Solution-based formation of high quality Al_2O_3 gate dielectrics on graphene using microwave-assisted annealing

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For the development of high performance graphene field effect transistors (GFETs), it is essential to form a high quality gate dielectric layer without degrading the pristine properties of graphene. Generally, natural oxide layer of Al as well as ALD-grown Al_2O_3 layer is used as the gate dielectric layer for GFETs. The natural oxide of Al, however, shows substantial leakage current while the ALD requires a surface modification process beforehand to activate the hydrophobic surface of graphene. To overcome these limitations, we investigated a solution-based formation of an Al_2O_3 (sol-Al_2O_3) layer combined with a microwave-assisted annealing. In a solution process, a thermal decomposition process is indispensable to remove the solvent and the stabilizer, which mainly determines the dielectric properties of the film. Normally, the thermal decomposition process is carried out at high temperatures (> 600 ^{o}C) using a furnace annealing and an oven baking. At these high temperatures, hole doping and mechanical modification of graphene will occur. We have spotted the microwave-assisted annealing because it is a simple, short time, and low temperature process. This method has been widely utilized in low-temperature processes for the fabrication of oxide thin-film transistor (oxide-TFT) devices. In this study, we have used the microwave-assisted annealing for the first time to realize a high-quality sol-Al_2O_3 layer for GFETs. First, we prepared a single-layer graphene (SLG) on a SiO_2–covered Si substrate by transferring a CVD graphene. A sol-Al_2O_3 layer was then formed thereon. Figure 1 plots the peak positions of the G and G' bands of the Raman scattering spectroscopy for various decomposition annealing conditions, which conveys information on the hole doping concentration and the strain. When the sol-Al_2O_3 layer was directly fabricated on graphene, the original, almost charge-neutral pristine graphene turned into p-doped with a hole concentration of ~7×10^{12} cm^{-2}. This increase is related to the oxygen penetration from the sol-Al_2O_3 to graphene. This doping effects can however be suppressed by inserting a thin natural oxide layer of Al between the sol-Al_2O_3 and the graphene layers. In sharp contrast, no such doping was observed by microwave-assisted annealing even without inserting the natural oxide layer of Al. To evaluate the electrical characteristics of the sol-Al_2O_3 layer, we fabricated a MOS capacitor. As shown in Fig. 2, the large leakage current (~3.7×10^{-7} A at 1 V) observed for the natural oxide of Al drastically decreased to ~7.2×10^{-10} A for a sol-Al_2O_3 gate dielectrics fabricated with a high power and long time microwave-assisted annealing. This result indicates that the microwave-assisted annealing is very effective in forming a high quality sol-Al_2O_3 layer for GFETs.

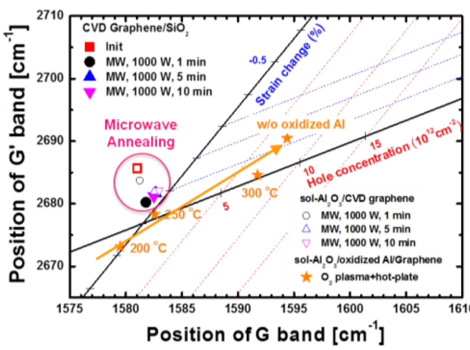

Fig.1. Change of doping and strain characteristics of SLG graphene after microwave-assisted annealing.

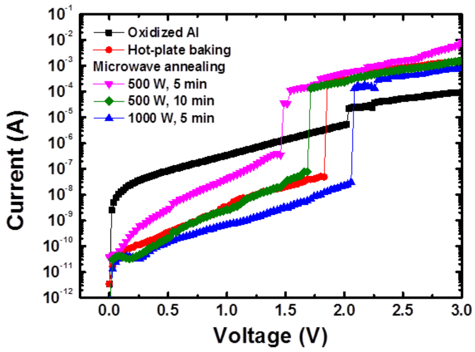

Fig.2. Leakage current and breakdown voltage characteristics of solution-based Al_2O_3 layers