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Structure stability of high aspect ratio Ti/Au two-layer cantilevers for applications in MEMS accelerometers

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ABSTRACT

This paper reports the structure stability of Ti/Au two-layer micro-cantilevers with various aspect ratios based on the results obtained from a 3D optical microscope and FEM simulation. The cantilevers were fabricated by MEMS fabrication process. The movable structure stability was investigated by observing the shape of the Ti/Au two-layer micro-cantilevers with the Ti layer thickness of 0.1 μm, and the Au layer thicknesses of 3 μm, 10 μm and 12 μm. The length was varied from 100 to 1000 μm. The results of the tip deflection observed from the 3D optical microscope were similar to those of the FEM simulation. The experimental results of the micro-cantilevers with the Au thickness of 12 μm indicated the highest structure stability. In conclusion, these results revealed that the Ti/Au two-layer structure can enhance the stability and reliability of the movable structure.

1. Introduction

Gold materials are widely known to have high chemical stability, corrosion resistance, electrical conductivity and density. They are all advantageous when applied as electronic components and device fabrication process techniques [1–3]. Recently, complementary metal-oxide-semiconductor-micro-electro-mechanical system (CMOS-MEMS) technology has been developed to design electronic devices with an improved performance [4,5]. Thus, we have developed the high sensitive micro-electro-mechanical system (MEMS) inertia sensor and the integrated CMOS-MEMS accelerometer using gold material as proof mass [6–8]. In order to realize the CMOS-MEMS structure, a post-CMOS process that would not affect the CMOS properties is required. Electroplating is a promising post-CMOS process to fabricate the MEMS devices [8] because of the simple process conditions and low temperature process, which is important since heat is one of the major concerns affecting properties of the CMOS. In addition, properties of the plated materials can be precisely controlled by the electrochemical parameters. Therefore, gold electroplating can be applied in fabrication of the movable structures in the MEMS accelerometer.

The reliability of the gold materials in micro-scale should be evaluated for practical applications in the MEMS. The reliability can be determined by the mechanical properties and structure stability of the materials. There are several reports on mechanical properties of the gold materials [9,10]. However, there are very limited reports on the structure stability of the gold materials, especially for the dimensions in micro-scale.

Based on Euler–Bernoulli beam theory [11], the structure stability is highly related to Young's modulus of the material used to fabricate the movable structures. Young's modulus of gold is 78.5 GPa [12], which is considered to be low when compared to the other commonly used materials in electronic devices, such as Cu (128 GPa) and Si (165 GPa) [13]. The structure stability is expected to be higher using two-layer structure composed of a material having Young's modulus higher than that of gold. Young's modulus of titanium is 120.2 GPa [12]. The structure stability has been reported to be improved using a thin titanium layer as the bottom layer in a two-layer Ti/Au structure [6–8]. In addition, the titanium layer can also be used to improve adhesion of the gold layer on SiO_2.

There is still no report on the structure stability of the Ti/Au two-layer structure with different aspect ratios. Therefore, this paper presents the structure stability of the Ti/Au two-layer cantilevers with different aspect ratios by varying the length and the gold thickness. The evaluations were carried out based on the results obtained from a

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3D optical microscope and finite element method (FEM) simulation (COMSOL Multiphysics software).

2. Experimental method

2.1. Structure design and fabrication process of the Ti/Au micro-cantilevers

Fig. 1 shows a schematic view of the Ti/Au two-layer micro-cantilever. The titanium layer was formed by evaporation to be used as the adhesive layer on SiO_2. Then a thin layer of gold was evaporated to be used as the seed layer in gold electroplating. The series of lithography and electroplating processes were conducted to fabricate the micro-cantilevers. More details of the lithography and electroplating processes could be found in a previous study [8]. The micro-cantilevers were annealed at 310 °C during fabrication process.

Micro-cantilevers with different dimensions were prepared, details are given in Table 1. Length (l) of the micro-cantilevers was varied from 100 μm to 1000 μm. Width (w) of the micro-cantilevers was 10 μm. Thickness of the Ti layer (t_{Ti}) was 0.1 μm. Thickness of the Au layer (t_{Au}) was either 3 μm, 10 μm or 12 μm. Distance between each micro-cantilever was 100 μm.

