研 究 速 報

Fabrication of Nanometric Oscillators

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1. Introduction

In noncontact mode atomic force microscope (AFM), a cantilever measuring 100μm with a sharp tip on its end is used for detection of force gradient acting between the tip and sample by detecting its resonance frequency shif[1,2]. For improvement of resolution of AFM, to decrease spring constant and to increase resonance frequency shift of the cantilever are desirable. Thus miniaturization of AFM cantilever is required[3,4]. We are developing nanometric oscillator which consist of mass and spring measuring 100nm to a few microns for detection of force gradient and mass in AFM[5,6,7,8,9]. In this paper fabrication results of several types of nanometric oscillators is mentioned.

2. Fabrication

For the fabrication, SOI (silicon-on-insulator) wafer is used, which has top Si layer (thickness, 1~3μm) /buried SiO_2 layer (thickness, 1~3μm) /substrate Si (thickness, 500μm). Nanometric oscillators are fabricated by selective etching of Si and SiO_2. 4 types of nanometric oscillators are fabricated. (1) Nanometric oscillator with filiform neck. (2) Nanometric oscillators with obliquely deposited Si leaf spring, (3) Nanometric oscillators with parallel spring, (4) Triangular shaped single crystal Si multi probe cantilever.

2.1 Nanometric oscillators with filiform neck

In Figure 1, fabrication process of nanometric oscillators with filiform neck is shown. First of all, top Si layer is etched to leave tetrahedral Si dots by combination of anisotropic etching by KOH and local oxidation of Si (LOCOS)[10,11]. In this fabrication, the size of the tetrahedral Si is determined by thickness of the top Si layer without depending on lithography technique, which enables high reproducibility and uniformity in fabrication of nanometric oscillators in final step. After fabrication of the tetrahedral Si, the SiO_2 layer is vertically etched by reactive ion etching with CHF_3 gas. The tetrahedral Si dots behave as the mask. And Si-SiO_2 columns are obtained as shown in Figure 1 (c). After that, SiO_2 layer is etched by BHF and it becomes thin. When the SiO_2 becomes thin to be desired thickness, the etching is stopped and nanometric oscillators with filiform neck are obtained. In Figure 2, nanometric oscillators with filiform neck fabricated above method are shown. According to calculation, spring constant and resonance frequency are (a) 8MHz, 1N/m, (b) 7MHz, 0.1N/m, (c) 300MHz, 1N/m, respectively.

2.2 Nanometric oscillators with Si leaf spring

In Figure 3, fabrication process is shown. First of all, top Si layer is etched to leave tetrshedral Si and SiO_2 is vertically etched to form Si-SiO_2 column. This is the same as the fabrication of nanometric oscillators filiform neck. From this point, instead of thinning the neck, Si is obliquely deposited by sputtering on one surface of the Si-SiO_2 column and annealing is performed. And then SiO_2 column is completely removed by BHF as sacrificial layer. Nanometric oscillators with obliquely deposited leaf spring are obtained like this way, as shown in Figure 4. According to calculation, spring constant and resonance frequency are (a) 30N/m, 12MHz, (b) 3N/m, 10MHz, (c) 0.1N/m, 3MHz, respectively. Thickness of the spring is easy to control by the deposition time of sputtering, which enables higher reproducibility.

2.3 Nanometric oscillators with parallel spring

In Figure, 5, fabrication process is shown. By utilizing oblique deposition twice, nanometric oscillators with parallel spring are fabricated. The mass is Si wire which consist of 4 of <111> surfaces. With the nanometric oscillators with parallel spring, mode of the oscillation is limited to just one. It is also useful to support a Si wire in air.

