Irradiation Induced Tunnel Barrier in Side-gated Graphene Nanoribbon

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***Abstract* — We investigated a method of forming tunnel barriers in monolayer graphene nanoribbon (GNR) using controlled ion irradiation. By using a helium ion microscope (HIM), we are able to reduce the width of exposure area down to 5nm. Source-drain conductance of side-gated GNR has been measured and the gate capacitances were extracted.**

I. INTRODUCTION

Graphene quantum dot (GQD) is a potential platform to realize spin qubit owing to predicted long coherence time in graphene[1]. However, several issues prevent the effective confinement in GQD. The absence of a band-gap in graphene poses challenge to completely shut off the current. In addition, electrons in graphene are Dirac Fermions with a linear dispersion relation associated with the well-known Klein paradox, in which electrons could tunnel into a potential barrier with no reflection. This unique feature makes electrostatically defined potential barriers not feasible for monolayer graphene.

One method to create a transport gap in graphene is to lithographically reduce the channel size beyond the active width of GNR of ~16nm. This method has been used to define constrictions in various GQD structures [2]. However further downscaling requires advanced patterning technology beyond the resolution of electron beam lithography (EBL). Recent progress on direct milling using ion beam[3] has shown very high patterning resolution. This method facing the problems of process integration and damage issue from high energy bombardment of substrates[4]. Here, we propose a new fabrication technique that tackles these issues by combining EBL and modest ion irradiation in HIM.

II. RESULTS AND DISCUSSION

A. *Fabrication methods*

Figure 1 shows the schematic of our device. The GNR was prepared by etching the EBL-defined pattern into exfoliated graphene. Both channel width and gate-to-channel distance are 50nm. The rest of the ribbon is 400nm wide. Tunnel barriers were formed by irradiating 5nm strips on the GNR by He^+ ions with an equivalent defect density of~8×10^{12} cm^{-2} as estimated from Raman spectrum[4]. By patterning two barriers with close proximity, a quantum dot structure can be effectively created. Two side gates (SG) are responsible for controlling the potential in the barriers one plunger gate (PG) tunes the central island. It should be noted that when zooming at high magnification (~80,000), imaging dose is comparable with patterning dose. Therefore it is crucial to mask the GNR to avoid any undesired exposure.

B. *Preliminary measurement*

We measured room temperature (RT) conductance after one 5nm strip was irradiated in the GNR channel (see Fig. 2). Figures 3, 4 show the contour plot of conductance as a function of V_{BG} and V_{SG} (Fig. 3) and V_{BG} and V_{PG} (Fig. 4), respectively. In the former case, two side gates are connected, i.e. $V_{SG\ (L)}=V_{SG(R)}$. Two distinct slopes (the trajectory of charge neutrality point (CNP)) can be observed, from which the gate capacitance can be observed outlining four different potential configurations: *p-n, p-p, n-n and n-p*. The side gate capacitances can be estimated from the diagonal slope (thick dashed line), $C_{SG} = C_{BG}(\frac{\Delta V_{SG}}{\Delta V_{BG}})^{-1} \approx 72nF$.Similarly, $C_{SG} \approx 60nF$. Another notable feature is the unipolar transport at *p-n* regime. However, the role of irradiation played here is yet clear at this point. Higher dose may be needed for more observable change.

III. CONCLUSION

5nm wide strip was irradiated on a side-gated GNR. Room temperature conductance measurement showed electrostatic modulation on the channel by side gates. These can be used as control gates to tune the potentials in both barriers and quantum dots formed by irradiation. This work was partly supported by JAPAN Grant-in-Aid for Scientific Research (S) 25220904.

REFERENCES

[1] B. Trauzettel, D. V. Bulaev, D. Loss, and G. Burkard, “Spin qubits in graphene quantum dots,” *Nat. Phys.*, vol. 3, no. 3, pp. 192–196, Feb. 2007.

[2] L. A. Ponomarenko, F. Schedin, M. I. Katsnelson, R. Yang, E. W. Hill, K. S. Novoselov, and A. K. Geim, “Chaotic Dirac billiard in graphene quantum dots.,” *Science*, vol. 320, no. 5874, pp. 356–8, 2008.

[3] N. Kalhor, S. A. Boden, and H. Mizuta, “Sub-10 nm patterning by focused He-ion beam milling for fabrication of downscaled graphene nano devices,” *Microelectron. Eng.*, vol. 114, pp. 70–77, 2014.

[4] S. Hang, Z. Moktadir, and H. Mizuta, “Raman study of damage extent in graphene nanostructures carved by high energy helium ion beam,” *Carbon*, vol. 72, pp. 233–241, 2014.

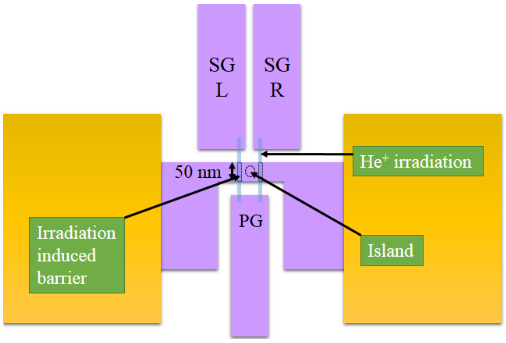

Fig.1 Schematics of our device. Single quantum dot is confined by two strips (blue) of insulating area made by ion irradiation.

