Unfazed by imperfections

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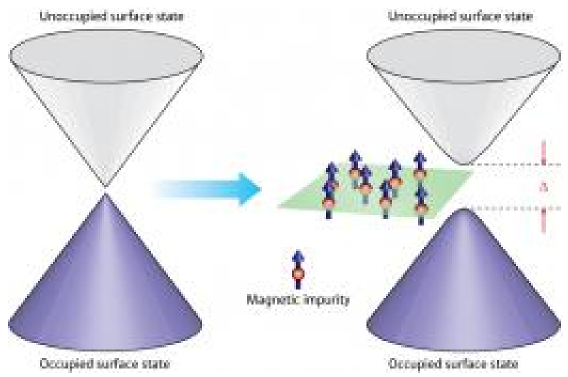

The introduction of magnetic impurities into a topological insulator causes a gap to open in the characteristic double-cone energy structure of the material (the x-axis shows electron momentum, the y-axis shows the energy). Credit: 2010 AAAS

While insulating against electrical currents in their interior, the surface of materials called topological insulators permits the flow of electron spins relatively unhindered. The almost lossless flow of spin information makes topological insulators a promising new class of materials for electronic applications: the electron spins could be harnessed to transmit information in the same way that electrical charges are used in conventional electronics. Electron spins are also susceptible to magnetic fields, so electrical control of the magnetic fields of these materials would offer further control over the properties of electronic devices. Magnetic impurities in these materials, however, have thwarted attempts by experimental physicists to fabricate topological insulators, because they destroy the characteristic energy structure of a topological insulator

(Fig. 1).

In a theoretical study, Kentaro Nomura and Naoto Nagaosa from the RIKEN Advanced Science Institute, Wako, have unexpectedly discovered that the electrical control of magnetization in topological insulators is actually enhanced by the presence of magnetic impurities. It may be possible, therefore, to develop novel devices from topological insulators by creating magnetization with electrical fields.

Topological insulators owe their unique properties to time-reversal symmetry: if the flow of time were reversed, the material would behave in the same way. Magnetic impurities break this symmetry, as magnetism is sensitive to time reversal; electrical currents flowing forward and backward in time create magnetic fields pointing in opposite directions. Physicists therefore expected that magnetic impurities would disrupt the magnetization generated by electrical currents on the surface of a topological insulator.

Nomura and Nagaosa's calculations, however, showed that randomly distributed magnetic impurities do not influence the strong coupling between electrical currents and magnetic fields. Electrical currents at the surface are quantized, which means that they change only in steps. Therefore, a change in the energy structure of the material would not affect the electric current and magnetization. The randomness of the impurities increases the usable energy range, says Nomura. "Usually impurities and disorder smear desired effects. In this case, imperfections enhance them."

This finding is welcome news for experimental physicists working on topological insulators. All samples fabricated to date contain so many impurities that observing spin currents at their surface is almost impossible. The discovery that magnetic impurities should have no detrimental effect improves the likelihood of observing the proposed control of magnetization. Consequently, says Nomura, "a number of experimental groups are already working on this issue. I think this effect will be observed, hopefully soon."

More information: Nomura, K. & Nagaosa, N. Surface-quantized anomalous Hall current and the magnetoelectric effect in magnetically disordered topological insulators. Physical Review Letters 106, 166802 (2011).

Chen, Y.L., et al. Massive Dirac fermion on the surface of a magnetically doped topological insulator. Science 329, 659–662 (2010).

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