形状記憶合金薄膜駆動型マイクロブレーカーの作製プロセス

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Fabrication Process of SMA Thin Film Based Micro Breaker

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Abstract

A micro breaker is designed and fabricated by using a Shape Memory Alloy (SMA) thin film. The SMA thin films (TiNi: Titanium Nickel) are deposited by RF magnetron sputtering and patterned by lift-off method and are annealed for crystallization and memorization. Shape memory angle and transformation temperature of Ti-51.8at. %Ni thin film after 10,000 times actuating indicated good stability of shape memory effect. The SMA thin film based micro breaker is like bridge structure between two electrodes on Si substrate and sized about 100 microns x 1mm. The micro breaker is fabricated by using various semiconductor production methods.

Keywords: Shape Memory Alloy, TiNi, thin film, actuator, breaker, fabrication

1 INTRODUCTION

For the past years, a variety of micro actuators have been developed, and SMA thin films are one of the most prominent actuator, because SMA provides large force and displacement and recovery stress. And SMA thin films can be fabricated by using surface micromachining such as sputtering and etching [1-4]. This fabrication process allows SMA thin films to easily attach semiconductors. From the point of view of semiconductors friendly, this paper deals with SMA thin film based micro breaker. Properties of SMA thin film are also described. Eventually, design and fabrication process of SMA thin film based micro breaker are reported.

2 SMA THIN FILMS

2.1 Fabrication

TiNi shape memory alloy (SMA) thin films are deposited onto Cu foil by RF magnetron sputtering, and then Cu foil is dissolved by 60% HNO_3 for getting SMA thin films only. SMA thin films without substrate are annealed for crystallization and memorization by using an infrared lamp annealing system. Table 1 and 2 show the conditions of sputtering and annealing on our research. These conditions, good stability and repeatability [5], are chosen among various conditions which effect properties of SMA thin films with sputtering parameters [6]. Composition of the SMA thin film is measured by Sequential X-Ray Spectrometer system, and the result is Ti/Ni = 48.2/51.8at. %.
SMA thin films are cut out to 10 x 6 mm sized u-shape after sputtering, and are memorized folding shape with 30 deg. When SMA thin films are heated, they move downwards. Table 3 shows SMA thin films actuating.

Table 1. Sputtering condition.

Target	Ti/Ni = 50/50 at. %
Electrodes distance	55mm
RF power	300W
Sputtering time	360min
Substrate temp.	573 K
Ar gas pressure	0.67 Pa

Table 2. Annealing condition.

Composition	Ti/Ni = 48.2/51.8 at. %
B.G. pressure	5.0×10^{-4}Pa
Solution treatment	973K 30min
Aging	773K 300min
Cooling	Atmosphere 200min

2.2 Evaluation method

Dynamic properties of the SMA thin films are evaluated with shape memory angle and transformation temperatures after 10,000 times actuating [5]. Shape memory angle is measured by reflected semiconductor LASER from SMA thin film surface on CCD camera, and transformation temperatures are measured by differential scanning calorimeter (DSC). Figure 1 shows the measurement system of shape memory angle. The precision of the angle measurement is less than 0.2 deg.
On our research, SMA thin films are heated by electronic

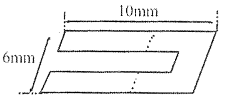
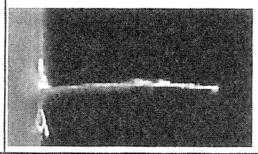
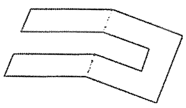
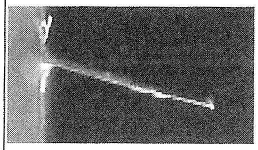
	Illustration	Photograph
290 K		
320 K		

Table 3. How SMA thin films work.

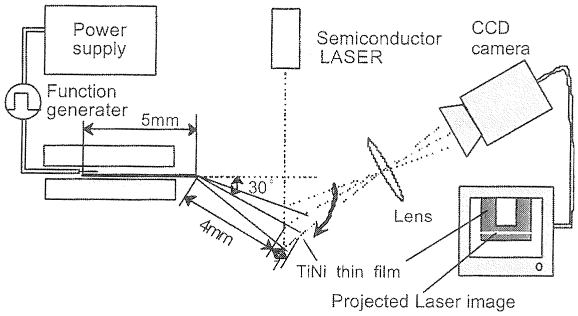


Figure 1. The measurement system of shape memory angle of SMA thin films.

power with function generator, and are cooled by L-N2 atmosphere. As to heating process, electronic power to SMA thin films is 1.65 W and pulse width of Electronic power is 0.05 sec. At the other hands, cooling process is spent 0.95 sec. Figure 2 shows the heat-cool cycle of SMA thin films. As and Af on Figure 2 indicate the starting point and the end point of SMA austenitic transformation temperature.

