Temperature Dependent Growth Properties of Epitaxial Graphene on Carbon-Face Silicon Carbide

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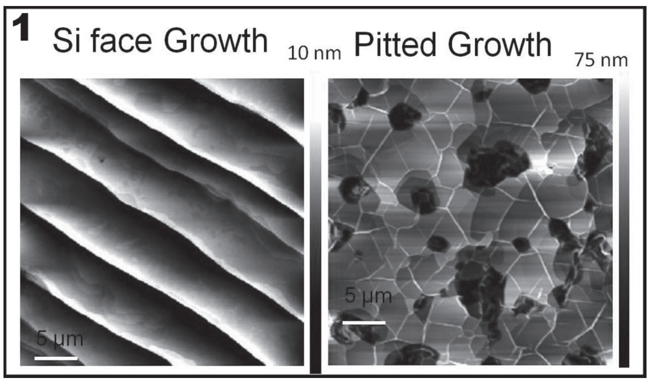
Abstract:

The use of silicon-based transistors has been a staple in computer technology for decades, but due to fundamental material and device limitations, progress in chip speed and computing power has begun to slow. Graphene-based transistors have the potential to break through these limitations and put us back on the path of increased performance gains with scaling. As a first step towards implementing graphene technology, it is necessary to have high-quality graphene sheets from which a chip with billions of devices can be fabricated. In this work, graphene was grown by silicon sublimation from semi-insulating silicon carbide (SiC) using a high temperature vacuum furnace. Both substrate preparation and growth processes were experimented with; variables included temperature, gaseous environment, and soak time. After growth, samples were characterized in a number of ways to determine sample quality, including Raman spectroscopy, atomic force microscopy, and van der Pauw electrical measurements. A relationship between growth temperature, graphene morphology, and sheet resistance was extracted.

Introduction:

Graphene has many important properties that make it exceptional for use in electronics, including high charge carrier mobility [1] and thermal conductivity [2]. However, obtaining significant quantities of graphene for industrial use has proven difficult. Graphene can be grown epitaxially on the surface of SiC simply by heating the substrate to a high temperature. Graphene can be grown on either of the species-terminating faces, silicon-face or carbon-face, of SiC, both of which show significant differences in graphene morphology and electrical properties. The atomic force microscopy images (Figures 1 and 2) reveal how the surface morphology differs between graphene grown on the silicon-face and the carbon-face. The silicon-face graphene grows along straight terraces, while the carbon-face graphene nucleates at certain points, grows outward, and ultimately forms domains which meet in a ridge or pucker. Carbon-face graphene is rotationally stacked, which allows for individual monolayers in a thick, stacked film to behave as electrically isolated graphene monolayers [3].



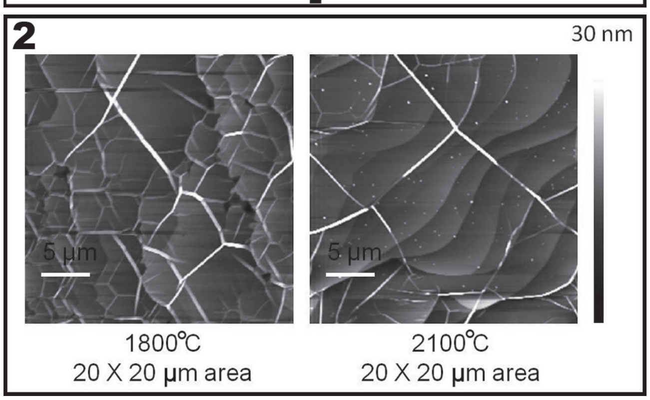


Figure 1, top: On the right is an image of silicon-face graphene. On the left is an image of pitted carbon-face graphene.

Figure 2, bottom: The right image is carbon face graphene grown at 1800°C, on the left is carbon-face graphene grown at 2100°C.

Experimental Procedure:

The temperature dependence of epitaxial graphene growth was tested by cleaning 4 × 4 mm pieces of SiC with acetone, methanol, and isopropanol for five minutes each in an ultrasonic bath. The samples were then dried with a nitrogen gun and immediately loaded into the vacuum furnace.

The samples were hydrogen-etched in the furnace to remove chemical mechanical polishing damage by flowing 3000 standard cubic centimeters per minute (sccm) of argon (Ar) and 1000 sccm of H_2 at 1400°C. The cleaned samples were then graphitized without exposure to air by heating the system to 1400°-2100° C for 10 minutes at a pressure of ~ 10^{-5} Torr.

The samples were characterized with atomic force microscopy imaging, Raman spectroscopy, and van der Pauw electrical testing.

Results and Conclusions:

Graphene layers grown at higher temperatures show different electrical, spectroscopic, and morphological properties in comparison to graphene layers grown at lower temperatures. As shown in Figure 2, the graphene layers exhibit increased domain sizes at higher temperatures. However, as shown to the right in Figure 1, higher temperatures also lead to increased pitting in the graphene layers and SiC substrate which make device fabrication challenging. The Raman spectra obtained from grown graphene samples (Figure 3) exhibits two main peaks of interest, the D peak and the 2D peak.

The 2D peak is correlated to the thickness of the graphene layer and increases as the temperature increases. The D peak is correlated to defects in the graphene and is surprisingly not present in any of the Raman spectra, suggesting that the graphene grown in these experiments is high quality even in the presence of unwanted pits on the surface. The electrical measurements imply that as the growth temperature increases, the sheet resistance of the graphene layer decreases exponentially, thereby leading to exceptional conductivity at higher growth temperatures.

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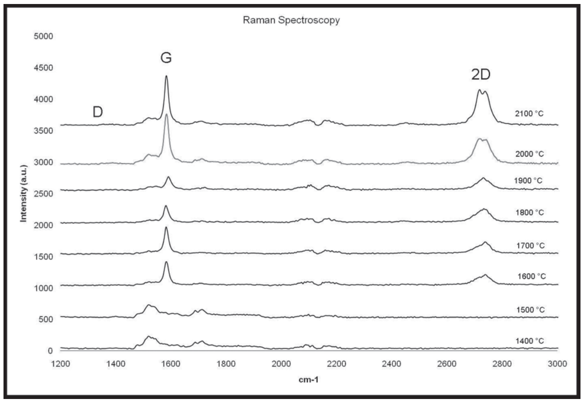

Figure 3, top: The Raman spectroscopy of carbon-face graphene grown at temps ranging from 1400°C to 2100°C.

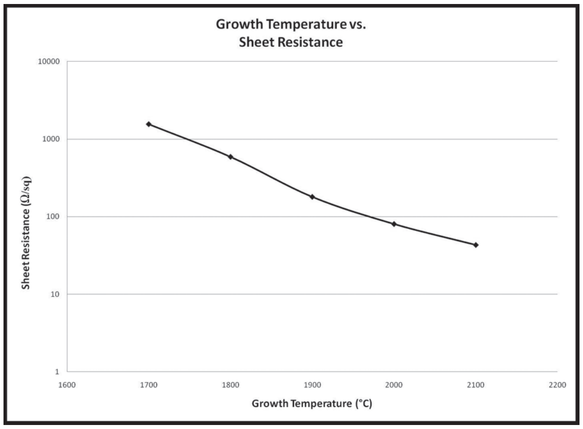

Figure 4: The sheet resistance of carbon-face graphene decreases as growth temperature increases, leading to improved resistivity at higher temperatures.