Nanofabrication of Graphene on SiC by Multi-Ion Beam Lithography and Low-Temperature Processing

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Promising techniques for growing graphene on SiC single crystals for electronic device fabrication include heating the crystals in UHV above the graphitization temperature (T_G)[1]; or processing them in vacuum using a pulsed excimer laser[2].

Here we report on an approach we have been developing for some time that combines ion implantation, thermal or pulsed laser annealing (PLA), and multi-ion beam lithography (MIBL) to both pattern and synthesize graphene nanostructures on SiC single crystals at low temperatures. This approach utilizes a MIBL system developed at the University of Florida (UF) in collaboration with Raith Inc. for implantation/nanofabrication, in combination with thermal annealing in vacuum or PLA with a 25ns pulsed ArF laser in air. To investigate the mechanisms and the effects of the implanted species, ion damage, and annealing, samples were also subjected to broad-area ion-implantations using facilities at the Australian National University.

We will show that implantation of Si, Ge, Au, or Cu followed by thermal annealing in vacuum below the T_G of SiC can selectively grow graphene only where the ions are implanted, and that graphene nanoribbons a few nanometers to microns wide can be formed using MIBL as shown in Fig. 1. Additionally, we will show that graphene can be formed on implanted and/or unimplanted SiC by ArF PLA in air, at fluences from 0.4-1.2 J/cm^2, keeping surface temperatures near room temperature as discussed in Fig. 2. Details of AES, SEM, X-sectional TEM, micro-Raman analyses and heat flow simulations will be presented to verify graphene growth and explain the effects and mechanisms involved. Implications for fabricating nanoelectronic device structures will also be discussed.

1. C. Berger, Z. Song, T. Li, X. Li, A. Y. Ogbazghi, R. Feng, Z. Dai, A. N. Marchenkov, E. H. Conrad, P. N. First, and W. A. de Heer, J. Phys. Chem. 108, 19912 (2004)
2. Sangwon Lee, Michael F. Toney, Wonhee Ko, Jason C. Randel, Hee Joon Jung, Ko Munakata,Jesse Lu, Theodore H. Geballe, Malcolm R. Beasley, Robert Sinclair, Hari C. Manoharan, and Alberto Salleo; ACS Nano Vol.4, No. 12, 7524-7530 (2010).

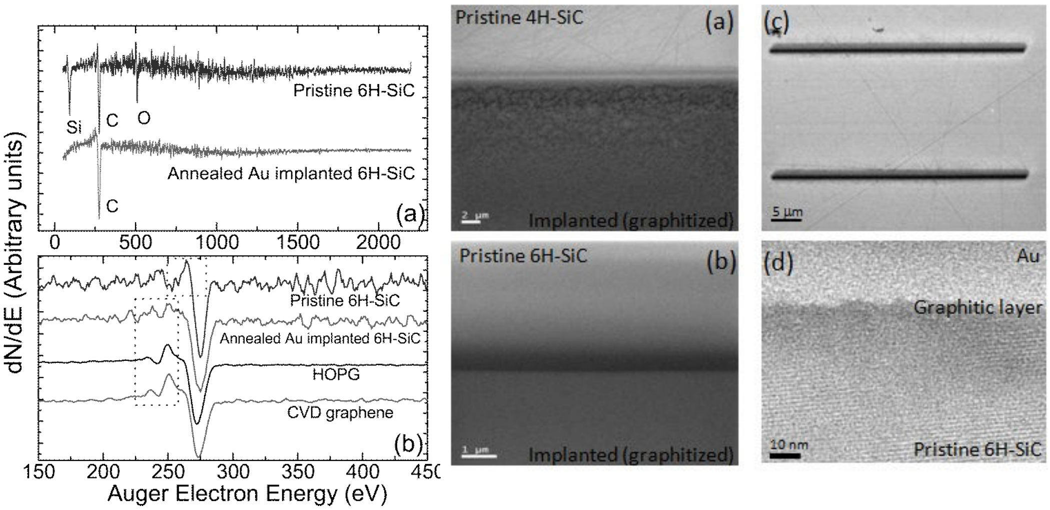

Fig. 1: SEM, AES, and X-Sectional TEM taken on thermally annealed SiC. SEM images at the right show the transition regions between pristine and implanted (graphitized) regions for (a) Au implanted 4H-SiC and (b) Si implanted 6H-SiC. Image (c) shows 200 nm graphene nanoribbons formed on the surface by thermal annealing, and (d) X-TEM image taken across the Au/graphene/6H- SiC confirming the underlying crystalline structure of the SiC. The AES measurements on the left probe ~3-5 A and confirmed the uniformity and bonding type of the graphene areas. The annealed but unimplanted SiC areas show large Si and C peaks at 1:1 ratios; but the observed Si and surface oxide peaks completely disappear on the annealed Au implanted samples. These conclusions were confirmed by correlated micro-Raman measurements.

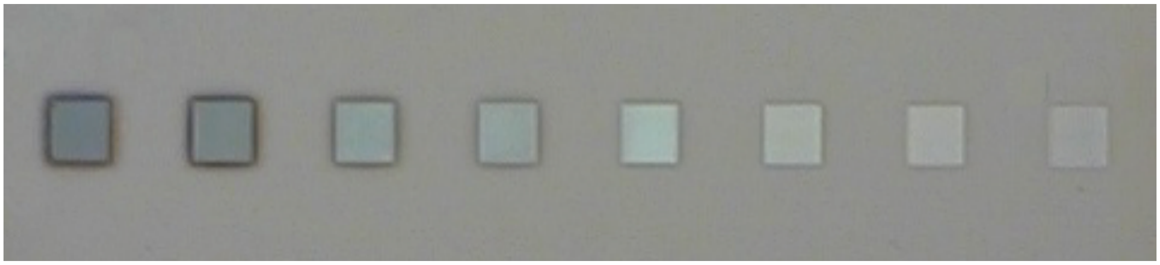

Fig.2 A 4H SiC single crystal implanted with Au, Cu, and Ge was annealed in air using a 25 ns pulsed ArF laser. Eight areas 44µm x 44µm in each implanted and unimplanted region were sequentially annealed with 500, 300, 100, 50, 10, 5, 2, and 1 pulses, at various fluences ranging from 0.2 -1.2 J/cm^2, and analyzed with Raman, SEM and AFM . Shown above is a representative optical image for Ge implanted SiC annealed at 0.6 J/cm^2 with 500 to 1 pulses, from left to right. Trends in results from these systematic measurements will be used to discuss potential mechanisms for the formation of graphene/graphite resulting from pulsed laser annealing.