

Tailor-made graphene for spintronic and nanoelectronic applications

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Graphene proved interesting for nanoelectronics and spintronics. There have been plenty of attempts to fabricate graphene-based devices. To realize the spintronic and nanoelectronic devices using graphene, particular concerns should be addressed to the following two issues: The first one is to form the well-defined interface between graphene and metal electrodes. The elucidation and control of the injection/detection processes of spin-polarized carriers through the graphene/metal interface are essential for designing device properties [1]. The second one is to synthesize graphene film with large area and uniform number of carbon layer. The most conventional and commonly used fabrication method of graphene is the micromechanical exfoliation of graphite [2]. However, this process cannot satisfy above requests due to the following reasons: limited sizes with large distribution in shape and layer number as well as the contamination and impurities introduced during the fabrication process. Ultrahigh vacuum chemical vapour deposition (UHV-CVD) [3] can be a promising alternative method. The UHV-CVD growth makes it possible to prepare an epitaxial graphene film on the metal surface with large area and uniform layer-number of carbon sheet. In UHV-CVD, it is considered that graphene grows by the dissociation and polymerization of hydrocarbon molecules as precursors on the catalytic metal surfaces. This allows us to control the crystallinity by the growth condition.

In this study, the process of the UHV-CVD growth of graphene on Ni(111) thin films and with benzene as a precursor are investigated using *in-situ* reflection high energy electron diffraction (RHEED) and Auger electron spectroscopy (AES) [4]. Figure 1 shows changes in the RHEED specular intensity and the Auger intensity ratio, I_C/I_{Ni} , of the C *KLL* peak, I_C , and Ni *LMM* peak, I_{Ni} , as a function of benzene exposure. It is successfully shown that SLG and bilayer graphene (BLG) can be synthesized by the control of benzene exposure in the range in $10\text{--}10^5$ langmuirs (L, $1\text{ L} = 10^{-6}$ Torr-sec) reflecting a change in the growth rate by three orders of magnitude in between the first and second graphene layer on the Ni(111) surface.

The electrical states of the transferred graphene sheets on the SiO_2 substrate are examined from the positions of the G peak and the 2D peak (Pos(G) and Pos(2D), respectively) in the Raman spectra. Figure 2 shows a plot of Pos(2D) vs. Pos(G) obtained from the randomly selected areas on the graphene sheets prepared with different benzene exposures and on the exfoliated SLG sheet. The linear increase of Pos(2D) with Pos(G) as seen in exfoliated SLG is reflective in the degree of hole doping, and the wide distribution of the peak positions, $1580\text{--}1592\text{ cm}^{-1}$ in Pos(G) and $2687\text{--}2704\text{ cm}^{-1}$ in Pos(2D), is due to the non-uniformity of the unintentional hole doping [1]. In case of the graphene sheets prepared by UHV-CVD, the Pos(G)-Pos(2D) relationship deviates from the linear one and there are rough tendencies to shift the G peak position to lower energy and the 2D peak position to higher energy with increasing exposure. These changes of the G and 2D peak positions with exposure are attributed to the increase of the layer

number. As a striking feature, it is found that the distribution of Pos(G) and Pos(2D) becomes extremely small in SLG and BLG sheets (62 L and $1.1 \times 10^5\text{ L}$, respectively). These graphene sheets are presumed to be hole-doped judging from Pos(G) and Pos(2D) which are rather close to the linear relationship in the exfoliated SLG sheet. It can be said that the uniformity of the doping degrees in graphene can be improved remarkably by using UHV-CVD under the well-controlled exposure conditions instead of micromechanical exfoliation.

The present results demonstrate that the UHV-CVD method enables a tailor-made growth of graphene which would be necessary for controls of spin transport properties including realization of a long spin diffusion length in the graphene-based spintronic devices beyond the limits of exfoliated graphene.

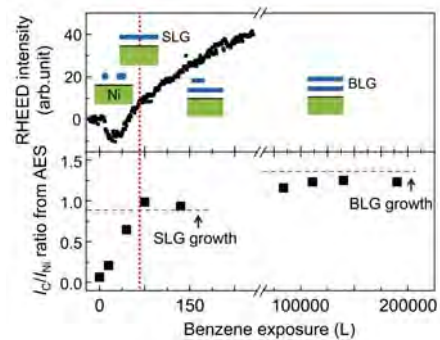


Fig. 1 (upper) Change in the RHEED specular intensities and (lower) plot of the AES intensity ratio, I_C/I_{Ni} , as a function of benzene exposure.

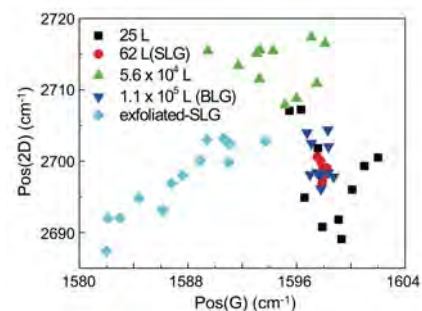


Fig. 2 Pos (2D) as a function of Pos (G). The symbols \blacksquare , \bullet , \blacktriangle , \blacktriangledown and \blacklozenge denote the data obtained from the different areas on the graphene sheets prepared at 25 L, 62 L, 5.6×10^4 L, 1.1×10^5 L exposures and on the exfoliated SLG sheet, respectively.

References

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