Topological photonics in a continuum

Mário G. Silveirinha

(1)University of Lisbon, Instituto Superior Técnico– Instituto de Telecomunicações, Avenida Rovisco Pais, 1, 1049-001 Lisboa, Portugal, mario.silveirinha@co.it.pt

Abstract:

The propagation of light in a photonic crystal is completely determined by its band structure and by the properties of the corresponding Bloch-Floquet modes [1]. By tailoring the photonic band structure it has been possible in the last few decades to control the light flow in photonic crystals to an unprecedented degree. In most applications, one is interested in the band structure properties in a relatively narrow frequency range, being the rest of the frequency spectrum nearly irrelevant for practical purposes. Remarkably, it was found that the light propagation in nonreciprocal photonic crystals may also depend on the global properties of the band structure, i.e., on some topological properties determined by all the photonic states over a wide frequency range, and on the manner how the different states are intertwined in the spectral domain [2, 3]. Topology is a discipline of mathematics that studies the qualitative geometrical properties of objects. A recurring example is that a sphere and a torus are topologically distinct because the two objects cannot be transformed one into the other with a continuous transformation.

Remarkably, when two topologically distinct photonic crystals are paired to form an interface it turns out that unidirectional gapless edge states emerge in a common bandgap. Extraordinarily, the edge states are topologically protected against back-scattering such that for an arbitrary perturbation of the system that does not change the topological (Chern) numbers, e.g. in presence of a defect or impurities, the edge states route around the defect with no back-scattering [2, 3]. Hence, topological materials may have extraordinary applications and determine new paradigms for a topologically protected transport of optical energy, largely immune to disorder or imperfections [3].

The usual topological classification of photonic crystals uses the fact that these structures are periodic. In this talk, I will show that it is possible to extend standard topological methods to an electromagnetic continuum with no intrinsic periodicity, e.g., to metamaterials modelled by some effective parameters [4-5]. I will discuss the validity of bulk-edge correspondence and the emergence of topologically protected edge states both in nonreciprocal and in time-reversal invariant electromagnetic continua [4-5]. This novel classification extends for the first time the theory of topological materials to a wide range of photonic platforms, and may enable the design of novel topologically protected photonic systems for waveguiding.

[1] J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Photonic Crystals: Molding the Flow of Light, (2nd Ed.), Princeton University Press, 2008.
[2] F. D. M. Haldane, S. Raghu, "Possible realization of directional optical waveguides in photonic crystals with broken time-reversal symmetry", Phys. Rev. Lett., 100, 013904, 2008.
[3] L. Lu, J. D. Joannopoulos, M. Soljačić, "Topological photonics", Nat. Photonics, 8, 821, 2014.
[4] M. G. Silveirinha, "Chern Invariants for Continuous Media", Phys. Rev. B, 92, 125153, 2015.
[5] M. G. Silveirinha, "Z_2 Topological Index for Continuous Photonic Materials", Phys. Rev. B, 93, 075110, 2016.