Topological Photonics in Integrated Waveguide

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Abstract: In this talk, we will show our recent works about exploration of valley photonic crystal waveguides towards the discovery of topological integrated photonics, particular for the silicon-on-insulator slab in telecommunication wavelength.
OCIS codes: (130.0130) Integrated optics, (130.5296) Photonic crystal waveguides, (160.3918) Metamaterials.

1. Introduction

Nanophotonic integrated devices, e.g. in silicon-on-insulator (SOI) platform, can potentially improve the capabilities of modern information-processing systems by replacing some of their electrical counterparts [1]. The discovery of topological photonics provides a new degree of freedom to control the flow of light, enabling robust information transfer and unidirectional coupling [2]. Recently, more and more works of topological photonics focus on integrated waveguide, because i) it provides a standard and advanced platform to experimentally explore a variety of topological phases, and ii) topological photonics gives a new paradigm to design integrated devices based on complex coupling of multiple degree of freedom, but the physics model is simple in “topology” language.

To develop topological physics into integrated photonic system, one of primary factors is all-dielectric design, which is compatible with low-absorbloss semiconductor materials. Recent developments of valley photonic crystals pave an alternative way to achieve high-performance topological nanophotonic devices in integrated waveguide [3-6]. To retrieve topological valley phase, a general method is to break spatial-inversion symmetry for accessing opposite Berry curvature profiles near Brillouin zone corners, i.e. K and K’ valley. The topological valley phase below light cone ensures high-efficient light confinement in the plane of chip, such that photonic valley degree of freedom (DOF) naturally makes a balance between in-plane robustness and out-of-plane radiation. This is a crucial condition to design topological integrated photonic structures. By employing valley degree of freedom, a theoretical proposal has been study on all-dielectric valley photonic crystals (VPCs) with nonzero valley Chern number [4]. Valley bulk state with chiral phase vortex is exploited, and it leads to the unidirectional excitation of light flow. Later, the experimental realization of all-dielectric VPCs has attracted much attention. The microwave experiment [6] work consider the TM_0 waveguide mode in hexagonal ceramic array sandwiched by two parallel metallic plates, as well as demonstrate the tunability of light flow in the VPC waveguide.

2. Results and discussions

Advanced in nanofabrication techniques, precise manufacture of the inversion-symmetry-broken nanophotonic structures is easy to implement nowadays. To do this, we design the VPC structures on SOI wafers with 220-nm-thickness silicon layers [7], as shown in Fig. 1(a). A bearded-stack interface is constructed by using two VPCs with opposite valley Chern index. Figure 1(b) gives the simulated patterns that the propagating light at λ = 1430 nm will smoothly detour by 120^o bending (60^o sharp corner). The valley-dependent topological edge states operate below the light cone so that the photonic crystal slab can strongly confine the propagating waves in the plane of chip. Benefit from near-quarter-wavelength periodicity, our VPC can develop a high-performance topological photonic device with a compact feature size. Based on the bearded-stack interface, we have fabricated flat-, Z- and Ω-shape topological channels. The measured results of these three devices in Fig. 1(c) show the flat-top high-transmittance spectra with relatively large bandwidth, even for sharp-bend geometry. Such phenomena give evidences for the observation of topologically robust transport at telecommunication wavelength.

Experimental realization of unidirectional coupling of topological edge states shows many promising applications in light manipulation, e.g. selectively routing the light path. In this work, we aim to develop an all-optical strategy, for unidirectional excitation of the valley-chirality locking edge states in the SOI platform [7]. We have experimentally demonstrated on-chip topological photonic routing. Such routing effect is based on the topological chiral channel of VPC. With introducing a subwavelength microdisk to serve as phase vortex generator, the valley-chirality-locked edge state is selectively excited (Fig. 2a). Thus the photonic valley-chirality locking property and topological routing effect were experimentally verified by far-field microscope images, as shown in Figs. 2(b-c).

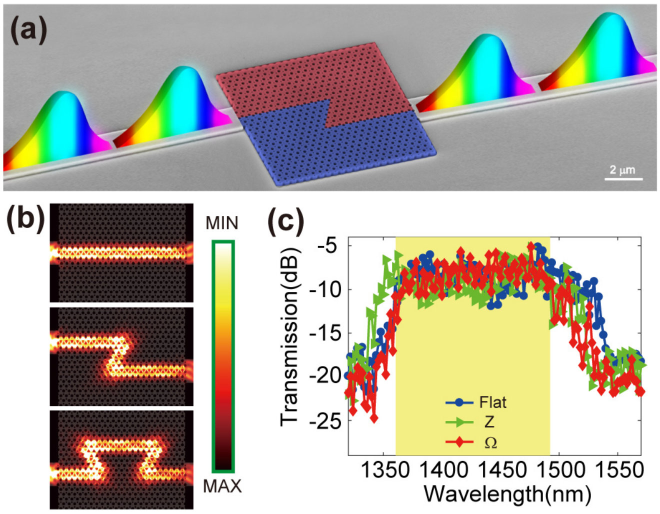

Fig. 1 Realization of valley photonic crystals in silicon-on-insulator slab and measurement of robust transport at telecommunication wavelength [7].

