Enhancement of Mechanical Properties in Au Films Electroplated with Supercritical Carbon Dioxide for Application in MEMS

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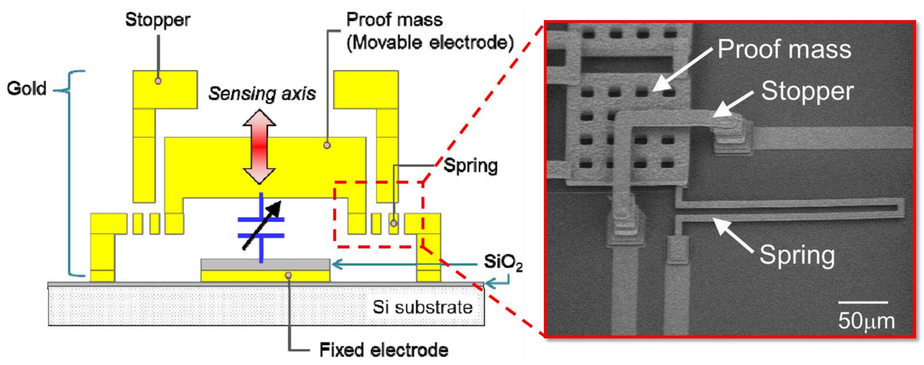
Background

MEMS devices with gold materials



D. Yamane et al., *APL* **104** (2014) 074102; D. Yamane et al., *ECS Trans.* **72** (2016) 7

- Au-based accelerometers
- Higher sensitivity than Si based conventional devices
- Density of gold: 19.3 g/cm^3
- Low mechanical strength among metallic materials

Concerns in the practical application of MEMS devices

Any strategy for strengthening ?

Application of $scCO_2$ in electroplating

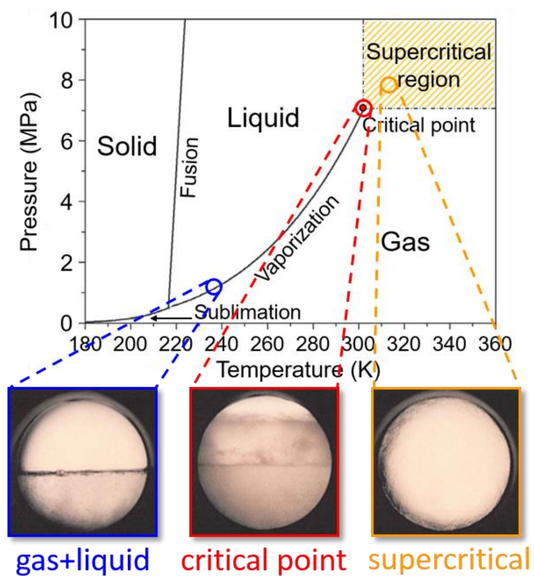
- Electroplating with $scCO_2$ contained electrolyte (EP-SCE)
- Smoother surface morphology
- **Grain refinement effects**

