Evaluation method of vibration spectra of nanomechanical resonators using Helium Ion Microscope

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A nanomechanical resonator is an important component of nanoelectromechanical systems (NEMS). Characterization of the resonator is needed for its further research. Frequency response is an important characteristic of the resonator and many methods to measure it quantitatively have been studied.

Now, Helium ion microscope (HIM) has attracted much attention as a high spatial resolution technology. HIM has various advantages such as surface sensitivity, and it is expected to lead to more advanced evaluation of nanomechanical resonators. In this study, we attempted to observe the vibrational state and identify the resonant frequency of a resonator by measuring its vibration spectrum using HIM.

Figure 1 (a) shows a schematic of the experimental setup for measurement of the vibration spectrum using HIM. A piezo device was installed into the HIM chamber to excite the nanomechanical resonator. It vibrates when an RF voltage is applied to the piezoelectric element. When RF voltage frequency is equal to the resonant frequency of the resonator, the amplitude of the resonator becomes large. In this experiment, a diamond-like carbon (DLC) cantilever was prepared as a nanomechanical resonator. DLC cantilever was fabricated by focused-ion-beam chemical vapor deposition. The diameter was about 100 nm, and the length was about 23 µm. This cantilever was set up on the piezo device inside of the HIM chamber.

In order to measure the vibration spectrum of the cantilever, Helium ion beam was irradiated at a spot close to the tip of the cantilever, as shown in Fig. 1 (b). When the cantilever was not vibrating, the beam did not hit it and no secondary electrons were generated. On the other hand, when the cantilever was vibrating, the beam hit it and secondary electrons were generated because the amplitude of it became large. In other words, secondary electrons were emitted in synchronization with the resonant frequency. Therefore, secondary electron signal was analyzed by a network analyzer to obtain the vibration spectrum. Figure 2 shows the spectrum obtained by the above method. There were two large peaks in this spectrum and these two peaks were considered to correspond to the resonant frequencies of the cantilever, respectively.

For observing the state of the cantilever in the vibration mode, the RF voltage of the resonant frequencies identified in the above method was applied to the piezoelectric element using a function generator. Vibration mode of the cantilever excited at each frequency was evaluated by observing it using HIM. Figure 3 shows the cantilever in vibration. The resonant frequency in primary mode was about 189 kHz, and one in secondary mode was about 1,319 kHz. These results indicate that HIM is a powerful tool to understand the behavior of nanomechanical resonators.

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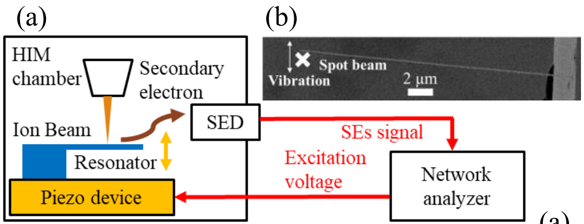

Fig. 1 The experimental setup.
(a) Schematic of the setup for the measurement of the vibration spectrum.
(b) HIM image of the DLC cantilever and the spot beam position.

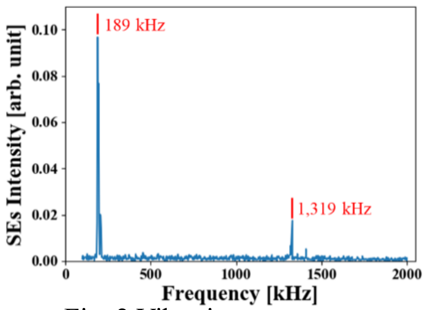

Fig. 2 Vibration spectrum.
Averaging factor was 50.

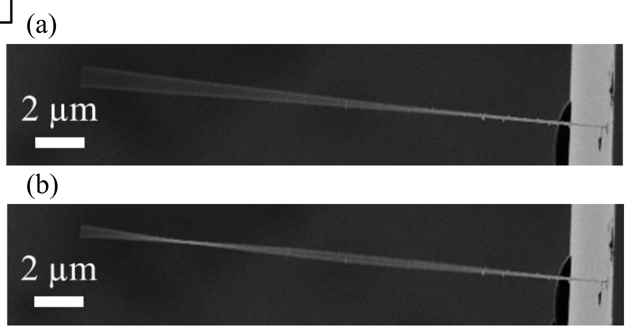

Fig. 3 HIM images of vibrating cantilevers. (a) primary mode (188,656.1 Hz) (b) secondary mode (1,318,671 Hz)