

Improvement of Morphology and Mobility through Argon-Assisted Growth of Epitaxial Graphene on Silicon Carbide

J.L. Tedesco¹, B.L. VanMil¹, R.L. Myers-Ward¹, J.C. Culbertson², P.M. Campbell², C.R. Eddy, Jr.¹, and D.K. Gaskill¹

¹ Advanced SiC Epitaxial Research Laboratory, U.S. Naval Research Laboratory, 4555 Overlook Avenue SW, Washington, DC 20375

² U.S. Naval Research Laboratory, 4555 Overlook Avenue SW, Washington, DC 20375

ABSTRACT

It has been observed that the ideal surface for semiconductor processing is one that is morphologically uniform and smooth. Previous attempts to grow epitaxial graphene on SiC in a hot-wall chemical vapor deposition reactor have resulted in graphene films with less than ideal morphologies. In order to solve the morphological problems that could affect transport properties, graphene films were epitaxially grown on both the C- and Si-faces of on-axis, semi-insulating 4H- and 6H-SiC(0001) samples under a partial argon atmosphere ($P \sim 100$ mbar). Graphene films were also grown on the same type of substrates under typical high vacuum synthesis conditions ($P \sim 10^{-3} - 10^{-5}$ mbar) [1]. Sample areas were 16×16 μm^2 . Following growth, samples were imaged with atomic force and Nomarski interference contrast microscopy, as well as Raman spectroscopy. The morphology of the films grown on the C-face was found to change significantly. C-face films grown in high vacuum conditions contained dense arrays of ridges and rows of shallow pits, while the C-face films grown under argon exhibited the same arrays of ridges but no pit formation, as shown in Figure 1. The morphology of the Si-face films was not significantly affected. The Hall effect mobilities and sheet carrier densities of the samples were measured at 300 K and 77 K. The measured mobilities of graphene films on both faces grown under argon typically increase over those grown in high vacuum conditions. With respect to films on the C-face, the increase at 300 K is $\sim 200\%$ to 300% and is greater than 400% at 77 K. For films on the Si-face, the increase is ~ 30 to 50% at 300 K and by $\sim 150\%$ to 200% at 77 K. Specific examples demonstrating these increases are shown in Table 1 below.

Table 1. Mobilities for graphene films measured at 300 K and 77 K for films grown under argon and films grown in high vacuum conditions.

| SiC Face | Temperature | Mobility ($\text{cm}^2\text{V}^{-1}\text{s}^{-1}$) | |
|----------|-------------|--|-------------|
| | | Under argon | High vacuum |
| C | 300 K | 3,170 | 950 |
| | 77 K | 7,200 | 1,240 |
| Si | 300 K | 450 | 330 |
| | 77 K | 2,650 | 940 |

The sheet carrier densities at both temperatures for the films decrease by at least an order of magnitude when grown under argon (e.g. 10^{12} cm^{-2} vs. 10^{13} cm^{-2}). The decrease in sheet densities suggests that the mobility improvements is due to a decrease in scattering in the films grown under argon, further suggesting that the improved morphology of the graphene films leads to

improvements in mobility. The Raman spectra were different for films grown under argon than those films grown in high vacuum, and these differences will be discussed.

Samples that had previously been grown in high vacuum conditions were also subjected to growth under argon to determine if either the morphology or the mobility of the re-grown samples would improve. It was determined that re-growth under argon following high vacuum growth did not affect the sample morphology. Furthermore, the mobilities of the re-grown films did not increase significantly at room temperature, but increased by $\sim 50\%$ at 77 K. The lack of a significant increase in the mobilities of the re-grown samples points to the graphene/SiC interface as being the location of the defects limiting the mobility in epitaxial graphene films.

ACKNOWLEDGEMENTS

This work was supported by the DARPA CERA Program and by the Office of Naval Research. JLT and BLV acknowledge support from the American Society for Engineering Education – Naval Research Laboratory Postdoctoral Fellowship Program.

REFERENCES

[1] B.L. VanMil, R.L. Myers-Ward, J.L. Tedesco, C.R. Eddy, Jr., G.G. Jernigan, J.C. Culbertson, P.M. Campbell, J.M. McCrate, S.A. Kitt, and D.K. Gaskill, *Mater. Sci. Forum in press*.

FIGURES

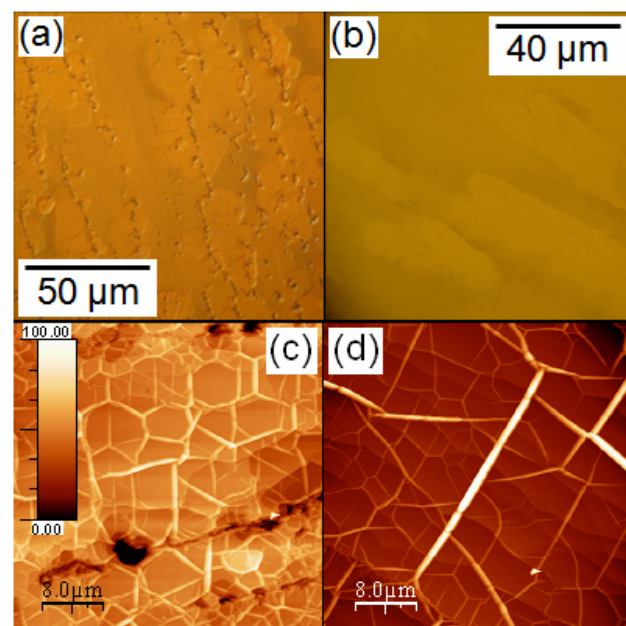


Figure 1. Nomarski interference contrast microscopy image of a graphene film grown on C-face SiC under (a) high vacuum conditions and (b) under a partial argon atmosphere. Atomic force microscopy images of (c) the C-face film shown in (a) and (d) the C-face film shown in (b). The RMS roughness of (c) is 18.3 nm and the RMS roughness of (d) is 13.6 nm. The scale for both (c) and (d) is the same and is in units of nanometers.