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FABRICATION OF TENSILE STRAIN APPLYING STRUCTURE TO SUSPENDED GRAPHENE FOR NANOMECHANICAL RESONATOR WITH HIGH FQ PRODUCT

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Abstract
We developed uniaxial tensile strain applying device to suspended single layer graphene (SLG) by thermal shrinkage of SU-8 patterns. An SU-8 structure for applying strain was formed on a suspended SLG with a cavity sealed drum structure. We demonstrated large uniaxial tensile strain of the suspended SLG of 1% after baking at 50 ℃. The uniaxial tensile strain obtained here showed the highest value compared with previous reports.

1. Introduction

Nanomechanical resonators using single layer graphene (SLG) are expected to application to MEMS device because of thin thickness, low density, high Young's modulus and high strength. [1-3] We focused on MEMS resonator which is mass sensor using SLG.

The critical figure of merit of a highly sensitive resonant sensor is mass sensitivity which is inversely proportional to the density and the thickness of the resonant membrane. Thus, SLG that is low density and ultra-thin membrane is suitable to achieve high sensitivity. On the other hand, SLG is imposed degradation of the frequency resolution of resonator due to lightweight. To solve this problem, techniques for applying strain to graphene was proposed to improve both the resonant frequency and a quality factor (fQ product) which are the evaluation indexes of resonance characteristics.[4]

In this work, we developed a uniaxial tensile strain applying device by thermal shrinkage of resist to suspended SLG for improvement of fQ product. The applying uniaxial tensile strain was evaluated by Raman spectroscopy.

2. Design and fabrication

Design

Fig. 1 is a schematic view of a suspended SLG above a cavity with SU-8 patterns which employ on the suspended SLG for applying strain. Cavity size are 6 to 34 µm square and the spacing of the SU-8 patterns is designed to be narrower than the Si cavity size, therefore the SU-8 patterns are deployed on the suspended SLG. Different from the previous report of bridge structures, a microcavity formed into a Si substrate is sealed by a transferred CVD graphene, thus the microcavity sealed structure offers resist deposition by spin-coating and patterning of SU-8 by standard photolithography on the suspended graphene. Uniaxial tensile strain in the proposed device is applied by thermal shrinkage of the SU-8 patterns. By applying strain, the f-Q product of the graphene nanomechanical resonator increases, resulting in improving frequency resolution of the graphene resonator. Owing to the mechanical robustness of the suspended SLG with the cavity-sealed drum structure by the suspended SLG, wet process can be applied to the suspended SLG.

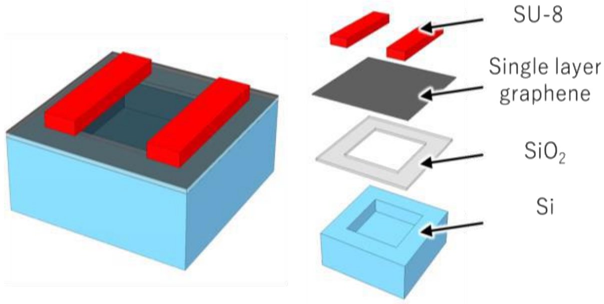

Figure 1. Schematic of strain applying structure to suspended SLG.

Fabrication

The fabrication process of the SLG device to apply tensile strain is shown in Fig. 2. An SiO_2 thin layer was formed on a Si substrate by thermal oxidation [Fig. 2(a)]. Cavities with depth of 1.8 µm were created by Deep RIE process [Fig. 2(b)]. CVD grown graphene was transferred on the SiO_2/Si substrate under vacuum [Fig. 2(c)]. Using this low-pressure dry transfer process, the inside of the cavity can be sealed with the transferred graphene, which allows wet process by preventing solution entering the cavity. [5] SU-8 (Nippon Kayaku SU-8 3005) with diluted about 3 times was spin-coated and patterned on the suspended SLG by standard photolithography [Fig. 2(d) (e)]. For releasing the suspended SLG after development of SU-8 using wet process, CO_2 supercritical drying was performed to reduce surface tension force of rinsing liquid. By these process, the applying uniaxial tensile strain device to suspended graphene is developed.

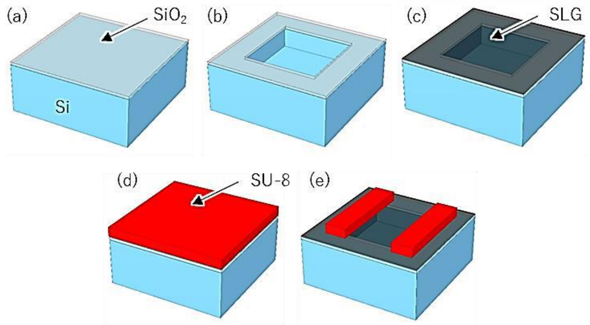

Figure 2. Fabrication process of applying tensile strain device. (a) Thermal oxidation. (b) Cavity etching by DRIE. (c) Low-pressure dry transfer of CVD graphene. (d) Spin-coating of SU-8. (e) CO_2 supercritical dry process after SU-8 development.

