Self-standing process by using bimetallic effect of thin-film metallic glass

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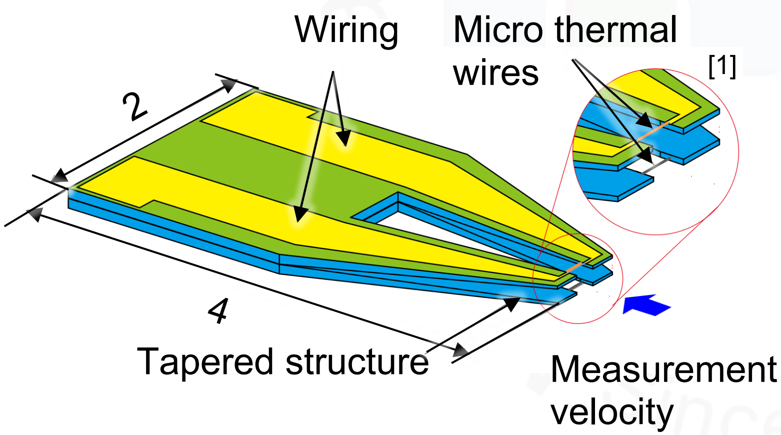
1. Introduction

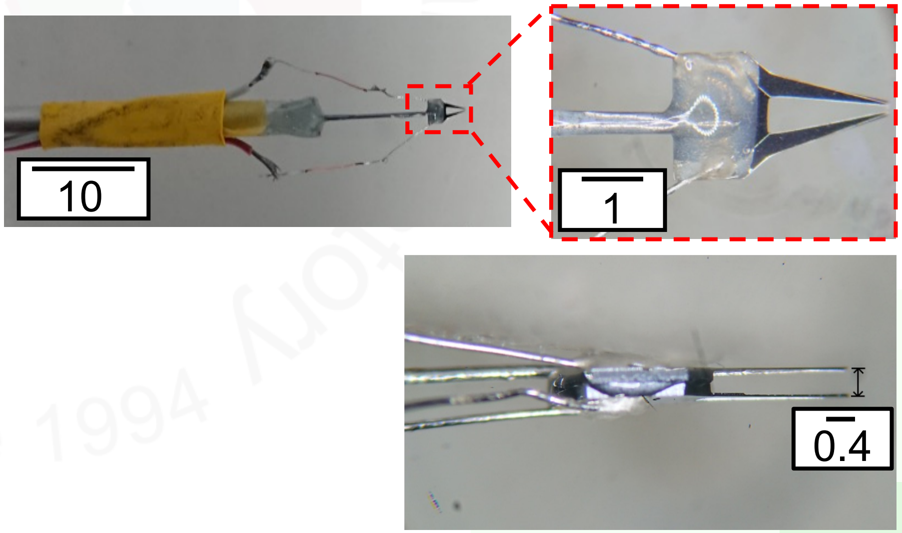
Background

The microprobe hot-wire velocimeter [1]

- Aiming to improve fuel efficiency of engines and turbines
- Micro thermal wires placed at the tip (sensing area)
- Heated thermal wires cooled by air flow

→ Measuring flow velocity and gas concentration from output of voltage change of hot wires





[1] D. Katsuta, Master thesis of Nagoya University (2020)

1. Introduction

Background

Problems in the previous study

- Manual assembly of probes fabricated by planar process
- Difficult to achieve 3D structures with conventional processes

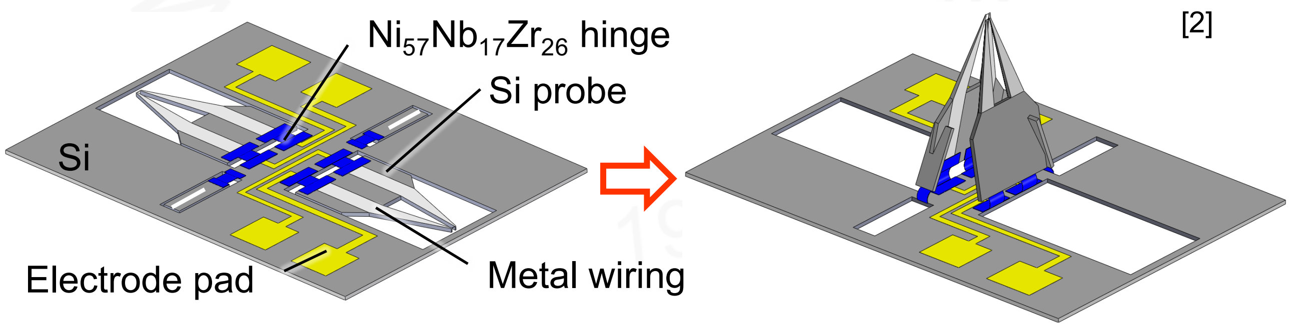
→ Integration for multi-component flow velocity measurement

