Physicists take photonic topological insulators to the next level

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Researchers at The University of Texas at Austin have designed a simulation that for the first time emulates key properties of electronic topological insulators.

Their simulation, which was described this week in Nature Materials, is part of a rapidly moving scientific race to understand and exploit the potential of topological insulators, which are a state of matter that was only discovered in the past decade. These insulators may enable dramatic advances in quantum computing and spintronics.

"The discovery of these materials, which are insulators in their volume while capable of conducting current on their surface, was a bit of a surprise to the condensed matter community," said Gennady Shvets, professor of physics in the College of Natural Sciences. "Before that, we classified solid materials into three categories, based on their ability to conduct electric current: insulators, conductors, and semiconductors. Topological insulators fall somewhere in between."

Shvets co-authored the article with his physics department colleagues Alexander Khanikaev, S. Hossein Mousavi, Wang-Kong Tse, Mehdi Kargarian, and Professor Allan MacDonald.

He said that what's particularly exciting about topological insulators is that they can conduct electrons—or in the case of photonic ones, photons—in a way that protects them from scattering or reflecting when they encounter obstacles.

"Usually when photons run into an obstacle, they reflect," said Shvets. "We are basically designing interfaces in such a way that they lock photons into one spin state. So in one direction they're in one spin state, and when they're going in another direction they're locked into another spin state. In that configuration they cannot reflect without changing their spin, which is forbidden by the design of the photonic crystal. They flow around defects and can be routed along arbitrarily shaped paths defined by the interface."

If this property could be achieved with electrons it would be particularly relevant to quantum computers, which are likely to require their electrons to maintain coherence for a much longer time than digital computers.

Over the past decade scientists have had modest success making or finding electronic topological insulators. But these substances are limited both in what they can do and in what they can reveal about the potential of this new state of matter.

"Those systems are very difficult to study systematically, because when you have a real material it is what it is. You're limited to studying its properties," said Shvets. "Nature doesn't give you the knobs to increase or decrease various aspects of it, so it's very difficult to benchmark the existing theories against what's observed."

Shvets and his physics department colleagues expect that their simulated photonic insulator will be a much more powerful and flexible tool for studying the general properties of topological insulators.

"With these purely artificial photonic crystals, we can study these systems in a more systematic way," he said.

In order for their insights from the photonic system to be applicable to electronic systems, Shvets and his colleagues had to make their simulated photons behave sufficiently like electrons. To do that, they designed simulated "metamaterials." These are artificial electromagnetic materials that can be tuned to influence photons in ways that are otherwise impossible. Other metamaterials are being used to develop invisibility cloaks.

Shvets and his colleagues designed what they've called SPINDOMs (spin-degenerate optically-active metamaterials). When arranged periodically, the resulting meta-crystals are the first demonstration that it's possible to control the spin of photons in a way that emulates what can be done with electrons.

This is significant on a few fronts. Even as a computer simulation it allows researchers to explore the properties of topological insulators. When these photonic topological insulators are physically built, as Shvets and his colleagues hope will be done soon, they'll allow more exploration. And there's great promise that such insulators may eventually be used to reduce interference in wireless communications systems.

"Right now if you put multiple emitting or receiving antennas in close proximity to each other, whether on a semiconductor chip or on top of a cellular base station, the radiation from each antenna is affected by the others," he said. "To deal with this you have to design around it. What would be better is if all cross talk between emitting/receiving sources could just be eliminated. That's what we believe could be done by photonic topological insulators, which can directionally guide electromagnetic waves."

Provided by University of Texas at Austin