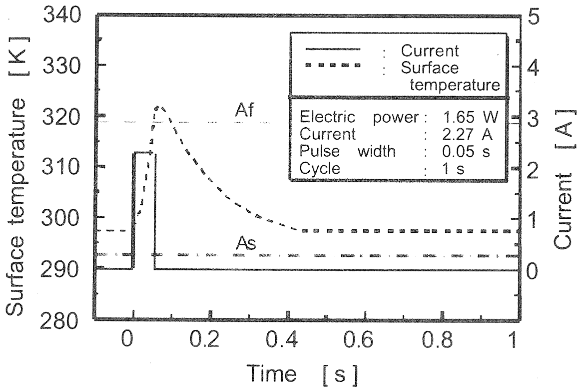


Figure 2. Heat-cool cycle of SMA thin films.

2.3 Dynamic properties

Shape memory angle is measured by the system shown on Figure 1. When SMA thin films are heated, they move downwards, and semiconductor LASER reflects on SMA thin film surface towards CCD camera. Projected LASER image indicates the location data of SMA thin film, and this data provides the shape memory angle by calculation. During SMA thin films heating over 10,000 times, the shape memory angle is measured at the time of 1, 10, 100, 500, 1,000 and each 1,000 times. Figure 3 shows the result of the shape memory angle measurement. The shape memory angle of SMA thin film keeps 29 ± 0.5 degree during 10,000 times actuating. Accuracy of the shape memory angle is less than about 3.3 %. This result indicates that influence from actuating numbers to shape memory angle of SMA thin film is very slight, and shape memory angle of SMA thin film is stable.

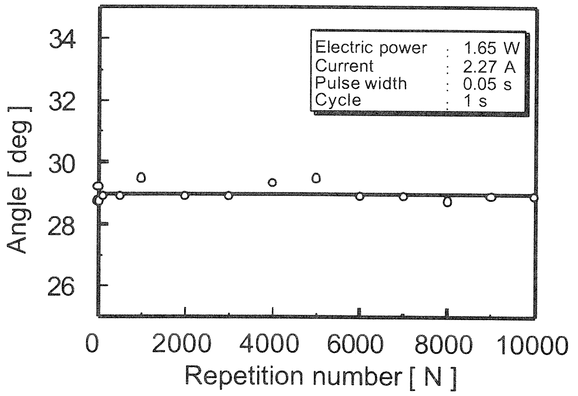


Figure 3. Shape memory angle of SMA thin film after actuating.

Transformation temperatures are measured by DSC at the time of 1, 10, 100, 500, 1,000 and each 1,000 times. Figure 4 shows the result of the transformation temperatures measurement. A1*, M1* and M2* on Figure 4 indicate the peak point of SMA austenitic and martensitic transformation temperature. Every peak points of austenitic and martensitic transformation

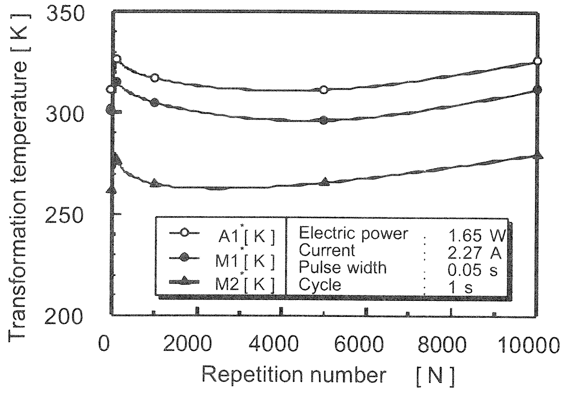


Figure 4. Transformation temperatures of SMA thin films after actuating.

temperature keep ±9K precision during 10,000 times actuating. This 9K precision is not crucial, because SMA thin films can actuate very quickly when are heated by using electric power. 9K difference is only 0.005 sec difference for pulse width. Looking precisely, peak points of austenitic and martensitic transformation temperature at 1, 10 and 100 times actuating flutter widely. This is from that SMA materials have property of training effect. So, transformation temperatures of SMA thin film are stable.

As described in this chapter, dynamic properties of the SMA thin films are so stable and repeatable that the SMA thin films are good enough for a micro actuator.

3 MICRO BREAKERS

3.1 Design of fabrication process

A SMA thin film based micro breaker, break temperature: 353 K, break response: over 30 Hz, shape memory angle: 30 degree, is designed and its fabrication process is also proposed. Figure 5 shows DSC profile of a SMA thin film for a micro breaker.

