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Development of sacrificial layer wet etch process of TiNi for nano-electro-mechanical device application

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***Abstract*—We report the wet etching of titanium nickel (TiNi) films for the production of nano-electro-mechanical (NEM) device. SiO_2 and Si_3N_4 have been selected as sacrificial layers of TiNi metal and etched with polyethylene glycol and hydrofluoric acid (HF) mixed solution. Volume percentage of HF are varied from 10% to 35% and the etch rate of the SiO_2, Si_3N_4 and TiNi are reported here. Within the various experiment results, 15% HF mixed polyethylene glycol solution show highest etch ratio between sacrificial layer and TiNi metal. Especially Si_3N_4 films shows high etch ratio with TiNi films. Wet etching results are measured with SEM inspection. Therefore, this experiment provides a novel method for TiNi in the nano-electro-mechanical device.**

***Index Terms*—Wet etch, nano electro mechanical device, TiNi**

I. INTRODUCTION

With consistently decreasing complementary metal oxide semiconductor (CMOS) device scale, the energy consumption of device has been steadily growing. Typically, conventional CMOS devices including static random access memory (SRAM), dynamic random access memory (DRAM), and flash memory have suffered from problems such as leakage current and short channel effects [1, 2]. At this point, nano electro mechanical non-volatile memory which is one of the promising next generation non-volatile memories, have been investigated intensively [3]. NEM memory has the advantage of low operating voltage and high sensing margin [4]. Recently studied NEM memory technologies are suggested as compact cell structure and composed of read word line, bit line, oxide-nitride-oxide (ONO) stack, and write word line. By using cantilever beam structure which has hysteresis property in bit line, bi-stable state could exist depending on the voltage level which has switching work mechanism that is applied to beam. That is, through electro static force on NEM memory structure, it is possible to materialize memory composition triggered by electro-mechanical movement. Because the information is stored by the cantilever beam's bending degree, a selection of beam material is considerably significant. Titanium nitride (TiN), the previous beam material, which has the advantage of high strength, chemical stability, and resistivity about corrosion was widely used [5]. However, this paper singled TiNi out as substitute material of cantilever beam largely because it has strong advantage of shape memory effect which is useful for out breaking of grapping force [6]. It is necessary for NEM memory with cantilever beam to possess movable air gap in NEM memory structure. This air gap can be made by eliminating sacrificial layer as wet etching process. Taking the wet etching process into consideration, the selectivity between sacrificial layer and cantilever beam material is greatly important. In this paper, we investigate selectivity of sacrificial layers in response to TiNi for NEM device.

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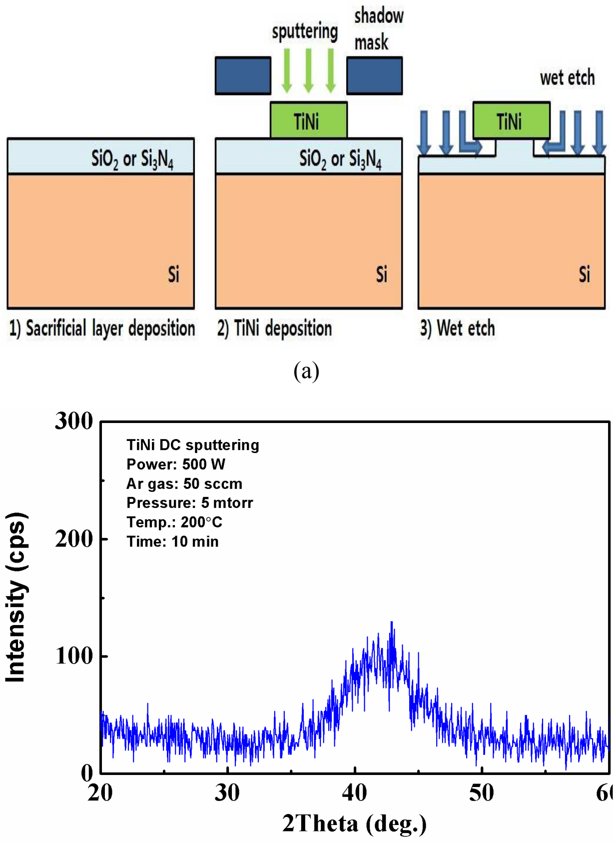
II. EXPERIMENT

