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Study on Ti/Au Two-Layered Cantilevers with Different Aspect Ratio for MEMS Devices

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Abstract

We report the structure stability of Ti/Au two-layered micro-cantilevers with the various ratios of length and width for the first time. The cantilevers were fabricated by gold electroplating, a key technology for post-CMOS process for CMOS-MEMS devices. Ti is conventionally used for adhesion layers of gold electroplating, while the mechanical properties of Ti/Au structures have not been investigated. To evaluate the structure stability, the lengths of Ti/Au cantilevers were varied from 100 µm to 1000 µm. The experimental results showed that the cantilever of less than 500 µm in length and 5 µm in width made the structure more stable. Moreover, the cantilever of 1000 µm-length and 15-µm width showed high flatness. These results reveal the potential of Ti/Au layers to be applied to MEMS structures.

1. Introduction

Gold materials are often employed in electronic devices because of the high chemical stability, corrosion resistance, electrical conductivity and density. Recently, CMOS-MEMS technology [1] has been developed as the attractive way to establish high performance of devices. In order to realize the CMOS-MEMS structure, many fabrication processes have been researched. Especially, post-CMOS process is one of the promising candidates for fabricating MEMS on CMOS. Post-CMOS process needs low process temperature to be compatible with CMOS process. Thus, we have employed the gold electroplating method to form the MEMS device structure [2-3]. We have developed MEMS structure by using the gold electroplating. However, the structure stability of movable structures made of Ti/Au has been rarely reported.

The structure stability is highly related to Young's modulus of the material used to fabricate the cantilevers based on Euler–Bernoulli beam theory [4]. Young's modulus of Ti (116 GPa) is much higher than Au (79 GPa). By evaluate the cantilever of Ti/Au, as shown in Fig. 1, we can obtain the structure stability characteristics.

In this study, structure stability of the Ti/Au two-layered cantilevers with different aspect ratio by varying the length and width is evaluated to examine effects of the Ti bottom layer.

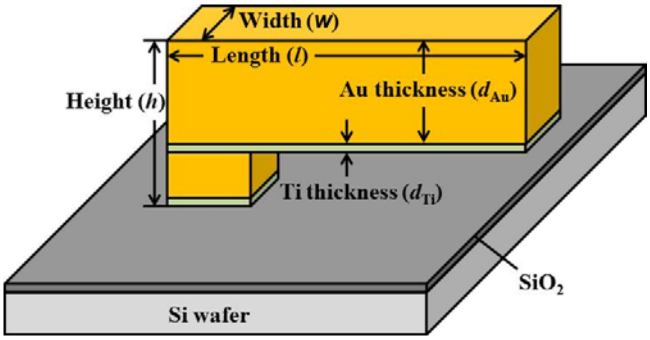

Fig. 1 Schematic figure of the cantilever.

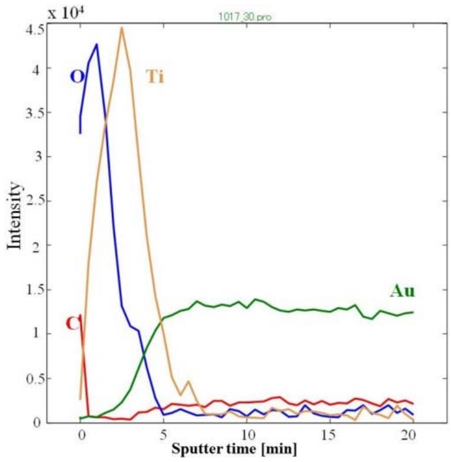

Fig. 2 Cross sectional AES spectra of the cantilevers

2. Experimental methods

Fig. 1 shows a schematic view of the Ti/Au two-layered micro-cantilevers. The Ti layer is formed by evaporation and the seed layer made of Au is also formed by evaporation. After the seed layer formation, lithography process and electroplating are carried out. More details can be found in the previous study [5]. The micro-cantilevers were fabricated on a SiO_2 layer. Thickness of the Ti layer (d_{Ti}) is 0.1 µm. Thickness of the Au layer (d_{Au}) is 3 µm. Length (l) of the micro-cantilevers was varied from 100 µm to 1000 µm. Width (w) of the micro-cantilevers was 5 µm, 10 µm and 15 µm, respectively. Distance between each micro-cantilever was 100 µm. After the fabrication process, the micro-cantilevers were annealed at 310 ℃.

