Self-collimation in 2D Complex P- and PT-symmetric systems

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Abstract-We predict the self-collimation phenomena (or equivalently, dynamical localization) in 2-dimensional P-symmetric and PT-symmetric complex potentials, with periodic modulations of both gain/loss and refractive index. Non diffractive propagation is analytically predicted and further confirmed by numerical integration of a paraxial model. The parameter space is explored to identify the self-collimation regime in crystals with different complex symmetries.

Artificial structured materials provide the ability to tailor the diffraction of propagating beams leading to the self-collimation phenomena (quantum mechanical analog of the dynamical localization, occurring in modulated lattices); and effect accounted by the appearance of flat segments in the dispersion curves of propagating modes. First predicted in Photonic Crystals (PhCs)1,2,3, the effect was latter shown that also Gain and Loss Materials (GLM) modulated in the wavelength scale 4,5. However, is both cases, either due to the unavoidable presence of losses in PhCs or to the anisotropy of gain in GLM, the absence of diffraction is generally accompanied by diffusive broadening. Yet complex materials allow the independent management of diffraction and diffusion of light beams, by independently modulating refractive index and gain/loss, representing therefore an ideal platform for beam tailoring.

In the present work we demonstrate self-collimation in 2-dimensional (2D) Parity (P) symmetric and Parity Time (PT) symmetric complex crystals (where index and gain/loss modulations are either in phase/counter-phase or de-phased a quarter of the wavelength of the modulation7). In this later case, we consider PT-symmetry eitherthe transverse (or longitudinal) direction and simultaneously in both transverse and longitudinal directions, see Fig.1.

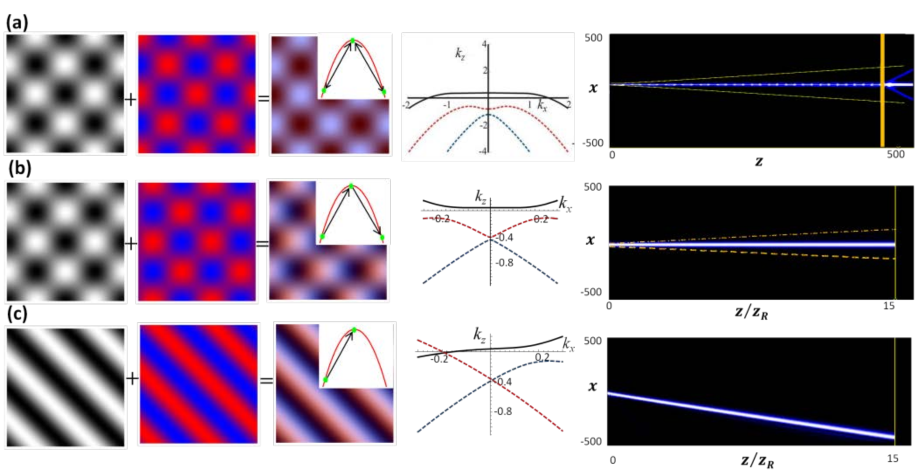

Figure 1. *Self-collimation in 2D complex crystals. The first/second rows display a schematic representation of the real/imaginary modulations of the optical potential, and the third merges both modulations where the inset indicates the coupling provided by the reciprocal lattice vectors — symmetric in (a) and asymmetric in (b) and*

(c)—. The forth row depicts the dispersion for the specific geometries and modulations amplitudes supporting self-collimation and the firth shows the corresponding numerical simulation of non diffractive light beam propagation within the corresponding crystal: (a) P-symmetric 2D lattice; (b) PT-symmetric lattice in the transverse, x, direction, while P-symmetric in z; (c) PT-symmetric lattice both in x and z. The yellow curves in the fifth row of a) and b) denote propagation of the considered beam in an homogeneous medium and are displayed for comparison.

The characteristics required for the suppression of diffraction, specific geometries and relative amplitudes of the gain/loss and index modulations, are analytically explored by a coupled mode analysis (some examples of flat dispersion bands supported for specific complex lattices are displayed in the third column of Fig.1, forth column)

For the case of P-symmetric complex crystals we find regimes of simultaneous suppression of diffusion and diffraction, self-collimated narrow light beams propagate without any distortion while being amplified, see Fig. 1a (since the amplitude of the beam is amplified, is here depicted renormalized at each propagation step). Besides, self-collimation is found either for collinear and non-collinear propagation in such complex crystals.

PT-symmetric lattices also offer the possibility to suppress diffraction. We analytically explore the characteristics of the spatial modulations required for the suppression of diffraction, for situations ranging from the pure PhC limit (system displaying real eigenvalues as for Figs. 1b,1c) to the pure GLM limit, that is to say, at either sides of the PT-transition exceptional point. Non-diffractive beams in GLM-like systems always experience self-broadening due to intrinsic diffusion. We analytically determine the self-collimation regimes for PT-symmetry in the transverse (Fig. 1b), longitudinal (found to be almost equivalent to the transverse one, except for the symmetric /asymmetric energy distribution among modes) and simultaneously in both directions (Fig. 1c). The analytical predictions are further confirmed by numerical simulations performed in paraxial approximation, finding a good agreement (see the last column of Fig. 1).

Finally, we analyze the beam dynamics in such regimes, in particular how the PT-symmetric potentials determine the energy distribution between spatial modes of the self-collimated beams either by the symmetric and or the asymmetric mode coupling. We show how complex lattices open the way to control the energy distribution among spatial modes. The predicted self-collimation effect in complex lattices may be useful to shape the beam profile in integrated optics or optical devices.

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