Abstract for 27th Workshop on Quantum Solar Energy Conversion, Rauris 22-27 March 2015

Preparation and study of semiconductors with a honeycomb nanogeometry

E. Kalesaki[1], M.P. Boneschanscher[2], J.J. Geuchies[2], C. Delerue [1,2], C. Morais Smith[3], W.H. Evers[4], G. Allan[1], T. Altantzis[5], S. Bals[5], and D. Vanmaekelbergh[2]

1. IEMN- Dept. ISEN, UMR CNRS 8520, Lille
2. Debye Institute for Nanomaterials Science, University of Utrecht
3. Institute for Theoretical Physics, University of Utrecht
4. Opto-electronic Materials Section, Kavli Institute of Nanoscience, Delft University of Technology
5. EMAT, University of Antwerp

The interest in 2-dimensional systems with a honeycomb lattice and related Dirac-type electronic bands has exceeded the prototype graphene. Currently, 2-dimensional atomic and nanoscale systems are extensively investigated in the search for materials with novel electronic properties that can be tailored by geometry. I will show how atomically coherent honeycomb superlattices of rock salt (PbSe, PbTe) and zinc blende (CdSe, CdTe) semiconductors can be obtained by nanocrystal self-assembly, covalent attachment, and subsequent cation exchange. A detailed analysis with STM, GISAXS, and HAADF-STEM of these systems learned that self-assembly and oriented attachment leads to buckled (i.e. silicene-type) honeycomb structures with a periodicity of about 6 nm.

Atomistic theory and analytical predict that these artificial graphene systems combine Dirac-type electronic bands with the beneficial properties of a semiconductor, such as the presence of a band gap and strong spin-orbit coupling, leading to the quantum spin Hall effect.

Finally, I will present the first experimental results on the opto-electrical characterisation of PbSe and CdSe honeycomb semiconductors.

Long-range orientation and atomic attachment of nanocrystals in 2D honeycomb superlattices
Boneschanscher, M. P., Evers, W. H., Geuchies, J. J., Altantzis, T., Goris, B., Rabouw, F. T., van Rossum, S. A. P., van der Zant, H. S. J., Siebbeles, L. D. A., Van Tendeloo, G., Swart, I., Hilhorst, J., Petukhov, A. V., Bals, S., Vanmaekelbergh, D.
Science **344**, 1377-1380 (2014)

Dirac Cones, Topological Edge States, and Nontrivial Flat Bands in Two-Dimensional Semiconductors with a Honeycomb Nanogeometry
Kalesaki, E., Delerue, C., Smith, C. Morais, Beugeling, W., Allan, G., Vanmaekelbergh, D.
Physical Review X, **4**, 011010 (2014)

Preparation and study of 2-D semiconductors with Dirac type bands due to the honeycomb nanogeometry
Kalesaki, E., Boneschanscher, M. P., Geuchies, J. J., Delerue, C., Morais Smith, C., Evers, W. H., Allan,

