Carbonaceous field effect transistor with graphene and diamondlike carbon

Susumu Takabayashi[1,2], Shuichi Ogawa[3], Yuji Takakuwa[3], Hyun-Chul Kang[1], Ryota Takahashi[1], Hirokazu Fukidome[1,2], Maki Suemitsu[1,2], Tetsuya Suemitsu[1,2], Taiichi Otsuji[1,2]

[1] Research Institute of Electrical Communication, Tohoku University,
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan
[2] JST-CREST, 5 Sanban-cho, Chiyoda-ku, Tokyo 102-0075, Japan
[3] Institute of Multidisciplinary Research for Advanced Materials, Tohoku University,
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan
stak@riec.tohoku.ac.jp

Selection of the gate dielectric is a critical issue for fabrication of topgate graphene field effect transistors (G-FETs).[1] Well-known oxide gate dielectrics are not applicable due to the oxidative destruction of the π-system of graphene during the deposition process.

Diamondlike carbon (DLC) is a carbonaceous material with an amorphous structure composed of sp^2 carbon, sp^3 carbon, and hydrogen.[2] DLC behaves widely in electrical characteristics as from a conductor to a dielectric by controlling the amount of hydrogen incorporated.[3] So far, dielectric DLC films have been challenged as topgate dielectrics of Si FETs, but have not become popular because the production accompanies carbon waste and resultant contamination so that it may not be suited for the clean-room fabrication process. On the other hand, in graphene devices, DLC may be applicable because of the affinity in material chemistry between graphene and DLC. In this work we have fabricated a topgate G-FET with a DLC film as a gate dielectric (DLC-gated G-FET).

Figure 1 shows the schematic cross section of the DLC-gated G-FET. Graphene used here is prepared on a 6H-SiC substrate by annealing.[4, 5] Pt was selected as the source and drain ohmic-contact metal because of its better adhesion and affinity to graphene.[6, 7] The channel width (W_C), channel length (L_C), and gate length (L_G) were 11, 6, and 5 μm, respectively. The DLC gate was prepared by photoemission-assisted plasma enhanced chemical vapor deposition (PA-PECVD).[8, 9] This consists of dc plasma triggered by UV-photoemission from the sample, giving much smaller output power to minimize the plasma damage to graphene. The thickness of the present DLC gate was 100 nm. The dielectric constant was 5.1 and the equivalent oxide thickness (EOT) was estimated to be 76 nm.

Figures 2 and 3 show the I_{DS}-V_{DS} and I_{DS}-V_{GS} characteristics, respectively. For both cases V_{GS} scans from (a) -12 and (b) +12 V, respectively. No drain current saturation is observed in the I_{DS}-V_{DS} characteristics (Figs. 2(a) and (b)), reflecting non-Bernal stacked gapless graphene formation. When V_{GS} scans from -12 V (Figs. 2(a) and 3(a)), the device operates in the ambipolar mode and the Dirac voltage (V_{Dirac}) is observed in the far positive region. On the other hand, when V_{GS} scans from +12 V (Figs. 2(b) and 3(b)), the ambipolar mode is also observed, but V_{Dirac} is observed in the far negative region. This hysteresis may be the difference of the hole or electron doping induced by V_{GS}. Theoretically in the ambipolar mode V_{Dirac} shifts with V_{DS} at the level of 1/2 V_{DS} where the concentration of electrons and holes are in equilibrium; however, the observed ones are much higher (lower) when V_{GS} scans from negative (positive), suggesting that the graphene channel is still *p*- (*n*-) doped.

Figure 4 shows the transconductance (g_m)-(V_{GS} – V_{Dirac}) characteristics obtained from Fig. 3(a). The maximum absolute g_m's in *n*- and *p*-channel modes of the ambipolar performance are 6.3 and 2.8 mS/mm, respectively. Considering that g_m is in proportion to the reciprocals of L_G and EOT, $|g_m|$ = 2-3 S/mm, which is an extremely high value, is expected when L_G = 100 nm and EOT = 10 nm.

Consequently, although the hysteresis is a critical issue to be solved, DLC can be a promising material as a gate dielectric of a topgate G-FET.