→ Need to face the hot wire vertically in flow velocity measurement

Fabrication of 3D structures by self-assembly process

Development of a new fabrication process for 3D micro forming

→ The probe is self-supporting at a deformation angles of over 90^{o} relative to the substrate.



[2] Nagai R, Onishi T, Oka C, Sakurai J and Hata S 2022 Self-standing process for microprobes Proceedings of JSME International Conference of Materials and Processing 2022

1. Introduction

3D micro forming using thin-film metallic glass (TFMG)

Metallic glass

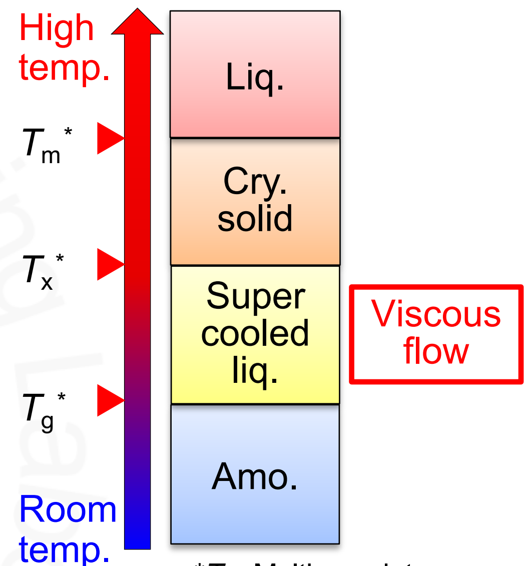
- Deformed by viscous flow in supercooled liquid range
  $T_g < T < T_x$
- Conductive, enabling 3D wiring

Molding by heating-deformation method

Molding process by using viscous flow during heating, applying an external force

→ Utilizing the self-weight of the Si probe

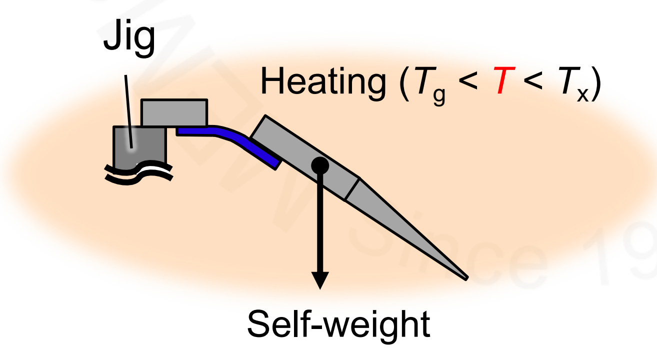
→ Difficult to achieve greater than 90°



*T_m: Melting point

*T_x: Crystallization temp.

*T_g: Glass transition temp.

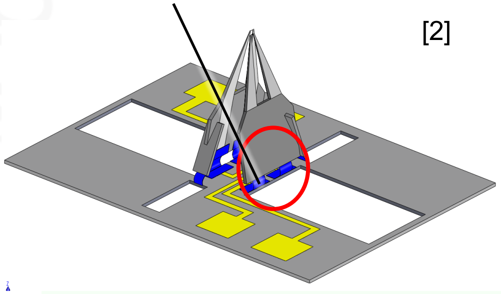


Purpose

Investigation of self-assembly process of 3D MEMS structure for ultra-small flow velocity sensors

