Mechanical Behaviour of Electroplated Gold Evaluated by Micro-Tensile Test for Application in MEMS Accelerometer

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42nd MICRO AND NANO ENGINEERING

Tokyo Institute of Technology

Abstract

Micro-mechanical tests of constant current and pulse current electroplated gold were performed using micro-sized tensile specimens. The micro-specimens were fabricated by a focused ion beam system and tested by a micro-mechanical testing machine. Manufacture of the fine grained electroplated gold was achieved, and strengthening by the fine grains was observed. A summary of the strengths obtained from this study and from the literatures were presented as the Hall-Petch plot.

Keywords:

Micro-tensile test,
Size effect,
Pulse current electroplating,
Electroplated gold,
Grain refinement strengthening,
Hall-Petch's law

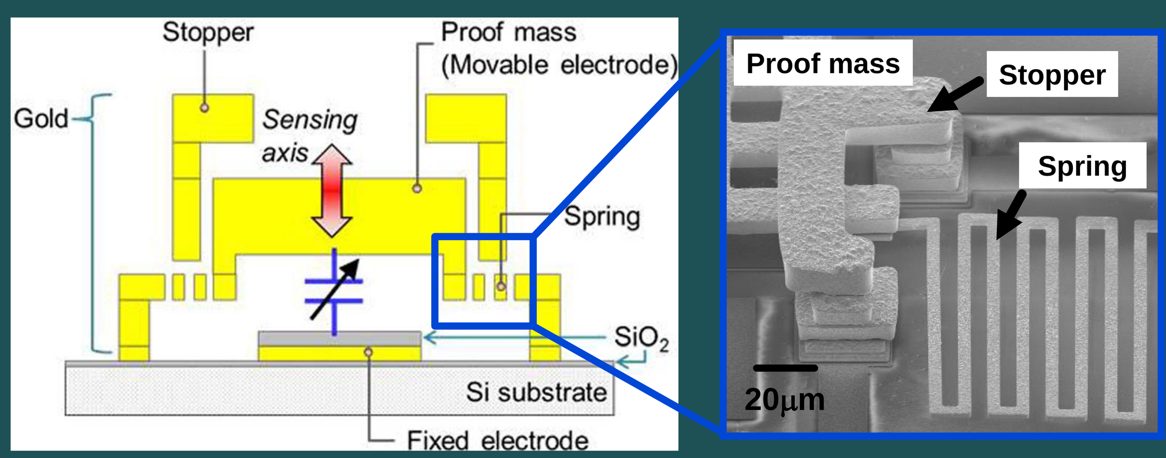
Introduction

Gold materials

✓High electrical conductivity
✓High chemical stability
✓High density → 19.3×10^3 [kg/m^3]

But low mechanical strength (55 - 200MPa)

MEMS accelerometer



Sub-1g MEMS accelerometer composed of gold materials[1]

Micro-mechanical test

There is a need to evaluate mechanical property of the materials to determine reliability of the products.

Ex) Size effect
Materials with small dimensions
→ Increase in the ratio of surface area per volume
→ Source truncation or source starvation
→ Smaller is Stronger

Investigating mechanical property of micro-sized specimens is very important.

[1] D. Yamane et al., Appl. Phis. Lett., 104 (2014) 74102

Experimental Procedures

Electroplating

Constant current electroplating (CE)

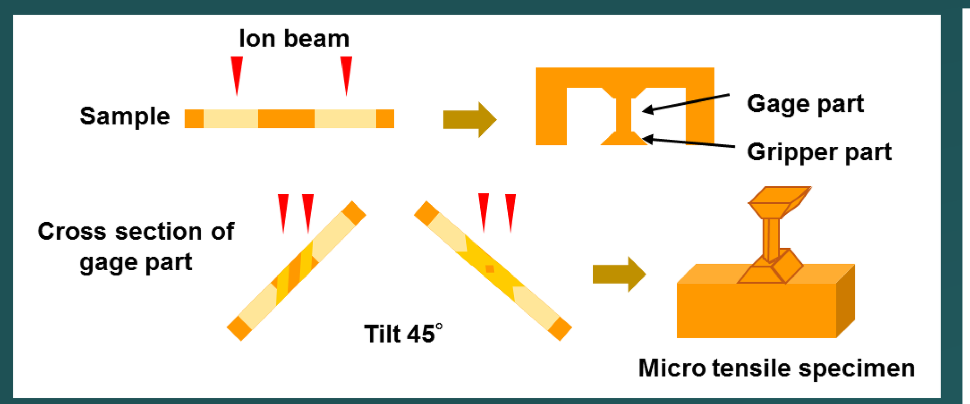
Current density: 5.0 mA/cm^2
Reaction time: 2000 s × 6 times (fresh Au electrolyte in each round) → CE1
6000 s → CE2

