Applications based on graphene on hexagonal and cubic silicon carbide

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Abstract

There is an intense research in graphene on silicon carbide to explore the properties of monolayer, bilayer, or multilayer graphene on the silicon or carbon face of silicon carbide.

The monolayer graphene with a buffer layer has shown an astounding performance in metrology. In fact, graphene on silicon carbide provides a several orders of magnitude better precision resistance standard in quantum Hall measurements that relates the Planck's constant, *h*, and the electron charge, *e*, than the current one based on gallium arsenide [1].

The graphene and silicon carbide can create a viable platform, for example by a monolithic transistor that uses the entire material system epitaxial graphene on silicon carbide [2]. This was shown to have an on/off ratio exceeding 10^4 and no damping at megahertz frequencies. The fabrication process requires, in the most simple realization, only one lithography step to build transistors, diodes, resistors and eventually integrated circuits without the need of metallic interconnects.

An issue in graphene is the lack of bandgap. Ribbons of graphene have shown a potential to create a bandgap of 0.5 eV [3]. The ribbons were created by forced topographical changes on SiC that produced narrow ribbons. This demonstrates the advantage of silicon carbide as an active substrate that creates graphene-substrate interactions to alter the properties of graphene to a metal-semiconducting transition.

Long spin relaxation times, up to 2.3 ns, in monolayer graphene have been shown, while the spin diffusion coefficient is strongly reduced compared to typical results on exfoliated graphene. The increase of spin relaxation times is probably related to the changed substrate, while the cause for the small value of spin diffusion coefficient remains to clarify [4].

Still there is room for a broad range of research. For example, the sensitivity to individual molecules opens a research area in biosensors in addition to those of electronics. A high surface to volume ratio and tunable electron transport properties due to quantum confinement effects strongly influence the electrical properties of graphene channels even by minor perturbations, such as molecules on the graphene surface. The biosensors work on the principle of a target disease biomarker that provides a change in the surface charge density [5]. This change can be detected as an electrical signal from the biosensor device. Both SiC and graphene have excellent biocompatibility with in vivo and in vitro studies showing no cytotoxicity responses. This field includes development of miniaturized systems for detection of disease biomarkers for use in the early diagnosis and monitoring of diseases.

Graphene has also shown to promote GaAs nanowire growth. Due to a self-catalyzed growth technique used, the nanowires were found to have a regular hexagonal cross-sectional shape, and are uniform in length and diameter. Epitaxial growth of a broad range of semiconductors on graphene can in principle be achieved by utilizing a reduced contact area of nanowires. The model is experimentally verified by demonstrating the growth of vertically aligned GaAs nanowires on graphite and few-layer graphene, including graphene on SiC [6].

Most work has been developed on hexagonal silicon carbide. An open research area is graphene on cubic silicon carbide. The commercial polytypes have the hexagonal structure. In our lab we study growth of cubic silicon carbide bulk material, and process graphene on the substrates. In fact, the cubic silicon carbide seems to have a process window that allows monolayer graphene [7] in at least similar quality as when using hexagonal silicon carbide. Large homogeneous areas of graphene monolayers (over 50 x 50 μm^2) have been grown on 3C-SiC (111) substrates. Differences in the morphology of the graphene layers on different SiC polytypes is related mainly to the minimization of the terrace surface energy during the step bunching process. The uniformity of silicon sublimation is a decisive factor for obtaining large area homogenous graphene. A lower substrate surface roughness results in more

uniform step bunching with a lower distribution of step heights and consequently better quality of the grown graphene.

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Figures.

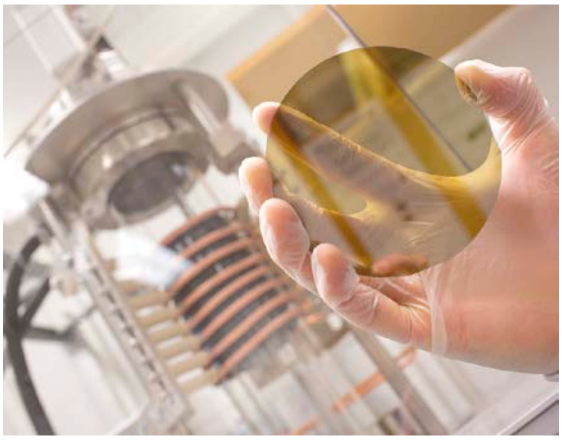

Figure 1. Silicon carbide wafers are used for large area graphene growth.

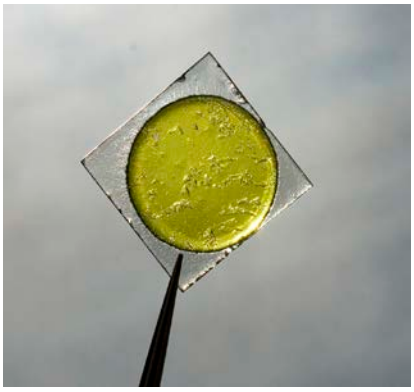

Figure 2. Cubic silicon carbide is a polytype that can further explore the graphene on silicon carbide properties.

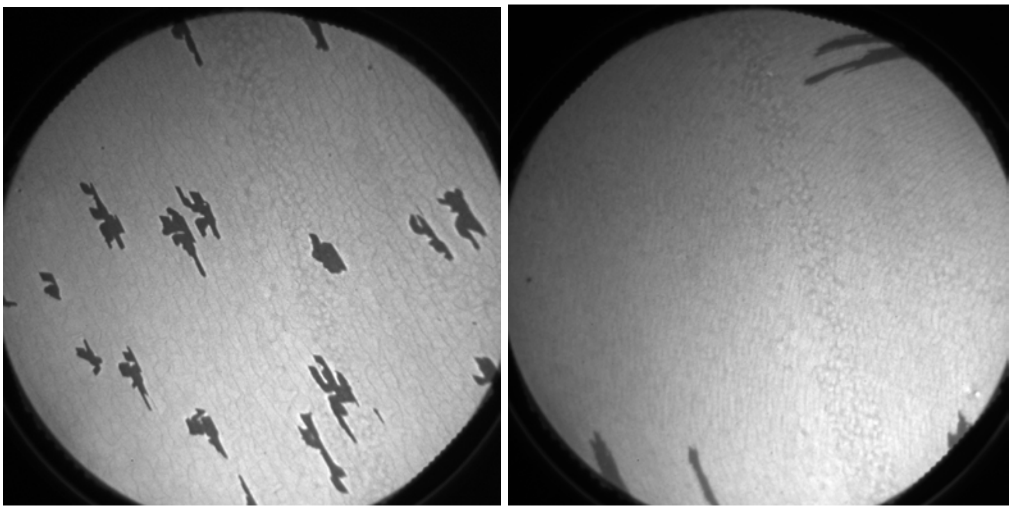

Figure 3. Low-energy electron microscopy images of 6H (left) and 3C (right), both showing large domains (>50 µm) and dominating monolayer graphene with dark areas of bilayer graphene. Images: Alexei Zakharov, MaxLab.