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Thickness-dependent resistance change of dual-gated thin graphite films

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We present fundamental researches on thin graphite film, with the goal of realizing future nanometer scale electronic applications. Because thin graphite films are by nature nanometer scale materials with remarkable electrical conductions, they are expected to be an important element in nano-carbon electronics. For a control of the conduction of the thin graphite channel, gating effect must be fully clarified.

Our starting materials are thin layers (thickness 1-10 nm) of graphite films pealed off from bulk graphite on SiO_2/doped-Si substrate. The thin film is connected to two or multiple metallic electrodes. In general, conduction of the graphite can be changed in gate voltage applied to the doped-Si substrate. In this configuration, the gate electric field can be applied from the substrate side (back-gate configuration). Observed resistance in the gate-voltage change shows ambipolar behavior based on clear carrier polarity change.

We attached a front gate, which was directly formed on the surface of the graphite film. We deposit an Al electrode on the graphite film (Fig. 1). The graphite channel and the Al electrode are naturally insulated by exposed in air. Then the Al electrode can be used as a front gate. The front gate also changes the conduction of the thin graphite film.

A scan of the top gate voltage (V_{tg}) generates a resistance peak in the ambiploar response. In relatively thicker film (~7 nm), the back gate voltage (V_{bg}) shifts the ambipolar peak depending only slightly (Fig. 2). On the other hand, the shift is clear in thinner film (~1 nm) (Fig. 2). The thickness-dependent peak shift is clarified in terms of the inter-layer screening length λ to the electric field in the dual-gated graphite film. We assume that the gate-induced carriers decay exponentially from both surfaces, and that the conductivity in each layer increases proportionally to the induced carrier density. The ambipolar peak corresponds to the situation that the carriers induced by the back gate is maximally ejected by the top gate. Then the condition for the ambipolar resistance peak in V_{tg} scan is obtained as a function of V_{bg}, λ, and the graphite film thickness d. Then, we estimated a screening length of 1.2 nm [1].

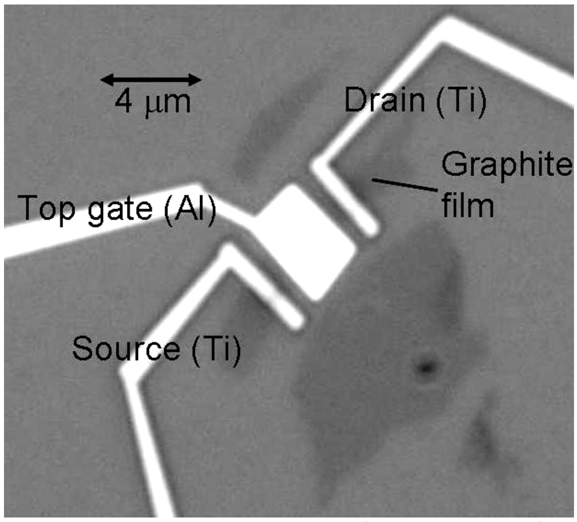

Fig.1 Optical microscope image of a thin graphite film with source-drain electrodes and a Al top gate on SiO_2/Si substrate.

In films thicker than 2 nm, ambipolar resistance peak decreases at large V_{bg}. This is because the carriers induced by the back gate cannot be ejected completely by the top gate in the films thicker the screening length. On the other hand, we observed enhancement of ambipolar resistance peak at large V_{bg} in 1 nm-thick films. This could be possibly caused by gap opening by perpendicular electric field. The energy gap estimated from the temperature dependence of the peak resistance is about 4 K. More experiments are necessary to clarify the mechanism of this phenomenon.

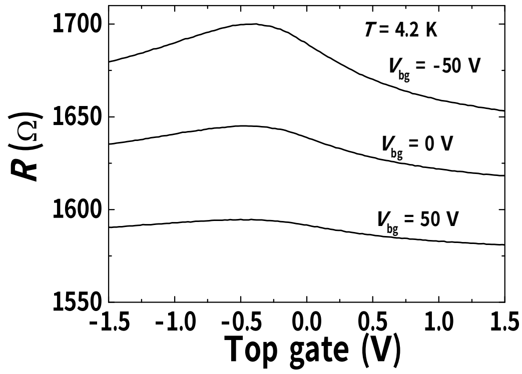

Fig. 2 Resistance dependence of 7-nm-thick graphite film on the top gate voltage at V_{bg}=-50, 0, and 50 V.

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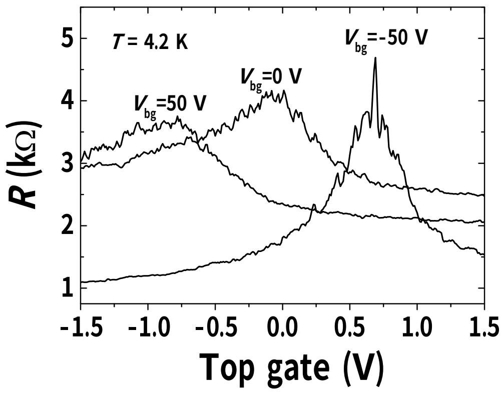

Fig.3 Resistance dependence of 1-nm-thick graphite film on the top gate voltage at V_{bg}=-50, 0, and 50 V.

References

[1] H. Miyazaki, S. Odaka, T. Sato, S. Tanaka, H. Goto, A. Kanda, K. Tsukagoshi, Y. Ootuka, and Y. Aoyagi, Appl. Phys. Exp. **1** (2008) 034007.