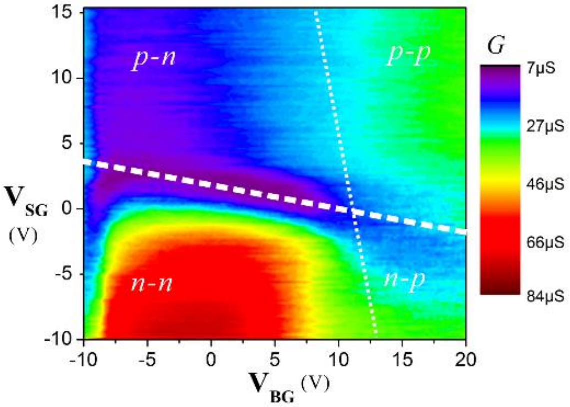

Fig.3 Contour plot of the source-drain conductance as a function of V_{SG} and V_{BG}. White dashed lines indicate CNPs for the bare (thin) and SG-controlled (thick) region

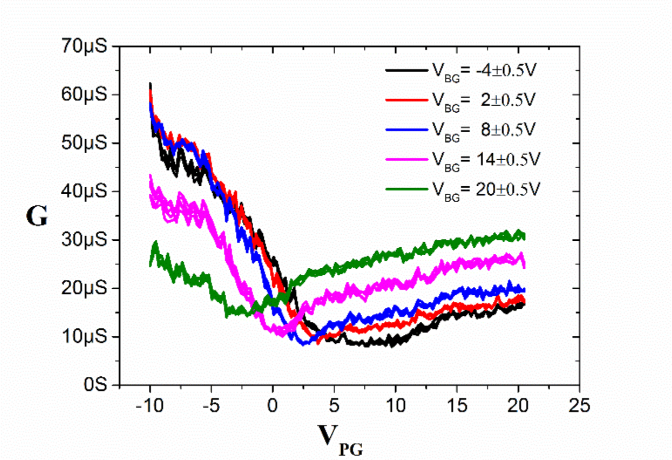

Fig. 5 Conductance as a function of V_{SG} for V_{BG}=-8, -4,0,4 and 8 V, as extracted from Fig.3. Unipolar transport can be observed by the black line.

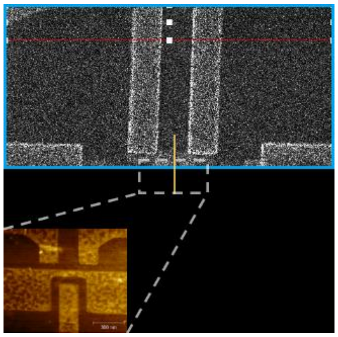

Fig.2 HIM irradiation of 5nm strip in the channel (yellow vertical line). The blue frame outlines the image region. Inset shows the AFM image of our device.Scale bar is 300nm.

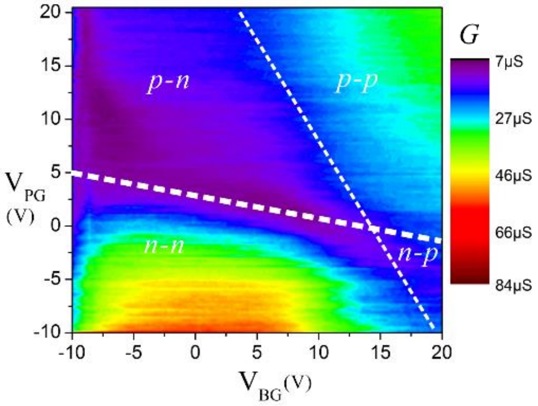

Fig.4 Contour plot of the source-drain conductance as a function of V_{SG} and V_{BG}. White dashed lines indicate the CNPs for the bare (thin) and PG-controlled (thick) regions.

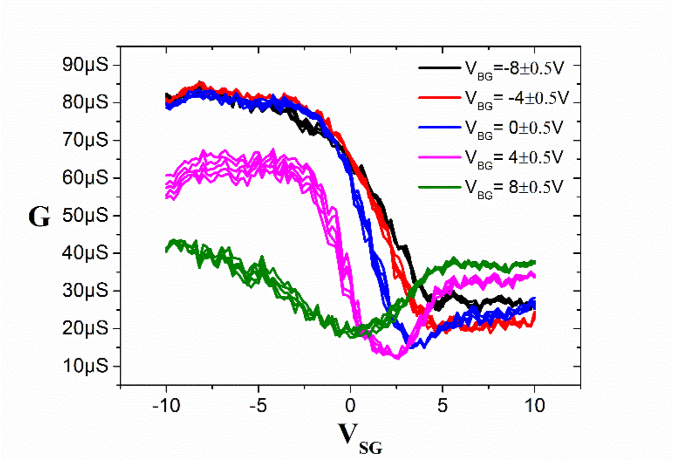

Fig. 6 Conductance as a function of V_{SG} for V_{BG}=-4,2,8,14 and 20 V, as extracted from Fig.4.