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Realization of the high-performance graphene transistor by controlling the interface between graphene and gate dielectric

Graphene is a 2D material which has superior electron transport characteristics. Graphene Field Effect Transistor (G-FET), which Graphene is used as a channel material, has a great potential for overcoming the limit of speed performance of present transistors. Graphene is the only material which enables us to gain the terahertz band operation. However, we cannot achieve the terahertz band operation by current G-FETs. To improve the high-frequency performance of G-FETs, it is needed that the device characteristics have both high-transconductance (gm) and saturating characteristics of I_d-V_d characteristics.

Previously, we could not achieve the saturation of I_d-V_d characteristics without using graphene nanoribbon (GNR) because the bandgap of Graphene is almost zero. Using graphene nanoribbon enables the saturation, but transconductance of the device using that is lower than that using normal graphene. Therefore, it is said that applications of graphene for high-frequency devices had a lot of difficulty.

We report the research result of gaining high transconductance and the pinch-off of the output characteristics by adopting Yttrium gate dielectric layer.

Graphene was produced by thermal decomposition of SiC substrate in Ar atmosphere. After graphitization, we observed the quality of graphene by Raman spectroscopy, and then observed the band dispersion by using Angle-resolved photoemission spectroscopy (ARPES). We applied and deposited Yttrium Layer (9 nm) to graphene, and oxidized in the air. Graphatization and production of G-FET were conducted in Super Clean Room, which clean level is class 10 (ISO 14644-1).

The result of ARPES of SiC Si face graphene (Figure 1) shows that that has typical linear band dispersion of graphene. Moreover, Fermi level is positioned upper than Dirac Point, it is observed that this graphene is electron-doped. This electron doping derives from the existence of buffer layer between Graphene and Si surface of SiC substrate.

Figure. 2 is the Raman spectra of Graphene channel of G-FET fabricated by using SiC heat-decomposition epitaxial graphene. This Raman spectra indicates that the quality of graphene did not deteriorated during the device fabrication, especially the Yttrium Oxide deposition. Therefore, this result shows that good interface between graphene and Yttrium oxide is formed.

After the fabrication, we observed DC electric characteristics of G-FET (channel width: 10 μm, gate length: 4 μm). Figure 3 is the I_d-V_d characteristics of G-FET, and Drain current value exceeds 1 A/mm. This result shows that this G-FET has great current gain performance comparable to the transistors such as GaN-HEMT [1]. Although it was difficult to realize both the high transconductance and the pinch-off of I_d-V_d characteristics, we could observe 300 mS/mm transconductance and the saturation of I_d-V_d characteristics. Forming good interface between graphene and Yttrium oxide insulator and the increase of gate modulation performance enhanced by Yttrium oxide, which is high-k material, enabled G-FET to gain these results [2]. Finally, we estimated f_{max} at 29 GHz from DC electric characteristics. This value indicates that G-FET can work at terahertz band with practical gate length 100 nm.

References

[1] K. Shinohara et al., IEEE Trans. Electron Dev., 60 (2013) 2986.
[2] S. J. Han et al., ACS Nano 6, No. 4 (2012) 5220.

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Figures

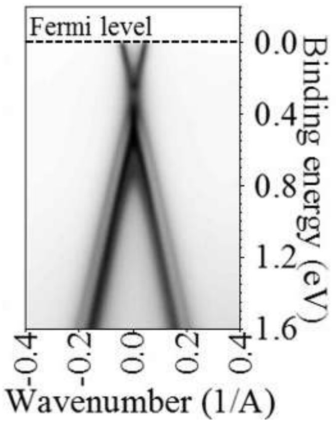

Figure 1: Band dispersion of graphene fabricated by thermal composition of SiC substrate.

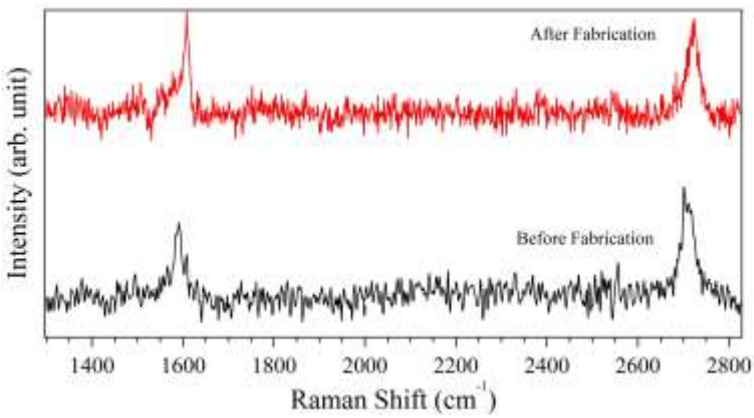

Figure 2: The Raman shift of graphene channel after fabrication process.

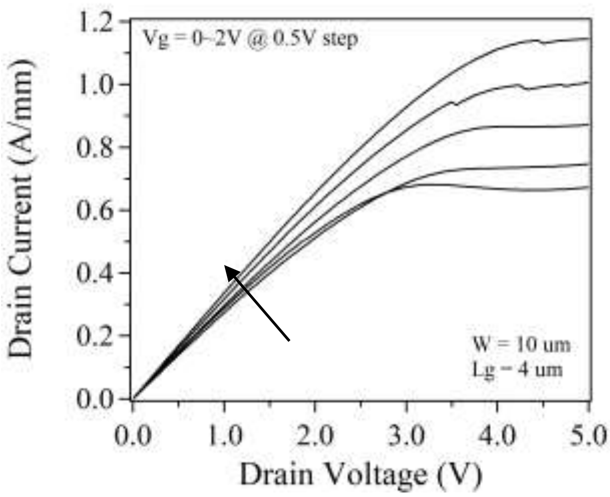

Figure 3: Output characteristics of GFET by using Yttrium gate dielectric.