Broadband Nonreciprocal Emission and Absorption Using Epsilon-near-zero Metamaterial

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The reciprocal relation between emission and absorption in materials that satisfies the Lorenz reciprocity places a fundamental constraint on a range of energy conversion processes, such as solar cells, thermophotovoltaics, and harvesting outgoing thermal radiation. The Kirchhoff's law of thermal radiation states that the emissivity and absorption are equal at the same angle and frequency. The Lorentz reciprocity relation shown in the Kirchhoff's law of thermal radiation can be broken in magnetic, nonlinear, or time-variant systems. Various photonic structures have been designed to achieve strong breaking of the Kirchhoff's law of thermal radiation, leading to a fundamental pathway for improving energy conversion. However, for approaching the ultimate thermodynamic limits of energy conversion which requires making use of the broad radiation spectrum, as well as for achieving nonreciprocal radiative thermal management, it is necessary to achieve nonreciprocal radiation over a broad spectral bandwidth. Existing designs of nonreciprocal emitters have limited bandwidth. A general way for achieving broadband nonreciprocal emission and absorption is lacking. In the poster we will introduce a general approach to achieve broadband nonreciprocal emission and absorption using gradient epsilon-near-zero magneto-optical metamaterial. To start with, we will discuss nonreciprocal emission in one magneto-optical layer calculated using the framework of fluctuational electrodynamics. To understand the mechanism of the nonreciprocal emission, we will discuss using temporal coupled mode theory to explore the evolution of resonance frequency and decay rates in response to magnetic field and angle. The coupled mode theory shows excellent agreement with direct calculation. We then introduce a general scheme to achieve broadband nonreciprocal emission and absorption by using gradient epsilon-near-zero magneto-optical metamaterials. We numerically demonstrate broadband nonreciprocal emission in gradient-doped semiconductor multilayer in the presence of external magnetic field. Finally, we show another numerical demonstration using gradient magnetic Weyl semimetal without external magnetic field.