Auger electron spectroscopy (AES) was conducted to confirmed composition of the Ti/Au two-layered structure. Structure stability of the micro-cantilevers was evaluated by observing the micro-cantilevers using the scanning electron microscope (SEM, S-4300SE, Hitachi) and the optical microscope (OM, VHX-5000, Keyence) equipped with a 3D display and measurement function. Structure stability was quantified by the change in height of the micro-cantilevers. The height (h) was defined as the distance from the top surface of the micro-cantilevers to the surface of the substrate, as shown in Fig. 1. The difference ($\Delta h_x = h_x - h_0$) in the height between a point away from the fixed-end (h_x) and the height at the fixed-end (h_0) was calculated to show height deviation of the micro-cantilever from the fixed-end. The height was determined by the Keyence OM. Also, standard deviation of height (σ_h) of the micro-cantilevers with different length was calculated.

3. Results and discussion

The two-layered Ti/Au structure was confirmed by the AES as shown in Fig. 2. The deformation was expected to occur in a direction perpendicular to the substrate surface. Therefore, height of the micro-cantilevers at different point away from the fixed-end was measured by the OM. Δh's of the micro-cantilevers with a different width of 5μm, 10μm, and 15 μm and a length of 300 μm, 700 μm, and 1000 μm are shown in Fig. 3(a) to (c), respectively. Δh_0 is the difference in height at the fixed-end (x=0), which is always 0 because $\Delta h_0 = h_0 - h_0 = 0$. From Fig. 3, the structure stability was found to decrease with an increase in the length. In addition, the structure stability was better for the micro-cantilevers with a wider width.

Most of the Δh's, as shown in Fig. 3(a) to (c), were positive. Therefore, standard deviation of the height was calculated to quantify the structure stability. The σ_h for the micro-cantilevers with a length varied from 100μm to 1000 μm is shown in Fig. 3(d). The results showed again that the structure stability decreased with an increase in the length, and this is because shear force at the fixed-end would increase with an increase in the length according to the Euler–Bernoulli beam theory for cantilever beam with uniformly distributed load [4], as the one used in this study. Then according to the same theory, bending of the cantilever is less likely to occur with an increase in cross-sectional area of the cantilever. Therefore, the increase in width (w) of the micro-cantilevers led to a lower σ_h and better structure stability. Although the structure stability was the worst for the w=5 μm micro-cantilevers, the structure stability was high when the length was less than 500 μm. A micro-cantilever with this aspect ratio is enough for MEMS devices.

4. Conclusions

Structure stability of the Ti/Au micro-cantilevers was evaluated. This is the first report to demonstrate that micro-cantilevers with a width in 5 μm could have sufficient structure stability when the length is below 500 μm. Furthermore, the results confirmed that the Ti/Au two-layered design has the potential to be applied as movable structures in MEMS devices.

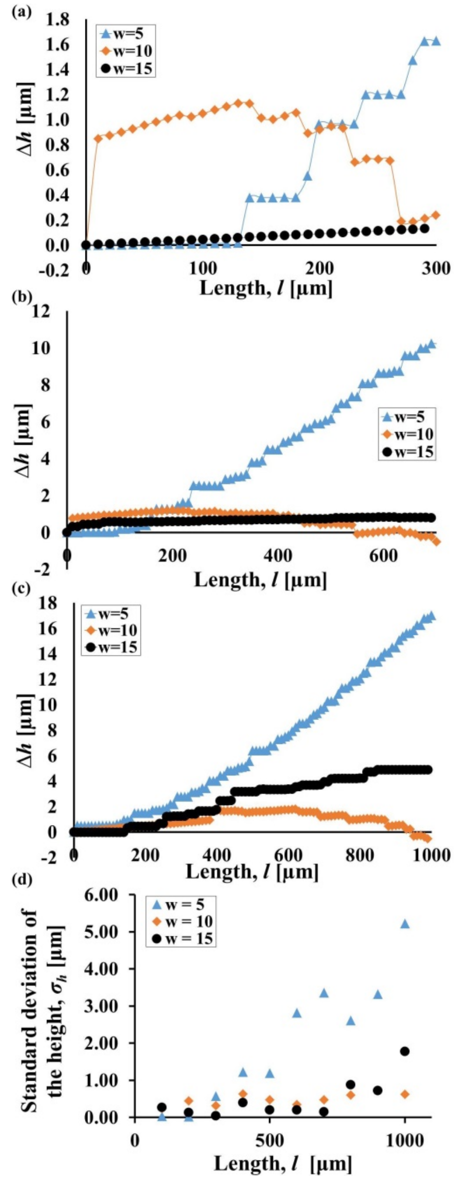

Fig. 3 Deviation in the height for the micro-cantilevers with a length of (a) 300 μm, (b) 700 μm, and (c) 1000 μm. (d) Standard deviation of the weight for the micro-cantilevers with the length varied from 100 to 1000 μm.

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