Study on magnetoresistance and carrier localization in graphene with defects induced by helium ion microscopy

NIMS[1], JAIST[2], Gunma Univ.[3], AIST[4], Hitachi Camb. Lab[5],

○Takuya Iwasaki[1*], Shu Nakamura[2], Manoharan Muruganathan[2], Masashi Akabori[2], Yoshifumi Morita[3], Satoshi Moriyama[1], Shinichi Ogawa[4], Yutaka Wakayama[1], Hiroshi Mizuta[2,5], Shu Nakaharai[1]

E-mail*: IWASAKI.Takuya@nims.go.jp

Since lattice defects in graphene has attracted interest for both theory and device application, some of experimental approaches for creating defects in graphene have been studied. Among these methods, helium ion irradiation by using the helium ion microscope (HIM) is a one of valuable way to introduce defects into graphene because the irradiation area can be precisely controlled due to high spatial resolution. Moreover, the crystalline integrity of graphene is preserved due to the defects in atomistic scale thanks to the high irradiation energy and dose level control. In previous, it was reported that the on/off current ratio of the graphene device is improved by introducing the defects by the HIM [1]. To elucidate the detailed mechanism, we investigated the carrier transport of helium-ion-irradiated graphene devices and observed the negative magnetoresistance [2]. For the fundamental understanding of this behavior, it requires the statistical analysis of the defective graphene devices with varying some experimental parameters. Here, we show the study of the carrier transport characteristics of the helium-ion-irradiated graphene devices with different dose and the channel length.

For device fabrication, graphene is transferred from highly oriented pyrolytic graphite onto SiO_2 (285 nm)/highly-doped-Si substrate by the mechanical exfoliation method. Cr/Au source-drain electrodes are fabricated by electron beam lithography, electron beam evaporation, and lift-off processes. After that helium ions are irradiated to graphene to define the effective channel region. The channel width of 500 nm is defined by insulating regions where the ions are highly dosed ($> 2\times10^{16}$ ions/cm^2). The channel length is varied from 10 to 100 nm, and the dose is controlled to 1×10^{14}, 5×10^{14}, 1×10^{15}, 5×10^{15}, and 1×10^{16} ions/cm^2. In the measurement, the electrical current is measured by two terminal DC configuration, and the back gate is used for gate modulation. Magnetic field is applied perpendicularly to graphene, and the temperature is varied from 1.6 to 300 K. From the measurement results of the device with the length of 40 nm, it was found that the magnetoresistance tended to more negative values at high magnetic field as increasing the dose. Furthermore, the magnetoresistance also has the tendency to be negative as the channel length becomes longer. These behaviors are distinctive at low temperatures, indicating that quantum interference contributes to the change in the conductivity of the defective graphene. Our study showed that the HIM enables the fine control of the channel area and ion dose level, which can control the metallic and insulating states of graphene. This paves a way to apply graphene for electronic device applications, and to investigate fundamental physics of graphene including quantum interference phenomena.

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