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Measuring Propagation Loss in Slow-light Valley-Hall Photonic Topological Waveguides

Christian Anker Rosiek[1,*], **Guillermo Arregui**[1], **Anastasiia Vladimirova**[1,2],
Marcus Albrechtsen[1], **Babak Vosoughi Lahijani**[1,2], **Rasmus Ellebæk Christiansen**[2,3],
and Søren Stobbe[1,2]

[1] *DTU Electro, Department of Electrical and Photonics Engineering, Technical University of Denmark, Ørsteds Plads 343, Kgs. Lyngby, DK-2800, Denmark.*
[2] *NanoPhoton – Center for Nanophotonics, Technical University of Denmark, Ørsteds Plads 345A, Kgs. Lyngby, DK-2800, Denmark.*
[3] *DTU Construct, Department of Civil and Mechanical Engineering, Technical University of Denmark, Nils Koppels Allé, Building 404, Kgs. Lyngby, DK-2800, Denmark.*
**chanro@dtu.dk*

Abstract: We measure the propagation loss in trivial and topological slow-light guided interface modes of a valley-Hall photonic topological insulator indicating that there is no topological protection from fabrication-induced disorder. © 2022 The Author(s)

Photonic-crystal waveguides in integrated photonics allow engineering the dispersion to form slow light, which enhances nonlinear effects and light-matter interaction [1]. However, the inevitable fabrication disorder in such structures leads to backscattering which is especially severe for slow light, eventually halting light propagation completely [2]. Waveguides formed from interfaces in photonic topological insulators (PTIs) [3] have recently received much attention in this context, since they promise robust propagation under some classes of crystal disorder. Waveguides based on the quantum-valley-Hall (VH) effect enjoy particular interest in photonics, since they can be implemented in time-reversal-symmetric platforms and are free of intrinsic radiative losses [4]. Spurred by this interest, theoretical studies have sought to quantify the robustness of VH waveguides [5], but computational demands have limited the studies to effective disorder models, warranting experimental investigation.

1. A valley-Hall photonic topological interface

We report here on the fabrication and experimental characterization of a set of VH-interface waveguides. The design of the PTI is based on a unit cell composed of two triangular holes arranged in a triangular lattice [6]. Using this unit cell, the interface is formed through juxtaposition of two mutually inverted PTIs [6]. Figure 1a shows a waveguide, fabricated in a 220 nm-thick silicon membrane. The structure acts as a waveguide with propagating modes confined around the interface and described by the dispersion shown in Fig. 1b. The symmetry enforces a degeneracy at the edge of the Brillouin zone [7] and the two modes, intersecting at this degeneracy point, can be characterized as trivial and topological based on transmission through sharp bends [8]. Both are single-moded over their entire transmission band and both exhibit slow light at similar and moderately high group indices near the edge of the Brillouin zone (see Fig. 1c).

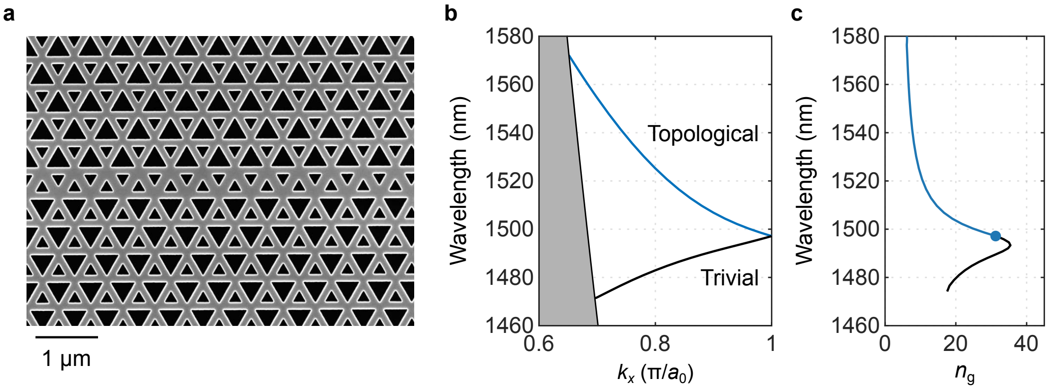

Fig. 1. A valley-Hall photonic-crystal interface waveguide. (a) Scanning electron microscope image of fabricated valley-Hall waveguide with lattice constant $a_0 = 512\,\text{nm}$. The interface is visible as the central row where the smaller triangles lie adjacent. (b) Dispersion diagram computed based the geometry extracted from (a). The light cone is shaded gray. (c) Group index for the waveguide modes corresponding to (b).

2. Measuring propagation losses

To characterize the propagation losses of the VH waveguides, we fabricate a series of photonic circuits containing VH waveguide segments of varying length. Figure 2a displays two example circuits. Other parts of the circuit are kept fixed to allow for the extraction of the propagation loss in the topological waveguides. The circuits are measured in transmission to obtain transmittance spectra for each waveguide in the ensemble, examples of which are shown in Fig. 2b. We observe a spectral shift of about 20 nm from the theoretical dispersion (Fig. 1b). The spectral region of high group indices is visible as a significant suppression in the transmittance at wavelengths, λ, around 1515 nm. Assuming an exponential decay in the ensemble-averaged intensity along the waveguide, we extract the propagation loss by fitting this model to the measured transmittance of a collection of fabricated circuits. We observe no significant difference in propagation loss of trivial and topological modes at high group indices [9], e.g., at a group index of $n_g = 25$ which is shown in Fig. 2c and d. Thus, we find no significant expression of topological protection against backscattering on disorder from realistic fabricaton imperfections.

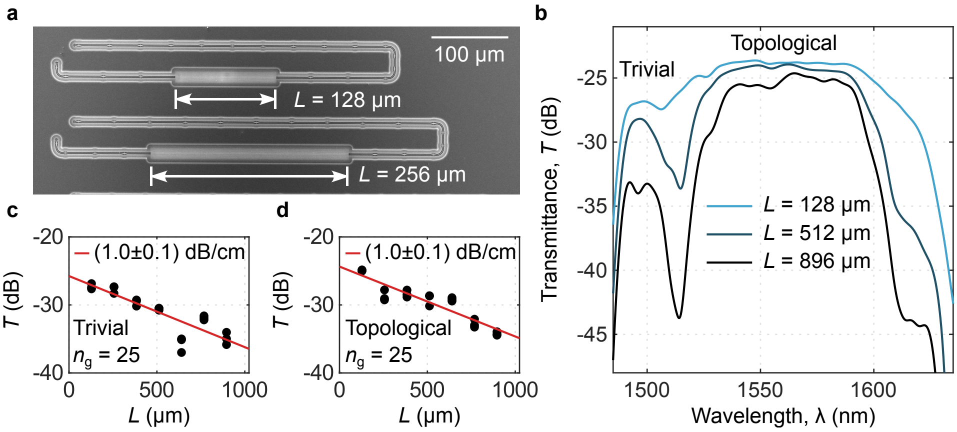

Fig. 2. Propagation loss of valley-Hall waveguides. (a) Image of two circuits which include waveguides of different lengths, L. (b) Transmittance spectra of waveguides. (c), (d) Transmittance, T, (points) and fitted propagation loss (red lines) at wavelengths $\lambda = 1506$ nm and $\lambda = 1520$ nm where the trivial and topological band both have group index $n_g = 25$.

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