Semiconductors with honeycomb nanogeometry: importance, synthesis, and opto-electronic properties

Daniel Vanmaekelbergh[1], C. Morais Smith[2] and C. Delerue[3]

[1]Debye Institue for Nanomaterials Science, University of Utrecht, NL
[2]Institute for Theoretical Physics, University of Utrecht, NL
[3]ISEN-IEMN, University of Lille, Fr

It has become clear recently that the bandstructure of 2-D semiconductors can be deeply changed by a superimposed nano-geometry. For instance, if 2-D semiconductors are molded in a honeycomb geometry, the valence- and conduction bands show a linear energy-wave vector dispersion relation, instead of a parabolic one; the other beneficial properties of the semiconductor become preserved. It is thus possible to design massless electron and hole excitations in conventional semiconductors by the action of geometry! The major question is how to fabricate these nanostructured systems. In the top-down route, lithography and etching is used to imprint the desired nanostructuring in the 2-D material. Secondly, the self-assembly and attachment of nanocrystals into atomically coherent 2-D semiconductors can be used.

Interfacial self-assembly and epitaxial attachment of colloidal Pb-chalcogenide semiconductors has resulted into two-dimensional *atomically coherent* PbX (X=S, Se, Te) semiconductors with remarkable geometry and strong electronic coupling between the nanocrystal sites. By Cd-for-Pb cation exchange, these honeycomb systems can be transformed into honeycomb semiconductors with a zinc blende CdX atomic lattice. Effective mass- and atomistic theory predict that 2-D semiconductors with honeycomb geometry have a bandgap similar to the 2-D quantum wells, however, with Dirac-type electronic conduction and valence bands. Due to strong spin-orbit coupling, the Dirac cone at the K-point can open, and host the quantum spin Hall effect.

I will discuss the theoretically predicted electronic band structure. I will show and discuss the first density-of-state measurements on honeycomb semiconductors and the transport characteristics of electrons and holes in these systems. Finally, the optical properties of freely suspended honeycomb semiconductors will be compared to those of simple quantum wells with the same thickness and same atomic lattice.

References
[1] Long-range orientation and atomic attachment of nanocrystals in 2D honeycomb superlattices
M. P. Boneschanscher, W. H. Evers, J. J. Geuchies, T. Altantzis, B. Goris, F. Rabouw, S. van Rossum, H. S. J. van der Zant, L. D. A. Siebbeles, G. Van Tendeloo, I. Swart, J. Hilhorst, A. V. Petukhov, Bals, and D. Vanmaekelbergh, Science 344, 1377 (2014).
[2] Dirac Cones, Topological Edge States, and Nontrivial Flat Bands in Two-Dimensional Semiconductors with a Honeycomb Nanogeometry. E. Kalesaki, C. Delerue, C. Morais Smith, W. Beugeling, G. Allan, and D. Vanmaekelbergh, Phys. Rev. X 4, 011010 (2014)
[3] Low-Dimensional Semiconductor Superlattices Formed by Geometric Control over Nanocrystal Attachment. W. H. Evers, B. Goris, S. Bals, M. Casavola, J. de Graaf, M. Dijkstra, D. Vanmaekelbergh, NanoLett. 13, 2317-2323 (2013)
[4] Topological states in multi-orbital HgTe honeycomb lattices. W. Beugeling et al. *Nature Communication s* 6, doi:10.1038/ncomms7316 (2015).

*E-mail: d.vanmaekelbergh@uu.nl