"Valleytronics" – a new type of electronics in diamond

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(Phys.org) —An alternative and novel concept in electronics is to utilize the wave quantum number of the electron in a crystalline material to encode information. In a new article in Nature Materials, Isberg et.al. propose using this valley degree of freedom in diamond to enable valleytronic information processing or as a new route to quantum computing.

In electronic circuits, bits of information (1:s and 0:s) are encoded by the presence or absence of electric charge. For fast information processing, e.g. in computer processors or memories, charges have to be moved around at high switching rates. Moving charges requires energy, which inevitably causes heating and gives rise to a fundamental limit to the switching rate. As an alternative it is possible to utilize other properties than the charge of electrons to encode information and thereby avoid this fundamental limit. An example of this is "spintronics" where the spin of the electron is used to carry information.

An alternative and novel concept is to utilize the wave quantum number of an electron in a crystalline material. This may lead to ultrafast computing with less power consumption. In a new article in Nature Materials, a group at Uppsala University, consisting of Jan Isberg, Markus Gabrysch, Johan Hammersberg, Saman Majdi and Kiran Kumar Kovi, together with Daniel Twitchen at Element Six Ltd in Britain, show that it is possible to generate, transport and detect electrons with a given valley quantum number in diamond at a temperature of 77 Kelvin.

Electrons travel through crystals as waves. These waves can be described by different quantum numbers such as their crystal momentum and spin. In vacuum, an electron attains its minimum energy for zero momentum but in a crystalline material this may not be so. In diamond, an electron has its minimum energy for a finite value of momentum along certain directions of high symmetry in the crystal. At low temperatures electrons will reside in these valleys of minimum energy, of which there are six in diamond.

Other materials than diamond, e.g. silicon and graphene also have similar valleys, but in diamond electrons reside in their respective valley for, in this context, extremely long times: about 300 nanoseconds at liquid nitrogen temperature. This is long enough to be useful for information processing. The analogy with spintronics also implies that a future application for valleytronics is within quantum computers.

"The observation that the electron resides in a valley for such a long period that it is possible to manipulate these states is an important step towards valleytronic devices. We hope that this will prove to be a first step towards integrated valleytronic devices in diamond", says Jan Isberg, professor in electricity at Uppsala University.

Carbon-based electronic materials, such as graphene, carbon nanotubes and diamond, have been the subject of intense research during the last decennium. Diamond is well known for its exceptional hardness. Less well known is that diamond is an exceptionally good heat conductor, with a thermal conductivity which is six times that of copper. Diamond is also a semiconductor that can be doped to become electrically conductive.

The physical properties of diamond together with recent progress in making synthetic diamond of high crystalline quality and high purity have led to a surge in the interest for diamond in electronics, photonics and spintronics. Possible applications are magnetic sensors with nanometre resolution, single-photon sources and quantum computing. It has been suggested that diamond is the material of the future for quantum mechanical applications, due to long spin relaxation times, its optical properties and its large bandgap. The possibility of utilising diamond's valleytronic properties adds yet another route to realising quantum computers in diamond.

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