Q factor enhancement of grapheme mechanical resonator by fluorine surface modification

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Nanomechanical resonator is a key component of nanoelectromechanical systems because the nanomechanical resonator enables us to detect various small physical quantities using vibration[1],[2]. And, because the lightweight structure is useful in order to achieve the high sensitive devices, the graphene attracts attention as a material of a resonant device. The high quality (Q) factor is also required for the high sensitivity. Therefore, Q factor improvement of a graphene mechanical resonator has been researched. Thus far, it had been reported that Q factor of nano- and micromechanical resonators was changed by the surface modification.[3],[4] And, Q factor was enhanced by surface with low surface free energy. This implies that the surface condition is an important factor in order to obtain higher Q factor. In this study, Q factor improvement of the graphene mechanical structure was tried by surface modification.

Figures 1(a) and 1(b) show scanning electron microscope (SEM) images of membrane-type fluorographene mechanical resonators fabricated in this study. These fluorographene mechanical resonators were fabricated on the Si substrate with a thickness of 280 nm, as shown in Fig. 2. Base structure of a graphene mechanical resonator was fabricated by electron beam lithography, reactive ion etching with CHF_3 gas and wet-etching process with a Tetramethylammonium hydroxide (TMAH). And, a monolayer graphene grown by alcohol-chemical vapor deposition (CVD)[5] was transferred onto the base structure made of SiO_2, as shown in Fig. 2-ii). Then, fluorination of graphene mechanical resonator was carried out with XeF_2 gas using a gas etching system (BP-3F, SAMCO Inc.).

Effect of fluorine surface modification to resonant properties of graphene mechanical resonators were evaluated under the vacuum of approximately 5 X 10^{-3} Pa by using an optical heterodyne vibrometer (MLD-230V-100, NEOARK Corp.), as shown in Fig. 3(a). Excitation of vibration was performed by photothermal excitation method using semiconductor laser with a wavelength of 408 nm. And, He-Ne laser with a wavelength of 632.8 nm was used for vibration measurement. Figures 3(b) and 3(c) show measurement results of resonant characteristics of a graphene mechanical resonator with a size of 2 µm square, as shown in Fig. 1(b), before and after fluorination. Flow time of XeF_2 gas for fluorination of this graphene mechanical resonator was 30 sec. Changes in the resonance properties were evaluated on vibration mode (1,1). As a result, Q factor of a graphene mechanical resonator was enhanced from 354 to 2722 by fluorine surface modification. This improvement ratio was higher than them of other nano- and micro-scale mechanical resonators [3], [4] although this is not suitable comparison because material, size and modification method were different from them of graphene mechanical resonator. Fluorine surface modification might work strongly for decreasing of surface energy loss on a graphene mechanical resonator with a large surface/volume ratio. At least, this result implies that the fluorine surface modification using XeF_2 gas is a useful method in order to improve Q factor. Effect of fluorination to resonant properties of graphene mechanical resonators will be reported in detail.

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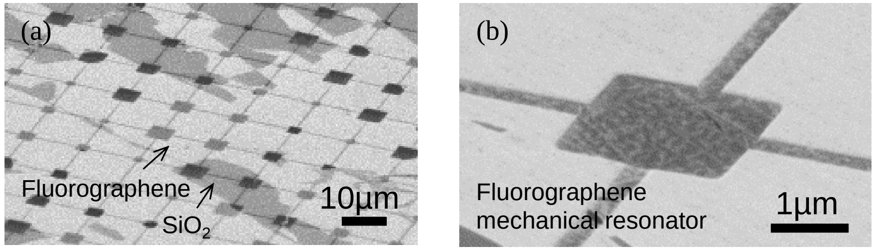

Figure 1. SEM images of fluorographene mechanical resonators: (a) Overview of fluorographene mechanical resonators with sizes of 2 µm, 3µm, 4 µm 5 µm square, (b) SEM image of a fluorographene mechanical resonator with a size of 2 µm square.

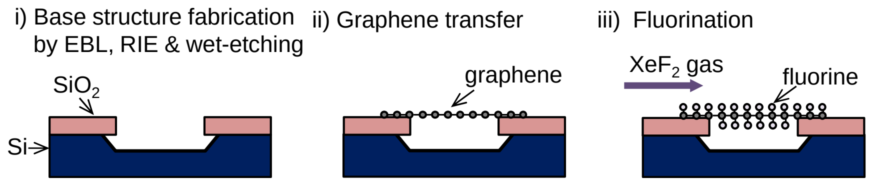

Figure 2. Fabrication process and fluorination process of a graphene mechanical resonator.

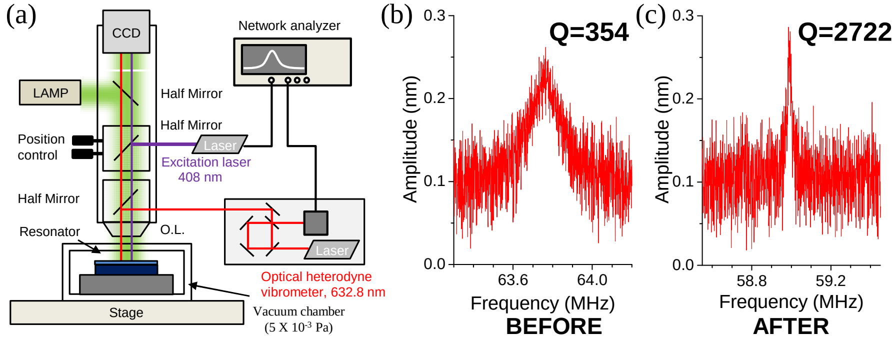

Figure 3. Effect of fluorination to Q factor of a graphene mechanical resonator with a size of 2 µm square: (a) Schematic of the experimental setup for evaluation, resonant characteristics (b) before and (c) after fluorine surface modification (Flow time of XeF_2 gas: 30 sec.). Resonance mode is (1,1).