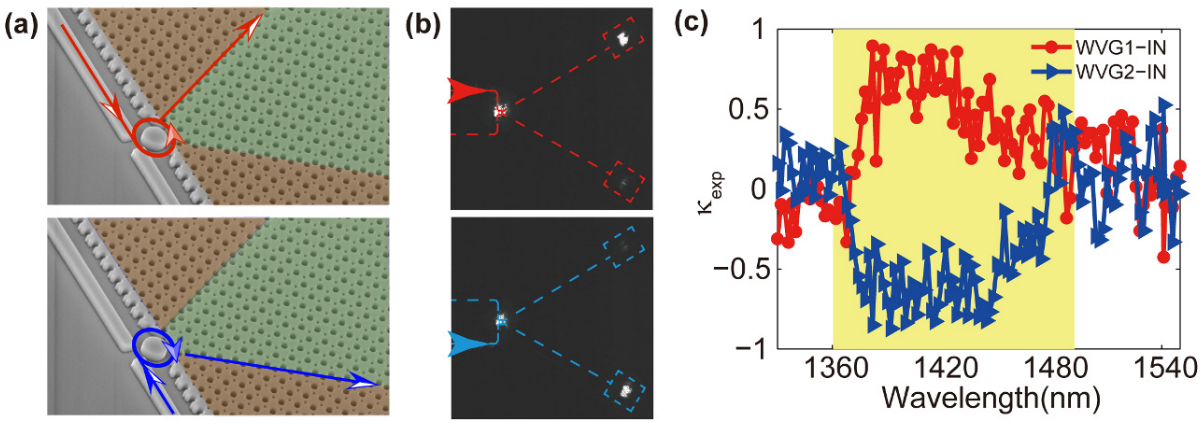

Fig. 2 Experimental demonstration of topological photonic routing in silicon-on-insulator slab [7].

Furthermore, we will show another type of topological integrated photonic waveguide based on bilayer photonic crystal slabs [8], i.e. all-dielectric layered photonic topological insulators (PTIs). Note that each layer can be considered as VPC slab (Fig. 3a). The introduction of layer pseudospin offers more dispersion engineering capability, leading to the layer-polarized and layer-mixed photonic topological insulators. As shown in Fig. 3b, their phase transition is demonstrated with a model Hamiltonian by considering the nonzero interlayer coupling. For one, layer-direction locking behavior of layer-polarized photonic topological insulators (Fig. 3c) results in the selective light refraction. For another, high transmission is observed in the bilayer domain wall between two layer-mixed photonic topological insulators in Fig. 3d, even when a large defect is introduced.

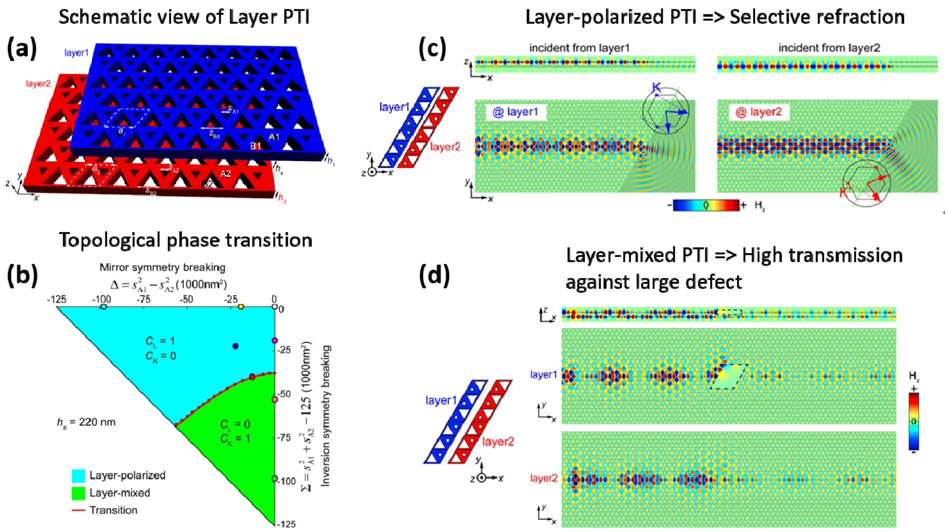

Fig. 3. All-dielectric layered photonic topological insulators [8].

3. Conclusions

In summary, we have successfully applied both valley and layer-pseudospin DOF to topologically manipulate the flow of light in silicon-on-insulator platform. Topological robust transport and topological photonic routing are experimentally demonstrated and confirmed at telecommunication wavelength. The emerging field of topological integrated photonics opens up an alternative route towards the discovery of fundamentally novel states of light and some promising applications. These works show a prototype of on-chip photonic devices, with promising applications for optical isolation, lasing, wavelength division multiplexing, directional antennas, single photon sources, and photonic analog of quantum information processing based on topological nanophotonic modes.

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