Contents

- Fabrication of samples for investigation of self-standing microstructures
  - Fabrication process
  - Results of fabrication
- Improving angles of deformation
  - Improvement by using bimetallic effect of metallic glass
  - Results of deformation
  - Causes of deformation irregularity



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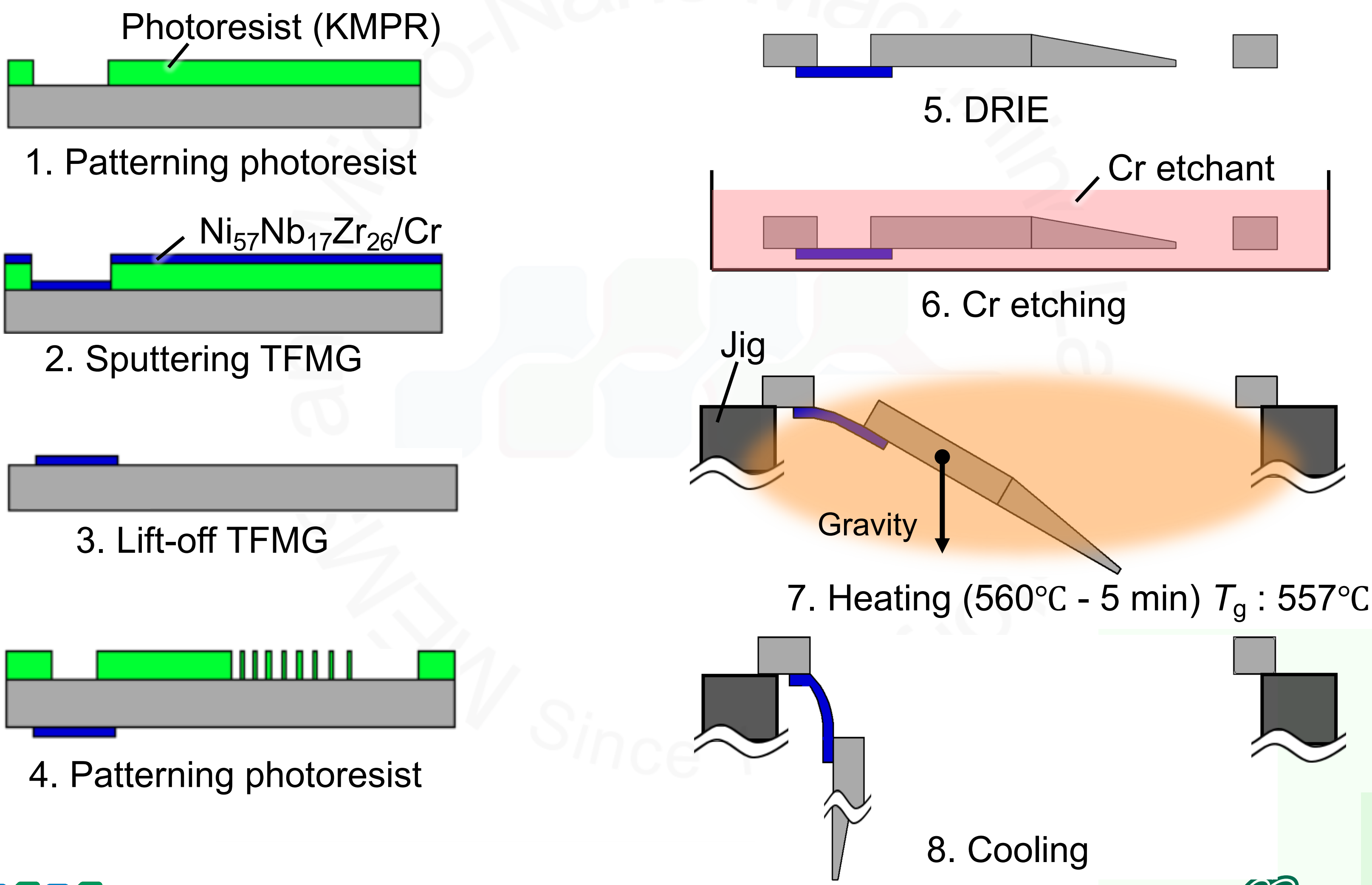
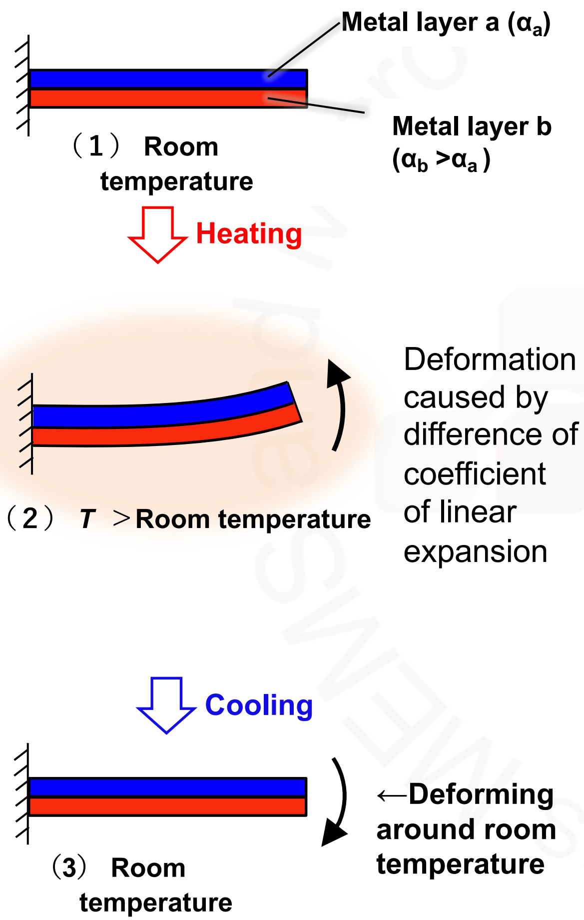
2. Sample fabrication

