Extreme light-matter interactions in nanoplasmonic systems

Fedor Shuklin

Abstract

Building a theory based on non-Hermitian Hamiltonians has always been an important but a very difficult task since non-Hermitian Hamiltonians do not guarantee the conservation of energy. In 1998, Stefan Boettcher and Carl M. Bender , within the framework of quantum theory, discovered a class of Hamiltonians that are not Hermitian and at the same time can have real eigenvalues. This is possible if the Hamiltonian is invariant under the simultaneous application of the operation of spatial inversion $\mathcal{P}$ and the operation of time reversal $\mathcal{T}$. Therefore, such Hamiltonians are called $\mathcal{PT}$-symmetric. An important property of $\mathcal{PT}$-symmetric Hamiltonians is the spontaneous phase transition breaking the $\mathcal{PT}$-symmetry. After such a phase transition, at least part of the spectrum of the Hamiltonian becomes complex-valued. The point at which the $\mathcal{PT}$ symmetry breaks down is called the exceptional point. At the exceptional point, at least two eigenvalues of the Hamiltonian become degenerate, and the corresponding eigenstates merge.

Due to the analogy between the wave equation in the paraxial approximation and the Schrödinger equation, the concept of $\mathcal{PT}$ symmetry was transferred to photonics. In optical systems, $\mathcal{PT}$ symmetry can be realized in systems with balanced gain and loss. In this thesis, I study the problems that arise in the description of $\mathcal{PT}$-symmetric photonic systems, the fundamental limitations of such a theoretical description, and theoretically describe the ways of implementing $\mathcal{PT}$-symmetric systems in optics in such a way as to overcome these limitations. I discuss the instability of explicit and implicit methods that arises in the numerical simulation of time evolution $\mathcal{PT}$-symmetric tight-binding periodic systems in the presence of an exceptional point, the problem of superluminal propagation and infinite group velocity in the vicinity of an exceptional point, arising from the neglect of material dispersion, as well as We propose a method for implementing the $\mathcal{PT}$-symmetric quasi-lattice with forward cascaded Brillouin scattering in a birefringent photonic crystal fiber.