PATTERNING HIGH ASPECT SILICON PILLARS ON CANTILEVER BY METAL ASSISTED CHEMICAL ETCHING FOR HUMIDITY SENSING

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ABSTRACT

Pillars formed by metal assisted chemical etching (MACE) process as a post process on a silicon cantilever are presented in this work. Although the cantilever is very fragile, the patterning of the pillar structures on the cantilever have been successfully demonstrated. The high aspect silicon pillar structures from 20 to 40 with smooth surfaces and vertically etched shapes on the cantilever are formed by MACE. In addition, silicon cantilever with high aspect ratio pillars on its surface is proposed for humidity sensing application. The humidity sensing utilize the principle that the pillars stack together based upon the condensation behavior of water vapor on their surfaces.

INTRODUCTION

Humidity sensing is necessary in many fields [1-2] such as environment control, process monitoring and biomedical analysis. Humidity sensing methods can be catalogued into resistive-type [3], capacitive-type [4], optical-type [5], hygrometric-type [6], and gravimetric-type [7]. The optical-type is one of the most sensitive method and shows quick response. It operates on the basis of cantilever bending due to the surface stress change from water molecules absorption and the detection of the bending by optical beam deflection techniques. However, the bending of cantilever is usually in a small value. In this work, the cantilever with high aspect ratio pillars on its surface has been proposed to enhance the bending during humidity sensing so that more high sensitivity can be expected.

Metal assisted chemical etching (MACE) has been paid attention recently [8-12]. MACE process is performed in a wet etching solution but it enables a formation of anisotropic silicon structures at room temperature and atmospheric pressure. This etching technique shows a potential ability in micro/nanofabrication for a wide range of micro/nano system applications. The overview concerning the applications of silicon nanostructures by MACE in the field of energy conversion, storage and sensors have been demonstrated in [8]. Silicon nanowire fabrication by MACE has been presented in [9]. The formation of through silicon vias (TSVs) by MACE has been investigated in [10]. In MACE, a metal catalyst deposited on a silicon substrate reacts with an oxidant and the oxidized silicon is removed by HF. A noble metal acts as a catalyst for generating patterns after oxidant reduction.

This paper presents the fabrication of a novel humidity micro-cantilever with high aspect ratio pillars on its surface using MACE technique. A novel process has been proposed. No mask is required for patterning pillars on a Si cantilever. Additionally, the fabricated device has also evaluated for humidity sensing application based upon the condensation behavior of water vapor on the cantilever.

DEVICE STRUCTURE AND WORKING PRINCIPLE

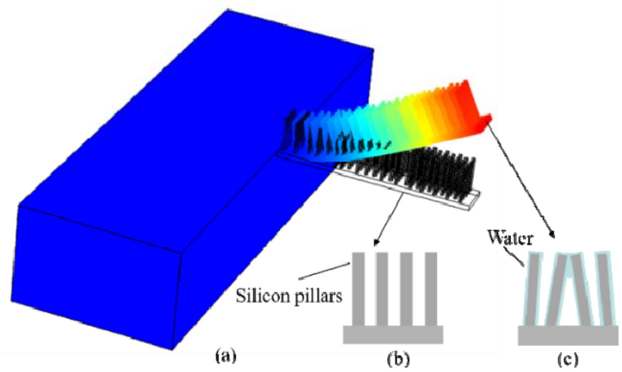

Figure 1. (a) Device structure. (b) Dry state. (c) Saturated state.

The device structure is illustrated as shown in Fig. 1. A commercial atomic force microscopy (AFM) cantilever with dimensions of 3 µm in thickness, 30 µm in width and 130 µm in length is employed. On its surface, silicon nano-pillars are formed by MACE. The cantilever does not bend in the dry state (Fig.1 (b)). However, it will be bended in the saturated state due to the surface tension of the condensed water layer which makes the pillars collapsed together. (Fig.1 (c)). Therefore, bending force to the cantilever is generated.

METAL ASSISTED CHEMICAL ETCHING

The MACE basically consists of two steps. Firstly, a noble metal such as Au, Ag, and Pt, etc., which acts as a catalyst, is patterned on a silicon substrate. The samples is then immersed in an etching solution consisted of HF and a H_2O_2 oxidant. The mechanism of MACE can be explained follows.