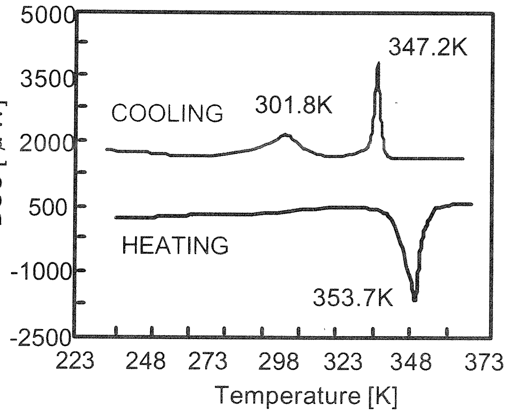
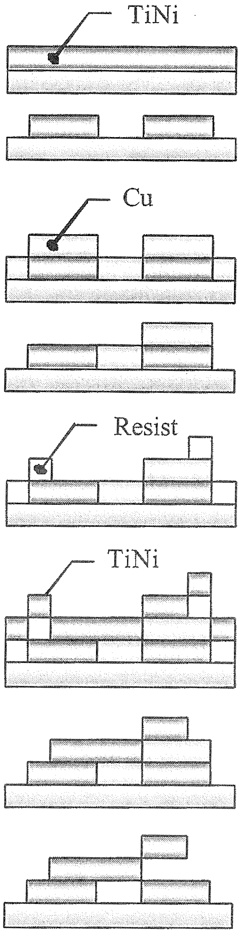


Figure 5. DSC profile of SMA thin film for a micro breaker.

Micro breakers consist of SMA thin film cantilever and two electrodes. Micro breakers are designed about 100 microns dimension size. TiNi thin films are also is chosen for electrodes, because TiNi is strong to chemicals. For example, Only HF+HNO_3 can dissolve TiNi. Other choice for electrodes could be Ni and Ti. Cu thin film is chosen for a sacrificial layer for making SMA thin film cantilevers. Other choice for a sacrificial layer could be SiO_2. After SMA thin film cantilevers are fabricated, micro breakers are annealed for crystallization and memorization by using an infrared lamp annealing system. After that, SMA thin film based micro breakers are accomplished. This fabrication process needs conventional semiconductor production technique. Figure 6 shows fabrication process of a micro breaker.

3.2 Experimental

Micro breakers are fabricated according to the process shown on Figure 6. TiNi thin films are sputter deposited on Si wafers with the same condition as Table 1. Thicknesses of TiNi thin films for electrodes and cantilever are 0.5 micron and 1.0 micron. TiNi thin films are patterned with photo lithography and are etched by HF (10ml) + HNO_3 (10ml) + H_2O (80ml). Cu thin films are deposited on TiNi thin films by vacuum evaporation system. Thicknesses of Cu thin films are over 0.5 micron. And Cu thin films are patterned with photo lithography and are etched by HNO_3 (50ml) + H_2O (50ml) for sacrificial layer. Now Cu thin films are on the only one electrode. Next process is 1.0 micron resist coating for lift-off method. Resist is also etched with photo lithography. After 2nd TiNi thin films are also sputter deposited on resist, all resist is dissolved and TiNi thin films on resist are lifted off. The last process is Cu sacrificial layer dissolving by HNO_3 (50ml) + H_2O (50ml). So SMA thin film based micro breakers are accomplished. Figure 7 shows a SMA thin film based micro breaker fabricated with the proposed process.



1. TiNi deposited on 4 inch Si wafer by RF sputtering

2. TiNi etched by HF+HNO_3 with photo lithography

3. Cu deposited by vacuum evaporation

4. Cu etched by HNO_3 with photo lithography

5. Resist coated and etched for lift-off method patterning for TiNi

6. TiNi deposited by RF sputtering same as process #1

7. Resist dissolved and TiNi patterned (lift-off)

8. Cu dissolved by HNO_3 TiNi cantilever accomplished

Figure 6. Fabrication process of a SMA thin film based micro breaker.

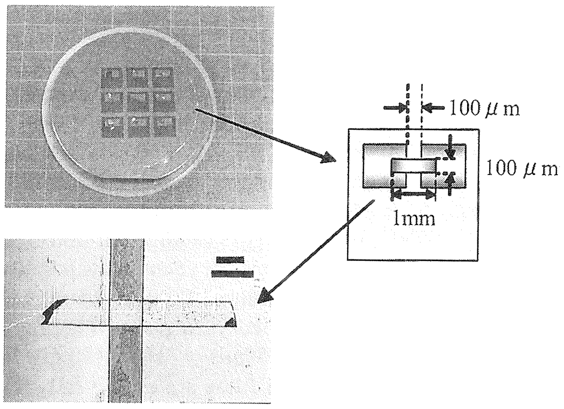


Figure 7. Schematic illustration and Photograph of top view of SMA thin film based micro breaker.

Upper left side photo and lower left side photo are top view of 4 inch wafer after fabrication and close shot of a SMA thin film cantilever. Right side illustration is top view of a SMA thin film based micro breaker. Size of a SMA thin film cantilever is about 100 microns x 1mm. As described in this chapter, proposed fabrication process is valid for SMA thin film micro breakers.

4 CONCLUSIONS

In conclusion, properties of SMA thin films for micro breakers were evaluated on shape memory angle and transformation temperatures, and properties of SMA thin films are so stable and repeatable that SMA thin films are good enough for a micro actuator. And a 100 microns x 1mm sized SMA thin film based micro breaker is fabricated with the process proposed in this paper.

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