Pulse current electroplating (PE)

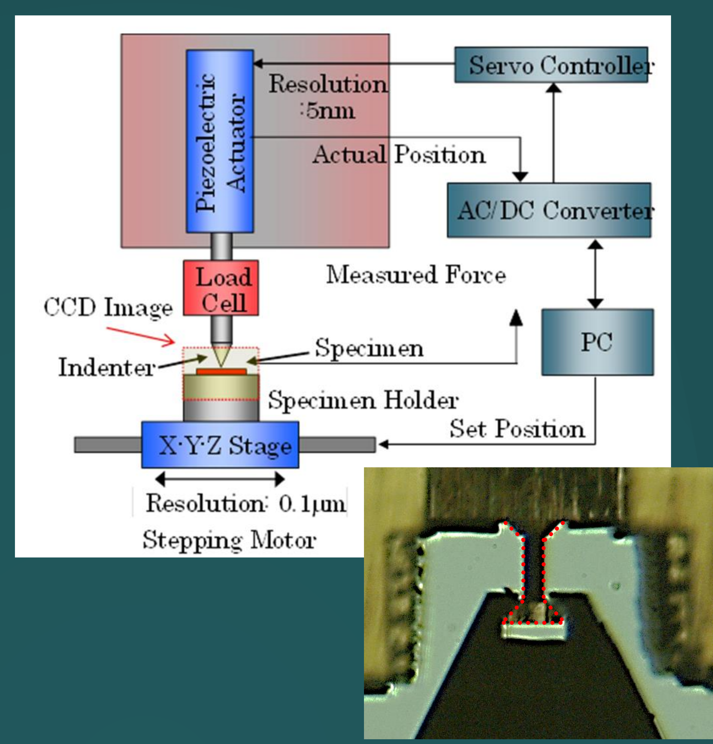
Current density: on-time 10 mA/cm^2, off-time 0 mA/cm^2
Reaction time: 6000 s (on-time and off-time interval are both 10 ms)

Sulfite-based gold electrolyte Reaction temperature: 40 ℃

Micro-tensile test



Flow chart of the fabrication of non-taper micro-tensile specimens by FIB.



Micro-mechanical testing machine

Specimen size

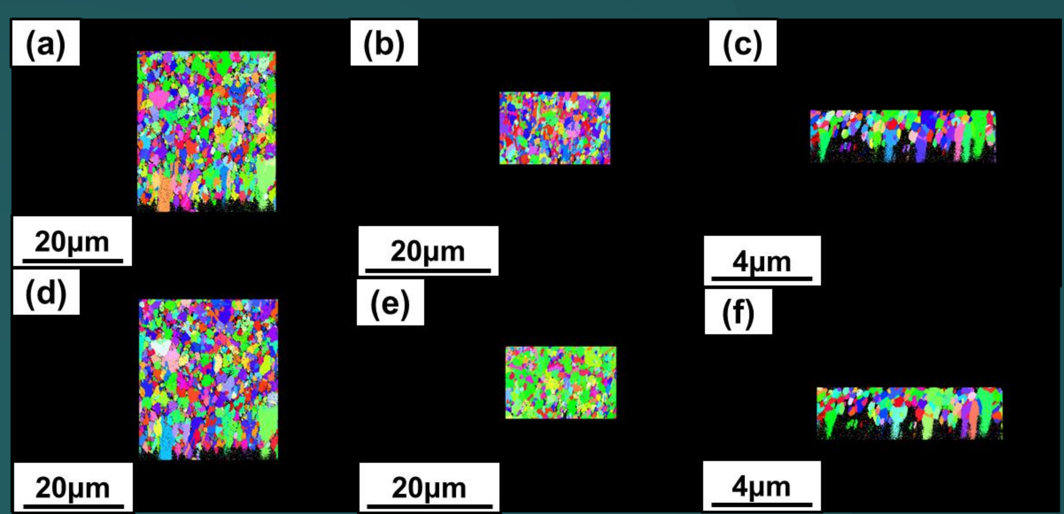
10×10×40 μm^3 (CE) 8×8×32 μm^3 (PE)

Testing condition

Displacement controlled at 0.1 μm/s
Room temperature

Results and Discussion

EBSD analysis



EBSD mappings of the micro-tensile specimens:
(a) CE1, (b) CE2, and (c) PE in loading direction
(d) CE1, (e) CE2, and (f) PE in film growth direction

