Nano-scale Stack Fabrication on thin Graphite Flake using Focused Ion Beam 3-D Etching Technique

Venugopal Gunasekaran,* Sang-Jae Kim#
School of Engineering, Jeju National University, Jeju 690-756 Republic of Korea
*Email: *guna@jejunu.ac.kr, # kimsangj@jejunu.ac.kr*

We have demonstrated the fabrication of nano-scale stack (along *c*-axis) on thin graphite layer by using focused ion beam (FIB) 3-D etching technique [1] and studied the electrical transport characteristics. We fabricated a stacked-junction along *c*-axis with height of 100 nm on thin graphite flake (thickness ~ 500 nm). We followed the 3-D etching technique by tilting the substrate stage up to 90° automatically for etching thin graphite flake. In FIB, we have freedom to tilt the substrate stage up to 60° and rotate up to 360°. The side plane with the height of several nanometers was fabricated by rotating the sample stage by an angle of 180º, then tilting by 60º anti-clockwise with respect to ion beam, and milling along the *c*-axis direction. The FIB image of fabricated *c*-axis stacked-junction (size W = 0.5 μm, L = 0.5 μm, H = 100 nm) is shown in the Fig.1 (image scale bar is 2 μm). The schematic diagram of stack arrangement along the *c*-axis is clearly shown in the inset (left bottom).

The electrical transport characteristics were studied for this fabricated stacked-junction as the graphite is considered as a typical layered structure consists of stacked-layers of multiple graphene sheets bonded by weak interlayer interaction forces (Van der Waals force). From the current *(I)* - voltage *(V)* characteristics, we observed a nonlinear concave-like *I-V* characteristics at all studied temperatures from 25 K to 300 K. No nonlinear behavior is observed when the sample is low-biased, which is shown as inset in Fig. 2. The resistivity versus temperature (ρ-T) relation of the stack is shown as an inset (top) in Fig. 2. It is observed a semiconducting behavior till 50 K and then metallic behavior below 50 K. Our results of *c*-axis conduction in stacked-junction well agree with earlier observation reported on *c*-axis conduction of bulk graphite [2]. Below 50 K, the impurity-assisted interlayer hopping conduction combined with scattering of carriers can be responsible for the metallic behavior. Above 50 K, thermal excitation of carriers plays a major role for semiconducting temperature dependence Further, it will be explained in detail with size-dependence of stacked-junction having various *c*-axis heights. These results may open new route to futuristic nonlinear electronic device application and developments.

1] S. J. Kim, Y. I. Latyshev and T. Yamashita, Appl. Phys. Lett. 74, 1156, (1999).

[2] K. Matsubara, K. Sugihara, and T. Tsuzuku, Phys. Rev. B 41, 2, 969 (1990).

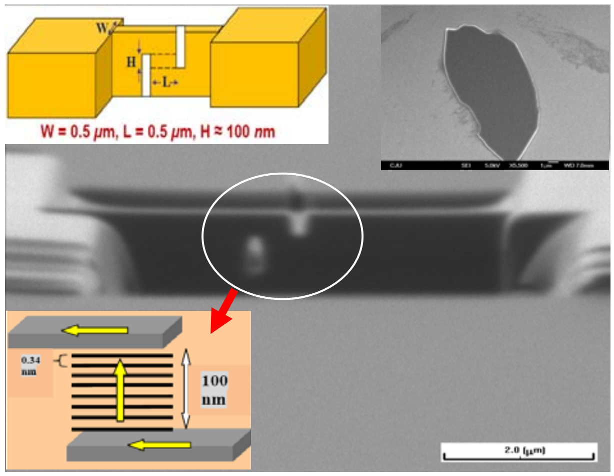

Fig. 1. The image of fabricated nanoscale stacked-junction on thin graphite flake using the 3D FIB etching technique. Inset (left bottom) shows the schematic diagram of arrangement of stacked-junctions (with interlayer distance 0.34 *n*m) in to *c*-axis. The vertical yellow arrow indicates the current flow direction through the stacked-junctions. Inset (top right) shows the SEM image of thin graphite flake used in this experiment (image scale bar is 1 *μ*m). The schematic image of stack geometry and dimensions are given as inset (top left).

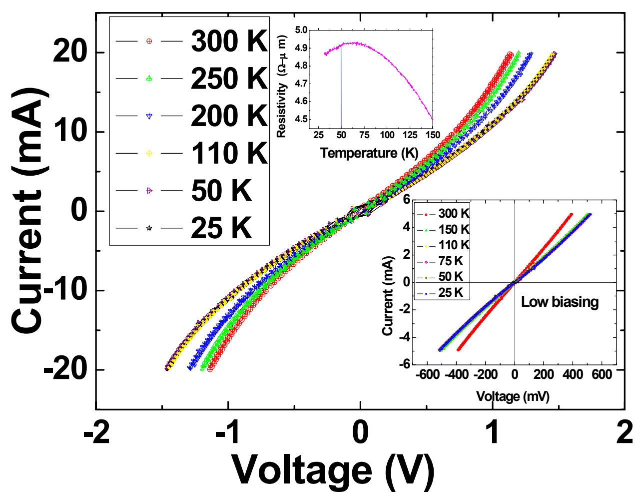

Fig. 2. The *I-V* characteristics of nano-scale stack shows nonlinear concave-like characteristics. Inset (top) shows resistivity versus temperature (*ρ-T*) relation of stacked-junction. Inset (right bottom) shows *I-V* characteristics of the same sample with low biasing.