Ultra-fine Graphene Nanoelectronic Devices Carved with Tightly Focused Helium Ion Beam

S. Hang[1], Z. Moktadir[1] and H. Mizuta[1,2]

[1] Nano Research Group, University of Southampton, United Kingdom
[2] Japan Advanced Institute of Science and Technology (JAIST), Japan

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We have fabricated and measured a down-scaled bent [1] graphene nanostructure using a novel approach involving combination of helium ion microscope (HIM) with conventional electron beam lithography (EBL). Mono- and multiple-layer graphene (exfoliated) nano-ribbons (GNR) of 150 nm in width were prepared by EBL followed by lift-off of Ti /Au as ohmic contacts. A 30nm wide U-shape graphene channel was carved afterwards using a highly focused helium ion beam (fig. 1).

HIM was initially designed as a powerful imaging instrument with a higher resolution than that of the scanning electron microscope (SEM). Owing to the smaller *de Broglie* wavelength of helium ions and a confined interaction volume where the secondary electrons are generated, the spot size of the beam can be as small as 0.35nm. In addition, the high energy helium ions bombard atoms away effectively from the lattice when the beam hits the surface, making HIM a unique tool capable of milling ultrafine structures on atomically thin materials such as graphene and its multilayers. The precise cutting using HIM has been previously demonstrated [2-3], but its full potential remains unexplored. By using HIM, we have achieved a record-small graphene double quantum dots (DQD) structure (fig. 4). No extensive measurements have been reported on any HIM-made nano-devices so far, to our best knowledge.

We made preliminary measurement on a bent GNR after the HIM patterning. The milled GNR with a U-shape channel shows a linear *I-V* characteristic (fig. 3). These measurements show drain current fluctuations, particularly at high bias. This fluctuation is possibly due to charge trapping/de-trapping caused by trapped helium ions near the oxide surface during milling.

In conclusion, we demonstrated a novel technique combining electron beam lithography with helium ion milling that enables the reproducible patterning of extremely down-scaled graphene devices with sub-nm resolution.

References:

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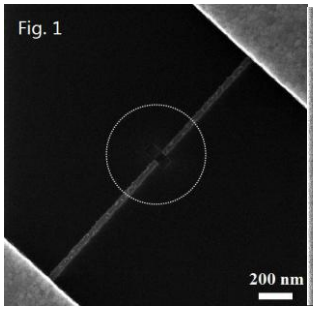

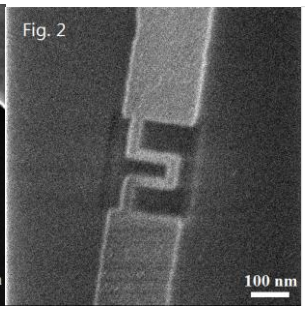

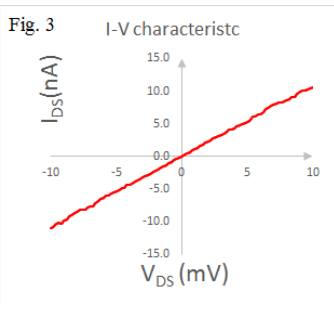

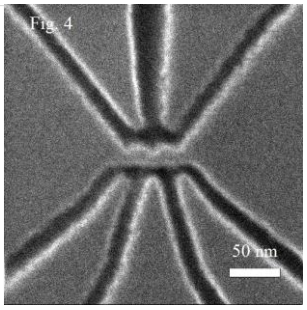

Fig. 1: HIM image of a tri-layer graphene nano-ribbon (W=80nm, L=2µm). The circle indicates the region where the HIM milling was taking place. Fig. 2: HIM image of a tri-layer U-shape graphene channel (W≤50nm) carved by a focused helium ion beam. A square area of SiO_2 surrounding the channel was also milled as defined by the pattern. Fig. 3: the preliminary *I-V* characteristic of the device shown in fig. 2. Fig.4: a well-defined DQD structure showing the patterning potential of HIM. The dot size is 20 nm while the distance between side gates and the dots/constrictions is around 10 nm.