Average grain size [μm]

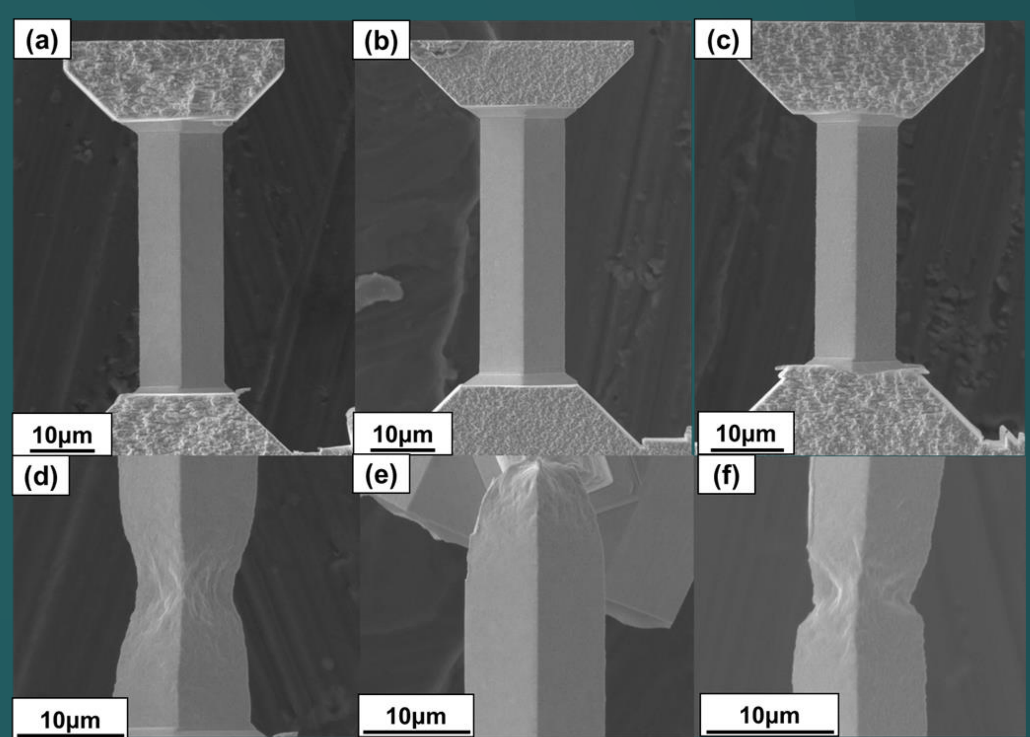
CE-1	CE-2	PE
1.6	0.97	0.30

Grain refinement was observed, especially in PE. (grains in nano scale)

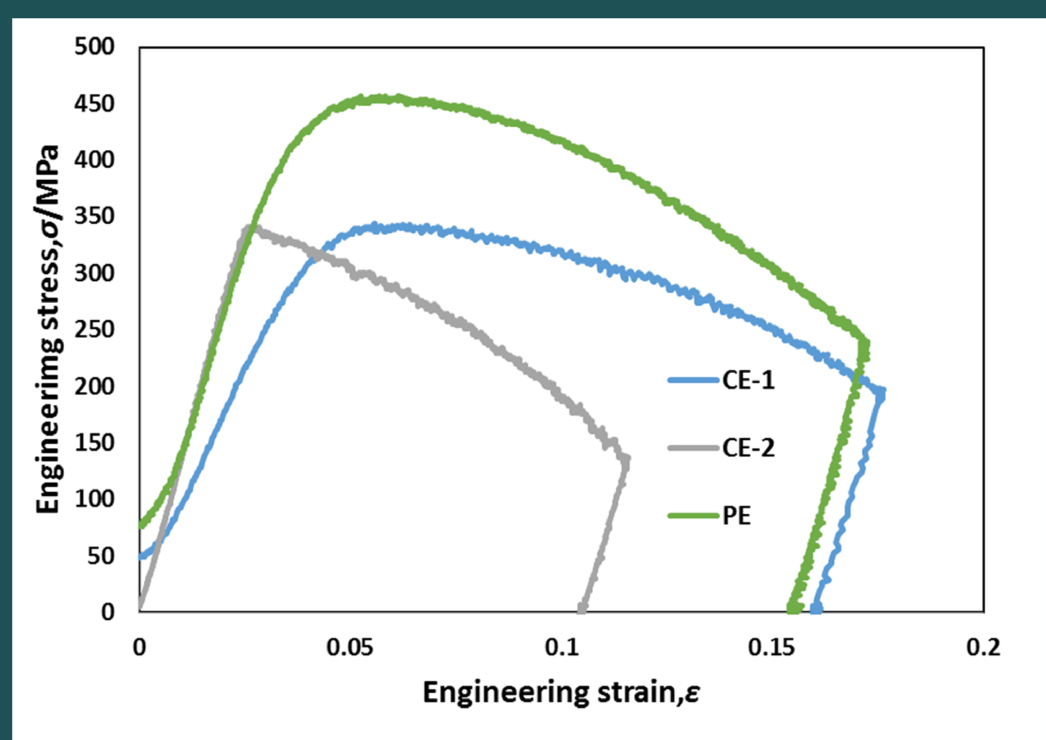
The grain refinements can be explained by the mechanism of PE. An increase in the nuclei density can be achieved to obtain electroplated films with finer grains.

