Carbon Nanomechanical Resonator Fabrication from PMMA by FIB/EB Dual-Beam Lithography

R. Kometani, T. Hatakeyama, S. Warisawa, S. Ishihara
Graduate School of Engineering, The University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
kometani@mech.t.u-tokyo.ac.jp

A resonant mechanical nanostructure attracts attention for realization of an extremely sensitive sensing device, because various small physical quantities can be detected using changes in vibration properties. And, a wet-etching process is a usual method to fabricate the three-dimensional (3-D) structure as a resonant nanostructure. However, wet-etching process often causes the fabrication error such as the formation of an undercut structure. In addition to this, we must use a dangerous chemical solution such as a hydrofluoric acid in some cases. A novel risk-free technique with the high-precision is needed to obtain the arbitrary resonant nanostructures in safety. Therefore, the 3-D nanostructure fabrication by dual-beam lithography using a difference of the penetration depth between focused-ion-beam (FIB) and electron-beam (EB) was researched in this study.

Figure 1 shows schematics of a fabrication process for carbon nanoresonators. In this study, polymenthyl methacrylate (PMMA) was used as a negative resist to fabricate carbon mechanical structure because carbon structures are useful to achieve the high-frequency device. And, in the FIB/EB dual-beam lithography process, 30 kV Ga^+ FIB and 50 kV EB were used to fabricate the suspended structures and base structures, respectively, as shown in Fig. 1-i). 30 kV Ga^+ FIB is suitable to fabricate the resonator with a thinner thickness because its penetration depth is approximately 70 nm. After the expose, a development using acetone and distilled water was carried out to fabricate the 3-D structure made of PMMA, as shown in Fig. 1-ii). Figures 2(a) and (b) show the 3-D PMMA structures fabricated by dual-beam lithography. We demonstrated that the 3-D nanostructure without undercut structures could be achieved in safety using dual-beam lithography process. After then, we tried to harden the PMMA structure by ion-beam (IB) modification using 30 kV Ga^+, as shown in Fig. 1-iii). We found that PMMA was carbonized as a diamond-like carbon (DLC) by IB irradiation with doses of 1×10^{15} ions/cm^2 and 1×10^{16} ions/cm^2, as shown in Fig. 3.

Furthermore, vibration properties of a beam-type DLC resonator were evaluated. In this experiment, a curing process for a suspended PMMA structure as shown in Fig. 4(a) was carried out by IB irradiation with doses of 1×10^{15} ions/cm^2 and 1×10^{16} ions/cm^2. As a result, a resonant frequency of a DLC resonator was increased after IB modification, as shown in Fig. 4(c), though the length and diameter became long and thin as shown in Fig. 4(b). This result implied that the carbonization, Ga^+ implantation and shrinkage of PMMA were induced by IB modification. In addition to this, this result indicates that a DLC resonant structure made from PMMA can be used for the nanomechanical device fabrications. Carbon nanoresonator fabrication by FIB/EB dual-beam lithography process and their mechanical characteristics will be reported in detail.

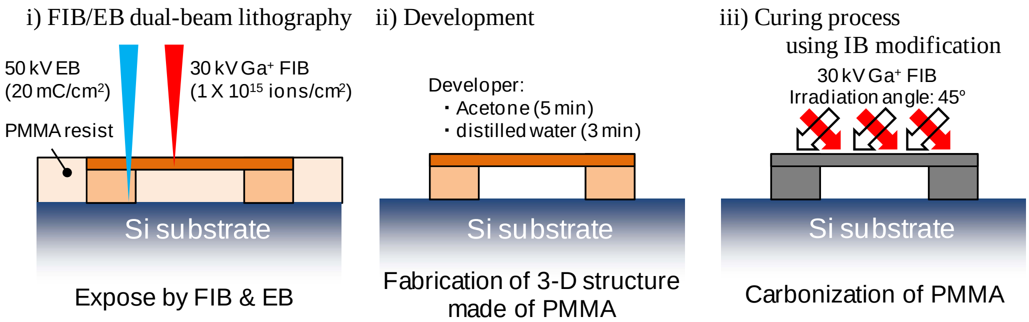

Figure. 1: Fabrication process of carbon mechanical structure by FIB/EB dual-beam lithography and curing technique using IB modification.