Fabrication process

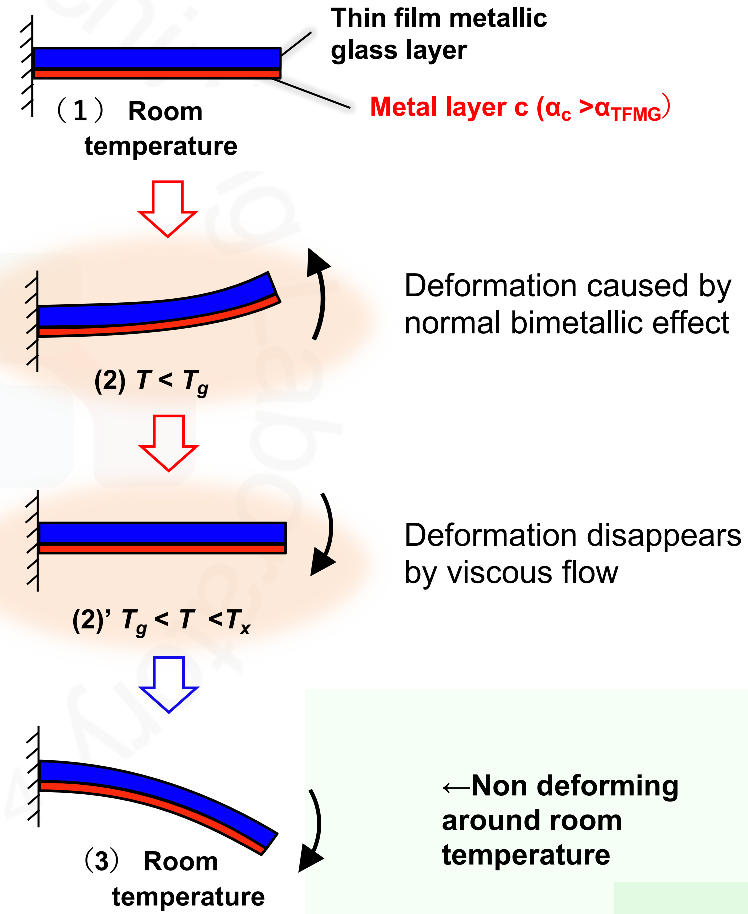


Bimetallic effect of Thin-film metallic glass

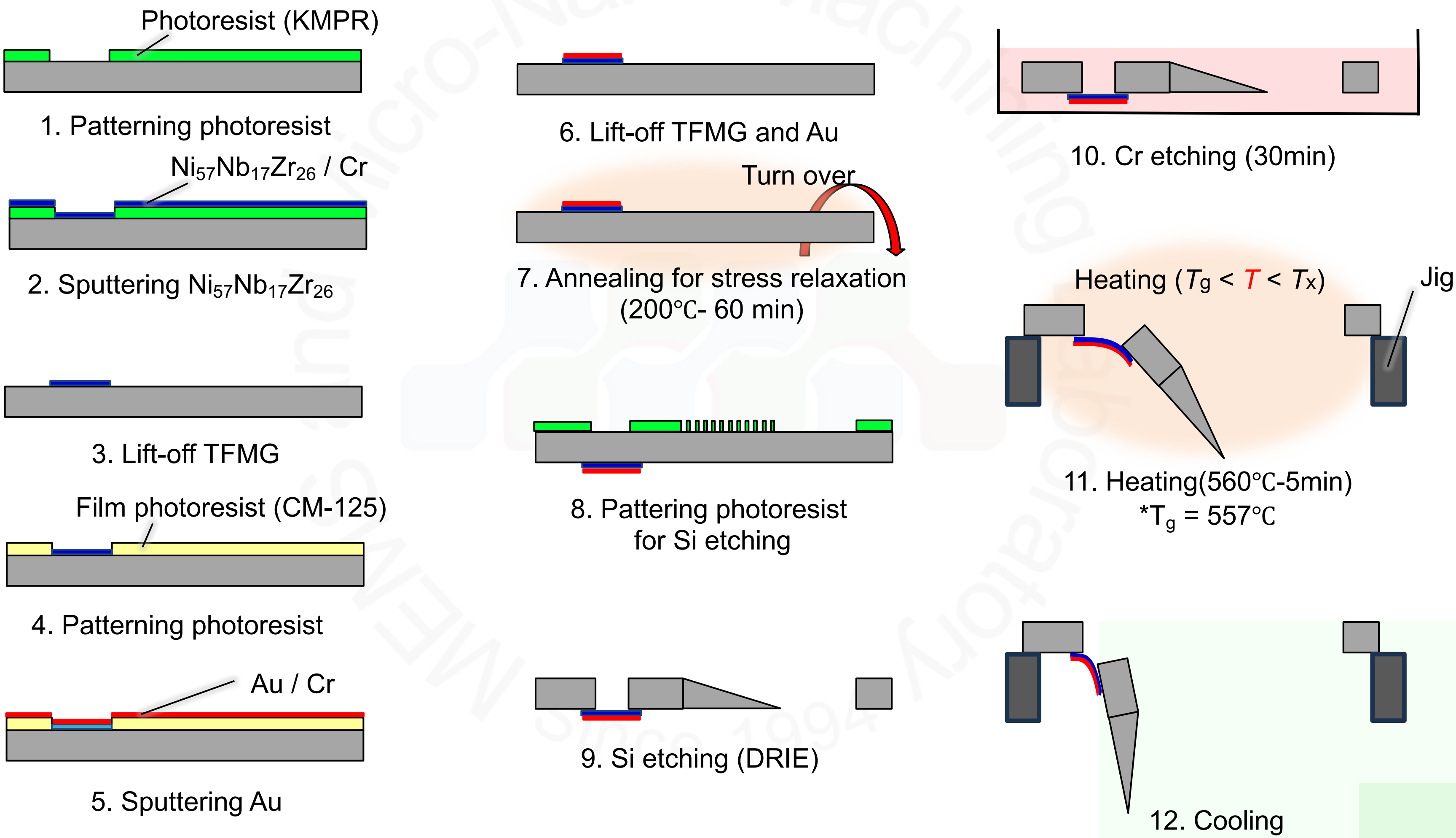
- Elastic materials



- Thin-film metallic glass



Fabrication process for utilizing bimetallic effect



3. Improving angles of deformation

Results of deformation

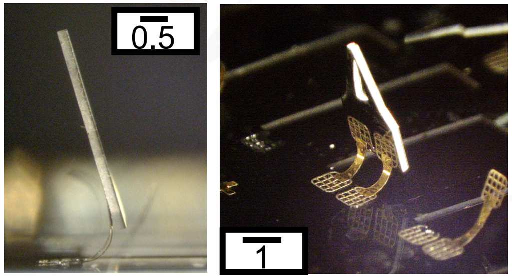
Heating treatment conditions

- Temperature : 560℃ (*T_g = 557℃)
- Heating rate : 20 K / min
- Heating time : 5 min

