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Fabrication of extremely-scaled graphene single-electron transistors by using He ion beam milling technology

サザンプトン大 [1], 北陸先端大 [2], ﾆｰﾏ・ｶﾙﾎｰ [1], ｼｭｵｼﾞﾝ・ﾊﾝ [1], ○岩崎拓哉 [2], ｻﾞｶﾘｱ・ﾓｸﾀﾃﾞｨｰﾙ [1], ｽﾃｭｱｰﾄ・ﾎﾞｰﾃﾞﾝ [1], ﾏﾉﾊﾗﾝ・ﾑﾙｶﾞﾅﾀﾝ [2], 水田博 [1,2]

Univ. of Southampton [1], JAIST [2], Nima Kalhor[1], Shuojin Hang[1], Takuya Iwasaki[2], Zakaria Moktadir[1], Stuart Boden[1], Manoharan Muruganathan[2], Hiroshi Mizuta[1,2]

E-mail: s1230010@jaist.ac.jp

Currently, the most established graphene device fabrication technique uses EB lithography to pattern resist deposited on top of the graphene, followed by oxygen plasma etching (Fig. 1(a)). However, parameters such as proximity effect, thickness uniformity of resist layer, and manual development of samples after e-beam lithography have limited the resolution of this method. Recently, a new patterning technique based on direct milling of graphene using a focused beam of helium ions generated in a helium ion microscope (HIM) has emerged. HIM is a new surface imaging technique that involves scanning a focused beam of helium ions across a surface to generate an image from the resulting secondary electron emission, in a similar way to scanning electron microscopy (SEM). Researchers have demonstrated that the tool can also be used to selectively sputter graphene to create intricate nanoscale designs, offering the potential of resist-free patterning of graphene on a finer scale compared to other techniques [1].

We have recently developed a new graphene nanofabrication method based on direct milling of graphene by using atomic-size helium ion beam in the HIM combined with EB lithography [2]. Metal contacts on graphene flakes were first fabricated by EB lithography using a typical bilayer resist (MMA/PMMA) and lift-off process. This step was performed first to prevent fine milled features by HIM on graphene samples from getting damaged during resist coating and/or lift-off. The prepared samples were then taken for HIM milling. We realized that the surface of graphene flakes became contaminated during the process of fabricating the metal contacts by getting exposed to resists and solvents. This contamination could increase the surface roughness of the flakes. To clean our graphene flakes the samples were annealed at ≈330 °C with 1.3 L/min forming gas flow (6% H_2 and 94% N_2) for 1.5 hours in a furnace. For mono-layer (bi-layer) graphene flakes a He dose of 0.6 nC/μm^2 (0.65 nC/μm^2) was decided to be the optimum dose for fabricating graphene devices. Figure 1(b) shows successful milling results for double quantum dots patterning after annealing. We also discuss the results of electrical characterization for fabricated QD devices.

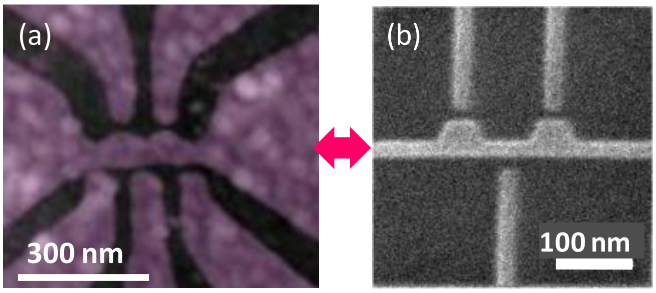

Fig. 1 Single-electron devices with double quantum dots fabricated using EB/RIE (a) and HIM-based method (b).

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