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Band-gap opening of graphene nanoribbons on vicinal SiC substrates

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1 Introduction

Graphene has attracted much interest because of its novel electronic properties due to massless Dirac fermions in the π band states. Modification of its band structure such as carrier doping and band-gap formation is the key for its potential applications. Graphene nanoribbon (GNR) is expected to have a band-gap in the π band due to quasi one-dimensional confinement of the carriers depending on its width and orientations [1]. So far, the band-gap opening and/or the presence of the edge state has been reported only on the GNRs made by lithographic process [2] and CVD growth [3]. In the present study, a high-density array of GNRs with ca. 10 nm width was grown on a vicinal SiC(0001) substrate by molecular beam epitaxy (MBE). The band-gap opening of at least 0.14 eV and its dependence on the GNR width have been confirmed by angle-resolved photoelectron spectroscopy (ARPES) [4].

2 Experimental

The GNRs have been grown in a separated chamber. After high-temperature etching in the H_2 gas, the vicinal 6H-SiC substrate 4°-off toward [1-100] direction exhibits periodic arrangement of terrace and step-bunching region with ca. 20 nm period (nanosurface). The carbon atoms are deposited until the terrace is covered by ($6\sqrt{3} \times 6\sqrt{3}$) R30° buffer layer. A periodic arrangement of GNRs with ca. 10 nm width is obtained by hydrogenation of the buffer layer [5] and confirmed by atomic force microscopy (AFM) observations. The polarization dependence in the Raman spectra and the line-nodes in the scanning tunneling microscopy (STM) images in vicinity of the step edges suggest the existence of arm-chair edges. At the SES-200 station of BL-13A, the samples are degassed at ~700 K before the measurement of ARPES and X-ray photoelectron spectroscopy of C 1*s* and Si 2*p* cores.

3 Results and Discussions

Figure 1 shows the dispersion relation of the π band along Γ-K-M line which is perpendicular to the extending direction of GNRs. A single and linear π band confirms the high-quality single-layer graphene on the terrace. The dots in vicinity of the K point indicate the peaks in the ARPES spectra. There is no states between the valence band maximum and the Fermi level, and the band-gap at least 0.14 eV is opened at the K point assuming the conduction band minimum at the Fermi level. We have also investigated the 5 nm width GNR grown on a 4H-SiC substrate. Its π band shows slightly larger band-gap opening. This is qualitatively consistent with the carrier confinement in the GNR.

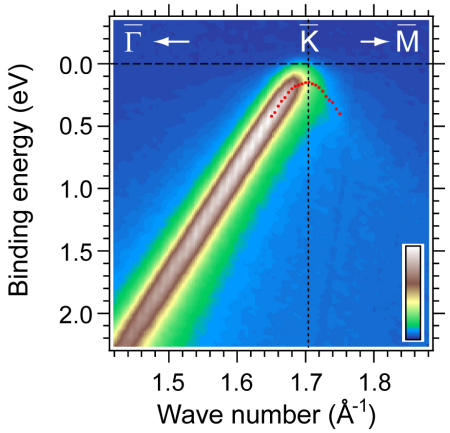

Fig. 1: The band dispersion of GNR near the K point.

4 Summary

We have investigated the π band structure of GNRs grown on vicinal SiC substrates. It shows at least 0.14 eV band-gap opening which can be attributed to the carrier confinement in the GNR.

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References

[1] K. Nakada *et al.*, *Phys. Rev. B* **54**, 17954 (1996).
[2] M. Y. Han *et al.*, *Phys. Rev. Lett.* **98**, 206805 (2007).
[3] J. Cai *et al.*, *Nature* **466**, 470 (2010).
[4] T. Kajiwara *et al.*, *Phys. Rev. B* **87**, 121407(R) (2013).
[5] C. Riedl *et al.*, *Phys. Rev. Lett.* **103**, 246804 (2009).

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