Electronic and photonic properties of graphene layers and carbon nanoribbons

Recent advances in fabrication techniques have made it possible to produce graphene, which is a two-dimensional honeycomb lattice of carbon atoms forming the basic planar structure in graphite. Graphene has stimulated considerable theoretical interest as a semi-metal, the electron effective mass of which may be described by an unusual massless Dirac fermion band structure. Several novel many-body interactions in graphene have been investigated. In recent experiments, the integral quantum Hall effect (IQHE) has been reported in graphene. The quantum Hall ferromagnetism in graphene has been investigated from a theoretical point of view. Graphene has a number of interesting properties as a result of its unusual band structure, which is linear around two inequivalent points (K and K') in the first Brillouin zone. The single-electron quantum states near K and K' are described by the Dirac equation, where the wave functions are pseudo-spinors because of the two-point basis of the honeycomb lattice. In the presence of a magnetic field, the graphene structure shifts both the Shubnikov–de Haas oscillations as well as the step pattern of the IQHE. Both these effects have recently been studied experimentally. The spectrum of plasmon excitations in a single graphene layer embedded in a material with an effective dielectric constant $\varepsilon$ in the absence of an external magnetic field ($B = 0$) was calculated.

For two carbon layers, the nearest-neighbour tight-binding approximation yields a gapless state with parabolic bands touching at the K and K' points, instead of conical bands.

More accurate consideration gives a very small band overlap (about 1.6 meV), but, at larger energies, bilayer graphene can be treated as a gapless semiconductor. Consequently, the QHE for bilayer graphene differs significantly from both single-layer graphene and conventional semiconductors, as found experimentally.

This brief summary shows the diverse and interesting phenomena which have been studied in two-dimensional graphene as well as its related layered structural arrangements, thus making it a suitable candidate for a theme. This is an appropriate topic since research on graphene is expanding rapidly both theoretically and experimentally. There are several new developments which are discussed in this Theme Issue. These include: (i) the electron–electron and electron–hole pairing in graphene structures, (ii) Bose–Einstein condensation and superfluidity of trapped polaritons in graphene embedded in a microcavity, (iii) the electronic and optical properties of monolayer and bilayer graphene,

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(iv) the fractional quantum Hall effect in suspended graphene probed with two-terminal measurements, (v) the ballistic conductance and optical conductivity of graphene nanoribbons in magnetic and electric fields, (vi) band structure and gaps of triangular graphene superlattices, (vii) nanophysics in graphene quantum rings and superlattices, (viii) characterization in graphene and carbon nanotubes using Raman spectroscopy, and (ix) a review of the nano-analysis of graphene layers using scanning probe techniques.

These topics are indeed timely, in that they will be valuable in developing new devices involving the use of graphene in electronics and photonic devices. Graphene, first generally acknowledged to exist just 6 years ago, turns out to have a variety of unique, and potentially very useful, characteristics, as described above. Since several researchers are actively trying to better understand and turn the benefits of graphene into real-world applications, it would be helpful if an overview of some important topics could be given by experts in the field and, simultaneously, have them present new and useful results obtained in their current work and/or ongoing collaborative research.

Electrical engineering and physics are the two cross-disciplinary fields brought together by this topic. For example, graphene could also substitute for copper to make the electrical connections between computer chips and other electronic devices, providing much lower resistance and thus generating less heat. Additionally, it also has potential uses in quantum-based electronic devices that could enable a new generation of computation and processing.

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