Characterization of mechanical properties of the carbon mechanical nanostructure fabricated from SU-8 resist by FIB/EB dual-beam lithography

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Dual-beam lithography (DBL) by combining focused-ion-beam (FIB) and electron-beam (EB) is a useful fabrication technology for the precious three-dimensional (3-D) nanostructures. This technique enables the various 3-D nanostructures using difference of penetration depth of each beam, as shown in Fig. 1. Thus far, nanomechancical resonators had been researched using FIB/EB DBL[1, 2]. However, material characteristics evaluation was not enough to perform the arbitrary design of functional structures. Especially, relationship between fabrications and mechanical properties was needed in order to enable fabrication of nanomechanical devices with superior resonance properties. Therefore, detail characterization of the mechanical properties was carried out in this study.

Figure 1 show the DBL process using SU-8 resist. After pre-bake at 95 deg. C for 1 min, DBL were carried out using 30 kV Ga^+ FIB with a beam current of 40 pA and 50 kV EB with a beam current of 10 pA, respectively. Then, development and annealing treatment were carried out. Figures 2(a) and 2(b) were an example of a carbon resonant structure fabricated from SU-8 by DBL. In this study, relationships between Ga ion dose, annealing temperature and material mechanical properties of carbon nanostructures fabricated from SU-8 were especially investigated. Figure 3 show ion dose dependency of Young's modulus on each annealing temperature. These Young's modulus was measured by nanoindentation. Young's modulus was decreased with the increase in ion dose. And also, density was measured by using resonance of cantilever structure, as shown in Fig. 4(a) and 4(b). In the low dose region (< 0.8 ions/cm^2), it seems the drastically-decreasing of density was induced by effect of Ga elimination because carbonization by FIB irradiation was not so influential. On the other hand, there was no big difference in high dose region (> 0.8 ions/cm^2) although the annealing temperature dependency appeared. This result implied that the effect of carbonization by FIB was dominant. These results indicate that the low dose exposure and high temperature annealing is suitable for the nanomechanical resonator with a superior resonance, such as higher resonant frequency. These material mechanical characteristics obtained in this study would be useful as a guideline on the functional device fabrication. Relationship between fabrication, material characteristics and resonant properties will be also reported in details.

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[1] 1.R. Kometani, *et. al.*: J. Sci. Vac. Technol. B **29**, 06FE06 (2011).
2 S. Warisawa, *et. al.*: J. Photopolym. Sci. Technol. **25**, 37 (2012).

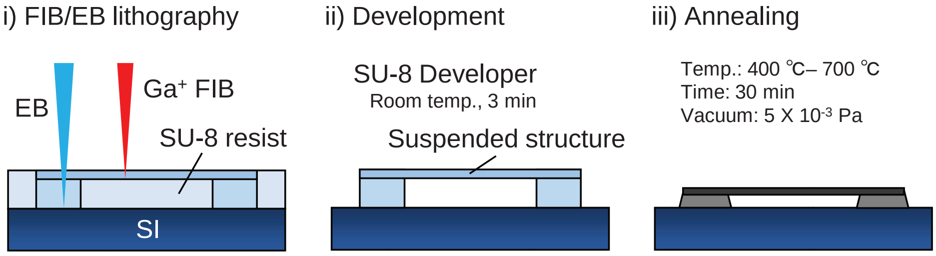

Figure 1: Fabrication process of the overhang carbon nanostructure fabricated from SU-8 resist by FIB/EB dual-beam lithography: i) SU-8 resist (SU-8 3005, MicroChem Corp.) exposure by 30 kV FIB and 50 kV EB, ii) Development of SU-8 resistusing SU-8 Developer (MicroChem Corp.), iii) Annealing treatment for 30 min under vacuum of 5 X 10^{-3} Pa

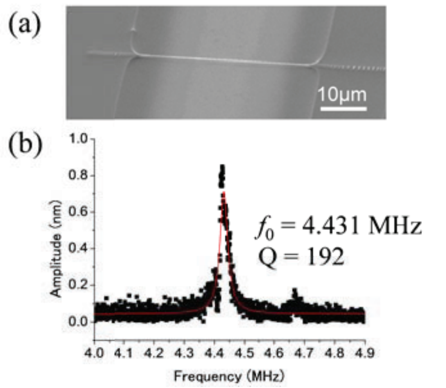

Figure 2: Example of a carbon mechanical resonator fabricated by FIB/EB dual-beam lithography: (a) SEM image of carbon resonator after 600 deg. C annealing for 30 min. (b) A resonant property

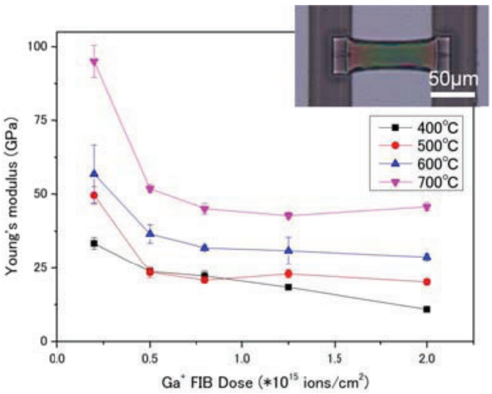

Figure 3 Young's modulus of annealed SU-8 thin film measured by nanoindentation: Inset shows an optical microscope of a measured SU-8 thin film. And, compression load was 10 μN.

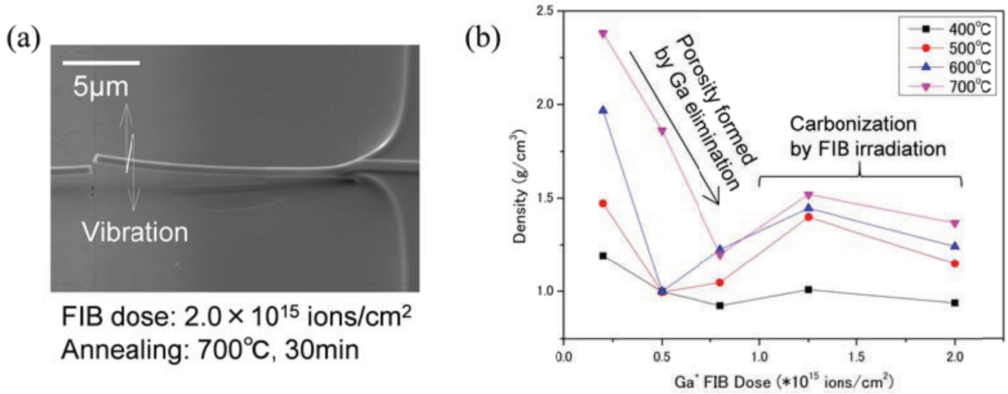

Figure 4 Density measurement using resonance of carbon nanocantilevers: (a) SEM image of a carbon cantilever fabricated by FIB/EB dual-beam lithography, (b) Relationship between Ga^+ FIB dose, annealing temperature and density. Resonance was measured under the vacuum (5 X 10^{-3} Pa) by an optical heterodyne vibrometer