First Principles Calculation of Topological Invariants of Lossy Photonic Crystals

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Topological systems have exciting properties that may lead to new physics. The Chern numbers of a material platform are usually written in terms of the Berry curvature which depends on the normal modes of the system. From a computational point of view the calculation of the Chern number can be a rather formidable problem. Here, we use a gauge invariant Green's function method (Phys. Rev. B, 99, 125155, 2019) to determine the topological invariants. We apply the method to a lossy photonic crystal formed by a hexagonal array of ferrite cylinders embedded in air with radius r=0.35a [Fig.1a]. The Chern numbers are calculated from first principles, i.e., without a tight-binding approximation.

The ferrite is characterized by a standard gyrotropic model with losses included. The band structure of the photonic crystal (with $E=(wa/c)^2$ where w is the oscillation frequency) is plotted in Fig.2a for a lossless system. The band-gap is shaded in blue. Figures 2bi-iii show the projection of the band structure on the complex plane, $E=E'+iE''$as the real-valued wave vector is swept along the Brillouin zone for non-zero and increasing values of the material loss. In the non-Hermitian case the projected band structure is formed by two non-intersecting regions separated by a band-gap (vertical strips shaded in blue).

The gap Chern number is given by an integral of the photonic Green function over the first Brillouin zone and over a line parallel to the imaginary frequency axis in the band-gap. The Green function is found using a standard plane-wave expansion. The first Brillouin zone [Fig.1b] is sampled with N points along each direction of space. Figures 3a and 3b show (for the lossless case and for the lossy case corresponding to Fig. 2bii, respectively) that for moderately large N the numerically calculated Chern number Cquickly approaches unity. The computation time is a few minutes in a standard personal computer. Our formalism not only allows for a rigorous characterization of the topological phases of Hermitian and non-Hermitian systems, but may also enable theoretic developments that shed light on the origin of the topological numbers.

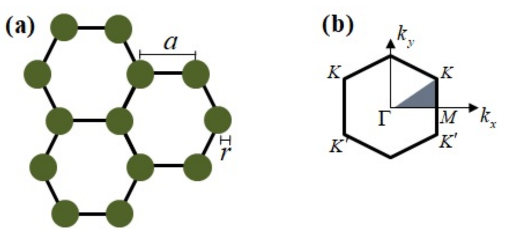

Figure 1.hexagonal array of ferrite cylinders.jpg

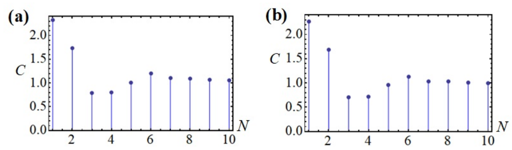

Figure 3.the numerically calculated chern number of the photonic crystal.jpg

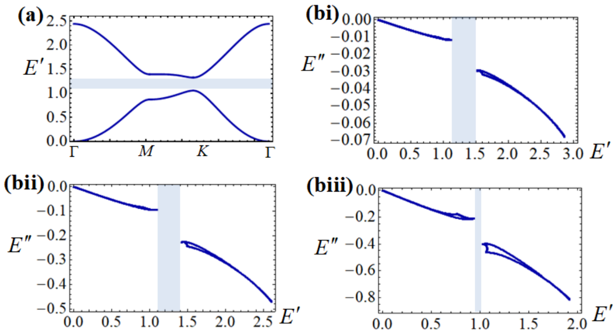

Figure 2.photonic band structure of the photonic crystal.png