A nanoscale landscape

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Stripe-like contours on a surface modulate electrons that behave like light

CHESTNUT HILL, MA (October 25, 2012) – In the relatively new scientific frontier of topological insulators, theoretical and experimental physicists have been studying the surfaces of these unique materials for insights into the behavior of electrons that display some very un-electron-like properties.

In topological insulators, electrons can behave more like photons, or particles of light. The hitch is that unlike photons, electrons have a mass that normally plays a defining role in their behavior. In the world of quantum physics, where everyday materials take on surprising and sometimes astonishing properties, electrons on the outer surface of these insulators behave and look uncharacteristically like light.

These unique properties have piqued the interests of scientists who see future applications in areas such as quantum computing and spintronics, or other realms rooted in the manipulation of electronic properties. The early challenge to those researchers is to begin to understand some simple ground rules for controlling these materials.

Boston College researchers report that the placement of tiny ripples on the surface of a topological insulator engineered from bismuth telluride effectively modulates so-called Dirac electrons so they flow in a pathway that perfectly mirrors the topography of the crystal's surface.

Associate Professor of Physics Vidya Madhavan and Assistant Professor of Physics Stephen Wilson report in the current online edition of Nature Communications that scanning tunneling microscopy is capable of revealing the characteristics of these tiny waves as they rise and fall, enabling the researchers to draw a direct connection between the features of the ripples and modulation of the waves across the material's surface.

Instead of chaotic behavior, the electrons flow in a path that mirrors the metal composite's surface, the team reports in an articled titled "Ripple-modulated electronic structure of a 3D topological insulator."

"What we've discovered is that electrons respond beautifully to this buckling of the material's surface," said Madhavan, the project director.

So harmoniously do the waves flow across the ripples – placed approximately 100 nanometers apart – that the researchers say further modifications of the crystal's "nanoscale landscape" could produce enough control to produce a one-dimensional quantum wire capable of carrying current with no dissipation.

The rippled surface appears to exert greater control and run less risk of creating imperfections than other methods, such as introducing chemical dopants, used in attempts to modulate the flow of electrons on the surface of other topological insulators, the researchers found.

Madhavan said the team had to provoke the electrons, which lay placidly atop the surface-state of the insulator, much like the glassy surface of an undisturbed lake. The team disrupted the electrons by introducing impurities, which had an effect similar to that of dropping a stone in a calm lake. This provocation produced waves of electrons that behave like waves of light as they travel pathways that mirror the contours created in the crystal.

"We did not expect the electrons to follow the topography," said Madhavan. "The topography imposes a sinusoidal potential upon the waves. The ripples create that potential by giving the electrons a landscape to follow. This is a way of possibly manipulating these electrons in topological insulators."

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