Band-gap engineering in graphene through functionalization with fluorine

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Graphene – a single layer of sp2 bonded carbon atoms arranged in a honeycomb pattern – is an indefinitely large aromatic molecule, of unique interest in the field of transparent organic electronics. This is a transparent material where charge carriers (relativistic Dirac fermions) exhibit mobilities (>10^6 cm^2/Vs) higher than Si at room temperature. However, the energy dispersion of graphene is gap-less, and this would limit its applications in electronic devices. For instance, in a graphene-based transistor the absence of the gap in the band-structure results in a relatively small resistance difference between the electro-neutrality (Dirac) region and a region with large carrier concentration (i.e., between the "on" and "off" states). Due to this significant limitation in the use of graphene in electronics, intensive research is currently underway aimed at the creation of a (tunable) gap in graphene's energy spectrum.

The ability to chemically functionalize graphene, for instance with fluorine [1] and hydrogen [2] atoms, paved the way towards band-gap engineering. This type of functionalization transforms the graphene planar crystal structure, with sp2 bonds between the carbon atoms, into a three-dimensional structure with sp3 bonding between them. Theoretical predictions show that a band gap of 3.8 eV and 4.2 eV is expected for hydrogen and fluorine for 100% functionalization, respectively [3, 4].

Here I will review recent results on fluorinated graphene transistors [1] produced by mechanical exfoliation of natural graphite which is fluorinated to 24% and 100% (as measured by mass uptake). Transport measurements over a wide range of temperatures (from 4.2K to 300K) show a very large and strongly temperature dependent resistance in the electro-neutrality region. The strong temperature dependence of fluorinated graphene is due to the opening of a mobility in gap in the energy spectrum of graphene where electron transport takes place via localised electron states.

Magneto-transport experiments through fluorinated graphene as a function of gate voltage, bias voltage, and temperature show that a magnetic field systematically leads to an increase of the conductance on a scale of a few tesla. This phenomenon is accompanied by a decrease in the energy scales associated to charging effects, and to hopping processes probed by temperature-dependent measurements. All these results demonstrate that disorder induced sub-gap states originate strong localization effects in the transport of charge carriers for energies below the energy-gap of fluorinated graphene.

References

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