Negative magnetoresistance of helium-ion-irradiated graphene in the strong Anderson localization regime

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

Toward graphene-based electronics applications, introducing atomic-scale defects in graphene is an effective way to modify graphene's electronic properties.[1] So far, we have reported on charge-carrier transport properties in helium-ion-irradiated graphene under a perpendicular magnetic field to clarify the transport mechanism in the defective graphene.[2] In contrast to graphene without ion irradiation, we observed the negative magnetoresistance (MR) in the ion-irradiated graphene devices at low temperature < 200 K, and a slightly negative sign at room temperature. However, in the previous samples, only a part of graphene channel was irradiated with helium ions. Hence, the observed results could include contribution from the non-irradiated graphene area forming series resistance, which made quantitative analysis of the irradiation effect difficult. Here, we investigate the MR in the helium-ion-irradiated graphene with a new device design to exclude the contribution from the non-irradiated graphene. In the new design as shown in Fig. 1(a), helium ions are irradiated to the overall active graphene channel. We vary device conditions such as the active channel length (L), width (W), and ion dose by fabricating multi-channel devices as shown in Fig. 1(b). Note that the distance between electrodes (L_{gap}) is almost same as L. Thus, the contribution from the minimized non-irradiated graphene area should be negligible. As a result, we observe the negative MR at room temperature in the devices with the certain condition. Compared to the previous results,[2] the negative MR is robust for high magnetic fields up to 6 T, and does not change to be positive (Fig. 1(c)). Therefore, the change of a sign in the MR in the previous study could be attributed to the contribution from the non-irradiated graphene region. Our results indicate that the negative MR is caused in the ion-irradiated area and its magnitude follows the size of the irradiated area and the ion dose level. This study contributes to the development of graphene electronics and Anderson localization physics in Dirac materials.

This work was partially supported by JSPS KAKENHI 19K15385. T. Iijima and Y. Morita are acknowledged for the usage of the HIM at AIST SCR Station.

References: [1] S. Nakaharai *et al.*, *ACS Nano* **7**, 5694 (2013). [2] T. Iwasaki *et al.*, *The 66th JSAP Spring meeting*, Tokyo Institute of Technology, Mar. 9-12, 2019.

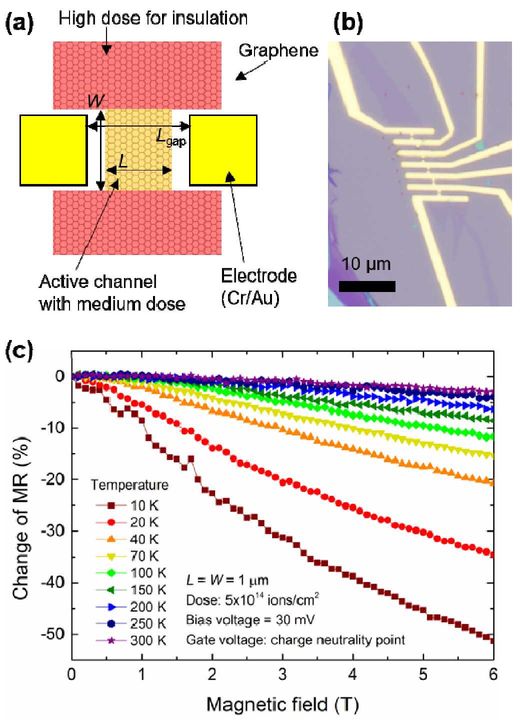

Fig. 1. (a) Schematic design of helium-ion-irradiated graphene device. (b) Optical image of a typical device. (c) MR as a function of a magnetic field.