A Stable “Flat″ Form of Two-Dimensional Crystals: Could Graphene, Silicene, Germanene Be Minigap Semiconductors and Have Huge Magnetoresistance??

F. V. Kusmartsev, A. O'Hare K. I. Kugel, T. H. Hewett, M. B. Gaifullin, F. A. Mamari, and O. E. Kusmartseva

Physics Department, Loughborough University, LE11 3TU, UK
F.Kusmartsev@lboro.ac.uk

The discovery of a flat two-dimensional crystal known as graphene has contradicted Landau−Peierls−Mermin−Wagner arguments that there is no stable flat form of such crystals. Here, we show that the “flat” shape of graphene arises due to a microscopic buckling at the smallest possible interatomic scale. We show that the graphene, silicene, and other two-dimensional crystals are stable due to transverse short-range displacements of appropriate atoms. The distortions are small and form various patterns, which we describe in a framework of Ising model with competing interactions. We show that when temperature decreases, two transitions, disorder into order and order into disorder, arise. The ordered state has a form of stripes where carbon atoms are shifted regularly with respect to the plane. The flat graphene, silicene, or germanene planes look like a microscopic “washboard” with the wavelength of about couple of interatomic spacing of appropriate sublattices, which for graphene is about 1.8−3.6 Å. At lower temperatures, the ordered state transforms into a glass. Because of up−down asymmetry in buckled graphene, silicene and other two-dimensional crystals deposited on substrate, a minibandgap may arise. We derive a criterion for the minigap formation and show how it is related to the buckling and to the graphene−substrate interaction. Because of the bandgap, there may arise new phenomena and in particular a rectification of ac current induced by microwave or infrared radiation. We show that the amplitude of direct current arising at wave mixing of two harmonics of microwave electromagnetic radiation is huge. Moreover, we predict the existence of miniexcitons and a new type of fermionic minipolaritons whose behavior can be controlled by the microwave and terahertz radiation.

Moreover, using enhanced Raman microscope mapping we found graphene nanodomes which exist in graphite or any substrate where it was placed. In particular, we found a highly inhomogeneous network of graphene nanodomes on graphite. Such network of the graphene nanodomes is responsible for extraordinary magnetoresistance which we have measured. Our theory described the experiments well and revealed that the magnetoresistance depends most strongly on the density of these nanodomes, causing a huge effect at their optimal density. Indeed when graphene covers 46% of the surface we found a largest linear magnetoresistance that reaches up to 200% even in small magnetic fields even below 0.5T. The analysis is very general and applicable to any two phase graphene systems in arbitrary magnetic field. The discovery of inhomogeneous graphene nanodomes in graphite and other substrates provides a possibility for many potential practical applications, especially due to the huge magnetoresistance observed at low magnetic fields. Using the effect we designed simple working devices as magnetic sensors.

References

[1] A. O'Hare, F. V. Kusmartsev, and K. I. Kugel,
dx.doi.org/10.1021/nl204283q | Nano Lett., 2012, 14,1-6

Figure 1

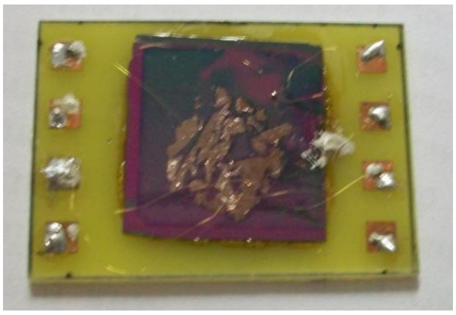
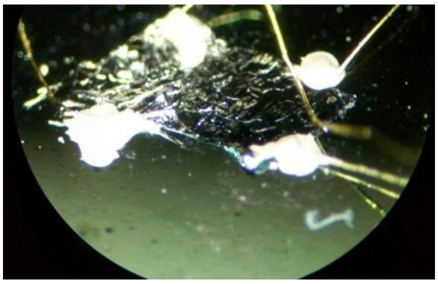
a)  b) 

Figure caption: A microscopic image of the samples with four-point probe Van der Pauw configuration: a) dimension ~2.64x0.16 mm^2; b) dimension ~1.33x0.87 mm^2)

Figure 2

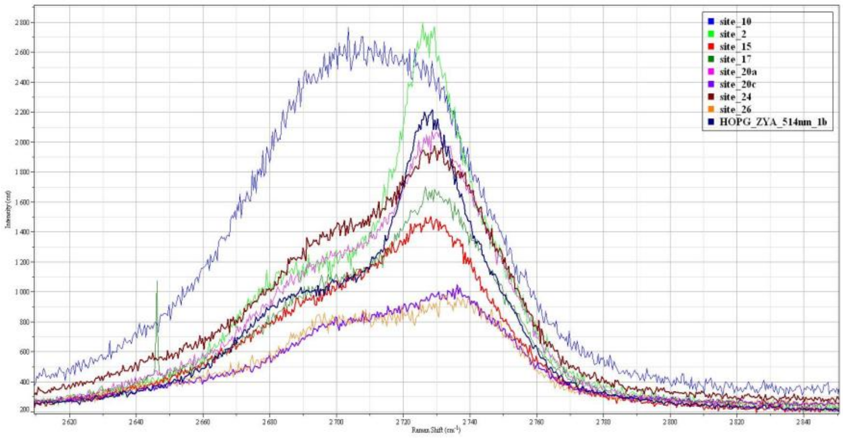


Figure caption: Raman spectral lines of graphene nanodomes detected on a surface of HOPG sample with mosaicity 0.4°±0.1° and deposited on Si/SiO$_2$ substrate, excited by the 514.5 nm line laser.

Figure 3

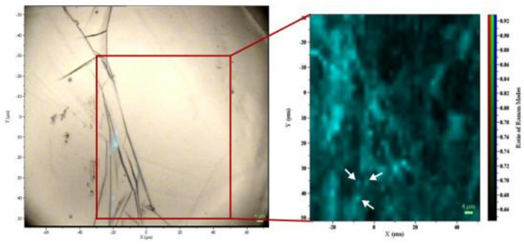
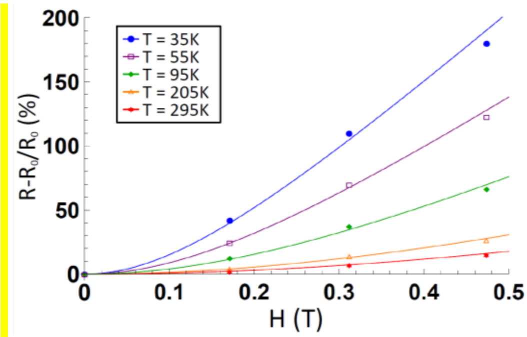
a)  b) 

Figure caption: a) Optical image of the flake and its Raman mapping tomography: the Nanodomes of graphene (in light color) are formed on a surface of graphite (in dark blue); Some nanodomes are indicated by white arrows. b) Magnetoresistance associated with the formation of nanodomes as a function of magnetic field for five different temperatures. Dots are experiments, the theoretical fitting of the experiments are described by solid curves.