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Transmission Experiments on Photonic-Crystal Waveguides With a Symmetry-Protected Dirac Point

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Abstract: Slow-light photonic-crystal waveguides suffer from Anderson localization and propagation losses due to fabrication imperfections. Here we investigate a novel photonic system exhibiting a symmetry-protected two-dimensional Dirac-point feature and observe a >50-fold group-velocity slowdown.

OCIS codes: (220.0220) Optical design and fabrication; (230.5298) Photonic crystals.

1. Introduction

Topological insulators holds promise of developing robust devices for various quantum applications. The highlight of these devices is the topologically protected degeneracy points (Dirac-points), which in special cases are immune to disorder-related backscattering. These concepts may find important applications in photonics [1] where backscattering from imperfections is prevalent in particular in one-dimensional systems, which suffer from Anderson localization [2]. Photonic-crystal waveguides have long been a contender for realizing slow-light phenomena. However, as light is slowed down, so is the sensitivity to inevitable fabrication disorder. Here we study a photonic system inspired by topological insulators. In this type of waveguide, the existence of the Dirac point is protected by a glide-plane symmetry, which exists along the propagation direction [3,4]. Although disorder would in general break the glide-plane symmetry, it remains an open question to what extent disorder-robust transmission can be observed in this system.

2. Design

A schematic of the glide-plane waveguide and the numerically calculated dispersion diagram are shown in Fig. 1. The key idea is to shift the lower half of the photonic-crystal cladding by half a lattice constant along the propagation direction, which leads to a Dirac point in the dispersion relation [3]. Further, a single-mode waveguide band has been constructed by engineering the photonic-crystal structure, i.e., by changing the size and position of the holes around the waveguide section [5].

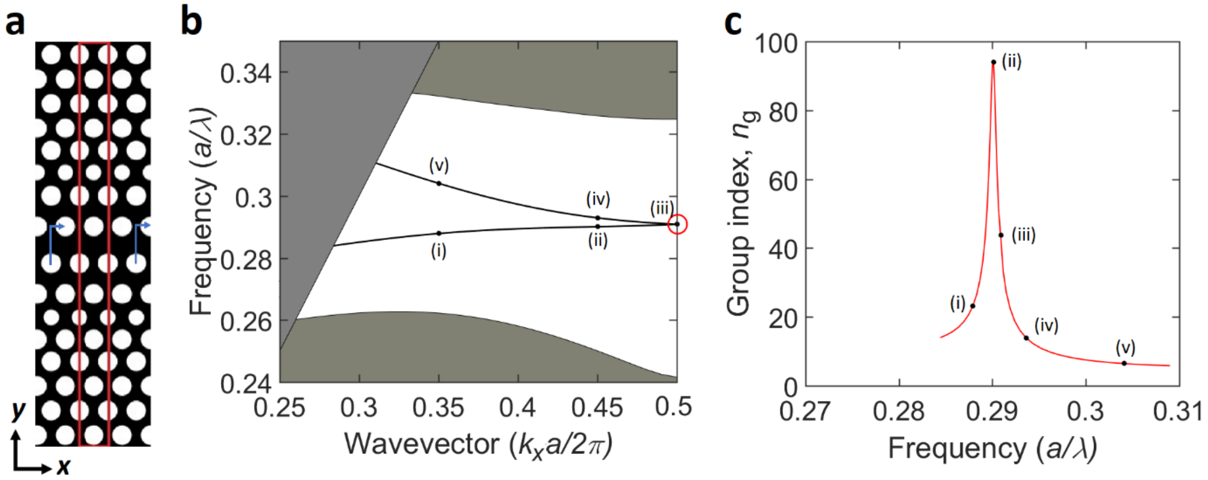

Figure 1. **(a)** A schematic of the glide-plane waveguide configuration. Note that the lower half of the crystal lattice is shifted along the waveguide axis by half a lattice constant, indicated by blue arrows. The unit cell is highlighted in the red box. **(b)** The photonic-crystal waveguide dispersion curve incorporating the glide-plane symmetry design. The Dirac-point is highlighted by the red circle. **(c)** The group index versus frequency.

3. Results

Figure 2 shows a scanning electron micrograph of the dispersion-engineered glide-plane photonic-crystal waveguide fabricated using a silicon-on-insulator platform, which enables us to fabricate a membrane structure. This is done using 100 kV e-beam lithography for patterning the nanostructures, followed by dry and selective wet etching. The high refractive index of silicon and the photonic-crystal structure ensure a strong confinement of the waveguide modes both vertically and in-plane. The low material loss along with the mature fabrication techniques make silicon an excellent candidate to study slow-light effects.

