Experimental demonstration of topological beam shaping using Jackiw-Rebbi states in metasurfaces

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Abstract: We experimentally demonstrate topological beam shaping using Jackiw-Rebbi states in metasurfaces. By engineering Dirac-mass distributions in thin-film dielectric structures, we create domain walls that enable customized beam profiles, confirming our approach through flat-top beam generation.

1. Introduction

Precise control of light beams is essential for laser machining, optical communications, and quantum technologies, yet traditional approaches using refractive and diffractive elements require complex heuristic optimization algorithms that limit adaptability for nanophotonic structures.

In this work, we demonstrate topological beam shaping using Jackiw-Rebbi states in guided-mode resonance structures, exploiting the wave-kinematic analogy between guided modes and Dirac fermions to achieve customized beam profiles—including flat-top beams—without tedious optimization steps.

2. Theory

The leakage-radiation beam shaping is illustrated in Fig. 1. A waveguide grating supports leaky guided modes with a prescribed standing-wave envelope profile $f(x)$, emitting the desired beam through first-order diffraction. Our approach exploits the mathematical analogy between guided mode resonance (GMR) and 1D Dirac fermions. The Bragg-reflection rate κ in GMRs corresponds to mass m of a Dirac fermion, with positive κ representing the topologically trivial phase and negative κ representing the non-trivial phase.

A GMR topological junction between these phases supports a localized state analogous to the JR soliton. By engineering the fill-factor distribution of the waveguide grating according to the relation $\kappa(x) = -c\,\frac{1}{f(x)}\frac{df(x)}{dx}$, we can achieve precise control over the resulting beam shape.

3. Results

We fabricate GMR samples using e-beam lithography on SiN/quartz and observe angle-resolved spectra confirming topological phase transitions and JR state at junction, shown in the left panel of Fig.2. To demonstrate our beam shaping capability, we design junction structures with specific Dirac-mass distributions, achieving controllable beam profiles including flat-top configurations whose leakage-radiation distributions (shown in the right panel of Fig.2) match well with simulations, confirming the validity of our topological beam shaping approach.

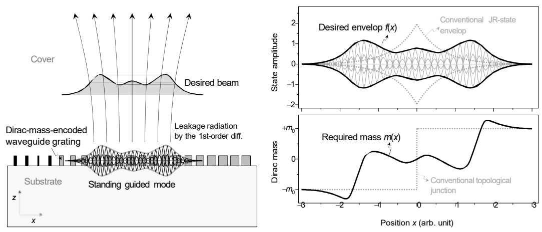

Fig. 1. Concept of topological beam shaping.

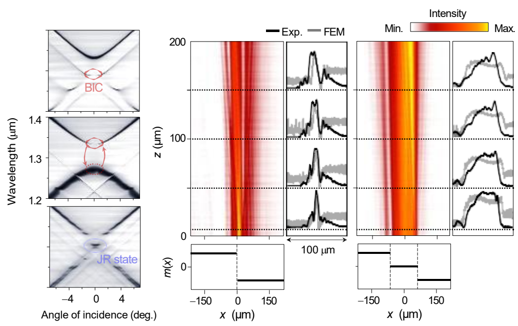

Fig. 2. Experimental results.

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References

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