2.2. Evaluation of the Ti/Au micro-cantilevers

Structure stability of the micro-cantilevers was evaluated by observing the micro-cantilevers using a scanning electron microscope (SEM, S-4300SE, Hitachi) and a 3D optical microscope (OM, VHX-5000, Keyence) equipped with a 3D measurement function. Structure stability was quantified by the difference between the height of the cantilever at the tip and the height of the cantilever at the fixed end or Δh. 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 height was determined by the Keyence OM.

2.3. FEM simulation for Ti/Au micro-cantilevers

FEM simulation was carried out by using the simulation software COMSOL Multiphysics to analyze the deformation behaviors of micro-cantilevers. The micro-cantilever was modeled on a beam part by using original material constant which is provided by COMSOL. Constraint condition was used as a fixed-end to monitor tip deflections, and symmetry condition was applied along the length of the micro-cantilever to reduce a computation time. The equations of linear elastic material were selected in the category of solid mechanics. The properties of linear elastic materials such as Young's modulus, thermal expansion coefficient, Poisson's ratio and density were applied in the simulation. The effect of the increase in the temperature from 20 to 310 °C on deformation behaviors of the micro-cantilevers was simulated.

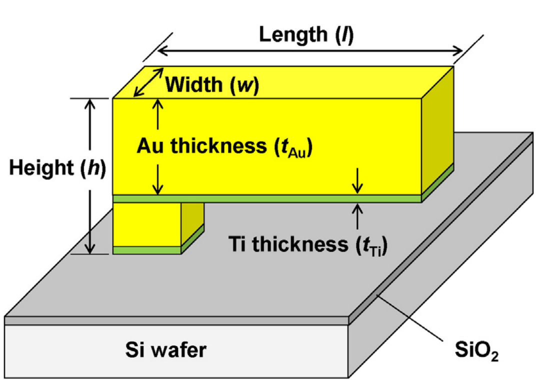

Fig. 1. Schematic view of the Ti/Au two-layer micro-cantilever.

Table 1
Design parameters of the micro-cantilevers.

		l	w	t_{Au}	t_{Ti}
Cantilever	A			3 μm	
	B	100 μm –1000 μm	10 μm	10 μm	0.1 μm
	C			12 μm	

3. Results and discussion

Fig. 2(a) shows an optical micrograph of top view of the Ti/Au micro-cantilevers (type A, which thickness of the Au layer is 3 μm). More details of the fixed-end were observed from the SEM image, as shown in Fig. 2(b). The fixed-end was composed of multiple layers of the Ti/Au two-layer structure. From the top view, there was no obvious deformation in the directions parallel to the substrate surface. The result is expected since deformation in the directions parallel to the substrate surface is mostly caused by inadequate fabrication process or poor handling of the samples.

The deformation was expected to occur in a direction perpendicular to the substrate surface. Therefore, height of the micro-cantilevers at a different point away from the fixed-end was measured by the OM, shown in Fig. 3. In general, the micro-cantilevers had a downward deflection because of the weight of the micro-cantilevers. This is why the titanium layer is used as the bottom

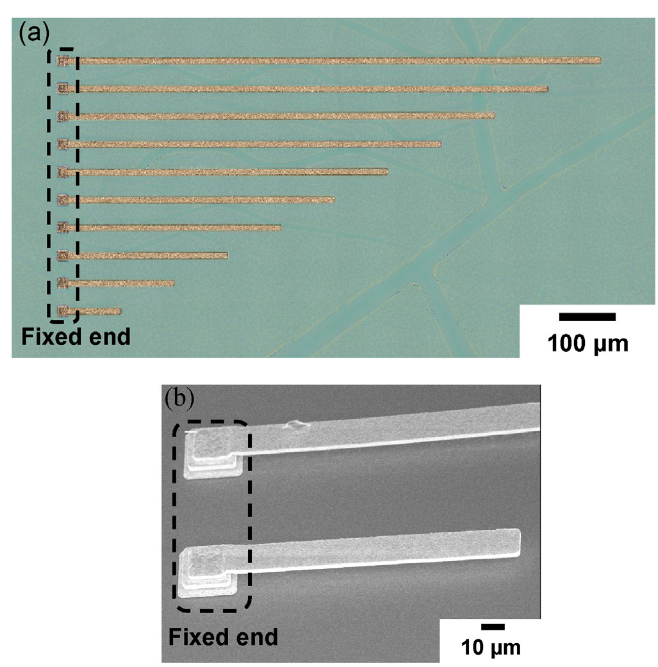

Fig. 2. (a) Optical photomicrograph of the as-fabricated micro-cantilevers and (b) SEM image of the as-fabricated micro-cantilevers magnified at fixed-end.