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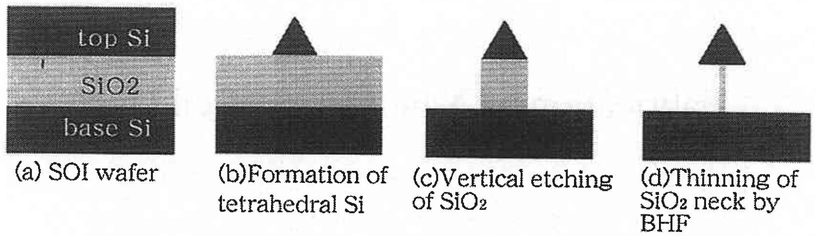

Fig. 1 Fabrication process of nanometric oscillators with filiform neck.

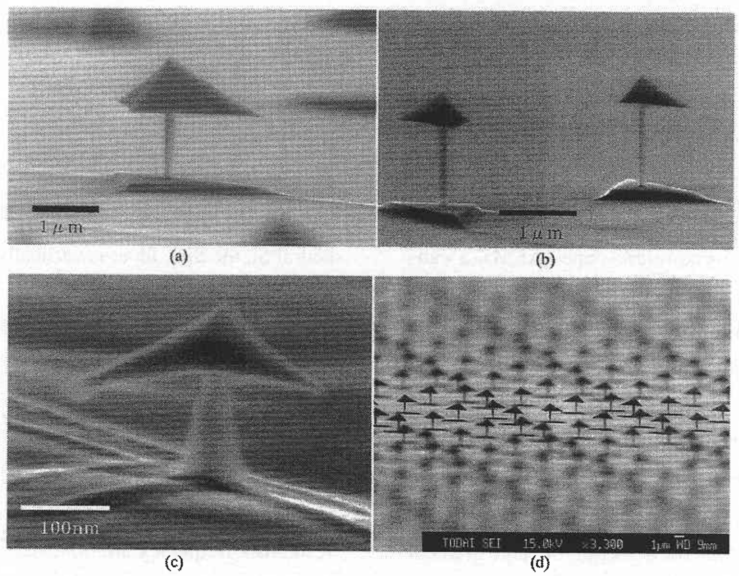

Fig. 2 SEM images of nanometric oscillators with filiform SiO_2 neck.

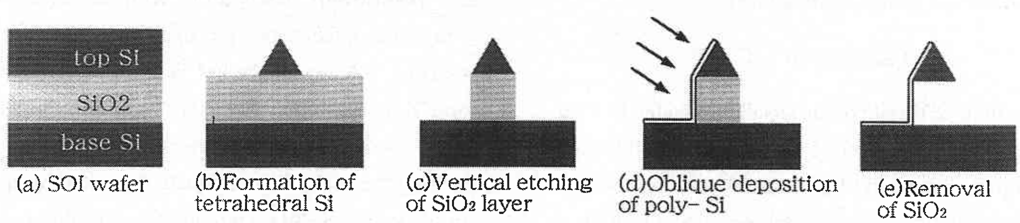

Fig. 3 Fabrication process of nanometric oscillators with leaf spring.

2.4 Single crystal Si multi-probe cantilever array

Fabrication process is shown in Figure 7. Fabrication utilizes three time anisotropic etching of Si and twice LOCOS. With this fabrication method, small cantilevers measuring a few microns with sharp tips can be fabricated without precise lithography technique and alignment. Thickness of the cantilever is controlled by the first KOH etching. The length and thickness are tailored to be 2μm to 8μm and 30 nm to 100 nm, respectively. The height of the tip is determined by the thickness of the top Si layer. In Figure 8, SEM images of single crystal Si cantilevers are shown. The length and thickness are (a) 2.5μm, 60 nm, (b) 4μm, 30 nm, (c) 8μm, 60 nm, respectively. According to calculation, spring constant and resonance frequency are (a) 10N/m, 10MHz, (b) 0.06N/m, 2.4MHz, (c) 0.3N/m, 1.3MHz, respectively. With this fabrication method, the cantilevers are arranged every 10μm. And 10,000 cantilevers are there in $1mm^2$. We are aiming at simultaneous operation of AFM with this cantilever array[14,15,16,17,18,19).

