Theoretical physicists design 'holy grail' of materials science

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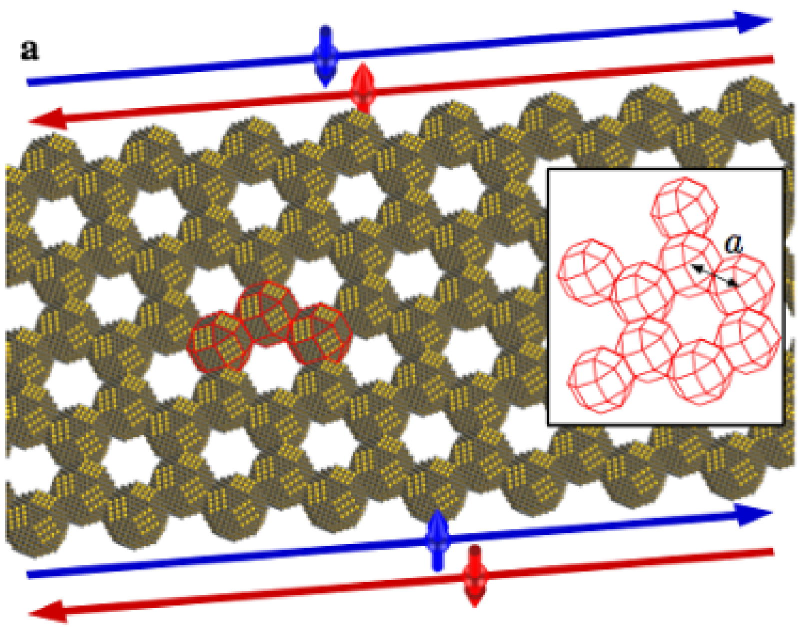

Honeycomb nanoribbon formed by the HgTe nanocrystals. Red and blue colours correspond to top and bottom edge for spin up, bottom and top edge for spin down, respectively. Credit: Utrecht University

Physicists of Utrecht University and their French colleagues have theorized the 'holy grail' of material science. It's a material that should exhibit a unique combination of the exceptional electronic properties of graphene with the important properties that graphene misses at room temperature. "If we manage to synthesize this 'holy grail' and it exhibits the theoretically predicted properties, a new field of research and applications opens up we can't fathom yet," says Prof. Cristiane Morais Smith from Utrecht University. Their findings are published in *Nature Communications* on 10 March 2015.

Graphene is a form of carbon in which the atoms are connected in a honeycomb structure. The possible 'holy grail' has this same structure, but is made of nanocrystals of mercury and tellurium. In their paper, the theoretical physicists show that this material combines the properties of graphene with the qualities graphene lacks. At room temperature, it is a semiconductor instead of a conductor, so that it can be used as a field-effect transistor. And it fulfills the conditions required to realise quantum spintronics, because it may host the quantum spin Hall effect at room temperature.

Quantum spin Hall effect and a honeycomb structure

Graphene, which was produced for the first time in 2003, is the first material discovered in which electrons move as if they have no mass. This is caused by the honeycomb structure of the Carbon atoms, which induces the electrons to behave as relativistic particles. However, it cannot realise the exotic quantum spin Hall effect, not even at very low temperatures. In their search for the holy grail, the challenge for the theoretical physicists was to find a way to shape a material with the potential to realise the quantum spin Hall effect at room temperature in a honeycomb structure.

Mercury tellurate

The quantum spin Hall effect, which was predicted in 1971, was only realised experimentally in 2006 by Prof. Laurens Molenkamp of the University of Würzburg and his team. They used mercury telluride/cadmium telluride quantum wells at a very low temperature. This inspired the theoretical physicists to design several honeycomb structures of mercury telluride nanocrystals and calculate their properties. Several structures turned out to have all the properties they were looking for. At Utrecht University, Prof. Daniël Vanmaekelbergh has already managed to synthesize this kind of honeycomb structure by using cadmium-selenide nanocrystals.

Realizing the holy grail

"However, at the moment, Prof. Laurens Molenkamp is the only expert in the world working with mercury telluride. So we are happy that he is very interested in synthesizing the honeycomb structures we designed with mercury telluride," says Prof. Cristiane Morais Smith from Utrecht University. "Although it is not yet possible to realise it experimentally, he expects that the technology necessary will be available within a short time, given the developments that are going on in his lab right now. If we succeed in synthesizing it and the material indeed exhibits the unique combination of exotic properties at room temperature as we predicted, a field of fundamental research and technological innovations opens up that lies beyond our imagination."

Spintronics

For one thing, it could be used in spintronics, a technology that may be the next step in speeding up computers and the Internet. In spintronics, the electron 'spin' is used instead of the electric charge. Spin up and spin down are used to describe whether electrons rotate clockwise or counter-clockwise. If all electrons with spin up move to the left and all electrons with spin down to the right, then they create a spin current instead of an electric current. Spin currents can interact with nanomagnets and lead to applications in the context of fast reading and writing of magnetic memories.

More information: Topological states in multi-orbital HgTe honeycomb lattices, W. Beugeling, E. Kalesaki, C. Delerue, Y.-M. Niquet, D. Vanmaekelbergh, and C. Morais Smith, *Nature Communications*, 10 March 2015, DOI: 10.1038/ncomms7316

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