Valley current control shows way to ultra-low-power devices

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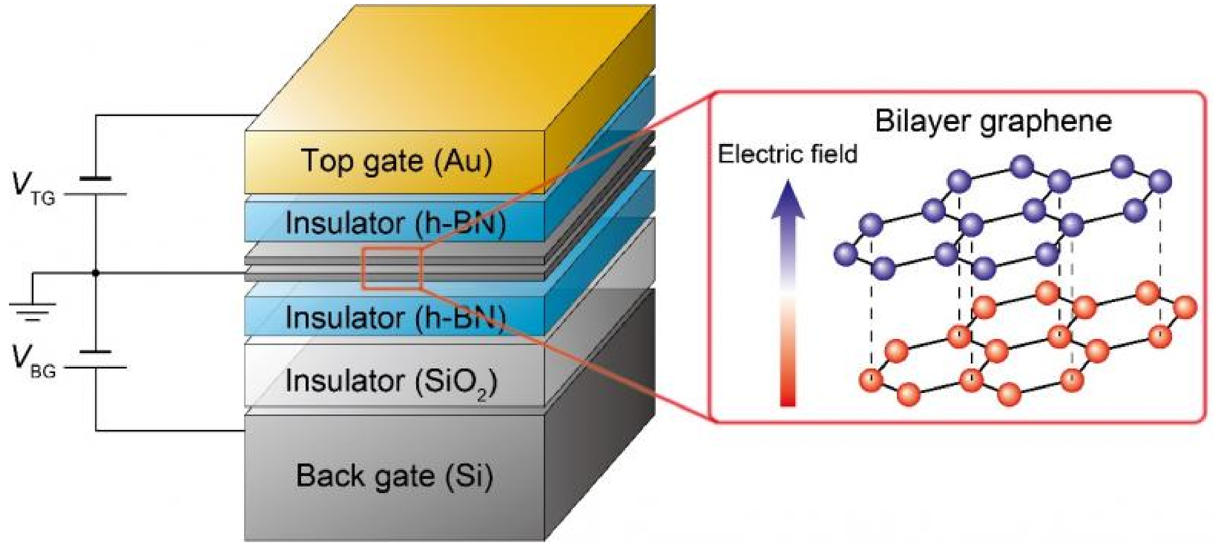


Bilayer graphene is encapsulated on top and bottom by hexagonal boron nitride (an insulator). By applying a voltage to the top and bottom gates it is possible to control the state of the bilayer graphene. Having two gates allows for independent control of the electron density and the vertical electric field. An applied vertical electric field creates a small but significant energy difference between the top and bottom layers of graphene. This difference in energy breaks the symmetry of graphene allowing for the control of valley. Credit: (c) 2015 Seigo Tarucha

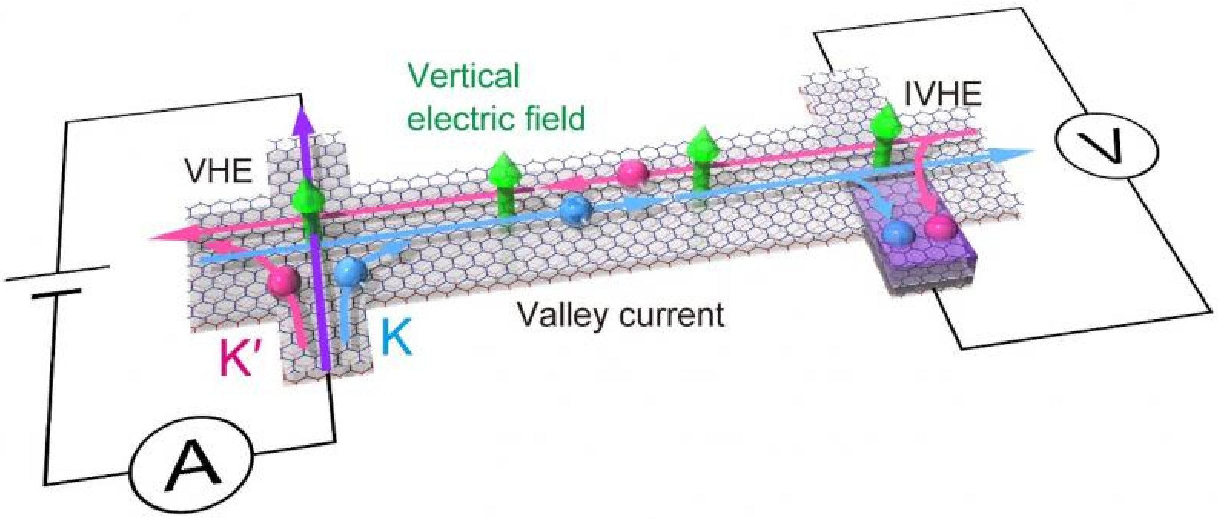
University of Tokyo researchers have demonstrated an electrically-controllable valley current device that may pave the way to ultra-low-power "valleytronics" devices.