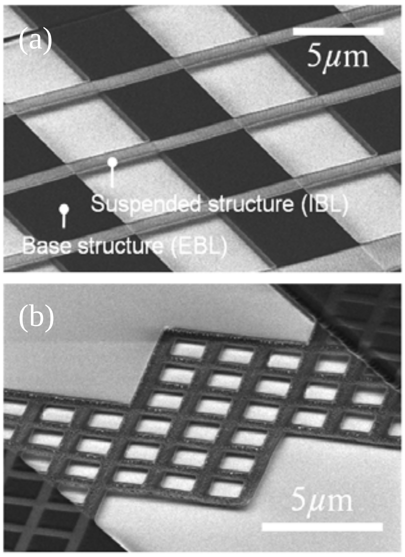

Figure. 2: The 3-D PMMA structures fabricated by dual-beam lithography, (a) a beam-type resonant structure, (b) a suspended mesh structure.

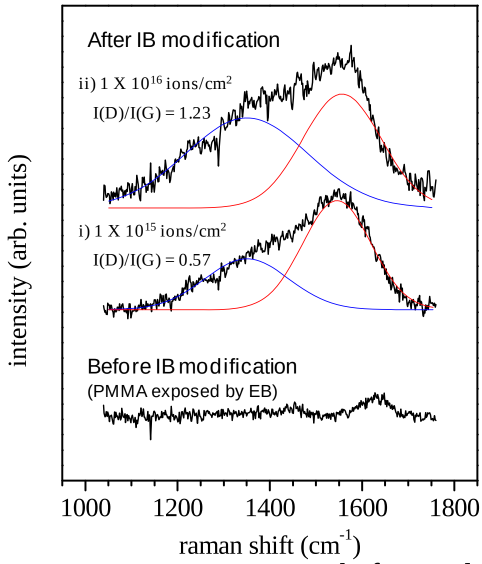

Figure. 3: Raman spectra before and after curing using IB modification with doses of i) 1 X 10^{15} ions/cm^2 and ii) 1 X 10^{16} ions/cm^2.

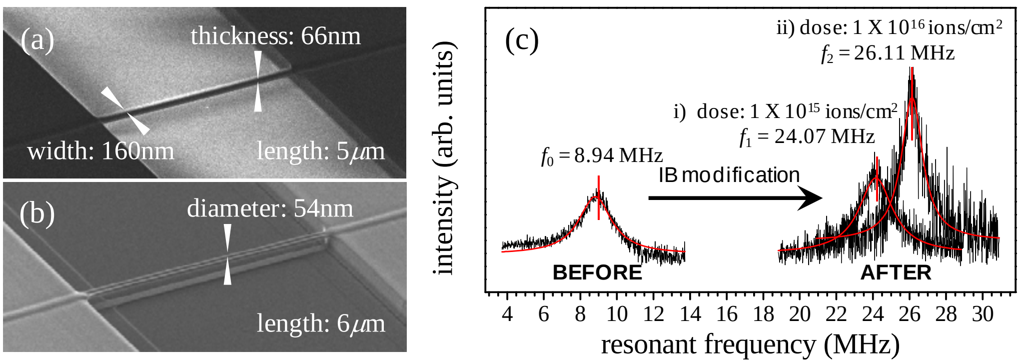

Figure. 4: Vibration properties of a beam-type DLC resonator. Scanning ion microscope images of the beam-type DLC resonator (a) before and (b) after curing using IB modification, and (c) vibration spectra obtained under the atmosphere by an optical heterodyne interferotype vibrometer.