Non-Hermitian Doping of Epsilon-Near-Zero Media

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Recently, the intriguing concept of *photonic doping* in epsilon-near-zero (ENZ) media was put forward (I. Liberal *et al.*, Science 355, 1058, 2017), showing that a *single* particle could be exploited to tune the effective permeability of the medium over a broad range of positive and negative values, while maintaining the ENZ character, irrespective of the particle position. Thus, for instance, it is possible to engineer extreme-parameter responses, such as perfectly magnetic conductors and epsilon-and-mu-near-zero, without resorting to magnetic material constituents. These results, validated experimentally at microwave frequencies, pave the way to new developments in reconfigurable and flexible photonics, nonlinear optics, and quantum metamaterials.

In the original investigation above, emphasis was placed on the *lossless* case, and some follow-up studies have explored the use of active (gain) constituents to compensate for the unavoidable losses. (E. Nahvi *et al*., Conference on Lasers and Electro-Optics (CLEO), May 2018). However, inspired by quantum-mechanics concepts such as parity-time symmetry, the emerging field of non-Hermitian optics and photonics (L. Feng *et al.*, Nat. Photon, 11, 752, 2017) has provided new insights and perspectives in the judicious tailoring of the gain-loss interactions, which can give rise to exotic effects that go far beyond the mere compensation. This is especially interesting in ENZ media, which are known to dramatically enhance the effects of relatively low levels of loss and/or gain.

In an ongoing investigation, we are exploring the effects produced by non-Hermitian dopants, in the form of non-magnetic core-shell cylindrical particles (with gain in the core and loss in the shell, or vice versa) in an ENZ medium. We found that it is possible to tailor the parameters so as to induce a resonant phenomenon that yields large tunability of the real and imaginary parts of the effective permeability, both in sign and amplitude. Preliminary results seem to indicate the intriguing potentials to switch from impedance-matched (epsilon-and-mu-near-zero) to strongly mismatched configurations via small variations of the gain, which may find interesting applications in reconfigurable photonics.