Nanomechanical Tuning Forks Fabricated by Focused-ion-beam Chemical Vapor Deposition

H. Ashiba, R. Kometani, S. Warisawa, S. Ishihara
Graduate School of Engineering, The University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
ashiba@nanome.t.u-tokyo.ac.jp

Numbers of researchers have been working on nanomechanical resonators to realize various novel devices including sensors of ultra-high sensitivity. Quality factor (*Q*-factor) enhancement of the nanomechanical resonators is of great interest to the researchers because the resolution of the resonator sensors is determined by the *Q*-factors[1]. In this paper, we employed tuning forks, which are schematically depicted in Fig. 1, to achieve high-*Q* on the nanomechanical resonators. Although tuning forks are known as a traditional high-*Q* mechanical resonator, they have rarely been employed for the *Q*-enhancement of the nanomechanical resonators. The nanomechanical tuning forks were fabricated by focused-ion-beam chemical vapor deposition (FIB-CVD). A schematic of the fabrication is shown in Fig. 2. A focused gallium ion beam was irradiated on a silicon substrate in the phenanthrene ($C_{14}H_{10}$) atmosphere of 10^{-4} Pa. By controlling the irradiation point of the FIB, nanomechanical tuning forks made of diamond-like carbon (DLC) were fabricated perpendicular to the silicon surface. A scanning electron microscope image of the nanomechanical tuning forks is shown in Fig. 3. The arms of the tuning forks were 3.6–6.9 μm long, 1.1 μm wide, and 0.3 μm thick. For the vibration characteristics comparison, DLC cantilevers of the same size order were also fabricated by FIB-CVD.

Vibration characteristics of the nanomechanical tuning forks were investigated with a laser-Doppler vibration measurement system. An oscillation laser was irradiated around the base of the tuning forks and a measurement laser was irradiated around the tip of the tuning fork arms. A network analyzer was used to obtain resonant curves from the laser-Doppler measurement. The resonant frequencies and *Q*-factors of the tuning forks and cantilevers measured at 10 Pa and room temperature are plotted in Fig. 4(a). Comparing the cantilevers and the in- and anti-phase mode of the tuning forks, the anti-phase mode represented the highest *Q*-factor. The result proved that the tuning forks possess the superiority of *Q*-factor even in the nanometer-order scale. Subsequently, the same samples were measured in the air. As shown in Fig. 4(b), in contrast to the measurement in the vacuum, the anti-phase mode represented the lowest *Q*-factors. On the nanomechanical tuning forks, since the distances between the arms are too small (below 2 μm in our sample), the motion of the arm is considered to affect each other through the air between the arms. Detailed theoretical discussion about the resonant frequency and *Q*-factor of the tuning forks will be provided in the paper.

---

[1] K. L. Ekinci and M. L. Roukes, Rev. Sci. Instrum. **76**, 061101 (2005).

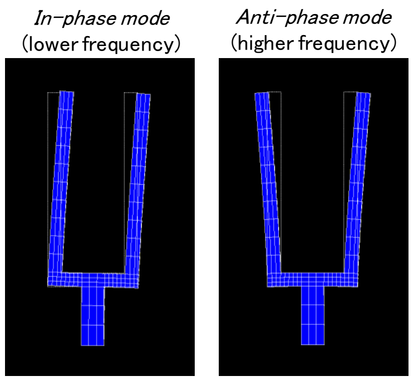

Figure 1: Tuning forks and its primal resonant modes: Since the anchoring loss is decreased, the anti-phase mode represents higher *Q*-factors.

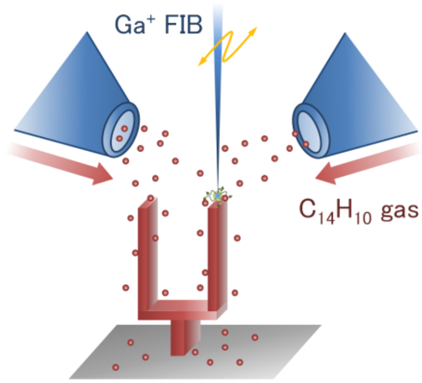

Figure 2: Schematics of tuning fork fabrication by FIB-CVD: The irradiation point of the FIB was controlled by a function generator.

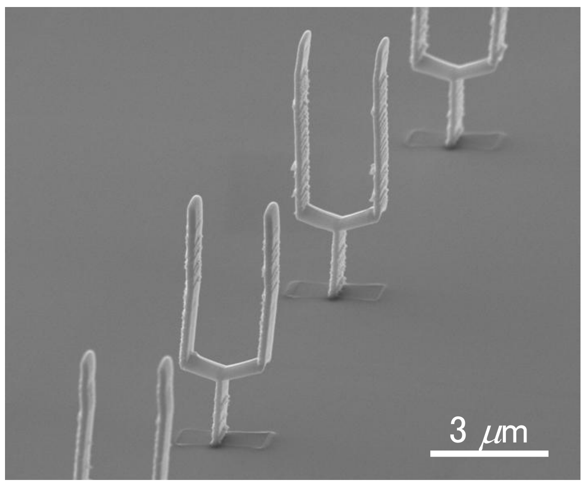

Figure 3: Scanning electron image of nanomechanical tuning forks fabricated by FIB-CVD: An acceleration voltage and a beam current of the FIB used in the fabrication were 30 kV and 7 pA, respectively. Fabrication time of the tuning forks shown in this image was 4 minutes per sample.

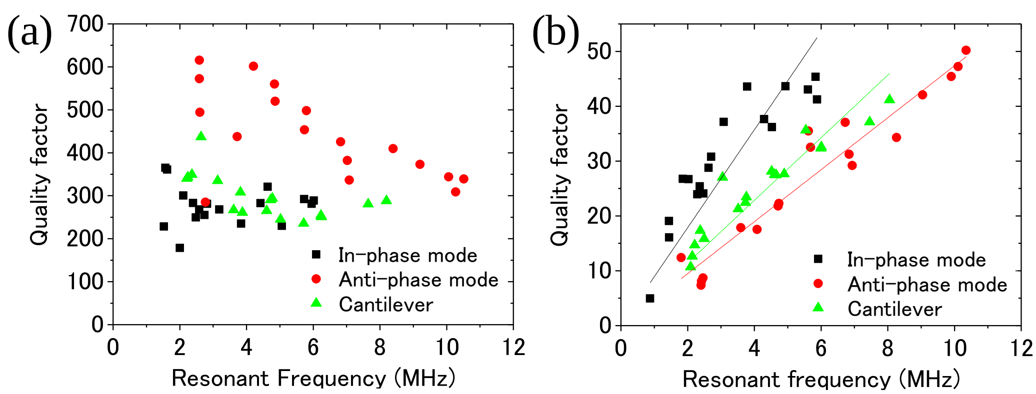

Figure 4: Experimentally measured resonant frequencies and Q-factors of nanomechanical tuning forks and cantilevers: (a) Measurement at 10 Pa. (b) Measurement in the air.