Fabrication of nanomechanical resonators elastically coupled in series for sensitive thermal stress detection

Kodai Tanaka[1], Etsuo Maeda[1], Shin'ichi Warisawa[1,2], Reo Kometani[1,2]
[1]*Graduate School of Engineering, The University of Tokyo*
7-3-1 Hongo, Bunkyo, Tokyo, 113-8656 Japan
[2]*Graduate School of Frontier Sciences, The University of Tokyo*
5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8561 Japan
Email:kodaitanaka@lelab.t.u-tokyo.ac.jp

Nanomechanical resonator with plasmonic structures has been researched in order to achieve high resolution wavelength detector. Plasmonic structures give the wavelength dependency to light absorption and irradiated light induces thermal stress. The thermal stress causes resonant frequency shift of nanomechanical resonator. The wavelength is detected by measuring the resonant frequency shift.[1] In this method, detection resolution is dependent on Q factor and Q factor reduces by heat absorption.[2] In this study, Q factor independent thermal detection was researched to achieve higher resolution wavelength detection.

Elastically coupled nanomechanical resonators were applied in order to detect thermal stress. Two coupled resonators have symmetric and antisymmetric modes, and the amplitude of antisymmetric mode significantly changes by applied stress.[3] By measuring the amplitude change, it is expected to achieve sensitive thermal detection. Symmetric and antisymmetric modes need to be mutually separated because the two modes overlapping interferes measurement of the amplitude of antisymmetric mode. In this study, nanomechanical resonators elastically coupled in series were proposed and the resonators achieved to separate two modes more than conventional structures. The resonators were fabricated by focused-ion-beam (FIB) ion implantation and wet-etching process, as shown in Figure 1. The central part for coupling two nanomechanical resonators was fabricated by high dose FIB irradiation. Therefore, Si substrate was etched, and a pillar supporting two resonators had a hollow structure. Figure 2 shows a scanning electron microscope (SEM) image of the nanomechanical resonators elastically coupled in series.

Resonant characteristics were measured by using an optical heterodyne vibrometer, as shown in Figure 3. Vibration of the resonator was excited by using semiconductor laser (408 nm) irradiated on the central coupling part and measured by using He-Ne laser (632.8 nm) irradiated on the right part. Thermal stress was applied by using power variable laser (1546 nm) irradiated on the left part with power of 0-700 μW. As a result, the amplitude of antisymmetric mode changed by thermal stress. We found that the maximum thermal stress detection resolution was 643 Pa by the spectrum analysis. This implies that nanomechanical resonators elastically coupled in series have superior performance for thermal stress detection. These resonators are expected to achieve higher resolution wavelength detection.

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1 E. Maeda and R. Kometani: Appl. Phys. Lett. **111**, 13102 (2017).
2 J. P. Mathew, *et. al.*: Nano Lett. **15**, pp.7621-7626 (2015)
3 H. Okamoto, *et. al.*: Appl. Phys. Lett. **98**, 010143 (2011)

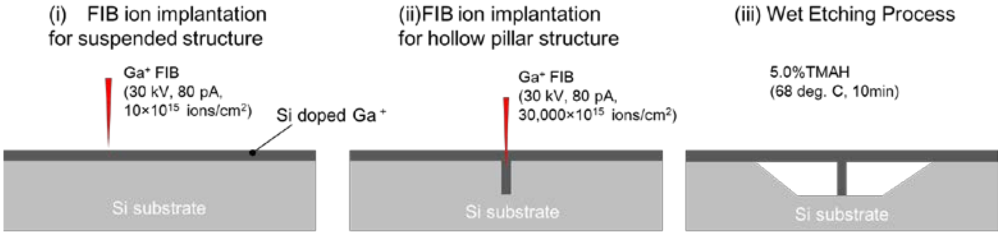

Figure 1: Fabrication process of nanomechanical resonators elastically coupled in series by FIB ion implantation and wet-etching process

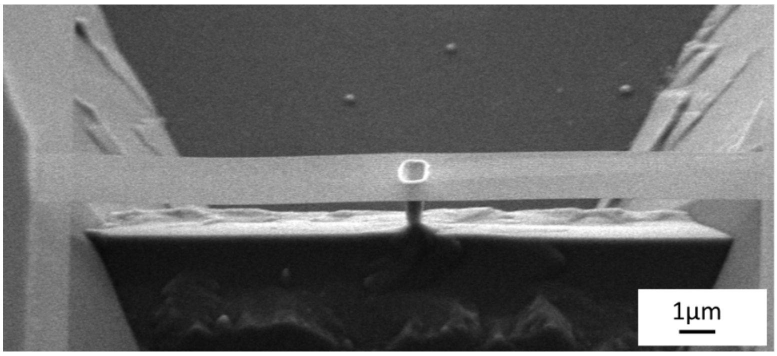

Figure 2: SEM image of nanomechanical resonators elastically coupled in series: Length, width and thickness of the resonator were 20 µm, 2µm and 50 nm. Length and width of the central coupling part were 500 nm and 750 nm.

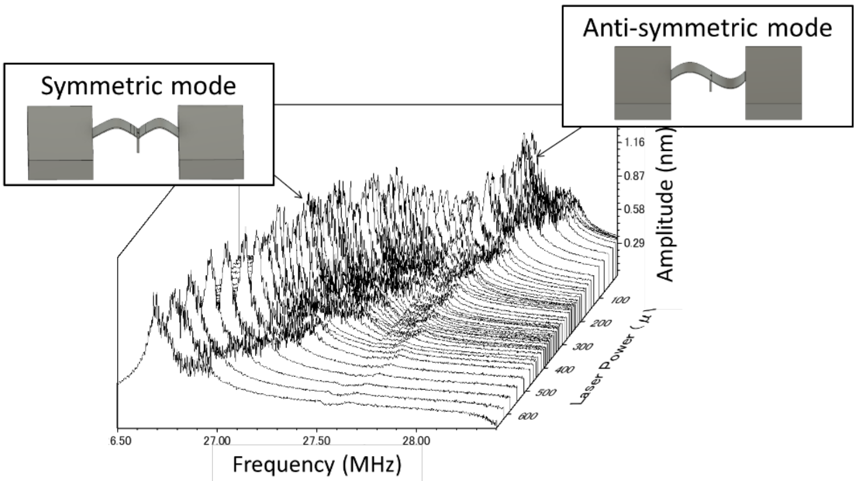

Figure 3: Resonant characteristics of nanomechanical resonators elastically coupled in series: Resonant characteristics were measured under vacuum of approximately 5 X 10^{-3} Pa and at room temperature.