FERROELECTRIC THIN FILM DISPLACEMENT SENSORS FOR
ATOMIC FORCE MICROSCOPE

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INTRODUCTION

Atomic force microscope (AFM) is a promising technique for characterizing material surface profile with angstrom precision. Since the displacement of AFM cantilever beam must be monitored to provide surface characteristics, optical lever is widely used for this purpose. In this system, samples for the observation have to be moved for the scanning while the cantilever beam is positioned at a same location throughout the observation for the optical lever alignment. However, cantilever beam scanning is a better approach especially for evaluating large samples which are not easily moved rapidly. Techniques for realizing the cantilever beam scanning include piezoresistive detection[1], optical interference[2], capacitive detection[3] and piezoelectric detection[4].

Among them, the use of ferroelectric thin film as a displacement sensor is a realistic solution because of its relatively simple device design. Although zinc oxide thin film has been used as a displacement sensor, the resolution of the sensing was not particularly good (~1μm) because of relatively poor performance of the film as a sensor[4]. In this study, we used lead zirconate titanate (PZT) as a displacement sensor for a AFM cantilever beam, and evaluated its performance.

SAMPLE PREPARATION

Silicon cantilever beam with PZT thin film was fabricated by conventional silicon processing techniques described in Figure 1. First, silicon(100) wafer was coated with 0.1μm-thick Si₃N₄ film using a plasma CVD and then a photoresist patterning was carried out on the bottom side to initiate a void for cantilever beam (1-1). The part of the Si₃N₄ film which was not protected by the photoresist was removed by reactive ion etching (1-2). Photoresist patterning was again carried out on the top side for the void formation, though the area corresponding to the beam itself was kept covered with the photoresist on this side (1-3). Then the
Si$_3$N$_4$ film was removed accordingly (1-4). At this stage, all the photoresist was removed and the wafer was soaked in a KOH solution for chemical etching. The silicon nitride film served as a protection layer from KOH dissolution and the uncovered area was dissolved from both sides to form the cantilever beam and the void space for its movement (1-5).

![Schematic flow of the process for fabricating silicon cantilever beam with PZT thin film sensor.](image)

Finally, Pt/Ta electrode was deposited as lower electrode by sputtering and PZT thin film was formed on the electrode also by sputtering. A technique for this film formation, which was characterized by low temperature film deposition and high temperature annealing, was previously reported [5] and we used this approach again in this study except that sputtering was employed rather than MOCVD to improve processing reproducibility. Gold film was deposited later on the top surface as upper electrode.

Fabricated cantilever beam was 0.5 to 1.5 mm long, 0.2 to 0.5 mm wide, and 20 to 140 $\mu$m thick. This dimension was larger than that of conventional AFM cantilever beam, but was sufficient for our purpose of evaluating the PZT film and provided mechanical strength necessary for our evaluation method. The thickness of the PZT film was approximately 1 $\mu$m.
CARACTERIZATION

The dielectric constant of the PZT film was 1250 and the loss was 0.05 measured at 1 KHz. The remanent polarization was 30 μC/cm² and the coercive field was 175 kV/cm, also measured at 1 kHz.

The cantilever beam was mounted on a base and a thin PZT ceramic plate was attached to the base to induce the natural resonance of the cantilever beam. The amplitude of resonance was measured by a Doppler interferometer while the piezoelectric output signal from the PZT film was monitored. For this experiment, the beam with 1500 x 500 x 140 μm dimension was mostly used. The resonance frequency of this beam estimated from a simple resonance model was 84.1 kHz and the optically measured resonant frequency was 83.8 kHz.

Figure 2 shows typical examples of piezoelectric signal from the PZT thin film on the cantilever beam resonating at the frequency. When the amplitude of the resonance was about 500 nm, the output signal was 22 mV (2-1). When the amplitude was reduced to 100 nm by reducing the voltage applied to the PZT ceramic plate accordingly, the output signal was about 4 mV (2-2). By using a high resolution voltmeter rather than a digital oscilloscope, signals in 10² μV range was detected. This enabled us to measure surface profile in the order of nm.

Evaluation of the cantilever beam with 500 x 200 x 20 μm dimension is being currently undertaken. It is installed in a AFM apparatus and experiments are being carried out to find a force.
detection mode most suitable for the cantilever beam with ferroelectric thin film.

CONCLUSION

Lead zirconate titanate thin film was formed on a silicon cantilever beam as a displacement sensor and showed a capability of measuring surface profile in the order of nm. The cantilever beam can be used as a AFM probe if suitable force detection mode is established.

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REFERENCES