On the atomic scale, matter behaves as both a particle and a wave. Electrons, therefore, have an associated wavelength that usually can have many different values. In crystalline systems however, certain wavelengths may be favored. Graphene, for example, has two favored wavelengths known as K and K' (K prime). This means that two electrons in graphene can have the same energy but different wavelengths - or, to put it another way, different "valley."

Electronics use charge to represent information, but when charge flows through a material, some energy is dissipated as heat, a problem for all electronic devices in use today. However, if the same quantity of electrons in a channel flow in opposite directions, no net charge is transferred and no heat is dissipated - but in a normal electronic device this would mean that no information was passed either. A valleytronics device transmitting information using pure valley current, where electrons with the same valley flow in one direction, would not have this limitation, and offers a route to realizing extremely low power devices.

Experimental studies on valley current have only recently started. Control of valley current in a graphene monolayer has been demonstrated, but only under very specific conditions and with limited control of conversion from charge current to valley current. In order for valley current to be a viable alternative to charge current-based modern electronics, it is necessary to control the conversion between charge current and valley current over a wide range at high temperatures.

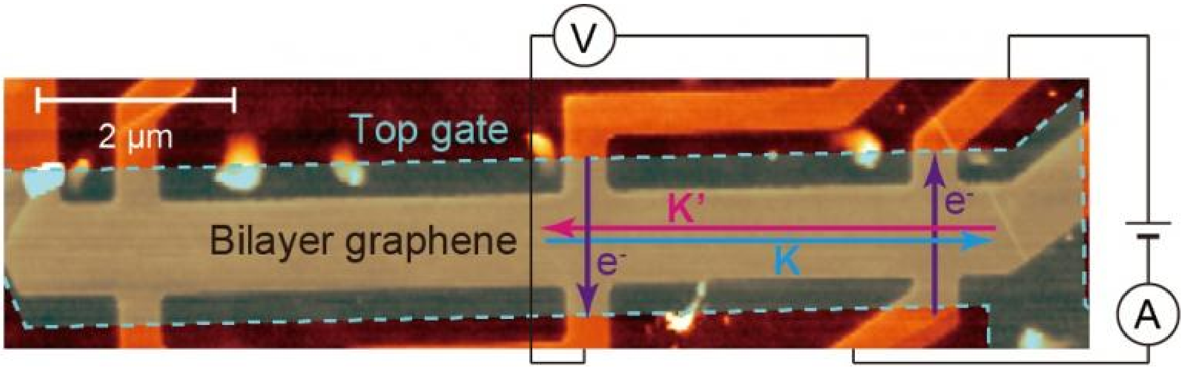
Now, Professor Seigo Tarucha's research group at the Department of Applied Physics at the Graduate School of Engineering has created an electrically controllable valley current device that converts conventional electrical current to valley current, passes it through a long (3.5 micron) channel, then converts the valley current back into charge current that can be detected by a measurable voltage. The research group used a graphene bilayer sandwiched between two insulator layers, with the whole device sandwiched between two conducting layers or 'gates', allowing for the control of valley.



A vertical electric field (green arrows) breaks the symmetry of the bilayer graphene allowing for selective control of valley. A conventional, small electrical current (purple arrow) is converted into valley current via the valley Hall effect (VHE). (The electrons in the K valley, blue, travel to the right; while the electrons in the Kâ€� valley, pink, travel to the left.) Pure valley current travels over a significant distance. At the other side of the device the valley current is converted back to charge current via the inverse valley Hall effect (IVHE) and is detected as a voltage. Credit: (c) 2015 Seigo Tarucha

The group transferred valley current over a distance large enough to exclude other possible competing explanations for their results and were able to control the efficiency of valley current conversion over a wide range. The device also operated at temperatures far higher than expected. "We usually measure our devices at temperatures lower than the liquefaction point of Helium (-268.95 C, just 4.2 K above absolute zero) to detect this type of phenomena," says Dr. Yamamoto, a member of the research group. "We were surprised that the signal could be detected even at -203.15 C (70 K). In the future, it may be possible to develop devices that can operate at room temperature."

"Valley current, unlike charge current is non dissipative. This means that no energy is lost during the transfer of information," says Professor Tarucha. He continues, "With power consumption becoming a major issue in modern electronics, valley current based devices open up a new direction for future ultra-low-power consumption computing devices."



An Atomic Force Microscope image of the valleytronics device. The bright orange area is bilayer graphene. The light blue area shows the area of the top gate. Current is injected from the right side of the device, and converted to valley current. The valley current is converted back to charge current and detected as a voltage signal. Credit: (c) 2015 Seigo Tarucha

More information: Y. Shimazaki et al. Generation and detection of pure valley current by electrically induced Berry curvature in bilayer graphene, *Nature Physics* (2015). DOI: 10.1038/nphys3551

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