Graphene nanomesh patterned by helium ion beam milling towards the application of quantum devices

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Graphene quantum dots attract much interest to both fundamental physics and device engineering [1-2]. However, in contrast to the silicon devices with two-dimensional electron gases, graphene has no bandgap to build the energy barrier for the gate modulated quantum dots performance. The most common method is to pattern the graphene into graphene nanoribbons (GNRs), which profits from the geometrically confined energy gap [3]. In order to obtain larger geometrical confinement, the GNRs need to be smaller than 30 nm [3]. On such a small scale, the substrate defects will significantly affect the transport properties of the GNR [4]. Although the substrate can be removed to achieve the suspended structure, the suspended ultra-scaled GNR in sub-10 nm is quite challenging both in fabrication and characterization [5]. From the recent report [6], graphene nanomesh (GNM) devices show an activation energy exponentially increment by decreasing the porosity, which can be treated as ultra-scaled GNRs arrays. In this study, we fabricated the graphene nanomesh devices by using the helium ion beam milling technique, and the coulomb blockade oscillation was observed at the low temperature, which leads the way to use GNM devices for the application of quantum devices.

The suspended GNM devices were fabricated by milling periodic nanopores on the suspended large area (500 nm long and 1200 nm wide) GNR device (Fig. 1). By controlling the dwell time at 45000 us and beam current at 1 pA, the nanopore diameter was measured as 6 nm by contrast from the pores. We defined that pitch is nanopore center to center. In this condition, the smallest pitch we achieved was 15 nm (Fig. 2-3). A pitch limitation caused by the surrounding defected region was proposed. We characterized the gate modulation for a GNM device with a 30 nm pitch size at 300 K and 5.6 K. The p-doped silicon substrate was used as a back gate. At 5.6 K, a wide transport gap was observed between 0 to 20 V. And in the transport gap region, the Coulomb blockade oscillation was also identified. In comparison, we showed the same characterization for the identical size of the GNR device (500 nm long and 1200 nm wide) in Fig. 5. It indicated that the GNM can be used as a primary element to build quantum devices on a large area of graphene, which can overcome the fabrication limitation of the ultra-scaled GNR devices.

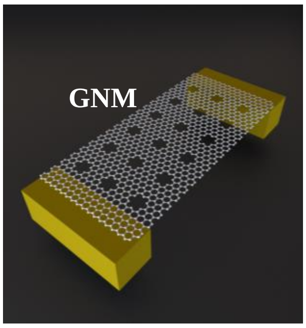

Fig. 1: Schematic illustration of GNM

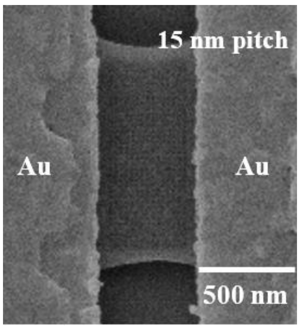

Fig. 2: Successfull with 15 nm pitch

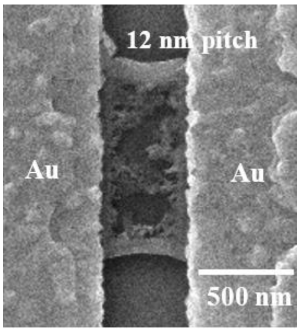

Fig. 3: Failed with 12 nm pitch

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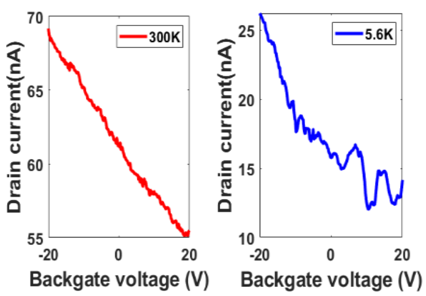

Fig. 4: Backgate characteristic of GNM with 30 nm pitch at 300 K and 5.6 K

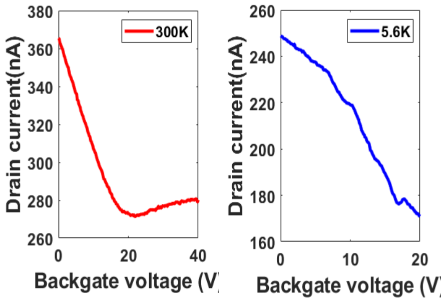

Fig. 5: Backgate characteristic of GNR with 30 nm pitch at 300 K and 5.6 K

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