Topological Majorana states in zigzag chains of plasmonic and dielectric nanoparticles

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Abstract

We propose a simple realization of topological edge states in zigzag chains of plasmonic or dielectric nanoparticles, mimicking the Kitaevs model of Majorana fermions. We demonstrate the correspondence between the coupled dipole equations in the zigzag chain and the Bogoliubov-de-Gennes equations for the quantum wire on top of superconductor, and support the theory by full-wave electromagnetic simulations. The localized plasmonic/Mie modes can be selectively excited at both edges of the plasmonic/dielectric zigzag chain depending on the incident field polarization.

1. Introduction

The study of *topological insulators* is one of the most rapidly developing areas of condensed matter physics [1]. Such structures possess bandgaps in the bulk and special edge/surface states inside the gap. Recently, a significant progress has been made in the study of the topological edge states of photons in various structures, such as photonic crystals, coupled cavities [2], waveguide arrays [3], photonic quasicrystals [4] and metamaterials [5]. Contrary to traditional Tamm states, these edge states are *topologically protected*. This means, that they appear without any special surface structuring and are stable against a certain class of perturbations that keep a general symmetry of the system, e.g. time-reversal symmetry or particle-hole symmetry. Robustness of *optical topological edge states* against certain disorder makes them promising candidates for future optical devices.

2. Results

Here we focus on the topological states in the zigzag chains of plasmonic and dielectric nanoparticles. Plasmonic clusters of different shapes demonstrate rich physics, and their *point* symmetry can be probed by analyzing the scattering spectra [6]. Our goal is to draw attention to the *topological* properties of the clusters eigenmodes. We demonstrate a one-to-one correspondence between the coupled localized plasmon modes in zigzag clusters and the Majorana edge states of the Kitaev's model for the quantum wire on top of superconductor [7]. Majorana fermions are unique

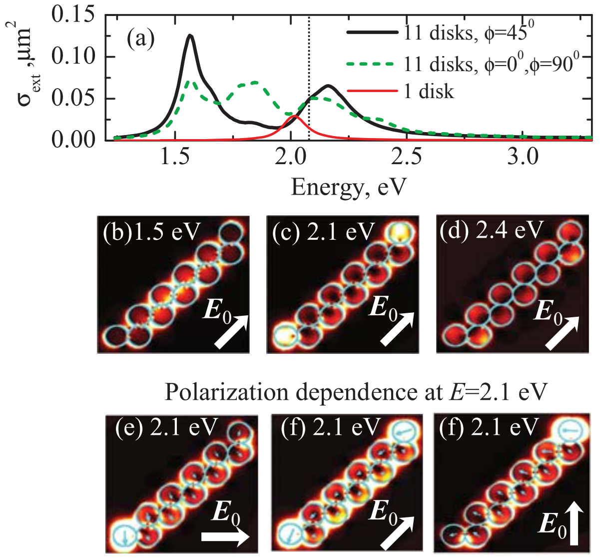

Figure 1: (a) Extinction cross section spectrum for the zigzag with 11 disks calculated at $\phi = 45^0$ (solid/black curve), and at $\phi = 0^0$ (dashed/green curve). Thin/red curve corresponds to the extinction for a single disk. (b)–(d) False color maps of the electric field intensity at the different energies, indicated in the panels. The field is polarized along the zigzag, as indicated by the white arrow. (e)–(f) False color maps of the electric field intensity at $E = 2.1$ eV and different incident wave polarizations $\phi = 0^0$, $\phi = 45^0$, $\phi = 90^0$, respectively, indicated in the panels by white arrows. Green lines schematically illustrate the real parts of the dipole momenta, induced in the particles.

fermionic particles being their own antiparticles, and they are now actively sought in solids [1] as well as in optics, and are potential candidates to realize robust qubits [7]. In our case the edge states are purely classical, however, their localization has exactly the same origin as that in the Kitaev's model for Majorana modes or in the Su-Schrieffer-Heeger model of the polyacetylene.

Our main results are presented in Fig. 1. Figure 1(a) shows the extinction cross section for the zigzag chain with 11 touching silver nanodisks with diameter equal to

60 nm (black/solid and green/dashed lines) and single disk (thin/red line) under excitation by a plane wave at normal incidence. When the incident wave energy is close to single disk resonance ($E = 2.1$ eV), the electric field has maxima near the chain edges [Figs. 1(b–d)]. Depending on the angle of the linear polarization of the incident wave with respect to the x axis the field is concentrated at the left edge ($\varphi = 0^0$), at right edge ($\varphi = 90^0$) or at both edges ($\varphi = 45^0$) [Figs. 1(e–f)]. This is due to the selective excitation of two degenerate x and y polarized states, localized at the opposite edges of the zigzag. Notably, the double-polarization-degenerate localized states appear at the same frequency for arbitrary number of particles in the structure $N \geq 3$, which reflects their topological character and makes them distinct from the propagating Fabry-Pérot-like modes.

Edge states of this kind can be realized in different structures of the same geometry. Particularly, we have numerically verified that qualitatively similar results are also valid for zigzag chains of silicon spheres at the frequencies of the Mie resonances.

3. Summary

We suggest a simple analogue of Majorana-like topological edge states in the zigzag chain of nanodisks or nanospheres. We have demonstrated an exact correspondence between Kitaev's model of a finite-extent quantum wire over superconductor to the model of coupled electric dipoles in the chain. This mapping is valid for the dipole-dipole interactions between nearest neighbors. The edge states have been shown to be robust against distant interactions. Their frequency is determined by the position of the resonance of the single disk, and is independent of the number of disks in the chain. The possibility to selectively excite two edges of the zigzag chain by changing the direction of the linear polarization of the incident wave has been demonstrated. The study of the topological properties of the polarization-entangled eigenmodes suggests a new way for engineering plasmonic and dielectric nanoparticle clusters for applications in nanophotonics.

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