Large-scale fabrication of 2-D honeycomb semiconductor superlattices and their incorporation in opto-electrical devices

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In 2-D semiconductor systems, it is possible to superimpose an additional periodicity on the nanoscale that can deeply influence the band structure of the semiconductor. For instance, when a 2-D semiconductor crystal is molded into a honeycomb geometry with a periodicity on the 5 - 50 nm scale, the band gap of the semiconductor remains comparable to that of a quantum well, but the highest valence and lowest conduction bands show a LINEAR (instead of quadratic) relation to the carrier momentum at the K-points[1]. As a consequence, such honeycomb semiconductors host massless electrons and holes by doping or optical excitation.

Semiconductor crystals can be molded into a honeycomb geometry by bottom-up self-assembly of nanocrystals[2,3], or by top-down lithography[4]. In this lecture, I will show the progress that we made on the self-assembly and lithographic pathways. With lithography, we obtained graphene-type honeycomb GaAs that is free-standing or already directly incorporated into a device. Furthermore, we show how interfacial self-assembly under reversible conditions results in honeycomb superlattices of the Pb-chalcogenide and Cd-Chalcogenide family. We have incorporated these monolayer sheets into transistors with electrolyte-gating and studied the electron transport characteristics. Although the electron mobilities of 10 cm^2/Vs are promising, the mobility is still partly determined by disorder, and not only by scattering to lattice phonons[5]. We also show how these 2-D superlattices can be incorporated in detectors for sensitive photon detection, and how such devices can be used for a study of the optical transitions and band structure.

References:

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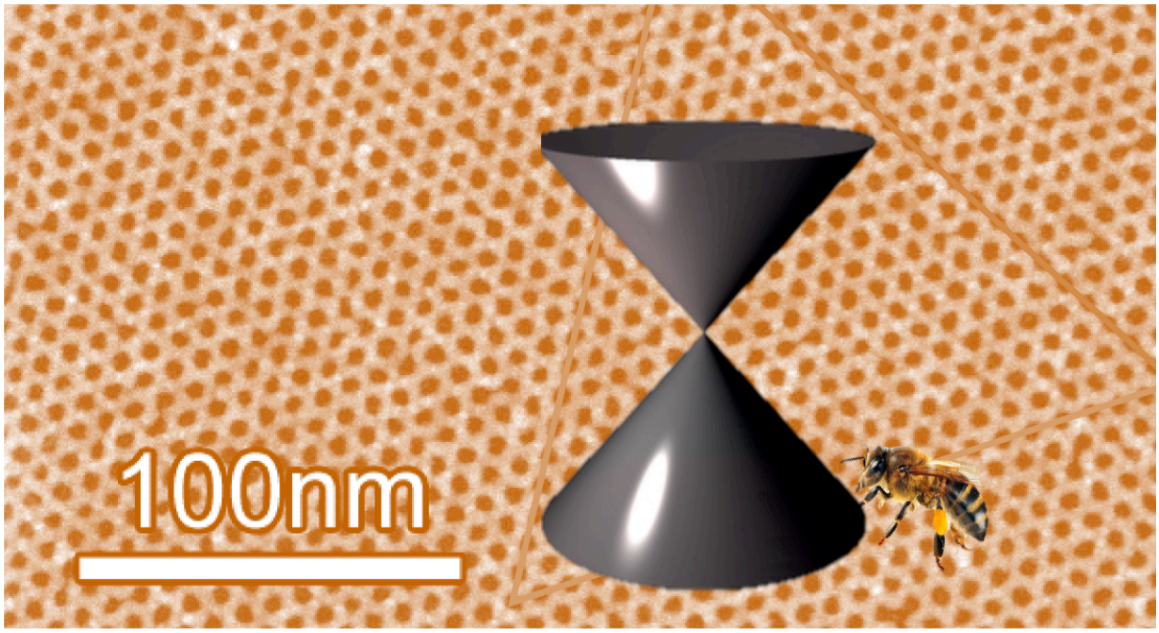

Comprehensive figure: On the background we see a part of a 2-D honeycomb lattice prepared by nanocrystal assembly and oriented attachment at the glycol/toluene/air interface. It is a single crystal of PbSe (or CdSe) with, however, a considerable amount of atomic and nanoscale disorder. Theory predicts that these 2-D semiconductors have similar properties as quantum wells with a typical quantum well band gap, depending on the compound. Furthermore, the highest valence bands and lowest conduction bands form Dirac cones at the two K – points in the hexagonal 2-D Brillouin zone.(see gray Dirac cone). This means that holes and electrons at these Dirac points should become massless and acquire a (1) high mobility, (2) topological properties including a quantum spin Hall effect.

At present, transport measurements in an transistor show a moderate mobility, while STM measurements are indicative for a Dirac cone in the CB. The coming years *we* (the bee in the picture) will have to fight disorder or minimize the effects of disorder to be able to fully display the opto-electronic properties of these novel Dirac semiconductors.