3. Characteristics of the nanometric oscillators

For the purpose of measurement of their static characteristics, we performed experiments of pushing or pulling the nanometric oscillators with a conventional AFM cantilever or STM tip with SEM-AFM[12,13). About the nanometric oscillators with filiform neck, they deformed as shown in Figure 9. They showed elastic deforma-

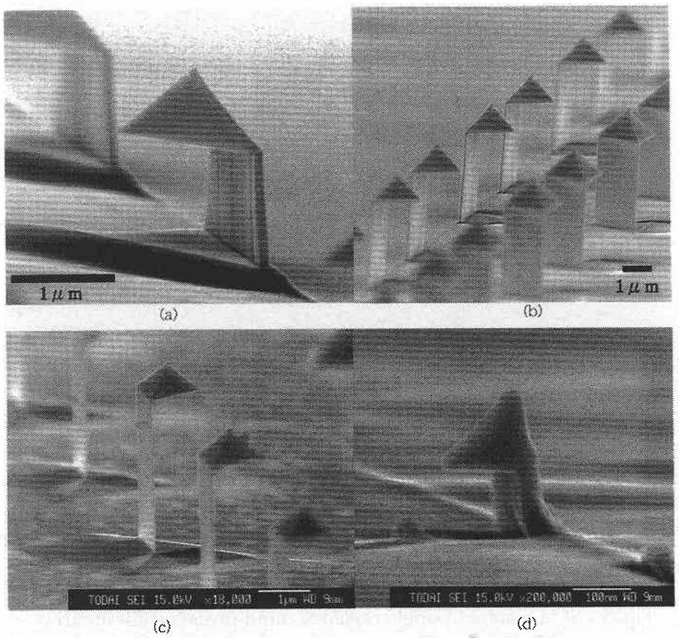

Fig. 4 SEM images of nanometric oscillators with leaf spring.

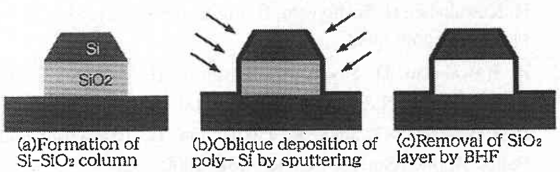

Fig. 5 Fabrication process of nanometric oscillators with parallel springs.

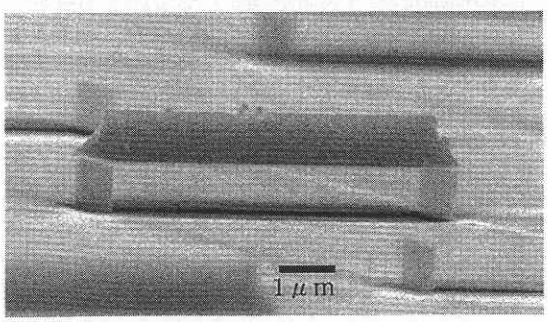

Fig. 6 SEM image of nanometric oscillators with parallel spring.

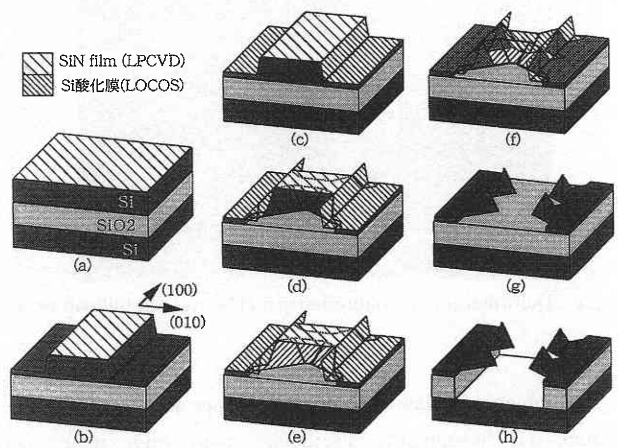

Fig. 7 Fabrication process of single crystal Si multi-probe cantilever array
(a) Deposition of SiN on SOI. (b) First anisotropic etching by KOH. (c) Local oxdation of Si (LOCOS). (d) Second anisotropic etching by KOH. (e) LOCOS. (f) Third anisotropic etching by KOH. (g) Removal of LOCOS SiO_2 film. (h) Etching of SiO_2 layer.