The wet etch test pattern fabrication is started on a p-type silicon wafer with (100) orientation and medium resistivity (1~50Ω.cm). In this work, SiO_2 and Si_3N_4 are investigated as sacrificial layer of TiNi metal considering CMOS fabrication compatibility [7]. Summarized process sequence is introduced in Fig. 1. After the deposition of low pressure chemical vapor deposition (LPCVD) nitride (300 nm) and plasma enhanced chemical vapor deposition (PECVD) oxide (300 nm), wet etch tests were performed with wet station and ellipsometer. Sacrificial nitride and oxide layers were etched in a polyethylene glycol and HF mixed solution at a room temperature and cleaned in deionized (DI) water. Chemical formula of polyethylene glycol is $H(CH_2CH_2O)_nOH$ and manufacturer is DAEJUNG CHEMICAL & METALS Co. LTD. This mixed solution was observed in the previous work [8]. At the previous work, etch rate of SiO_2 and Si_3N_4 were varied with HF percentage and had nonlinear relationship between etch rate and HF percentage. Volume percentage of HF was varied from 10 percent to 35 percent. For the investigation of wet etch selectivity, Ti/Ni (1 μm) was sputtered and patterned with shadow mask for the scanning electron microscopy (SEM) measurement. TiNi films were prepared by sputtering a TiNi target (with atomic percentage of Ti 50% and Ni 50%) with a in-line DC sputter system. The base pressure of the main chamber was 1.57×10^{-5} Torr and the working pressure was 5.00×10^{-3} Torr. Fabrication condition of sputtering is summarized in Table 1. The x-ray diffraction (XRD) measurement of deposited TiNi film is shown in Fig. 1(b). As shown in the Fig. 1(b), peak point of TiNi is observed at 2Θ = 42°. This result is well matched with previous works [9, 10]. The smooth peak shape means that sputtered TiNi film has amorphous phase [11]. Resistivity of TiNi film in this experiment is $2.51\text{x}10^{-4}$ (Ω•cm). This value is measured by four point probe.



(a)

(b)

Fig. 1. (a) Process sequence of TiNi wet etch test sample, (b) TiNi XRD data.

Table 1. Fabrication conditions of TiNi sputtering

DC power	500 Watt
Ar gas	50 sccm
Working pressure	5.00×10^{-3} Torr
Base pressure	1.57×10^{-5} Torr
Process temperature	Room temperature
Sputtering thickness	1 μm

III. RESULTS AND DISCUSSION

Etch rate data of sacrificial layers and TiNi film are shown in Fig. 2(a).

To achieve acceptable etch rate, HF volume percentage was limited by 35% and the samples were put into the etching solution for 3 minutes. All of the wet etch processes were performed in room temperature and atmosphere condition.

Etch rates of all films are increased with HF volume percentage. However the increase rate of etch rate are different from each other. This different can make optimal etchant ratio for TiNi layer etch. As shown in the Fig. 2(b), etch ratio of sacrificial layers to TiNi layer has maximum value in 15% HF solution. The results indicate that when 15% HF solution was used in the wet etch process, etch rate of Si_3N_4 became 33 times larger than

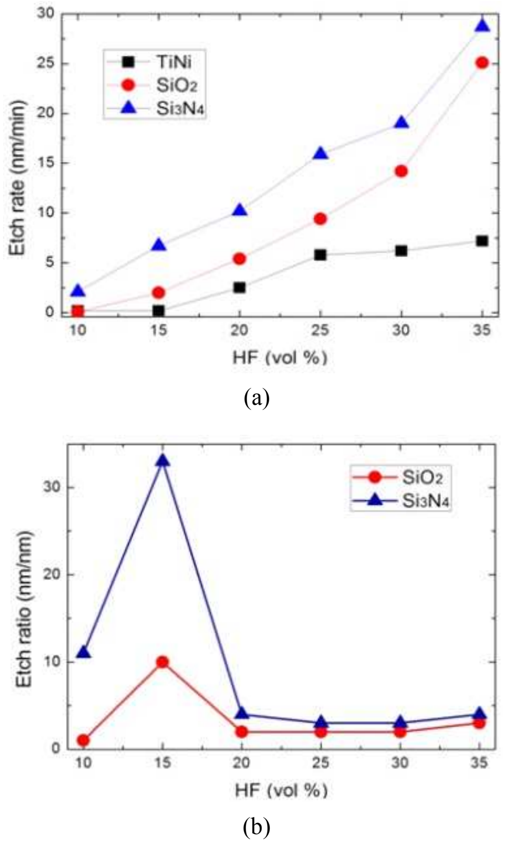


Fig. 2. Etch rate of sacrificial layers and TiNi film (b) Etch ratio of sacrificial layers to TiNi films.

that of TiNi films. Due to the nonlinear characteristics of etch rate with HF volume percentage change, each of the sacrificial layer has optimum HF volume percentage.

