Direct quantification of topological protection in symmetry-protected photonic edge states at telecom wavelengths

Topologically tailored photonic crystals (PhC) have opened up the possibility for attaining robust unidirectional transport of classical and quantum systems. The demand for unprecedented guiding capabilities that support unhindered transport around imperfections and sharp corners at telecom wavelengths, without the need for any optimization, is fundamental for efficient distribution of information through dense on-chip photonic networks. However, transport properties of experimental realizations of such topologically non-trivial states have been inferred by transmission measurements and even though robustness has been attested in the linear and nonlinear regimes, its exact quantification remains challenging.

In a new paper published in Light Science & Applications, a team of researchers led by L. Kuipers from Delft University of Technology and E. Verhagen from AMOLF both in The Netherlands, reports a rigorous robustness evaluation of photonic edge eigenstates at telecom wavelengths.

They fabricate a valley photonic crystal (VPC) that consists of two differently sized equilateral triangular holes per unit cell on a silicon-on-insulator platform. The band structure of a domain wall resulting from two parity-inverted copies of such a PhC lattice contains two degenerate edge-state eigenmodes with a linear dispersion. Since these states lie below the light line, they do not couple to far-field radiation and thereby feature negligible radiative losses. Each one of these edge-states has a unique pseudo-spin, resulting in a single direction in which the optical states propagate. A remarkably large broadband transmission, as expected from a topologically protected edge state, was measured. On visualizing the spatial wavefunction of the edge modes with a phase-resolved near-field optical microscope the researchers measured with high signal-to-background ratio an experimentally extracted dispersion diagram. The technique allowed them to separate forward propagating light from backward travelling waves with extreme sensitivity and thus perform “local monitoring of back-scattering along the domain wall.”

The researchers further complemented their quantitative analysis by measuring the properties of a mode propagating along a topologically trivial standard W1 PhC waveguide.

The team found that “In stark contrast to the forward and backward mode for a VPC, the W1 modes show significant loss across the defect. Moreover, the normalized backward amplitude map demonstrates that the dominant reflections already occur at the first 120° corner. The mode energy here is converted to a back-reflected wave and additionally experiences out-of-plane scattering”. Further, to obtain a complete picture of the back-scattering contribution, the researchers developed a transfer-matrix model which unambiguously revealed that:

“A topologically protected PhC lattice reduces the experimentally achievable back-reflection from individual sharp corners by two orders of magnitude over the entire frequency range of the edge state, in comparison to a standard W1 waveguide.”

S. Arora, T. Bauer, R. Barczyk, E. Verhagen and L. Kuipers
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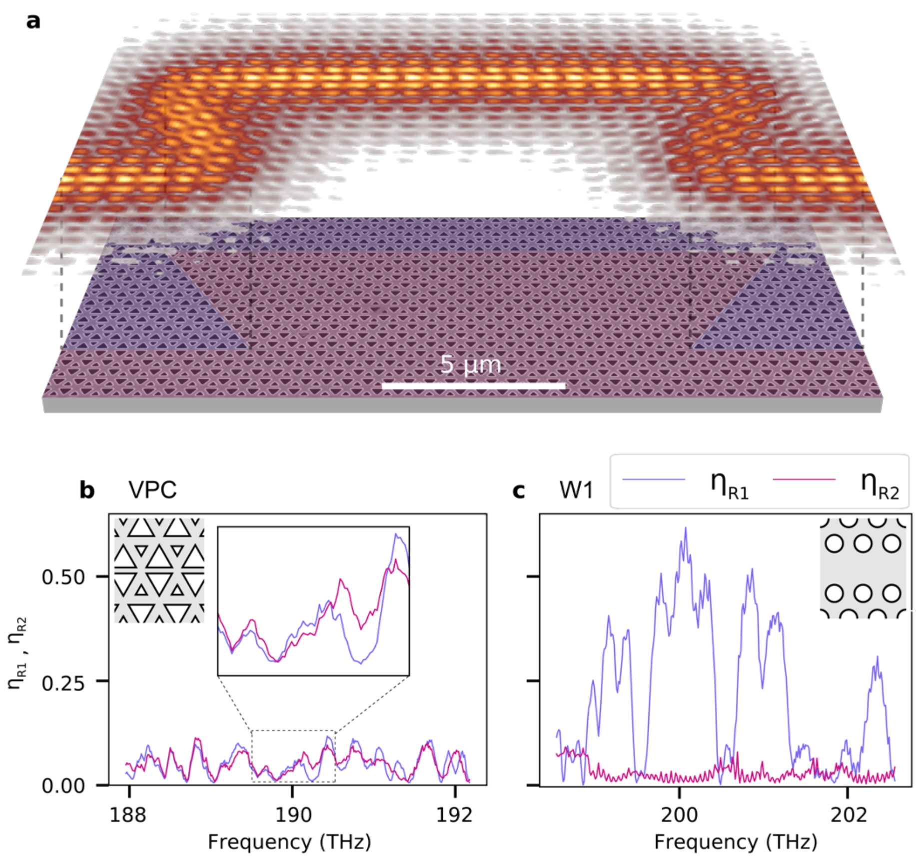

Figure | Experimental visualization and quantification of robustness in a valley photonic crystal.

a, 3D rendition of the scanning electron micrograph of the VPC with a trapezoidal (Ω-shaped) structure along the domain wall, comprising four sharp corners and the two parity-inverted VPCs shown in false colors. The upper extension shows the full two-dimensional real-space amplitude map of the propagating edge state. **b**, Calculated backward/forward energy ratio before (η_{R1}) and after (η_{R2}) the Ω-shaped defect in the VPC domain wall. The inset shows how the back-propagation energies before and after the defect in a VPC are almost indistinguishable over the frequency range. Comparing this to the backward/forward energy ratios for an unoptimised W1 waveguide in **c** allowed to quantify back-scattering at a single corner to be < 0,07%.

Contact

L. Kuipers
Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA, Delft, The Netherlands
l.kuipers@tudelft.nl

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