tion. And with larger stress, they showed plastic deformation or fracture. The maximum stress applicable to the neck is found to be 1GPa.

About the single crystal Si cantilever, it was deformed until it touched to the substrate. After release, the cantilever came back to its original position without any apparent evidence of plastic deformation. When the cantilever is pushed further, it broke at the support point. The spring constant of the single crystal Si cantilever measured by SEM-AFM was around 3 N/m. This is larger than the calculation results mentioned in 2.4. It is because, in measurement, tip of AFM cantilever when pushing, is on the middle part of the single crystal Si cantilever.

Our nanometric oscillators were found to be elastic and strong enough for the force detector in AFM. Dynamical measurement was done. The resonance frequency of the single crystal Si cantilever were 1MHz to 10MHz. And Q factor was 10 in air and 10,000 in vacuum.

Precise measurement is presented in another paper titled "Characterization of silicon nanocantilevers"

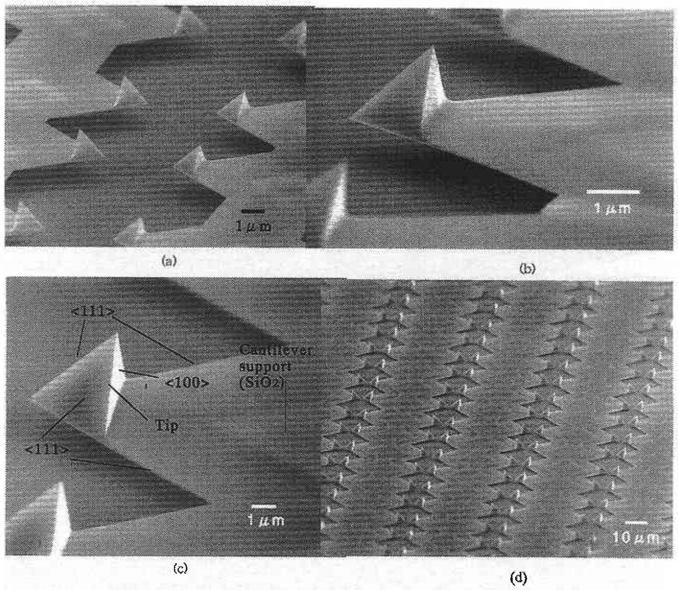

Fig. 8 SEM images of single crystal Si multi-probe cantilever array.

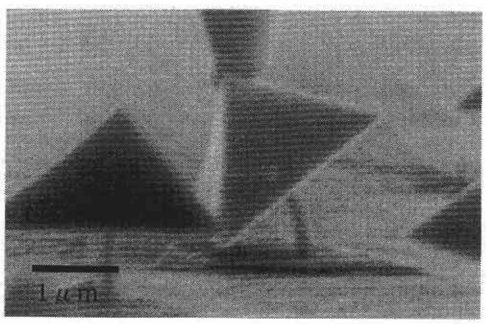

Fig. 9 Deformation of a nanometric oscillators with filiform neck.

4. Conclusion

Nanommetric oscillators with various shape and sizes were fabricated, (1) Nanometric oscillators with SiO_2 neck, (2) Nanometric oscillators with leaf spring, (3) Nanometric oscillators with parallel spring, (4) Single crystal Si cantilever array. They were found to be elastic and strong enough for force and mass detector in AFM.

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