3. **Experimental results**

An SEM photograph of the fabricated device is shown in Fig. 3. We succeeded in forming SU-8 structures with a spacing of 8 μm on suspended SLG with a cavity of 12 μm square. Suspended SLG produced by low-pressure dry transfer technique seems to be applied initial tensile strain by the SU-8 patterns.

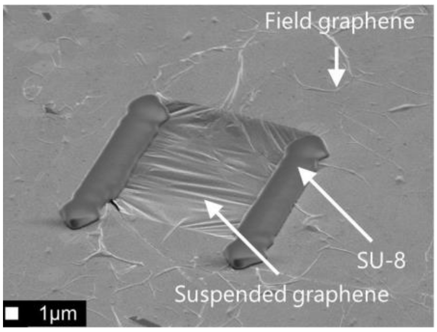

Figure 3. SEM image of the suspended SLG with SU-8 structure.

The SU-8 patterns was baked at 50-300 ° C for 10 min each to apply tensile strain, and the Raman shifts were measured by Raman spectroscopy. The G and 2D peaks are supposed to shift toward the lower and higher wave number side in the case of tensile and compressive strain, respectively. [6-8] In a previous study, the Raman shift of the G and 2D peaks induced with uniaxial tensile strain into graphene was reported to be -14.2 cm^{-1}/% and - 7.8 cm^{-1}/%, respectively. When the SU-8 was baked at 50 ℃, the G and 2D peaks of the suspended SLG shift to be -16.8 cm^{-1} and -23.3 cm^{-1} compared with the SLG fixed on the substrate, respectively.

To evaluate the strain, the position of the 2D peak versus the position of the G peak at each temperature is plotted in Fig. 5. Since it is reported that shifting to the right on the G-2D peak plot is the effect of hole doping in graphene [6], it is considered that hole doping occurred during the device fabrication. The blue line and red line show the Raman shift associated with hole doping and tensile strain, respectively. By consideration of hole doping, tensile strain induced by fabrication process is calculated 0.6%. Therefore, the tensile strain was induced to be 1.0% by thermal shrinkage of SU-8 patterns, which increases by one order of magnitude compared with previous reports of applying tensile strain with MEMS actuators and permanent tensile strain on graphene bridge. [9]

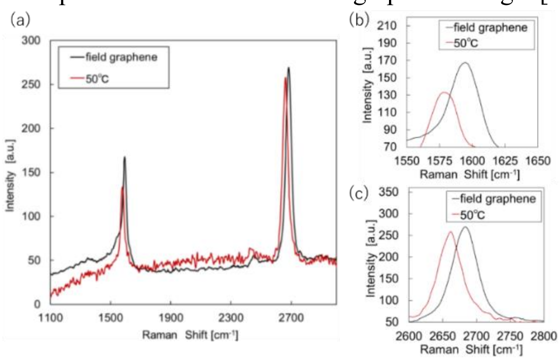

Figure 4. Raman shift after 50℃ bake (a) 1100 ~ 3000 cm-1 (b) Enlarged view of G peak (c) Enlarged view of 2D peak.

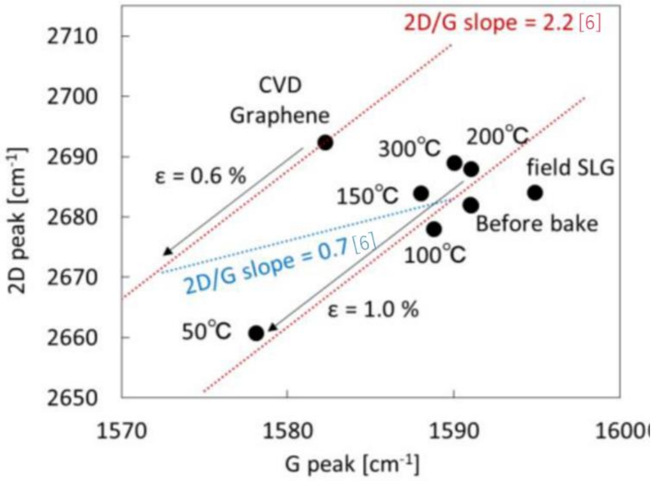

Figure 5. Position of the 2D peak versus the position of the G peak.

4. Conclusions

In this work, we fabricated a uniaxial strain applied device in suspended SLG to improve the frequency resolution of a graphene resonator. The peak shift of G, 2D peaks after baking at 50 °C was observed to be -16.8 cm^{-1} and -23.3 cm^{-1}, respectively, which suggested that 1.0% strain was obtained. Proposed device structure is capable of applying tensile strain and resonance vibration for a mass sensing and a radio frequency filter. In addition, it is possible to perform wet process for chemical functionalization or lamination of additional structures on the suspended SLG owing to the mechanically robust sealed-cavity structure. The strain applying structure obtained in this work contributes to high performance and high functionality of suspended graphene-based electromechanical devices.

Acknowledgements

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