Parity-time symmetric nonlocal metasurfaces: Focusing and imaging through balanced loss and gain

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Light focusing and imaging represent some of the oldest applications of optics. Despite centuries of developments, however, conventional optical systems still suffer from aberrations of different types and are limited to plane-to-plane imaging, issues that are inherent to the conventional laws of reflection and refraction [1]. Metamaterials and metasurfaces have offered a route to partially overcome these limitations and go beyond traditional lens designs [2]. However, metamaterial lenses have been found to be extremely sensitive to material losses due to their typical resonant nature. This is particularly evident in ‘perfect lenses’ based on slabs with a negative index of refraction. Recently, there has been increasing interest in the possibility to realize relevant metamaterial functionalities, such as negative refraction and cloaking, based on loss-immune platforms that suitably include active elements [3-5].

In this context, here we show that a pair of lossy and active nonlocal metasurfaces – in a balanced parity-time (PT) symmetric configuration – can realize all-angle negative refraction, planar focusing and volume-to-volume imaging [5]. We start by deriving, from first principles, the general requirements to achieve these functionalities in a transversely-invariant, linear, loss-immune platform. In particular, we show that the PT-symmetric structure should be operated at an exceptional point of its eigenspectrum in order to guarantee impedance-matching and unidirectional reflectionless response. Most importantly, the active and passive metasurfaces need to be spatially dispersive (i.e., nonlocal) to correctly realize the required response for any angle of incidence and source location, and we propose a suitable implementation of the required nonlocality. We then discuss the focusing and imaging properties of the designed PT-symmetric lens, in which the image formation is supported by negative phase and energy velocity in the central region of the lens, with waves flowing backward from the active metasurface to the passive one, the latter acting as an omnidirectional coherent perfect absorber (see figure). Interestingly, this device implements, at least in principle, the imaging functionality of so-called absolute optical instruments [1] (aberration-free three-dimensional imaging), similar to volumetric imaging by a plane mirror, but with a real image space. Finally, we discuss the temporal dynamics of the proposed PT-symmetric lens, and we show that the system can be made unconditionally stable by suitably designing the temporal dispersion of the metasurfaces. This work shows the potential of non-Hermitian systems for advanced, loss-immune wave manipulation, which may open uncharted directions in electromagnetics and optics.