Removal of Photoresist Residues of Graphene by Using Plasma Treatments

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Since the technique to apply scotch tape exfoliated graphene to field effect transistor was developed, there has been immense research work on graphene devices. They were awarded the Novel Prize in 2010, and this proved scientific significance and potential importance of graphene research. It is understand that unique properties of graphene, such as extremely high carrier mobility, 2 dimensional quantum phenomenon, and superior mechanical strength, are mainly originated from the linear energy dispersion relation. However, the linear energy dispersion relation results in no bandgap between valence and conduction bands, and this limits the application of graphene to switching devices.[1-3]

Plasmas is usually defined as a neutral gas consisted of charged and neutral particles, exhibiting overall charge density in the plasma to be zero. That is, the densities of positively and negatively charged particles compensate each other. As plasma can induce damages to graphene, bandgap can be created, accompanied by breaking symmetry of its electronic structure. Of course, opening graphene' s bandgap is traded off with lowering its carrier mobility. In addition, plasma processing can induce doping to graphene, which can be potentially important as a doping control method for 2 dimensional material.

Although capacitvely coupled plasma (CCP) is very effective to remove some residues remaining on the wafers, it produces highly energetic ions which can induce damage on the surface, as CCP power is directly applied to the wafer Usually ion energy of hundreds of volts is generated due to large sheath thickness over which positive ions can be accelerated to attain high energy. According to the previous experience, even at the low power range it is very difficult to avoid damage on graphene by the application of CCP. Therefore, we tested an inductively coupled plasma (ICP) system without applying power to the graphene sample.[4] Plasma sheath of ICP is observed very thin compared to CCP, and this can be confirmed by mathematical calculation. If low power ICP is used, it is even thinner. As a result, ion energy is low and damage to the graphene surface can be avoided. Meanwhile, in considering damage to the graphene, total energy accumulated to the graphene from plasma is critical. As main contributors to supply energy to graphene, not only ion energy but recombination energy is also significant. Since recombination energy is proportional to ion density, low power (4-5W in our system) is again preferred.

Photo-resist residues can be removed at low ICP power as they adhere weakly, by secondary bondings with graphene. That is, threshold energy to remove the residues is significantly lower than that to damage graphene. Therefore, graphene is clean even at long processing times. Whereas, the graphene is subject to damage at ICP power higher than 10W in our experiments, due to high ion density and high ion energy.

Since we wish to sustain good quality of graphene even after the device processing, we tested how inherent ambi-polar properties vary as a function of ICP processing time. We notice that inherent graphene properties are restored to the pristine level after certain processing times, in terms of carrier mobility and Dirac point (charge neutral point). Carrier mobility of graphene increases with time and Dirac point of graphene approaches to 0V. Interestingly We can notice that Dirac point shifts to the negative voltage with longer processing time. This substantiates electron trapping during the plasma processing.

In summary, the ICP treatment proposed for cleaning of graphene can have great potential for the application to high performance and high density integrated circuit devices in that it is compatible to the current processing platform, and enables large area, low temperature, and high throughput process.

References

[1] Novoselov, K. S.; Geim, A. K.; Morozov, S. V.; Jiang, D.; Zhang, Y.; Dubonos, S. V.; Grigorieva, I. V.; Firsov, A. A. Electric Field Effect in Atomically Thin Carbon Films. Science **2004**, 306, 666–669.

[2] Novoselov, K. S.; Geim, A. K.; Morozov, S. V.; Jiang, D.; Katsnelson, M. I.; Grigorieva, I. V.; Dubonos, S. V.; Firsov, A. A. Two-Dimensional Gas of Massless Dirac Fermions in Graphene. Nature **2005**, 438, 197–200.

[3] Zhang, Y. B.; Tan, Y.-W.; Stormer, H. L.; Kim, P. Experimental Observation of the Quantum Hall Effect and Berry's Phase in Graphene. Nature **2005**, 438, 201–204.

[4] Lim, Y. D.; Lee, D. Y.; Shen, T. Z.; Ra, C. H.; Choi, J. Y.; Yoo, W. J. Si-Compatible Cleaning Process for Graphene Using Low-Density Inductively Coupled Plasma, ACS Nano **2012**, 6, 4410–4417.