Observation of topological edge states in subwavelength resonant structures

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Abstract- We suggest a novel type of photonic topological edge states in zigzag arrays of resonant subwavelength particles. We experimentally verify our general concept for plasmonic nanodisks in visible and for dielectric spherical particles in microwave ranges. We demonstrate the ability to control the subwavelength topologically-protected electromagnetic edge modes by changing the polarization of the incident wave.

Topological insulators represent a novel class of materials with a topologically protected phase order. Such materials attracted a lot of attention in the past years due to the existence of novel types of conducting surface states in otherwise insulating bulk materials being protected by time-reversal symmetry, and they demonstrate exotic phenomena such as the quantum Hall effect. Recently, the concepts of topological states became attractive in optics for the realization of backscattering-immune topologically-protected flows of light [1]. Different types of electromagnetic topological states have been realized by now, for a number of microwave and photonic systems [2-4]. Recently, it was predicted theoretically that a novel type of topological edge states can be realized in the subwavelength regime for a zigzag chain of plasmonic nanoparticles [5]. Nontrivial topological properties of such a type of plasmonic edge states have been studied in the framework of the coupled-dipole approximation, and also by direct numerical simulations of Maxwell’s equations.

In this work we demonstrate experimentally a novel type of topological edge states realized in the subwavelength regime for a zigzag chain of gold nanodisk (see Fig. 1). We have fabricated a zigzag chain of seven gold nanodisks on a glass substrate using the electron beam lithography. The disks had a diameter of 250 nm and a height of approximately 40 nm, while the distance between adjacent disk edges was equal to 100 nm.

Fig. 1 (Left) Schematic illustration of the zigzag chain of plasmonic nanodisks. (Right) Experimental observation of topological edge states at the nanoscale. a,b, Near-field patterns of the polarization-sensitive localized plasmonic modes measured at the 100 nm distance from the substrate surface for 700 nm excitation wavelength for x- (a) and y- (b) polarizations. c,d, Spectral dependence of the normalized intensity of the hot spots for x- (c) and y- (d) polarizations.
The structure is illuminated from the substrate side by a weakly focused linearly polarized laser beam. As predicted by the analytical model, the distribution exhibits hot spots at the edges of the structure, which is the signature of the excitation of different edges of the structure depending on the polarization.

**Fig. 2** Experimental results. (a-d) Measured electric field intensity at the frequency of the magnetic quadrupole resonance of a single sphere for different incident wave polarizations $\theta = 0, 90, -45$, and 45 degree respectively, indicated in the panels by arrows.

As a second example, we employ microwave experiments with zigzag arrays of electromagnetically-coupled dielectric spheres and provide the first proof-of-principle experimental observation of optically-induced magnetic topological edge states operating in the subwavelength regime. We demonstrate that such topological edge states can be selectively excited with the linear polarization of the incident electromagnetic wave, and we visualize them directly by mapping the corresponding electromagnetic fields. We use MgO-TiO$_2$ ceramic spheres that are characterized by a dielectric constant of 15 and small dielectric loss factor in the 4–10 GHz frequency range. The sphere radius is equal to $R = 7.5$ mm and the spheres are touching each other. The near-field measurements are performed at the magnetic quadrupole resonance frequency. The near field was scanned at the 1 mm distance from the back interface of the zigzag array to avoid the contact between a probe and the sample. The polarization dependence of the structure response is examined by rotating the source antenna. Figures 2(a-d) show the electric field maps for different angles $\theta$ between the polarization direction of the incident magnetic field $H_0$ and the x axis. The maps present a direct confirmation of the edge excitation in the structure at the magnetic quadrupole resonance.

**REFERENCES**