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Figures

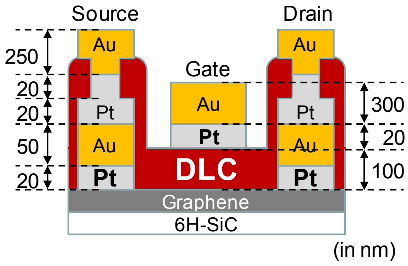
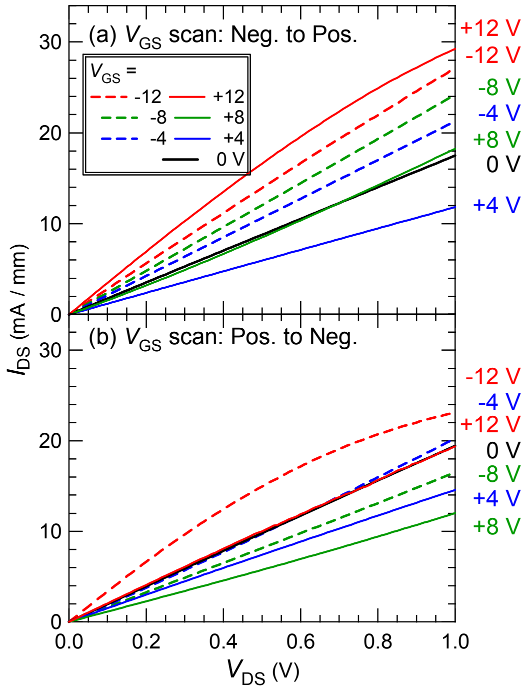


Figure 1 Schematic cross-section of the DLC-gated G-FET. The scale of each block is shown in nm.



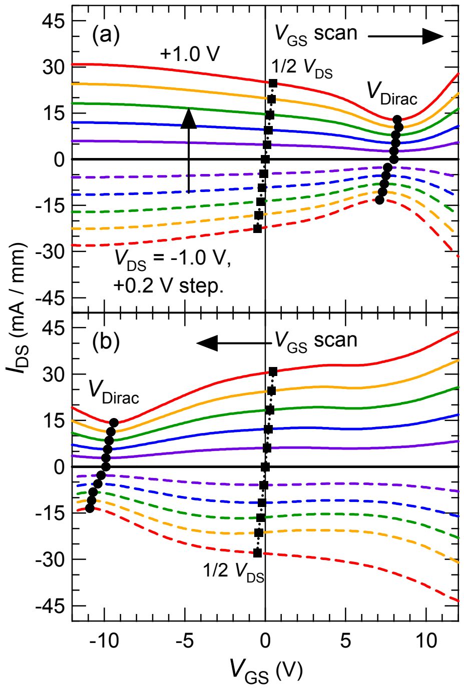


Figure 2 (left) I_{DS}-V_{DS} characteristics of the DLC-gated G-FET at different V_{GS}'s. V_{GS} was stepped by (a) +4 V from -12 and (b) -4 V from +12 V. V_{GS} applied at each curve is distinguished in color and line-shape (solid for positive and broken for negative signs), as explained in the figure.
Figure 3 (right) I_{DS}-V_{GS} characteristics of the DLC-gated G-FET at different V_{DS}'s corresponding to Figs. 2(a) and (b) V_{GS} scanned from (a) -12 and (b) +12 V with a V_{DS} step of +0.2 V from -1.0 to 1.0 V. V_{DS} applied at each curve is distinguished in color and line-shape (solid for positive and broken for negative signs), as explained in the figure. Black circle and square indicate V_{Dirac} and 1/2 V_{DS}, respectively.

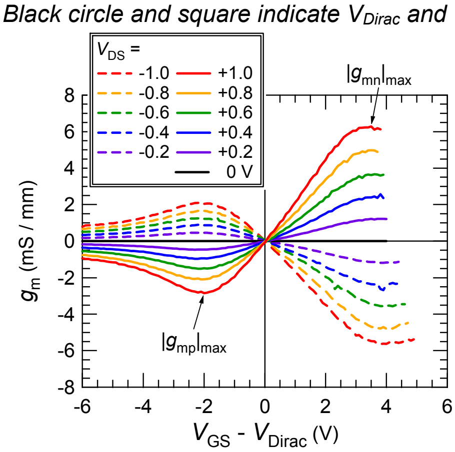


Figure 4 g_m curve in the ambipolar mode as a function of $V_{GS} - V_{Dirac}$ derived from Fig. 3(a). V_{DS} applied at each curve is distinguished in color and line-shape (solid for positive and broken for negative signs), as explained in the figure. $|g_{mn}|_{max}$ and $|g_{mp}|_{max}$ are indicated.