}{\beta \cos\theta} \tag{1}$$

where λ, β, *and* θ are X-ray wavelength (0.15418nm), full width at half maximum, in radians, and Bragg angle, respectively. The grain size was found to be about 14.7 nm. In this case, the boundaries observed in the SIM image might be nano-twin boundaries. The not-barrel-like deformation behavior and high compressive strength observed should be mainly caused by the nano-scale grain size and nano-twins.

4. Conclusions

Mechanical properties of electrodeposited gold materials in micro-scale were evaluted by a micro-compression test. The gold micro-pillars were fabricated by FIB. The deformation behavior was found to be irragular and different from what is usually obsereved in a compression test. A high compressive strength at 600 MPa was obtianed. The deformation behavior and high compressive strength were suggested to be casued by nanocrystals and nano-twins formed in the gold films. Grain size of the gold films was estimated to be about 14.7 nm.

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