Flexible yet robust

Researchers have demonstrated experimentally a new type of pathway for electromagnetic waves, which allows an easy reconfiguration into various shapes while suppressing backscattering and guaranteeing low transmission losses.

Bo Zhen and Marin Soljačić

Reconfiguring an existing pathway in various contexts is challenging, from pathways for water (canals) to pathways for traffic (highways). The same challenge applies to pathways for light. Additionally, any sharp turns or rough edges found in the pathway for electromagnetic waves will inevitably lead to back scattering, which will limit the transmission efficiency of light. Writing in *Nature Materials*, Alexander B. Khanikaev and colleagues have now demonstrated a new concept for building fully reconfigurable pathways for electromagnetic waves. They experimentally showed that such pathways could guarantee low losses for many cases of interest while being easily reconfigurable into almost any shape [1].

Back-scattering of waves is ubiquitous in nature. For example, sound waves traveling down a pipe will be partially reflected when part of the pipe is intentionally blocked or it naturally has sharp bends. The ultimate solution in order to deal with this problem is eliminating altogether the back-scattering channel, by building a one-way highway for waves with no route that would allow the waves to turn around. Such pathways can always guarantee perfect transmission, even in the presence of major obstacles. This idea was first demonstrated for electrons in the famous quantum Hall effect and later translated into electromagnetic waves utilizing similar concepts [2]. The demonstration [3] was by no means easy, as it requires explicitly breaking time reversal symmetry (or more essentially reciprocity [4]) of the system. In another realization [5], breaking z-reversal symmetry was sufficient to give rise to topological protection in the transverse plane (with z acting in place of a time axis).

The search for a system that is immune to back-scattering but without the requirement of breaking time reversal symmetry lead to the discovery of a fundamentally new type of material, topological insulators. Electronic topological insulators have indeed attracted much attention, both for fundamental physics investigation and potential for applications in quantum computing. Replicating such a behavior in photonics, however, is challenging, because electrons (which are fermions) and photons (which are bosons) respond fundamentally differently to the time reversal operation [6]; electrons (spin-1/2) can preserve the time reversal symmetry when spin-up states get transformed into spin-down, but photons lack such a fundamental degeneracy. In the absence of inherent degeneracies, can a synthetic one be possibly constructed? This is indeed the concept underlying many successful demonstrations in this direction [7, 8], as well as a theoretical proposal put forward in ref [9]: by carefully engineering a degeneracy between symmetric (TE-like) and anti-symmetric (TM-like) modes in a waveguide system, the authors managed to successfully restore the duality of the electromagnetic waves and construct a “pseudo-spin 1/2” system, which can mimic the electronic quantum spin Hall effect, but with photons.

Now, Khanikaev and colleagues have demonstrated this concept experimentally with microwave photons. The studied reconfigurable topological structure is formed between two parallel metallic plates with collar-bearing rods going through them, forming a triangular lattice (Fig. 1a). Depending on whether the collars are attached to the top plate or the bottom plate, each pseudo-spin will acquire one of the two distinct topological bandgaps. At the boundary between these two different domains (with rods attached to the top versus bottom plate), topological edge states can be observed, where pseudo-spin up (down) states are only allowed to flow from left to right (right to left), mimicking electrons in quantum spin Hall systems (Fig. 1b). The beauty of this configuration is in the ease of altering the domain wall (now the electromagnetic pathway), just by pushing the correct rods up or down. For example, if we push all rods in the region shaded in black down, we will obtain a domain wall in almost any shape we want – even the skyline of Manhattan (Fig. 1c). Electromagnetic waves will flow along this domain wall with no back-scattering despite the many sharp turns along the edge.

