# High Mechanical Strength Gold Micro-Components Fabricated by Pulse Electroplating

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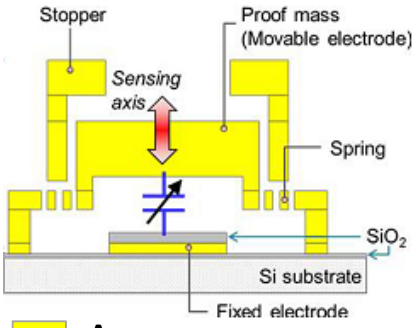
## Introduction

**First MEMS Motion Sensor with Au Micro-Components**

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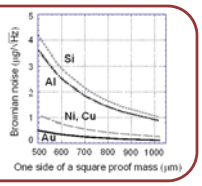
### Advantage of Au

- ❖ High chemical stability
- ❖ High electrical conductivity
- ❖ Higher density than Si

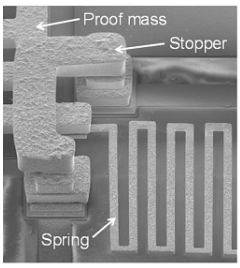
Au ($19.3\times10^3$ kg/m$^3$ ) >> Si ($2.33\times10^3$ kg/m$^3$ )

### Merits of Au Components

- ❖ Brownian noise ↓
- ❖ Size of Sensor↓
- ❖ Sensitivity ↑




## Background




- ❖ Proof mass and spring are movable components
  →Structure stability and reliability issues
- ❖ Lack of mechanical properties in micro-scale due to the size effect
- ❖ Bulk Au is soft, and typical yield strength of bulk Au estimated is 55-220 MPa
  →Improvement of the mechanical properties via structure control.

*Journal of the Mechanics and Physics of Solids 52, 667 (2004)*

## In this Study

**Hall–Petch relationship**

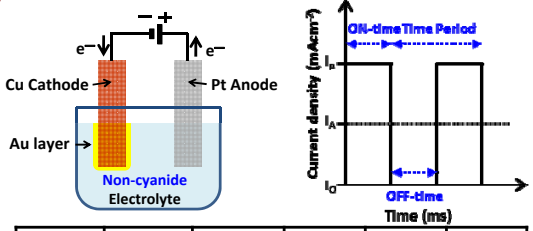
$$\sigma_y \uparrow = \sigma_o + \frac{k_y}{\sqrt{d}\downarrow}$$

$\sigma_y$: Yield stress
$\sigma_o$: Materials constant for the starting stress for dislocation
$k_y$: Strengthening coefficient
$d$: Average grain diameter

**Strengthening Au materials by reducing the grain size**

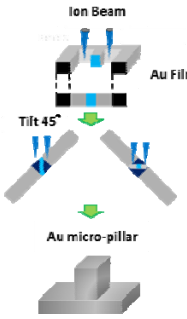
## Experimental Section

### Pulse Electroplating

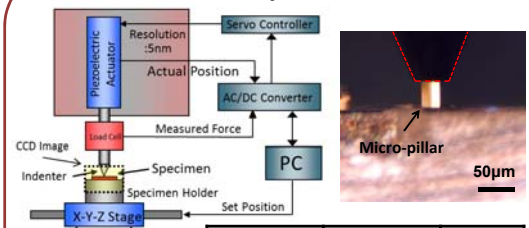



| Pulse Peak Current ($I_p$) | Pulse Peak Current ($I_o$) | Average Current ($I_A$) | Pulse ON-time | Pulse Off-time | Reaction Time |
|---|---|---|---|---|---|
| 10 mAcm$^{-2}$ | 0 mAcm$^{-2}$ | 5 mAcm$^{-2}$ | 10 ms | 10 ms | 100 min |

### Micro-pillar Fabrication



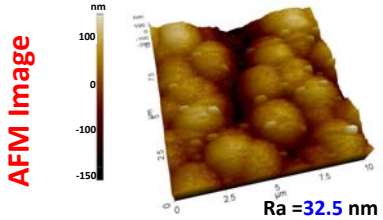

### Micro Compression Test



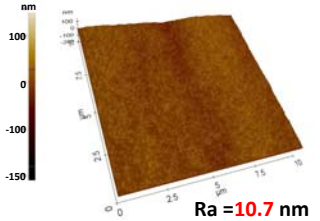

| Control | Displacement Rate | Load Resolution |
|---|---|---|
| Displacement Control | 0.1 μms$^{-1}$ | 10 mN |

## Au Film Characterization

### Conventional Electroplating (CE)




### Pulse Electroplating (PE)

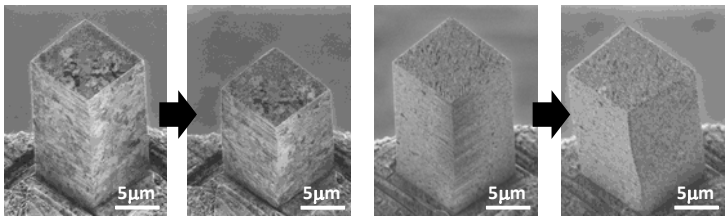


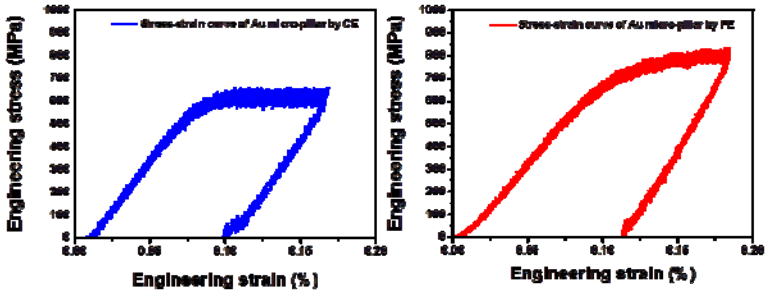

- ❖ By XRD analysis and Scherrer equation, grain size of the CE film was estimated to be 22.8 nm, and grain size of the PE film was 10.5 nm.
- ❖ PE favors the nucleation of Au nuclei and greatly increase the Au nuclei density resulting in finer grained deposit than the CE.

## Results of Micro Compression Test

### Conventional Electroplating (CE) Pulse Electroplating (PE)

**Appearance of the Pillar Before and After Compression Test**




- ❖ The micro-pillar by PE showed a high compressive strength of ca. 800 MPa. This strength is much higher than ca. 600 MPa of the micro-pillar fabricated from Au film fabricated by CE.

## Summary:

1. AFM image and XRD pattern show that Au film with smaller grain (particle) size can be achieved by pulse plating under the same average current density of 5 mAcm$^{-2}$. Defeat-free bright Au film with roughness of 10.7 nm and grain size of 10.5 nm were obtained.
2. The Au micro-pillar prepared by pulse plating shows a much higher compressive strength of ca. 800 MPa. The high strength is attributed to the results of size effect and Hall–Petch strengthening.

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