Topology-inspired routes to optical field confinement and enhancement in two-dimensional photonic crystals

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Abstract: *We explore the use of topological channels and symmetry breaking in two-dimensional silicon photonic crystals to establish new paradigms for the confinement and enhancement of light fields at the nanoscale. This includes highly degenerate Landau level flat bands in strained photonic crystals, as well as broadband localization of light due to suppressed backscattering in terminated topological waveguides.*

The suitable use and breaking of symmetries in crystals allows imprinting a range of topological phases and associated behavior on band structures for both electronic, photonic, and acoustic waves. This has proven a versatile new route to control the propagation of light at the nanoscale, in specially designed two-dimensional photonic crystal architectures. We explore the use of such principles to new paradigms for slowing and confining light waves at the nanoscale. By using either high degeneracy or inherently broadband operation, these mechanisms address some of the fundamental limitations of field confinement in resonant cavities, thus providing new opportunities for applications benefiting from enhanced light-matter interactions.

On the one hand, we demonstrate photonic Landau levels in photonic crystals with engineered strain in the lattice [1]. Judicious strain profiles establish pseudomagnetic fields for light, which create flat bands at discrete frequencies that are analogous to Landau levels for electrons in a magnetic field [1-3]. The high degeneracy of these bands mean that slow light and the associated field enhancement can be achieved over a relatively large surface, important to various applications in nonlinear photonics, quantum information processing, sensing, etc. We reveal that these states can exhibit ultrahigh quality factors, meaning that the slow light enhancement is accompanied by large storage times. We experimentally determine the practical limits to this approach and the possibility for precise engineering of dispersion and localization through local geometry.

On the other hand, we investigate what happens to light waves in topological edge channels that impinge on a suitably engineered termination of the channel [4]. We reveal that, if the symmetry of the termination is chosen appropriately, suppressed backscattering leads to a local build-up of optical field. This is associated with an inhibited valley flipping in the valley-Hall photonic crystal platform [5]. We study this effect through near-field microscopy, which shows both the sharp localization in a nanoscale volume as well as its broadband nature. This mechanism relates to the predicted effect of light confinement at the termination of nonreciprocal waveguides [6] and is as such inherently different from traditional approaches based on the excitation of discrete cavity modes.

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