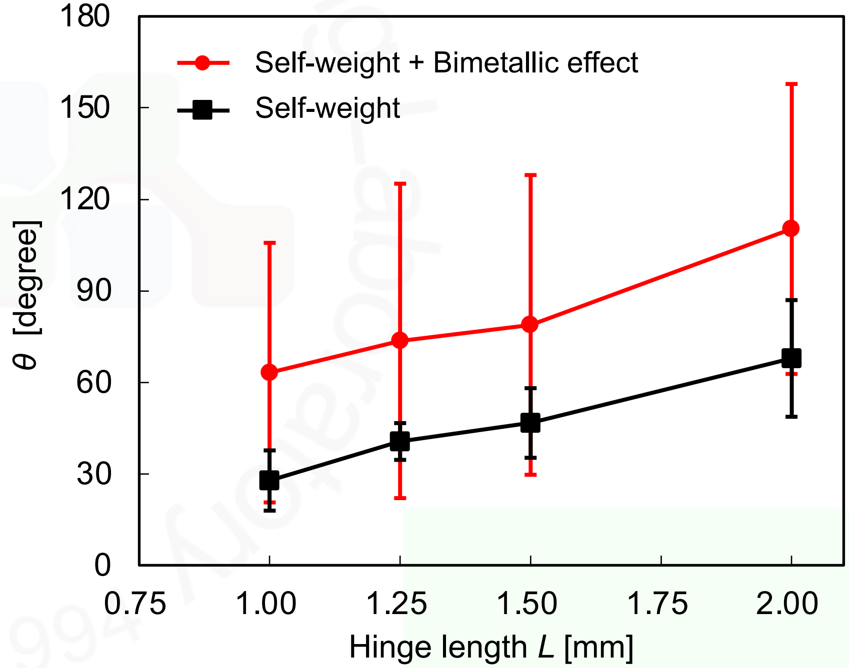
Results

- Increasing deformation angles
- Max deformation 157.3°(*L* = 2.00 mm) [2]
- Significant deformation irregularity

77.6° ± 44.8° (L = 1.00 mm)



L=1.00, 107.5°



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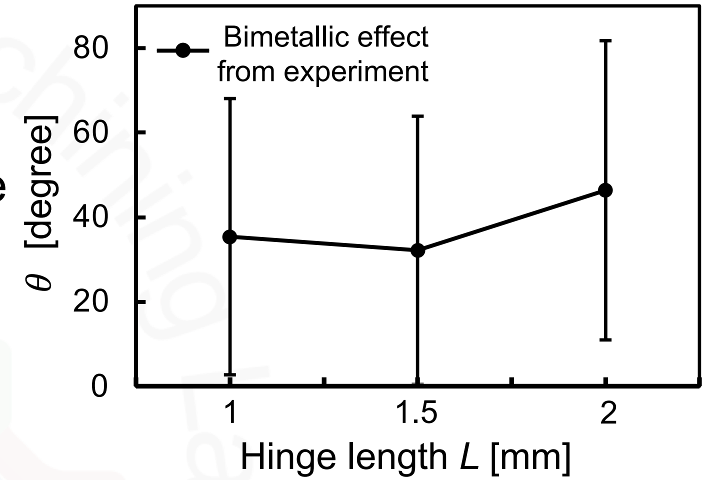
3. Improving angles of deformation

Causes of deformation irregularity

Expected factors

- **Film thickness** variation in both layers
- Variation of **heating temperature** on a substrate



Investigation of film thickness

- To assess thickness variations of each layer

Simplified model analysis

- To consider the effect of film thickness and heating temperature on deformation
- Uncovering tendency of deformation on each parameters

