Radiative topological states in one-dimensional resonant photonic crystals

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Abstract

We present a theory of topological edge states in one-dimensional resonant photonic crystals with compound unit cell. We demonstrate how the structure, despite being one-dimensional, can be characterized by topological indices. Contrary to conventional electronic topological states the modes under consideration are radiative, i.e., they decay in time due to the light escape through the structure boundaries. We demonstrate that the edge states survive despite radiative decay and can be detected both in time- and frequency-dependent light reflection.

1. Introduction

Topological insulator is an electronic material that has a band gap in its interior like an ordinary insulator but possesses conducting states on its edge or surface. The surface states of topological insulators have been extensively studied both in 2D and 3D materials. Recently it has been demonstrated that the 1D Aubry-André-Harper (AAH) model, or a “bichromatic” system (both incommensurate and commensurate), exhibits topological properties similar to those attributed to systems of a higher dimension [1, 2, 3]. This model allows states at boundaries between two distinct topological systems. Up to now AAH model was limited to the case of quasiparticles tunneling from one site to another. We consider a 1D sequence of sites with resonant excitations long-range coupled through an electromagnetic field. Such a system is open, its eigenfrequencies are complex and eigenstates are quasistationary due to the radiative decay. Hence, the resonant optical lattice stands out of the standard classification of topological insulators, developed for conservative and Hermitian electronic problems. We show that despite this it demonstrates the topological properties and formulate general condition for the edge state existence. We also demonstrate how the radiative character of the system opens new pathways to optical detection of the edge states.

2. Model

We consider a 1D resonant photonic crystal consisting of alternating resonant layers and spacers. The dielectric constant $\varepsilon$ of the spacer is frequency-independent while the thin resonant layer is characterized by single-pole amplitude coefficients of light reflection and transmission,

$$r(\omega) = -\frac{i\Gamma_0}{\omega - \omega_0 + i(\Gamma_0 + \Gamma)}, \quad t(\omega) = 1 + r(\omega). \quad (1)$$

Here, $\omega$ is the light frequency, $\omega_0$ is the resonance frequency, $\Gamma_0$ and $\Gamma$ are the radiative and non-radiative decay rates of resonant layer excitation. This model can describe excitonic, dielectric and plasmonic multilayers, coupled waveguides, or nuclear excitations [4].

We consider a bichromatic structure with the resonant layers centered at

$$z_n = d[n + \eta \cos(2\pi bn + \phi)], \quad (2)$$

Figure 1: (a) Illustration of the structure with $b = 1/3$. Vertical lines indicate the resonant layers, the colored layers are the spacers of different thicknesses. (b) The band structure as function of the “ancestor” lattice wave vector $\kappa = \phi - \pi/6$ characterizing the distribution of three resonant layers in the unit cell. The gray regions are the allowed polariton zones, while the white regions are the stop-bands. The lines show the dependence of the real part of the frequency of the left-edge (solid) and the right-edge (dashed) mode. For the value $\kappa = \pi/2$ (indicated by stars) the electric field magnitude distribution of the left- and right-edge modes is shown in panel (a) by blue and red curves, respectively.