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Graphene Nanoribbon Growth and Dual-Gated Graphene Transistors

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Graphene is a candidate for a transistor channel in future LSIs because of its excellent electrical properties, including extremely high carrier mobility. Graphene, however, does not have an intrinsic band gap. One of the methods to form a bandgap is to make graphene into a nanoribbon. In this presentation, we mainly explain two topics regarding graphene nanoribbons (GNRs). One is about self-organizing GNR formation on Cu twin crystals by chemical vapor deposition (CVD) [1]. The other is about novel dual-gated GNR transistors [2]. They are explained below.

Narrow twin crystal regions are often formed when Cu film is annealed. We have found that graphene can be selectively grown only on the twin crystal regions with a (001) or high-index surface by tuning the growth condition of CVD [1]. Scanning electron microscopy (SEM) images of graphene ribbons on twin crystals are shown in Figure 1, along with a scanning transmission electron microscopy (STEM) image. The optical microscopy images with Raman spectra are also shown. GNRs as narrow as ~90 nm were obtained in the experiments. We have found that the partial pressure of CH_4 in Ar/H_2 carrier gas is a key to controlling the selective growth. The preferential graphene nucleation and formation seem to be caused primarily by a difference in surface-dependent adsorption energies of reactants, which has been estimated by first principles calculations. Concentrations of reactants on a Cu surface have also been analyzed by solving a diffusion equation that qualitatively explains our experimental observations of the preferential graphene nucleation.

We proposed a P-I-N junction switching device with a GNR [2]. The device has two bulk graphene regions where the carrier type is electrostatically controlled by a top-gate, and the two top-gated regions are separated by a GNR (Figure 2). The GNR works as insulator, resulting in a junction configuration of (P or N)-I-(P or N). The operation principle is illustrated in Figure 2. The drain current modulation strongly depends on the junction configuration, while the nanoribbon is not directly top-gated. The off state is realized by applying voltages with different polarities to the two gates. The device with a P-I-N or N-I-P junction actually exhibited better switching properties, as shown in Figure 3. The width of the GNR in this case was about 40 nm. The switching characteristics are expected to improve further by employing narrower GNRs.

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[2] S. Nakaharai, T. Iijima, S. Ogawa, H. Miyazaki, S. Li, K. Tsukagoshi, S. Sato, and N. Yokoyama, Appl. Phys. Express **5** (2012) 015101.

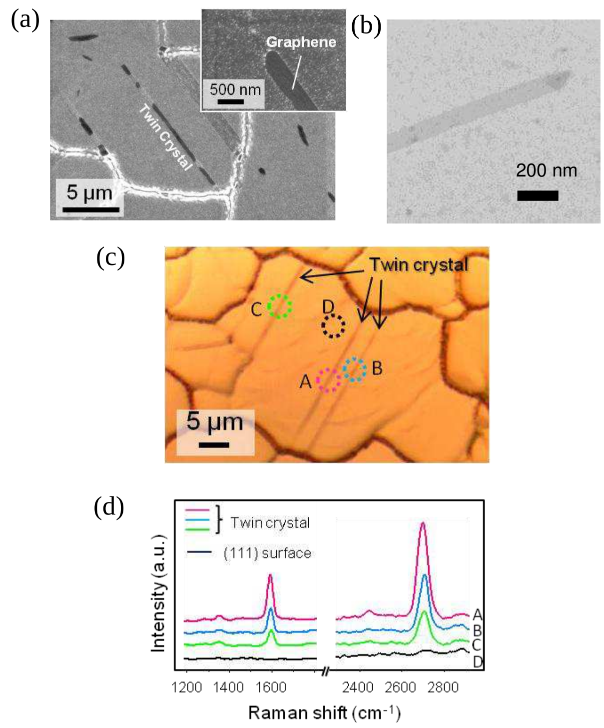

Fig. 1. (a) SEM image of Cu grains with twin crystal regions. Dark areas show the regions where graphene is formed. (b) STEM image of GNR. (c)Optical microscope image of Cu grains including twin crystal regions on which graphene is grown. (d) Raman spectra of the twin crystal and normal regions shown in (c).

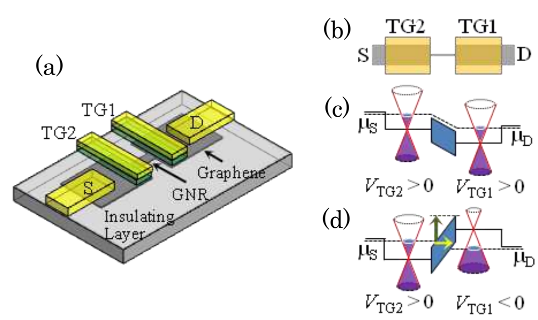

Fig. 2. (a) Schematic of proposed GNR device. (b) Top view of the device. (c) Band diagrams for the device in on-state. (d) Off-state is obtained by flipping polarity of either V_{TG1} (or V_{TG2}). Here, a small horizontal arrow represents barrier length and a vertical arrow represents barrier height for carrier transport.

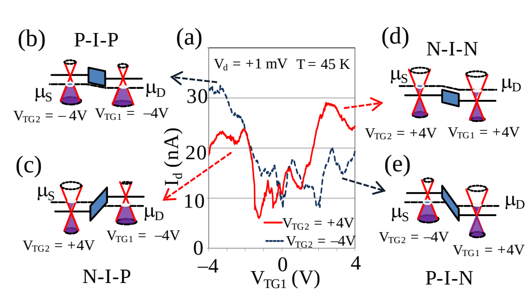

Fig. 3. (a) Top-gate modulation of drain current in P-I-N junction device at V_d = +1 mV and T = 45 K. I_d-V_{TG1} curve at fixed V_{TG2} = +4 V is colored in red, and corresponding junction configurations are illustrated in (c) and (d). Similarly, curve at fixed V_{TG2} = –4 V is in blue (broken) and illustrated in (b) and (e).