Cathode reaction at the noble metal and liquid interface generates electrical holes h^+ as Eq. 1. The reaction creates H_2O and at the same time injects holes h^+ through the noble metal into Si. The silicon atoms underneath the noble metal are oxidized by this h^+.

$$H_2O_2 + 2H^+ \rightarrow 2H_2O + 2h^+ \quad (1)$$

$$Si + 6HF + 2h^+ \rightarrow H_2SiF_6 + 2H^+ + H_2 \quad (2)$$

The anode reaction at silicon-metal interface dissolves silicon underneath the noble metal pattern by the HF solution. H^+ and hydrogen gas H_2 are produced by this reaction (Eq. 2). The noble metal patterns go down and penetrate into the space formed by the etched silicon. Eqs. 1 and 2 can be rewritten by equation below:

$$Si + 6HF + H_2O_2 \rightarrow H_2SiF_6 + 2H_2O + H_2 \quad (3)$$

EXPERIMENTS

Figure 2 presents a schematic of the fabrication processes. The commercial AFM cantilever is employed with dimension parameters mentioned above, as shown in Figs. 2 (a) and 3 (a). A 40 nm in thick Ag film is then deposited on the AFM cantilever (Fig. 2 (b)). The cantilever is sequentially annealed at 600ºC for 1 hour to de-wet the Ag film into a monolayer of Ag particles (Fig. 2 (c)). Ti-Au films with thicknesses of 1 nm and 20 nm, respectively, are deposited by electron beam (EB) evaporation. The Ag particle removal is performed by ultrasonic agitation (Figs. 2 (d)). The cantilever is then immersed in a mixture solution of HF (50%), H_2O_2 (30%) and Ethanol with a volume ratio of 5:1:1 at room temperature. The noble metal Au pattern goes down by etching Si and the high aspect pillars on the cantilever surface have been achieved (Fig. 2 (e)).

The de-wetted Ag particles on the cantilever is shown in Fig. 3 (b). The diameters of the Ag particles are ranging from 50 nm to 250 nm. Smaller particle sizes and higher particle densities can be achieved by decreasing the thickness of the deposited Ag layer. Figure 3 (c) shows the obtained Ti-Au catalyst mesh pattern after removing the sacrificial Ag particles. Figure 3 (d) presents the AFM cantilever after MACE process. High aspect silicon pillars from 20 to 40 with smooth surfaces and vertical shapes have been formed on the surface of AFM cantilever. Thus, although the AFM cantilever is very fragile, patterning of the pillar structures on this cantilever have been successfully demonstrated. Close-up and cross sectional images of the fabricated pillars on the cantilever are shown in Figs. 3 (e) and (f).

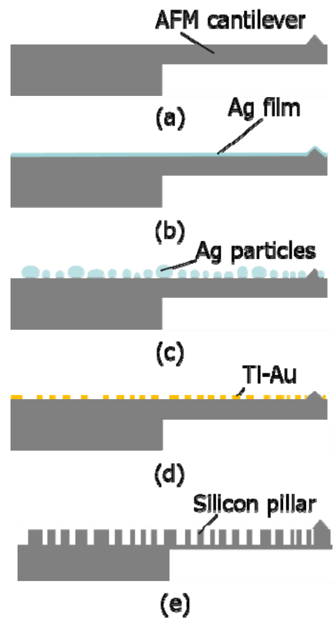

Figure 2. Fabrication process. (a) AFM cantilever. (b) Ag deposition. (c) De-wetted Ag particles. (d) Ti-Au deposition and Ag particle removal. (e) MACE process.

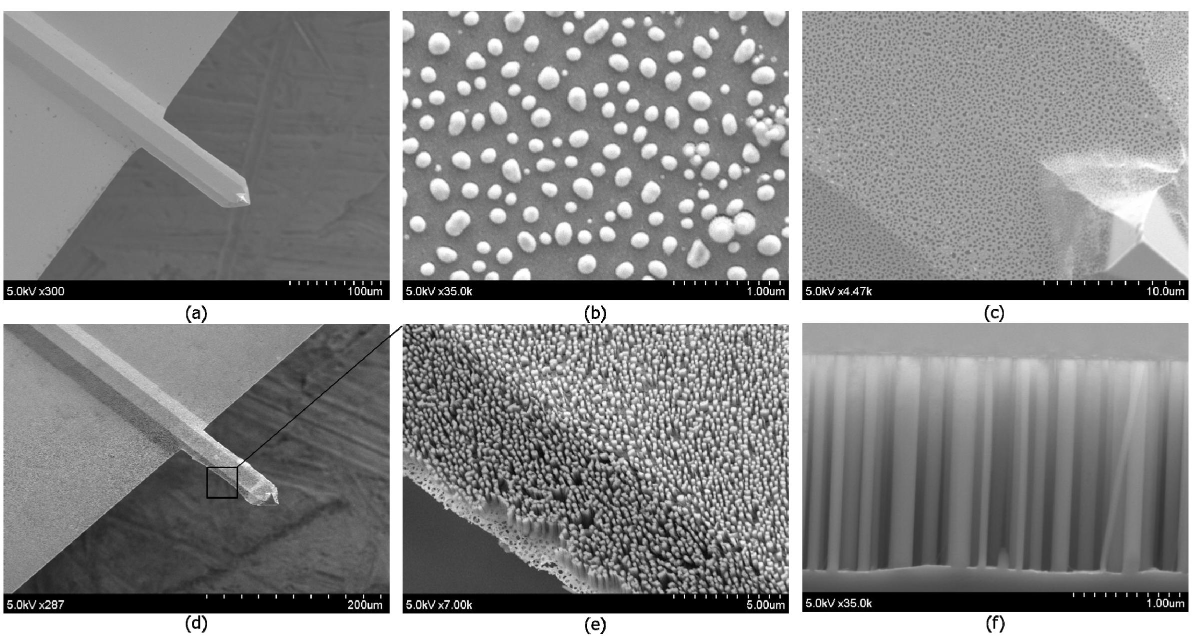

Figure 3. (a) AFM cantilever. (b) De-wetted Ag particles. (c) Ti-Au deposition and Ag particle removal. (d) AFM with silicon pillars. (e) Close-up images of the fabricated device. (f) Cross section of the fabricated device.