In CE2, grains orientated in [101] along film growth direction.

Micro-tensile test



SEM images of the micro-tensile specimens:
(a) CE1, (b) CE2, and (c) PE before loading
(d) CE1, (e) CE2, and (f) PE after loading



Engineering stress-strain curves

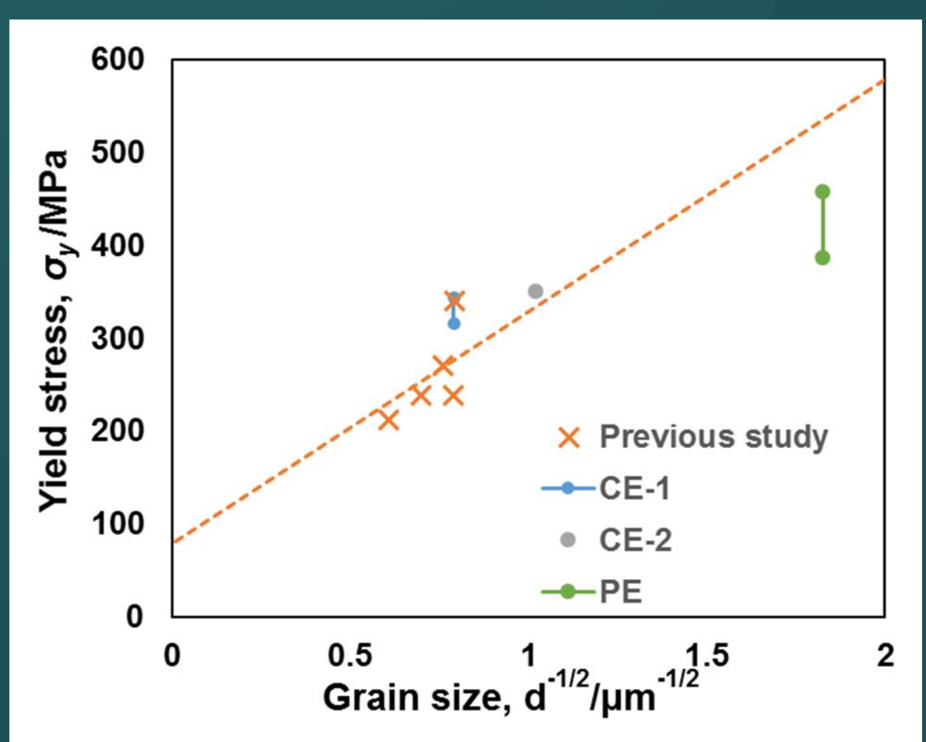
Yield stress [MPa]

CE-1	CE-2	PE
316-344	350	387-457

Gold specimen prepared by PE shows higher yield stress.

SEM images show concentrated deformation and necking.

In stress-strain curve, flow stress decreased because of necking. (Decreasing of cross-sectional area) →decreasing of elongation



Hall-Petch Plot of our work and previous study[2]

Hall-Petch law

$$\sigma = \sigma_0 + kd^{-1/2}$$

Finer grains have stronger yield stress

Experimental results meet the Hall-Petch relationship with previous reports[2].

Grain refinement strengthening was observed, especially for gold specimen prepared by PE.

[2] R. D. Emery et al., Acta Mater., 51 (2003) 2067

Conclusions

✓ Micro-tensile tests of gold obtained by constant current electroplating (CE) and pulse current (PE) were conducted.

✓ In PE, average grain size was located in nano-scale.

✓ SEM observations before and after the tests showed concentration of deformation, and stress-strain curves showed decreasing of flow stress by local necking.

✓ The present experimental results corresponded well with the Hall-Petch relation, and strengthening of grain refinement was observed.

Acknowledgement

This work was supported by CREST Project by the Japan Science and Technology Agency (JST).

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