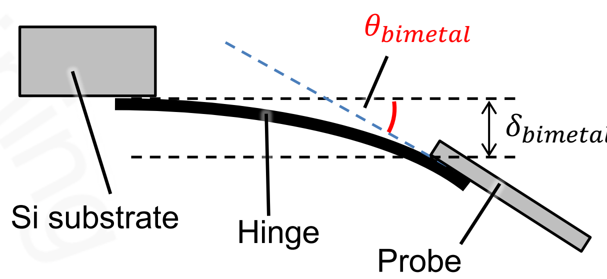
3. Improving angles of deformation

Causes of deformation irregularity

Analysis of the bimetallic effect

$$\theta_{bimetal} = \frac{6E_1(T-T_0)(\alpha_1-\alpha_2)th_1}{2th_1E_1(2h-h_1)+\eta h(h-h_1)}l \quad [3] \qquad (1)$$

$$\ln\eta = \ln 7.0 + \left(30 - \frac{T}{20}\right)\ln 10 \qquad (2)$$



$\theta_{bimetal}$: Deflection angle l : Hinge length , t : Deformation time , η : Viscosity of TFMG layer
E_1, E_2 : Young's modules of Au and TFMG layer
α_1, α_2 : Coefficients of Liner Thermal Expansion of Au and TFMG layer
T, T_0: Heating temperature, Original temperature h_1, h_2, h: Thickness of Au, TFMG layer and bimetallic layer

Variables

- Hinge length $L = 1.0, 1.5, 2.0\ \mathrm{mm}$, Heating temperature $T = 560\ ℃ \pm 2\%(548.8℃ - 571.2℃)$
- Thickness of Au layer $h_1 = 1\ \mu\mathrm{m} \pm 10\%$
- Thickness of TFMG layer $h_2 = 10\ \mu\mathrm{m} \pm 10\%$

	Young Modules [GPa]	Coefficient of liner expansion [1/K]	Viscosity [GPa·s]	Length of hinge [mm]	Temperature [C°]	Time [s]
Au Layer	78	14.2 × 10^{-6}	—	L	T	300
Ni-Nb-Zr Layer	30	8.00 × 10^{-6}	η			

[3] Hata S, Goto J, Sato K, Shimokobe A 2000 Fabrication of Micro Structures using Thin Film Metallic Glass - Fabrication of Thin Film Metallic Glass and Micro-Forming using the Supercooled Liquid State -

Causes of deformation irregularity

Analysis of the bimetallic effect

- Conditions for maximum deformation angles

$$\theta_{bimetal} = 62.1 \text{ deg}$$
$$\mathrm{L} = 2.0 \text{ mm}, T = 571.2℃,$$
$$h_1 = 0.9\ \mu\text{m},\ h_2 = 9\ \mu\text{m}$$

h_1 : Thickness of Au Layer, h_2 : Thickness of TFMG Layer

- Deformation irregularity : proportional to hinge length

⇒The smallest hinge length with a deformation angle of greater than 90°

- Greatest factor for deformation : Temperature
- Second greatest factor for deformation : Thickness of TFMG Layer

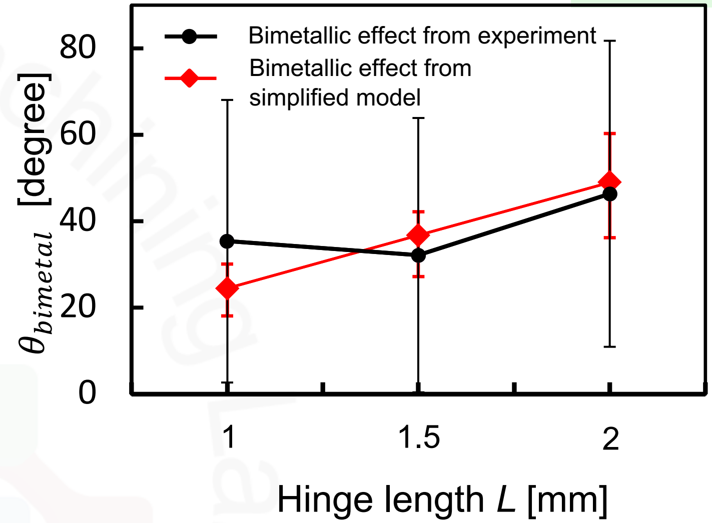


Table 1. Condition for the upper one-third deformation angle at hinge length L = 2.0 mm