MEASUREMENT SETUP AND RESULTS

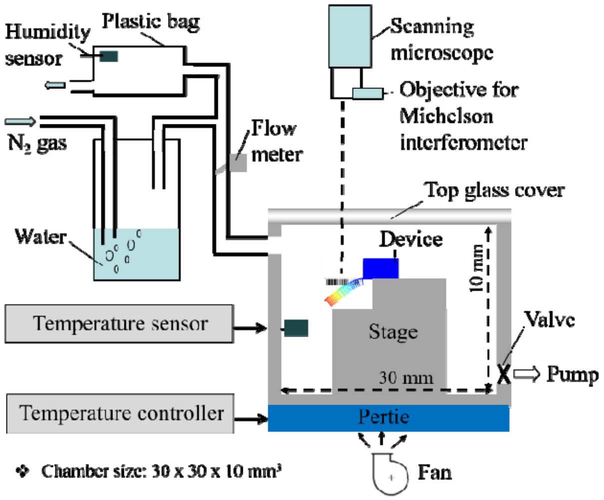

Figure 4. Evaluation setup.

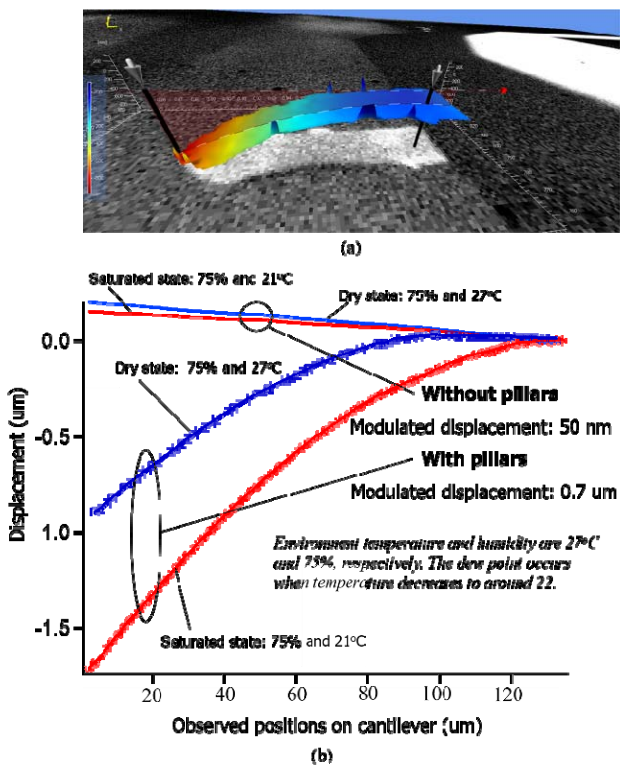

Figure 5. (a) Bending observation. (b) Modulated displacement.

Evaluation setup is shown in Fig. 4. A surface profile measurement system is employed to observe the displacement of the cantilever. A humidity-controllable chamber with a small size of 30 x 30 x 10 mm^3 has been used in this evaluation. Firstly, N_2 gas is flowed into the chamber to get a very low humidity around 1.5 %. The water bubbler is then introduced to chamber for increasing the humidity. The temperature controller is used for achieving condensation behavior. A small fan is employed to make the temperature distribution uniform for small chamber.

Figure 5 (a) show the surface profile measurement result of the cantilever. Cantilevers with and without pillars on its surfaces are evaluated and compared. A commercial AFM cantilever with thin metal layer coating on the cantilever is firstly evaluated. A low modulated displacement of 50 nm has been observed for this cantilever. The bending of this cantilever possibly results from the water adsorption on the thin metal layer. The large displacement of 0.7 μm can be achieved with the cantilever with pillars (Fig. 5). The possible reason is due to the pillars on cantilever surface collapsed together as mention above. The large displacement of the cantilever with pillars on its surface can be achieved. Thus, the proposed structure enhances the bending of the cantilever during humidity sensing so that more high sensitivity can be expected.

CONCLUSION

MACE for the production of high aspect ratio pillars on the silicon cantilever has been successfully demonstrated. The fabricated device is investigated as a humidity sensing application. Besides, this device may also be used for other applications such as chemical or biological sensing to enhance the sensitive detection.

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