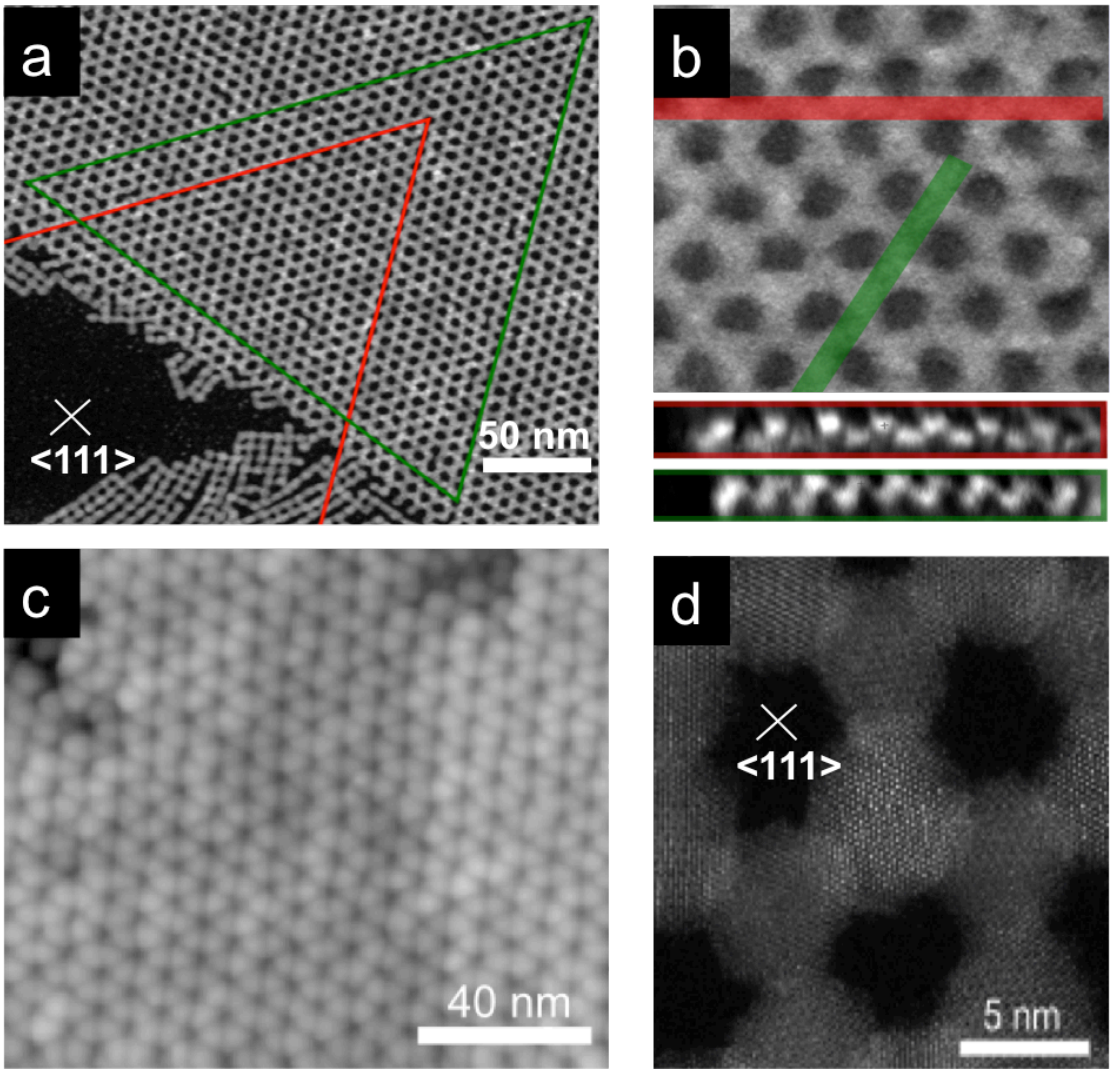

Figure 1. Experimental characterization of PbSe and CdSe honeycomb semiconductors obtained from the self-assembly and oriented attachment of PbSe nanocrystals. Figure **a** presents a HAADF-STEM image of 2-D PbSe crystal with honeycomb geometry: the white color presents the crystal, the voids are black. Red (and green) equilateral triangles have edges with the same number of honeycomb unit cells demonstrating long-range order. Electron diffraction showed that the structure is a single crystal with a <111> axis perpendicular to the honeycomb plane; **b** presents the results of tomography, i.e. a horizontal cross section and two vertical cross sections (along the red and green respectively) demonstrating that the structure is buckled, i.e. silicene. Figure **c** represents a scanning tunneling microscopy image of CdSe honeycomb structure obtained by Cd-for-Pb cation exchange; the defects reveal a double layered structure corresponding to a silicene lattice (see Fig. 2c,d) **d** presents a detailed HAADF-STEM image of a part of a CdSe honeycomb structure, obtained from a PbSe structure by cation exchange, showing that a <111> axis is pointing upwards; electron diffraction (not shown) reveals that the crystal structure is zinc blende.