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Strain dependent thermal transport in graphene

Due to its excellent thermal properties, graphene is expected as a thermal management material. Since the main heat carrier in graphene is phonon, the structural modifications such as isotopes [1] and defects [2] can modify the thermal transport properties in graphene. Recently, we have found that the thermal conductivity of graphene synthesized by chemical vapor deposition (CVD) also decreases when biaxial strain is applied to the graphene. As CVD-grown graphene is polycrystalline, the domain boundaries of graphene as well as the introduction of strain may be responsible for the thermal conductivity reduction. To identify the cause of the reduction, we investigate the change in the thermal conductivity of mechanically exfoliated single crystalline graphene by introducing biaxial strain. Graphene exfoliated from kish graphite was transferred onto the Si substrate, on which cylindrical holes with the diameter of 10 μm was first fabricated using photolithography and deep etching. Suspended drum-shaped graphene membranes were successfully fabricated as shown in Fig. 1. Because graphene is impermeable to air molecules [3], the pressure difference between inside and outside of the holes results in graphene bulges when the samples are located under vacuum. This deformation causes biaxial strain applied into the graphene membrane. The strain controlled by the pressure outside the holes can be estimated by Raman spectroscopy. The thermal conductivity of the suspended graphene drum during applying strain was also measured by Raman thermometry. Figure 1(b) portrays an AFM image of a graphene bulge at the chamber pressure of 110 Pa. The strain induced at the center of the bulge was estimated using the laser power dependence of the Raman G band peak shift (Fig. 2) [4]. Figure 3 shows the change in the thermal conductivity with respect to the strain applied to graphene. When the strain of about 0.06% is applied, thermal conductivity decreases by approximately 50%, showing the same trend as the result for CVD-grown polycrystalline graphene. These results imply that the graphene thermal conductivity change is attributed not to the phonon scattering by domain boundaries in graphene but to phonon transport property change induced by non-uniform strain.

References

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[3] J. S. Bunch et al., Nano Lett. 8 (2008) 2458.
[4] C. Androulidakis et al., Sci. Rep. 5 (2015) 18219.

Figures

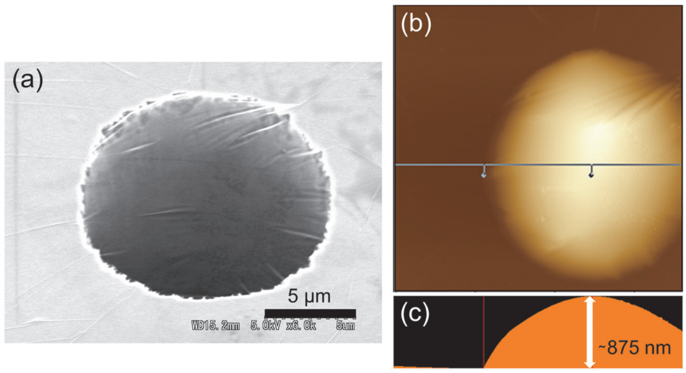

Figure 1: (a) Scanning electron micrograph of a suspended graphene. (b) Typical AFM image of a suspended graphene under 110 Pa. Top and (c) cross-sectional views.

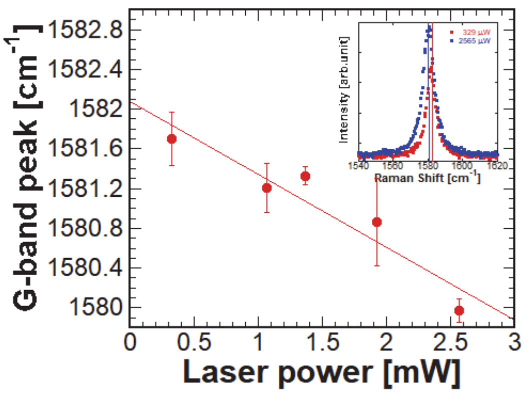

Figure 2: The laser power dependence of the Raman G band peak position at atmospheric pressure. Inset shows the G band peak at the two different laser powers.

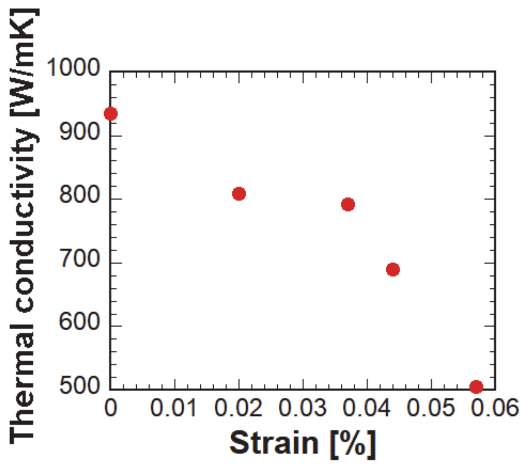

Figure 3: Thermal conductivity of mechanically exfoliated graphene with various strain.