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Beam splitter benefits from topological antichiral edge states

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A functional beam splitter is proposed with recently realized topological antichiral edge states, which offer multi-channel utilization, crosstalk-proof performance, and robustness against defects and obstacles.

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Beam splitters play a crucial role in a wide range of optical systems. A typical beam splitter consists of several transport channels, and an input beam from one channel is split into multiple output beams coupled into other channels. For traditional beam splitters, their transportation channels (either in free space or waveguides) are reciprocal, being sensitive to various perturbations caused by defects and obstacles.

Recently, researchers have been investigating novel approaches of beam splitting in the context of topological photonics[1], a burgeoning field that explores the topological properties of photonic materials and structures. These materials and structures have emerged as promising candidates for future optical applications as they support topological photonic states with remarkable resilience against defects and obstacles, such as forming one-way photonic propagation without reflection.

In the past years, several beam splitting mechanisms have been proposed replying on different topological states, such as chiral edge states[2], valley-locked edge states[3], and spin-polarized edge states[4]. Chiral edge states are unidirectional photonic states that are ideal for constructing robust channels of a beam splitter. Valley-locked edge states can be used to split beams based on their specific momenta. Spin-polarized edge states rely on the construction of photonic pseudospin, whose role is similar to that of electronic spin, to split the beam into different directions. These topological beam splitters offer unique advantages and can be used in different applications.

In a recent work published in *Opto-Electronic Science*[5], Jianfeng Chen and Zhi-Yuan Li report on the construction and observation of a novel topological beam splitter in an antichiral gyromagnetic photonic crystal (GPC). This innovative beam splitter showcases an easily adjustable splitting ratio and provides a highly efficient, compact design that allows for multi-channel utilization, crosstalk-proof performance, and robustness against defects and obstacles.

This beam splitter replies on the concept of antichiral edge states, which was first proposed in a modified Haldane model[6] and later experimentally verified in GPC[7,8]. These GPCs have been shown to support antichiral one-way edge states propagating along the same direction at two parallel zigzag boundaries. Notably, these edge states exist only at zigzag edges but not at armchair edges.

The proposed topological beam splitter consists of two rectangular antichiral GPCs (named as GPC 1 and GPC 2 in Fig. 1) biased by opposite external magnetic fields.

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These antichiral GPCs exhibit antichiral edge states with opposite propagation directions. At the interface of the two GPCs, there is no edge state due to the presentence of an armchair boundary. When an input source is placed at the center of the lower zigzag edge, the waves will be split into two beams propagating in opposite directions along the edge of the GPCs. The ratio between the right-to-left output beams can be adjusted by changing the incident angle of the excitation source. Alternatively, the input source can be placed at the center of the upper zigzag edge to construct another beam splitter. The two beam splitters are free of crosstalk, as there is minimal coupling between them even when they are close to each other. This property is especially important for applications where multiple channels need to function simultaneously.

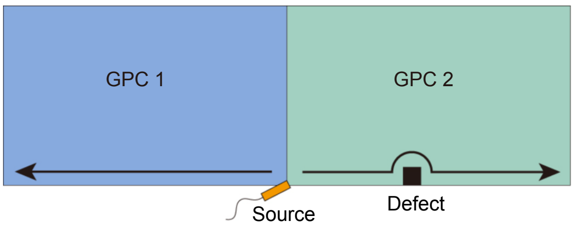

Fig. 1 | Schematic illustration of the topological beam splitter based on antichiral edge states.

One of the key advantages of antichiral GPCs is their robustness against defects and obstacles. For example, the waves can bypass a defect without reflection, as illustrated in Fig. 1. This property makes them particularly well-suited for use in harsh environments or applications where reliability is critical.

Overall, by leveraging the unique properties of antichiral GPCs, Chen and Li have demonstrated a highly efficient and versatile approach to beam splitting that has potential applications in a wide range of fields. The development of this configurable topological beam splitter has potential implications for a wide range of optical applications, including telecommunications, optical computing, and sensing. In telecommunications, for example, the splitter can be used to divide a single input signal into multiple output signals that can be transmitted over different channels simultaneously. In optical computing, the splitter can be used to route signals between different components or modules.

Nonetheless, there are still some shortcomings and drawbacks to this topological beam splitter. For instance, the antichiral GPC is gapless in its bulk, which will not exclude wave penetration like in photonic bandgap materials. Additionally, the current demonstration is in microwave regime. It remains a challenge to extend the realization to the optical spectrum. Lastly, it should be noted that this topological beam splitter is actually a one-dimensional (1D) splitter, as it utilizes the 1D edge states. It is possible that a two-dimensional (2D) splitter can be constructed by utilizing the surface states of a three-dimensional (3D) topological photonic system, such as 3D photonic Chern insulators[9]. As research in topological photonics continues to advance, we expect to see further developments in this direction with promising optical technologies.

References

1. Ozawa T, Price HM, Amo A, Goldman N, Hafezi M et al. Topological photonics. *Rev Mod Phys* **91**, 015006 (2019).
2. Skirlo SA, Lu L, Igarashi Y, Yan QH, Joannopoulos J et al. Experimental observation of large Chern numbers in photonic crystals. *Phys Rev Lett* **115**, 253901 (2015).
3. Zhang L, Yang YH, He MJ, Wang HX, Yang ZJ et al. Valley kink states and topological channel intersections in substrate-integrated photonic circuitry. *Laser Photonics Rev* **13**, 1900159 (2019).
4. Cheng XJ, Jouvaud C, Ni X, Mousavi SH, Genack AZ et al. Robust reconfigurable electromagnetic pathways within a photonic topological insulator. *Nat Mater* **15**, 542–548 (2016).
5. Chen JF, Li ZY. Configurable topological beam splitting via antichiral gyromagnetic photonic crystal. *Opto-Electron Sci* **1**, 220001 (2022).
6. Colomés E, Franz M. Antichiral edge states in a modified Haldane nanoribbon. *Phys Rev Lett* **120**, 086603 (2018).
7. Chen JF, Liang WY, Li ZY. Antichiral one-way edge states in a gyromagnetic photonic crystal. *Phys Rev B* **101**, 214102 (2020).
8. Zhou PH, Liu GG, Yang YH, Hu YH, Ma SL et al. Observation of photonic antichiral edge states. *Phys Rev Lett* **125**, 263603 (2020).
9. Liu GG, Gao Z, Wang Q, Xi X, Hu YH et al. Topological Chern vectors in three-dimensional photonic crystals. *Nature* **609**, 925–930 (2022).