Still, the current design is not robust against all disorder, as pointed out by the authors. This is because the topological protection in the current system relies on the preservation of the pseudo-spin for transported waves, and this can be disrupted by disorder or interfaces. For example, certain types of disorder may flip the pseudo-spin, while others may fundamentally break the electromagnetic duality and therefore nullify the notion of “pseudo-spin” in the first place. Such disorder, from the theoretical perspective, destroys the topological protection and allows for back-scattering to occur. In their experiments, however, the authors found that back-scattering can still be significantly suppressed even in realistic structures with various kinds of disorder, showing great potentials for practical applications, such as spin filters [10].

The current demonstration is performed in the microwave regime with physical components on the scale of centimeters. One of the most exciting future directions is to extend the same concept to much smaller devices and at much higher frequencies (e.g. telecommunication frequencies ~1.55μm); however, fabrication in this context consists a major challenge. Nevertheless, the work of Khanikaev and co-workers is marked progress towards the next generation of designs and devices in photonic systems that remain immune to the performance degradation, induced by fabrication imperfections or environmental changes.

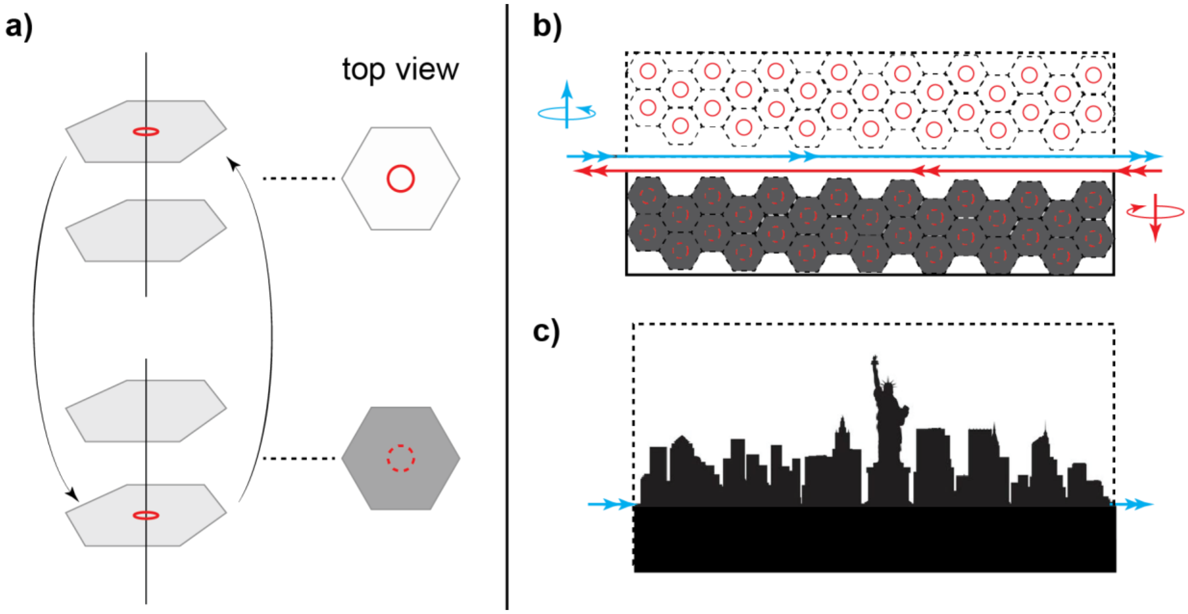

Fig. 1 Reconfigurable topological pathways for electromagnetic waves | a, In the experimental implementation [1], by pushing the collars up (down) so they become attached to the top (bottom) plate, yields two different topological bandgaps for each pseudo-spin. **b,** The boundary between the two domains with different topological gaps serves as the reconfigurable topological pathway for electromagnetic waves. Along this domain wall, electromagnetic waves with pseudo-spin up (down) in blue (red), are only allowed to travel from left to right (from right to left), due to the topological protection. **c,** By simply moving the collars up or down, various shapes of domain walls can be easily achieved (for example, the skyline of Manhattan). Electromagnetic waves flowing along the domain walls will not backscatter as long as the pseudo-spin of the transported waves is preserved.

Short-bio

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