Deflection angle [deg]	Au layer thickness [μm]	TFMG layer thickness [μm]	Temperature [℃]
62.1	0.9	9	571.2
61.9	1	9	571.2
61.6	1.1	9	571.2
56.1	0.9	10	571.2
55.9	1	10	571.2
55.7	1.1	10	571.2
52.9	1.1	9	560
52.6	1	9	560
52.2	0.9	9	560

Causes of deformation irregularity

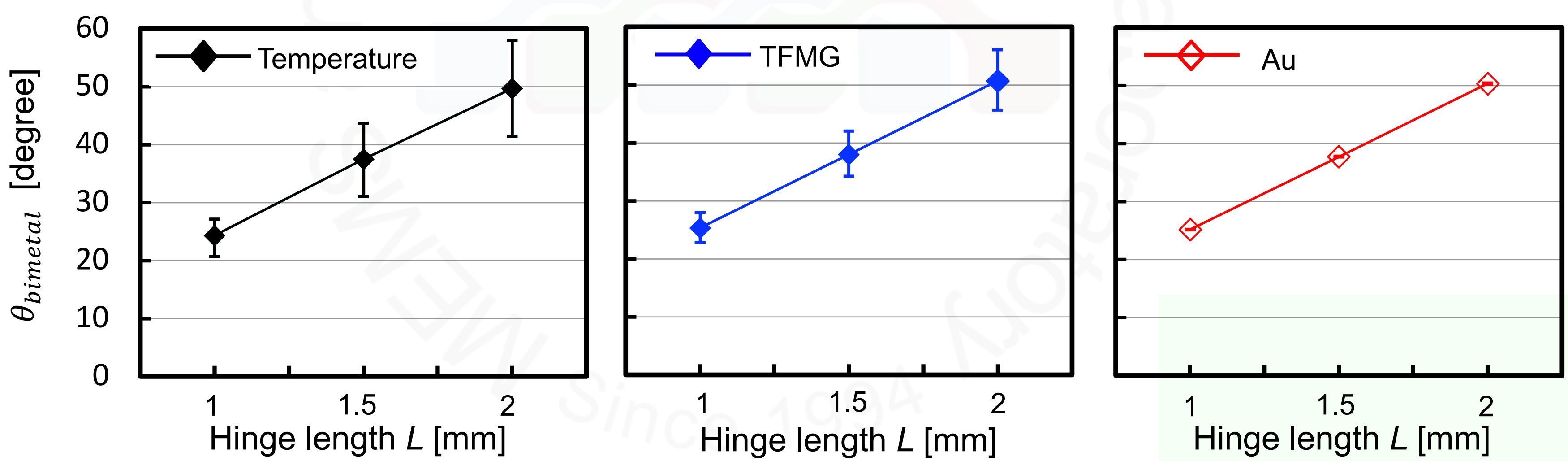
Comparison of respective parameters

- $T = 560℃ \pm 2\%$ (548.8℃～571.2℃), $h_2 = 10\ \mu\text{m} \pm 10\%$, $h_1 = 1\ \mu\text{m} \pm 10\%$

*h_2 : Thickness of TFMG Layer, h_1 : Thickness of Au Layer

- Largest contributor : Temperature
- Low effect by Thickness of Au layer

⇒Attention should be paid to the heating temperature.



Conclusions

We investigated the basic process for fabricating self-standing microstructures using $Ni_{57}Nb_{17}Zr_{26}$ thin-film metallic glass (TFMG).

- Deformation was not enough with simple TFMG hinge.
- Deformation greater than 90° was achieved by depositing Au layer on TFMG layer as a bimetallic layer.
- Significant deformation irregularity has happened.
- Attention should be paid to heating temperature.

Future works

- Conducting experiments to investigate the effect of heating temperature on the deformation angle.
- Improving deformation accuracy by control the thickness of both layers and heating temperature
- Realizing self-standing 3D structure
- Self-assembly using the surface tension of molten solder