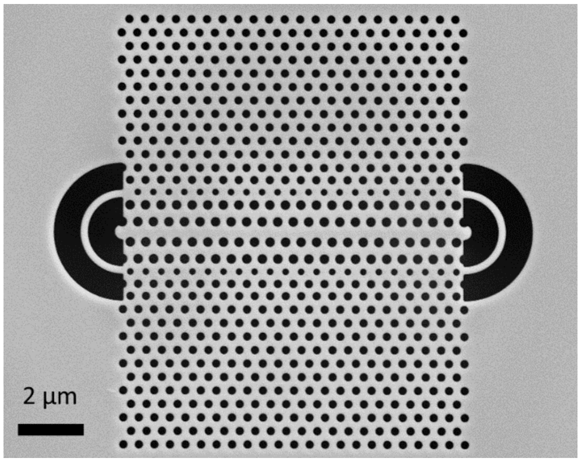

Figure 2. A top-view scanning electron micrograph of a glide-plane waveguide coupled with circular gratings.

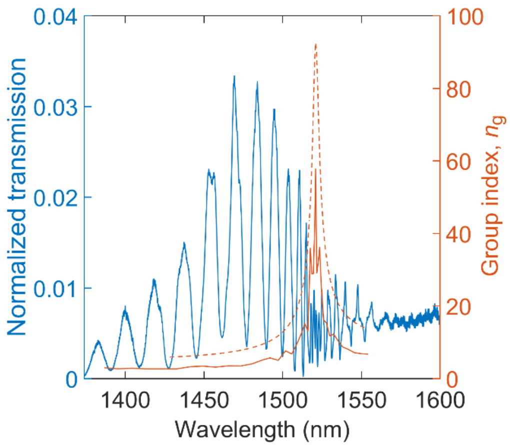

Figure 3. Normalized optical transmission spectrum (blue) of a 20 µm long glide-plane waveguide. The measured (solid red line) and simulated (dashed red line) group index are in good agreement.

We measure the transmission spectrum for various lengths of the waveguides and analyze the Fabry-Perot fringes. From this, we extract the group index, which is in line with theoretical predictions as seen in Fig. 3 although we note that the theoretical curve has been shifted by 19.5 nm to take a nanometer-scale offsets in hole radii and membrane thickness into account. Notably, we observe a 50-fold increase in the group index.

4. Conclusion and future work

In conclusion, we have demonstrated significant slow-down of light in photonic-crystal waveguides with glide-plane symmetry, which makes them promising candidates for slow-light technology. The high group indices observed in our samples highlights the promising prospects of using glide-plane waveguides for studying chiral quantum optics [6], where the slow-light effect translates into an enhanced light-matter interaction. We are currently carrying out systematic investigations of the losses in the glide-plane waveguides to facilitate a direct comparison to conventional waveguides.

5. References

[1] A. B. Khanikaev, and G. Shvets, “Two-dimensional topological photonics”, Nat. Photonics **11**, 763–773 (2017).

[2] L. Sapienza, H. Thyrrestrup, S. Stobbe, P. D. Garcia, S. Smolka, and P. Lodahl, “Cavity quantum electrodynamics with Anderson-localized modes”, Science **327**, 1352-1355 (2017).

[3] A. Mock, L. Lu, and J. O’Brien, "Space group theory and Fourier space analysis of two-dimensional photonic crystal waveguides", Phys. Rev. B **81**, 155115 (2010).

[4] I. Söllner, S. Mahmoodian, S. L. Hansen, L. Midolo, A. Javadi, G. Kiršanskė, T. Pregnolato, H. El-Ella, E. H. Lee, J. D. Song, S. Stobbe, and P. Lodahl, "Deterministic photon–emitter coupling in chiral photonic circuits", Nat. Nanotechnol. **10**, 775–778 (2015).

[5] S. Mahmoodian, K. P. Nielsen, I. Söllner, S. Stobbe, and P. Lodahl, "Engineering chiral light–matter interaction in photonic crystal waveguides with slow light", Opt. Mater. Express **7**, 43-51 (2017).

[6] P. Lodahl, S. Mahmoodian, S. Stobbe, A. Rauschenbeutel, P. Schneeweiss, J. Volz, H. Pichler, and P. Zoller, "Chiral quantum optics", Nature **541**, 473–480 (2017).