Extended Abstract of PSA-19
P-05

Focused Ion Beam-Atomic Force Microscopy Technique for Sidewall Roughness Measurement of Free-Standing Objects with Sub-μm Size

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(Received: May 15, 2019; Accepted: June 30, 2019)

A noble analytical technique basing on focused ion beam (FIB) and atomic force microscopy (AFM) to evaluate quantitatively the sidewall roughness of oblique faces of free-standing objects in micro electro mechanical systems (MEMS) devices was developed. The FIB sampling technique conventionally used for the preparation of transmission electron microscopy specimens was applied for fabricating AFM specimens of free-standing objects. The proposed FIB-AFM technique was employed to measure the surface roughness of sidewalls of free-standing Si bridges specially fabricated for this study. The results revealed that the developed FIB-AFM technique is effective to evaluate quantitatively surface roughness parameters of the order of sub-nm for free-standing objects with sub-μm size in MEMS devices.

1. Introduction

Surface roughness is one of the most important parameters in characterizing objects in micro electro mechanical systems (MEMS) since the surface roughness determines properties of MEMS devices, e.g., friction at interface in actuators and the propagation loss of photons in optoelectronic devices. One of the most powerful techniques for measuring the surface roughness with high resolution is atomic force microscope (AFM). Since AFM is basically utilized for the roughness measurement of the top surface, developments of AFM techniques to measure the sidewall roughness of μm-sized objects has been studied [1-3].

In MEMS devices, free-standing objects are important parts and the measurement of its sidewall roughness of free-standing object is frequently required. However, AFM techniques are not suitable for this purpose because of difficulties in the approach of an AFM tip to oblique faces of objects and influences of the vibration of objects on the AFM measurement. In the present study, therefore, we developed a new AFM technique to measure the surface roughness of oblique faces of μm-sized objects in MEMS. We applied the focused ion beam (FIB) technique, which is conventionally used for transmission electron microscopy (TEM) specimen preparation, to fabricate specimens for AFM measurements.

2. Experiments

As a test sample for this study, a free-standing Si bridge structure was specially fabricated on a silicon on insulator wafer by conventional Si device processes. The area of a bridge was 4×50 μm^2 and the thickness was 0.2 μm. In order to investigate whether the present FIB-AFM technique can provide quantitatively surface roughness parameters of sidewalls, the variation in the roughness parameters by H_2 annealing was evaluated. The H_2 annealing is known to be the process to smoothen the roughness existing on a Si substance surface [4]. Therefore, the free-standing Si bridge structure was annealed in H_2 atmosphere of 1.3×10^3 Pa at 1100°C for 60 s.

The apparatus used for FIB sampling was a FIB-scanning electron microscope (SEM) (Helios 650, FEI). The SEM function enables us to perform FIB sampling without the damage induced by FIB on the specimen surface measured by AFM. The W probe for FIB sampling was attached to a Si bridge by the W deposition. Then, the Si bridge was cut by FIB and mounted onto a mesh used for TEM observation by the W deposition. Finally, the W prove was separated from the Si bridge by cutting with FIB and the Si bridge sidewall was provided for the AFM measurement. The surface roughness was measured by an AFM apparatus (Dimension Icon, Bruker) with the peak force tapping mode. Scanning electron microscopy (SEM) observation of AFM specimens at high magnification was carried out using the SEM apparatus, (SU-8220, Hitachi) with a cold filed emitter without performing electrically conductive coating in order to avoid effects of coating on the roughness parameter. The acceleration voltage for scanning electron (SE) image observation was 1 kV.

3. Results and Discussion

Figure 1 shows a SE image of a typical AFM specimen of the Si bridge mounted on a pillar of a TEM mesh by FIB sampling technique. The Si bridge sample is attached to the top face of the pillar by W depositions. The Si bridge was mounted on the pillar so that the position of the sidewall is slightly higher than the sidewall of the pillar of the TEM mesh. This enables the AFM measurement of the Si bridge sidewall easier. Note that the surface roughness of oblique faces can be measured by mounting the Si bridge in different directions.

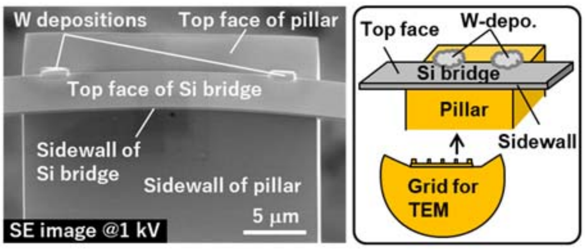

Fig. 1 SE image of a typical AFM specimen of a free-standing Si bridge mounted on the TEM mesh by FIB sampling. The sidewall of the Si bridge is provided for the AFM measurement.

Figure 2(a) shows the AFM image of the sidewall of the Si bridge before H_2 annealing. The vertical and horizontal line profiles are deduced from the AFM image and shown in Fig. 2(b) and 2(c), respectively. It is found that the surface roughness of the sidewall is quantitatively evaluated.

The AFM measurement was carried out for the sidewall of the H_2-annealed Si bridge. The roughness parameter, R_a, the arithmetic average of the absolute profile height deviations from the mean line, was found to be reduced from 1.1 to 0.4 nm by H_2 annealing. The present results confirmed that the sidewall surface roughness of the order of sub-nm can be quantitatively evaluated by the present technique.

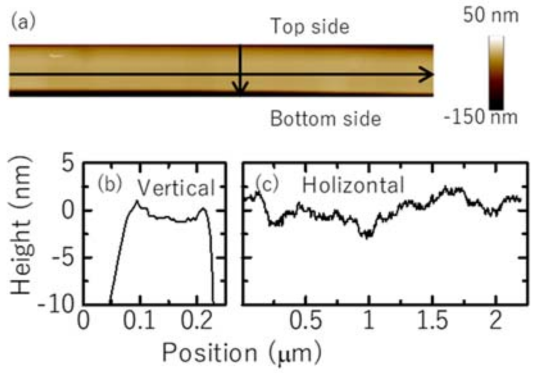

Fig. 2 (a) AFM image of the sidewall of the Si bridge before H_2 annealing. (b) Vertical and (c) horizontal line profiles deduced from the AFM image along arrows depicted in (a).

4. Summary

In the present study, the change in the surface roughness of the order of sub-nm by H_2 annealing was quantitatively evaluated for a free-standing Si bridge by the present FIB-AFM technique. It was confirmed that the present technique is a practical technique for the quantitative evaluation of the surface roughness of oblique faces of free-standing objects in MEMS devices.

5. References

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