However SiO_2 also has maximum etch ratio to TiNi layer with 15% HF solution, the amount of etch ratio is not enough to be accepted in NEMS wet etch process.

This result shows that Si_3N_4 layer is a strong candidate of TiNi NEMS sacrificial layer with wet etch process. Fig. 3 shows the microstructure of TiNi metal beam. Sacrificial layer, Si_3N_4 was etched with a polyethylene glycol and 15% HF mixed solution. As shown in Fig. 3(b) and (c), TiNi metal resist wet etching solution. This wet etch results can be applied to NEMS devices.

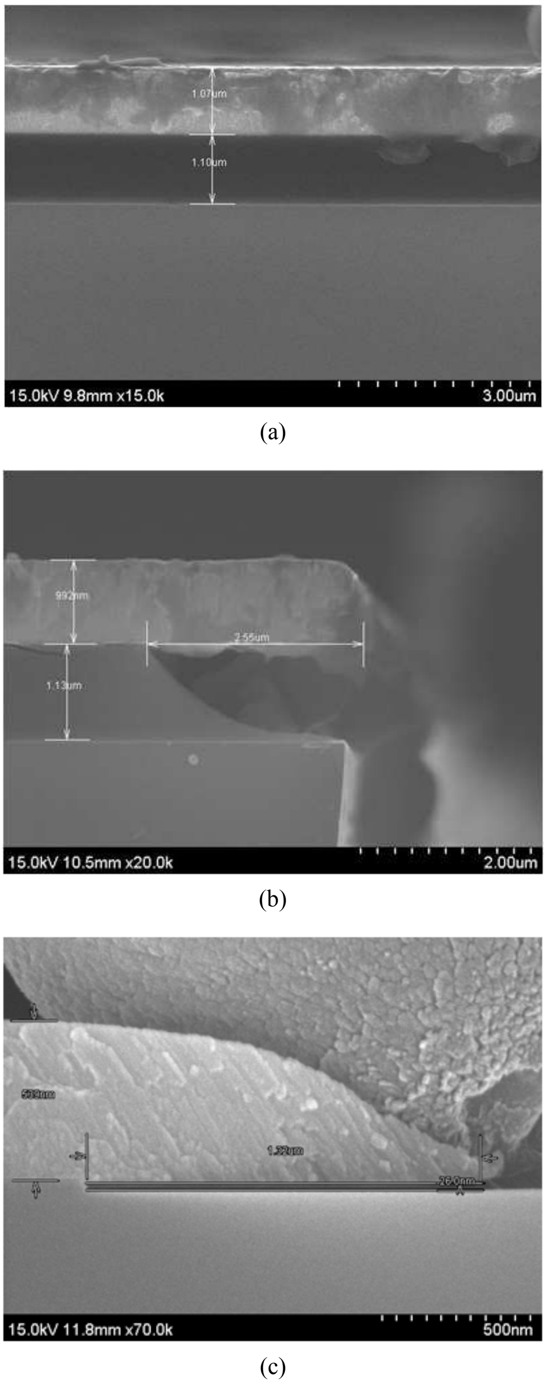


Fig. 3. SEM image of wet etching process of TiNi and Si_3N_4 layers (a) cross section and thickness of each layer, (b) under cut pattern of sample with 1.13 µm sacrificial layer, (c) under cut pattern of sample with 26 nm sacrificial layer.

IV. CONCLUSIONS

In this work, the sacrificial layer wet etching of the TiNi NEMS device has been demonstrated with a polyethylene glycol and HF mixed solution. The etch selectivity is strongly dependent on HF volume percentage and shows optimum volume percentage corresponding to the sacrificial layer. Within the two conventional sacrificial dielectrics, Si_3N_4 has best etch ratio corresponding to TiNi films with 15% HF and polyethylene glycol mixed solution. This optimum volume percentage is due to the nonlinear characteristics of etch ratio of each materials. Advantages of this etch condition are that it does not require additional equipment such as HF vapor machine, ant it is useful in adopting TiNi metal to the NEMS devices. Finally, experimental results of this work can applied to development of NEMS devices.

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