Disorder-Robust Nonlinear Light Generation in Topological Nanostructures

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Abstract: We observe topologically nontrivial nonlinear edge states of light in zigzag arrays of silicon nanoparticles. We image the edge states via the third-harmonic generation and demonstrate their robustness against disorder and structural perturbations. © 2019 The Author(s)

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1. Introduction

Topological photonics has emerged as a route to robust optical circuitry protected against disorder [1] and now includes demonstrations of topologically protected lasing [2] and single-photon transport [3]. Most of the topological photonic systems explored so far have been based on waveguide geometries, and the size of their building blocks is therefore larger than the wavelength of light. A zigzag array of coupled nanoresonators has emerged as the first nanoscale system with non-trivial topological states of light [4], as has been observed experimentally in the regimes of linear scattering [5] and lasing from excitonic–polaritonic nanocavities [2].

Recently nonlinear optical topological structures have attracted special theoretical interest as they enable tuning of topological properties by a change in the light intensity and can break optical reciprocity to realize full topological protection. In our system, we use the intrinsic nonlinearity of silicon to generate a third-harmonic signal from such an array. The presence and interplay of Mie resonances of both electric and magnetic origin lead to an enhancement of the nonlinear light generation. In addition, topological localization of the electric field at the edge of the array provides multifold enhancement of the nonlinear generation efficiency, which is also robust against perturbations.

Fig. 1. Nonlinear parametric generation of light from topological zigzag arrays. (a) Concept of THG in a zigzag array of nanoresonators. A beam of light with the frequency ω illuminates the array, and the nonlinear signal at the 3ω frequency is generated from its edge. (b,c) SEM images (top) and measured distribution of the third-harmonic field (bottom) of 11-nanodisk zigzag arrays of Mie-resonant dielectric nanodisks with and without introduced disorder.
2. Results and Discussions

Figure 1a presents the concept of nonlinear parametric generation of light driven by topological edge states. The formation of the edge states is described by a polarization-enriched generalized Su–Schrieffer–Heeger (SSH)-type model with a gauge-independent $Z_2$ topological invariant [4].

![Figure 1a: Concept of nonlinear parametric generation of light driven by topological edge states.](image)

We proceed with a systematic study of the robustness of the topology-driven THG against disorder. We fabricate a number of arrays with randomly generated bond angles between the disks as illustrated in Fig. 2a. The robustness of the edge states can be clearly seen in the calculated disorder-averaged spectra of the photon density of states (DOS) versus the disorder parameter $\Delta \phi$ (Fig. 2b). The edge states are topologically protected up to the point when the spectral gap collapses. We next calculated the field distributions excited in 10$^4$ random cases of disordered zigzags and confirmed that, while the spectral gap is open, the hot spots at the edges are always present. Once the gap is quenched, the edge states are no longer topologically protected, and the probability that they form drops rapidly (Fig. 2c). We verified these predictions experimentally by fabricating and measuring a number of disordered zigzags with $\Delta \phi$ ranging from 5° to 90°. Representative cases are shown in Fig. 2d. In our experiments, for $\Delta \phi < 20°$, the edge states were observed in all cases where $\Delta \phi > 20°$, the number of arrays supporting edge states drops rapidly as $\Delta \phi$ increases.

3. Conclusion

We have suggested novel opportunities for active and nonlinear topological photonics with dielectric nanoparticles by demonstrating enhanced and robust light generation at topological edge states. Our findings open the way to nonlinearity-induced topological effects.

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4. References