Experimental observation of spin-locked propagation of topological edge states in an open non-Hermitian metasurface

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Abstract. In this work we explore photonic topological edge states arising in dielectric metasurface based on a deformed honeycomb lattice. We demonstrate numerically the effect of pseudo-spin locking of the edge states and verify its existence experimentally in microwave frequency range. Our findings thus demonstrate that open non-Hermitian metasurface can support the topological edge modes despite the radiative losses.

1. Introduction

Inspired by the discovery of the topological phases in condensed matter systems, photonics analogues of topological insulators nowadays are under active investigation. Their fascinating properties such as disorder robustness and backscattering-immune propagation of the topological states have opened novel ways to control propagation of electromagnetic waves.

![Figure 1. Sketch of the dielectric metasurface for observation of pseudo-spin locking in microwave frequency range](image_url)
In the recent years, photonic topological systems have been studied theoretically [1,2] and investigated experimentally from microwave to optical frequency ranges [3-5]. But the number of recent theoretical proposals is still waiting for their experimental verification.

In this work, we consider dielectric metasurface with triangular honeycomb lattice and demonstrate numerically and experimentally the emergence of photonic topological edge states even if the system is open and consequently non-Hermitian.

2. Design and results
To prove our concept we utilize the recently proposed design based on a triangular honeycomb lattice [6]. The unit-cell of this lattice represents hexagon with specially arranged 6 parallel dielectric cylinders (Figure 1). The geometry of lattice possesses $C_6$ symmetry which gives in combination with time-reversal symmetry double-degenerate Dirac cone at the Γ-point of the first Brillouin zone in the case of $a_0/R = 3$. By deforming the honeycomb lattice topologically trivial (for shrunken structure – $a_0/R > 3$) and nontrivial (for expanded structure – $a_0/R < 3$) bandgaps are opened [6]. Thus, the interface between shrunken and expanded structures can host topological modes which was previously proved for pure Hermitian system [6]. For open non-Hermitian systems the situation can be different due to the leakage coupling of the wave to the free space. And it is needed to prove that in this case the topological edge states still persist.

To prove this idea, we create a finite numerical model in the license program package CST Microwave Studio (Figure 1). The model consists of dielectric metasurface with two neighbor domains (shrunken and expanded) and subwavelength dipole located on the center of a domain wall. Each domain comprises of 8x11 unit-cells with the same lattice constant $a_0 = 37.5$ mm, height and radius of the cylinders 10 mm and 1.5 mm, respectively. The permittivity of each cylinder is equal to 10. The sizes of the clusters R were chosen to be $a_0/R = 3.33$ and $a_0/R = 2.73$ for shrunken and expanded structures, respectively. We calculate electric field intensity map at the 2 mm distance above the metasurface and find the edge states excited by linear and circular dipoles at the frequency 6.84 GHz (Figure 2a,b). The results show bi-directional excitation of edge states for linearly polarized...
dipole and one-way propagation for circularly polarized dipole that attests the locking of the polarization an propagation direction and thereby confirms the topological nature of the excited modes.

To verify our simulation results we fabricate metasurface and perform near-field measurements for linearly and circularly polarized excitations. Metasurface is fabricated on a machine-processed substrate of extruded polystyrene foam with drilled holes. Each hole is filled by commercial high-index dielectric powder (Eccostock HiK with the permittivity 10 and negligible losses). As a receiving antenna, we utilize subwavelength vertical electric dipole. The results of near-field measurements are in a perfect agreement with our simulations (Figure 2 c,d).

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