

Artificial 2-D lattices as quantum simulators. What is the relevance for real materials?

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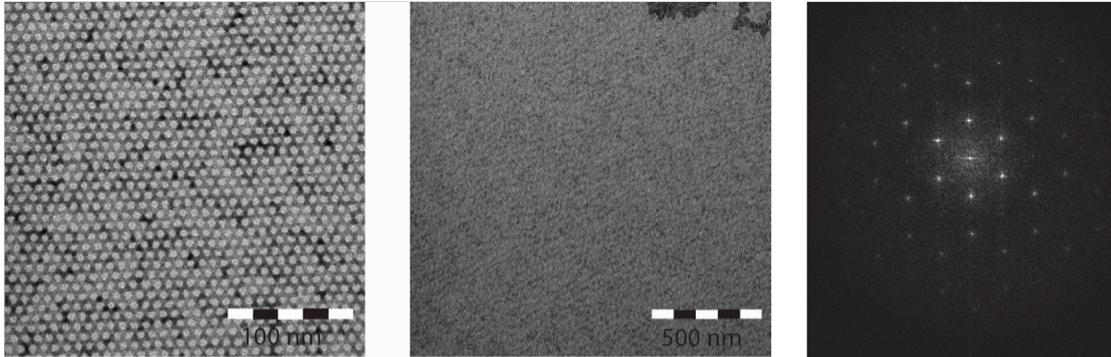
Theoretical work of the last two decades have shown that, besides the atomic registry and overall dimensions, also a superimposed periodicity on the nanoscale (the nanogeometry) can have a deep influence on the band structure of electronic materials. For instance, a planar III-V or II-VI semiconductor has, due to its dimensions, the band structure of a quantum well, resulting in specific optical properties and, in a magnetic field, to the quantum Hall effect. But if we are able to superimpose a honeycomb nanogeometry on this semiconductor, the top valence and bottom conduction bands become Dirac-type around the K-point in the Brillouin zone. The challenge is to make planar materials (semiconductors, semimetals, superconductors) that have such a nanoscale periodicity. In the Figure below, we show examples of a honeycomb InAs structure obtained by lithography (with a periodicity in the 30 nm scale) and a honeycomb PbSe superlattice obtained by nanocrystal self-assembly. In both approaches, experimental results show that there is still some structural disorder to overcome.

A great idea to the study the relationship between nanogeometry and electronic band structure is to use *artificial lattices as quantum simulators*. We built a number of artificial lattices in an STM and studied on the same time the electronic band structure. Atomic manipulation in an STM is used to position ad-atoms or CO molecules on the metal surface in order to form arrays or repulsive scatters that force the surface electrons into certain patterns. In this way, arrays of artificial atomic sites can be engineered, as well as the quantum coupling between these sites in a given lattice. In such a way, artificial lattices form a nearly ideal platform to study the relationship between the lattice geometry and electronic band structure of 2-D systems. This includes the study of Dirac bands and topological electronic phases emerging from the lattice geometry and the nature of the scatters^{1,4}. I will discuss the progress obtained in this field in recent years by us and other groups. I will also show the relevance of this work for real materials with a Dirac or topological band structure^{5,6}.

References in red are from the Vanmaekelbergh group

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Figures



TOP: A honeycomb PbSe superlattice prepared by nanocrystal assembly and oriented attachment at two different length scales; right a fast fourier transform of the picture shows the honeycomb geometry. BOTTOM: Density of states and wavefunction maps of an artificial honeycomb superlattices defined by positioning CO molecules (black) on a Cu(111) surface. This defines artificial atoms (crosses) that couple and result in an S-type Dirac band, a P-type flat band, and a P-type Dirac band.