Hall-Petch relationship

$$\sigma_y \uparrow = \sigma_0 + k_y / \sqrt{d} \downarrow$$

Enhancement of mechanical strength

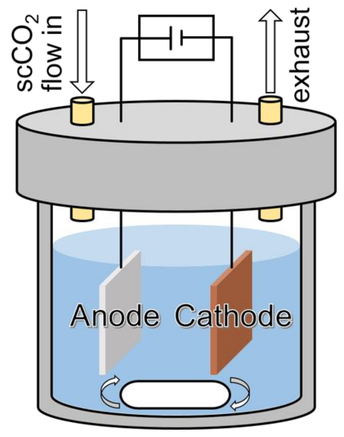
Objective



Evaluate mechanical property of Au films fabricated by EP-SCE

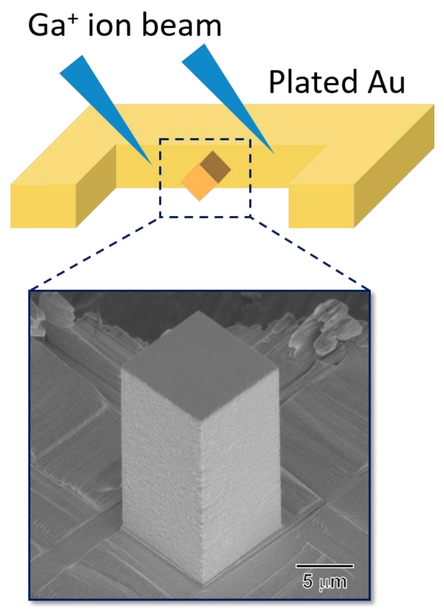
Experimental

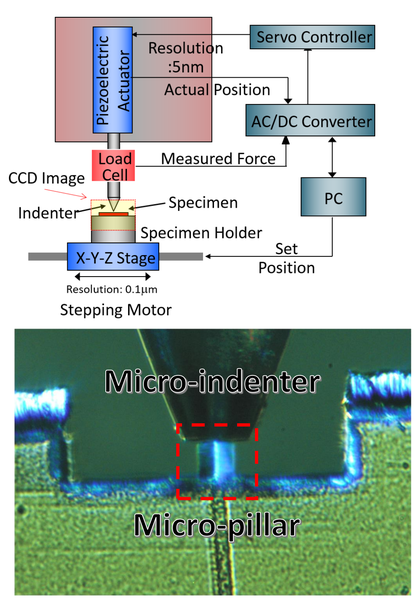
Electroplating with $scCO_2$



- $scCO_2$ contained electrolyte (SCE)
  - Sulfite gold electrolyte
  - CO_2 vol. = 20 %
  - P_{CO2} = 10 MPa
- Electroplating
  - CD = 5 mA/cm^2
  - Temp. = 40 °C
  - Thickness = 2 / 50 μm
- Characteristics
  - SEM (morphology)
  - AFM (roughness)
  - XRD (crystal structure)

