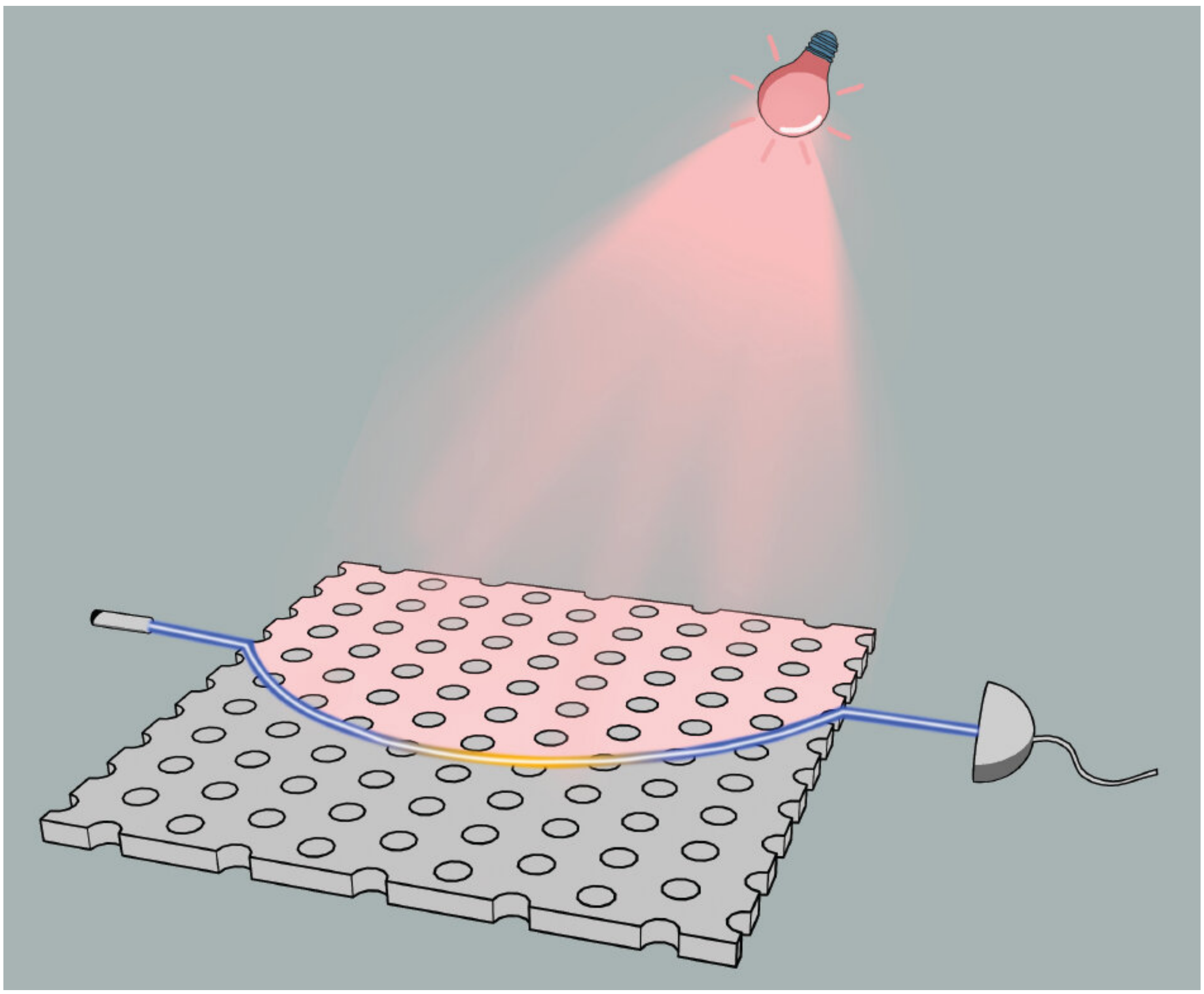
Researchers discover new topological phases in a class of optical materials

September 18 2019, by Erica K. Brockmeier



Using insights from topology, Penn physicists have discovered a new way to create optical materials and devices that can break optical reciprocity, paving the way to create "one-way" systems for light to travel and enabling more more efficient optical systems in the future. Credit: Beverley Zheng

Optical devices create, guide, and detect electromagnetic waves and include lasers, telescopes, and solar cells. Most of the materials used in these devices are challenging for certain applications because of a phenomenon known as optical reciprocity, an inherent symmetry which forces light to travel bidirectionally. One example of an application-based challenge is a high-powered laser, where back-scattered light caused by optical reciprocity can damage the instrument.

A new study published in *Nature Communications* describes how optical reciprocity can be broken using insights from topological physics. Induced topological states, infusing the material with new properties, can help create "one-way" systems for light to travel, making it possible to create more efficient optical devices in the future. The research was led by Assistant Professor Bo Zhen and postdoc Li He in collaboration with Professor Eugene Mele and graduate students Zachariah Addison and Jicheng Jin, as well as Professor Steven Johnson from MIT.

While there are some naturally existing materials that can break optical reciprocity, this magneto-optical effect is often very weak, and the materials can only be used in static systems. These limitations mean that the materials are too bulky to use on small optoelectronic chips. "It's a technical barrier that exists," says Zhen. "Besides this magneto-optical effect, we're asking what other scientific possibilities can implement similar effects."

Zhen and He studied $LiNbO_3$, an optical material that can be made into thin films and could be used as a coating on optoelectronic chips and small devices. As a class of optical material that physicists refer to as nonlinear, $LiNbO_3$ can break optical reciprocity when placed in a dynamic setting, such as being shaken instead of left standing still, or a static system.

Nonlinear optical materials are quite common; most classroom laser pointers have nonlinear optical crystals that convert invisible infrared light into visible green light. The hurdle faced by researchers is that there's very little known about topological phases in nonlinear optical materials, especially when they are in dynamic settings.

With the researchers' expertise in topological photonics and in studying materials with optoelectronic applications, they developed a physical theory to explain what happens in nonlinear optical materials. To confirm the theory, He ran simulated experiments on LiNbO3 photonic crystals and found that topological phases could be induced if the material was in a dynamic system.

More importantly, the researchers say, these topological phases appear to have no direct counterparts in electronic systems, which could lead to unique features in future applications. "For example, we could potentially also achieve a unidirectional amplifier or attenuator," says He.

Zhen says a subtle aspect of their findings is that they provide a better understanding of energy conservation in dynamic systems, which is less straightforward than static systems. For example, when photons of light go through a dynamic system, the number of photons stays the same, but the total amount of energy can change as photons pick up or release energy. Having a better understanding what is conserved and what is not in dynamic systems was one of the highlights of this research for Zhen and his team.

As one of the first papers to provide a foundation for future study of topological states in nonlinear optical materials, this work can provide guidance for future theoretical work while providing a starting point for upcoming experiments.

"It's truly the beginning of a very exciting field," says Zhen. "We laid down the underlying theoretical framework and showed that even if the static system is trivial, if we shake it in the right way, it becomes something very interesting."

More information: Li He et al. Floquet Chern insulators of light, *Nature Communications* (2019). DOI: 10.1038/s41467-019-12231-4

Provided by University of Pennsylvania