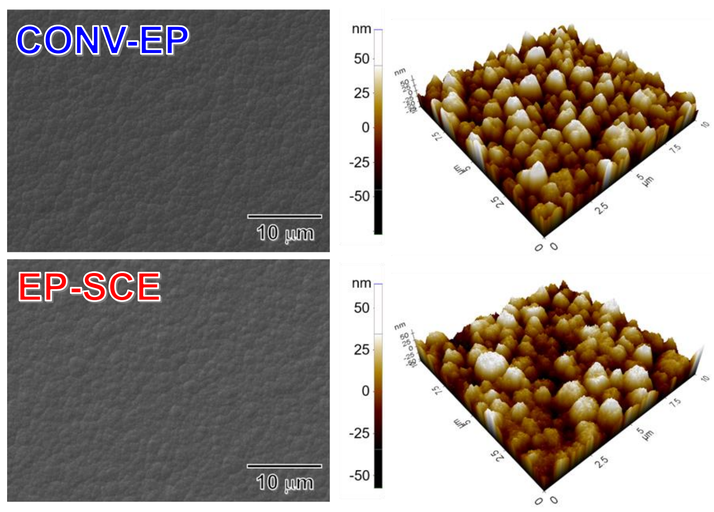
FIB milling & micro-compression tests





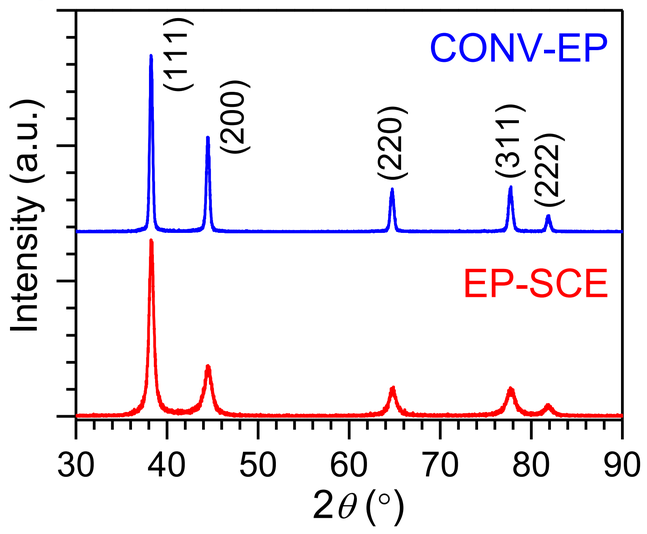
Results & Discussion

Surface morphology & roughness



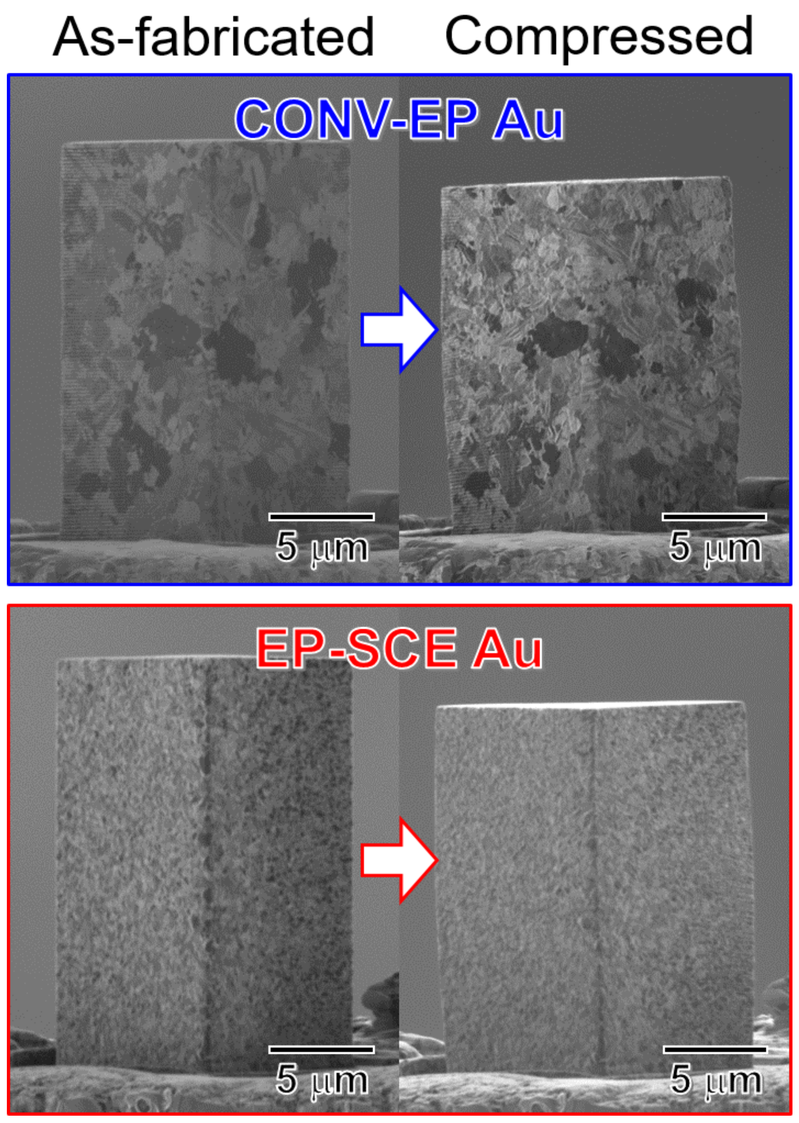
- Similar surface morphology (R_a ~13 nm)
- Brightener ⇒ leveling effect

Crystalline structure of Au films



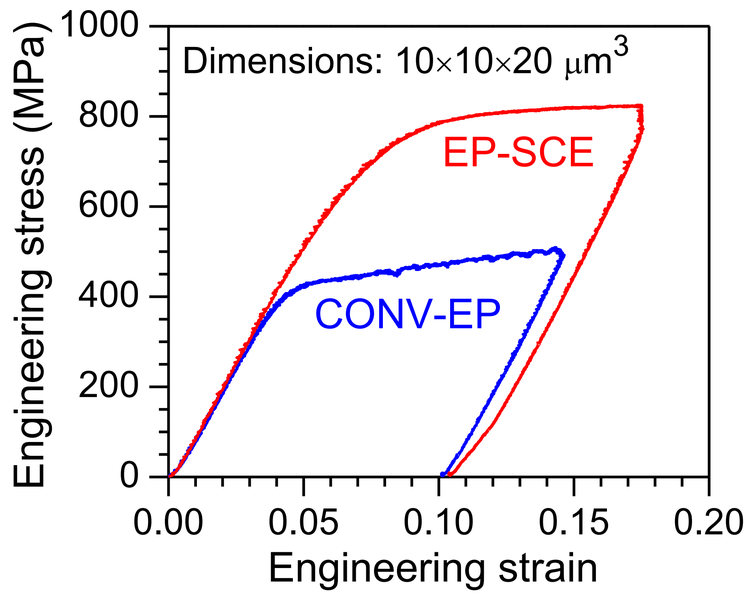
- Peak broadening in EP-SCE film
- Grain size of EP-SCE film: ~13 nm

Deformation of Au micro-pillars



- Typical polycrystalline deformation
- Clear grain boundary in CONV-EP pillar
- Inconspicuous grains in EP-SCE pillar

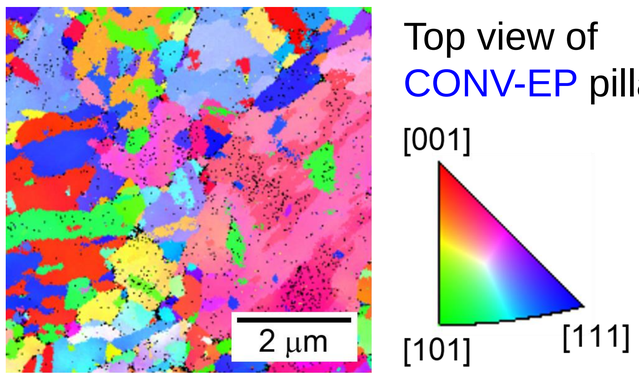
Strain-stress curve of Au pillars



✓ Higher yield strength and flow stress in EP-SCE
⇒ $\sigma_{y,CONV}$ = 380 MPa; $\sigma_{y,SCE}$ = 520 MPa

✓ Based on the Hall-Petch relationship, finer grain can lead to stronger strength.

Grain distribution by EBSD



- CONV-EP: GS = 0.8–0.9 μm; EP-SCE: undetectable

Conclusions

✓ Micro-mechanical strength of gold films fabricated by EP-SCE method were evaluated.
✓ High mechanical strength was obtained in EP-SCE film. σ_y: 520 MPa
✓ Ultra-fine grain can lead to a higher strength. ⇒ Grain boundary strengthening

Acknowledgement

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