

Anomalous energy flow in passive elastic layers with exceptional points

Gal Shmuel, Ben Lustig, Guy Elbaz, Alan Muhafra

Faculty of Mechanical Engineering, Technion-Israel Institute of Technology, Haifa 32000, Israel

Recent interest in metamaterials has led to a renewed study of wave mechanics in the different branches of physics. Elastodynamics involves a special intricacy, owing to the coupling between the volumetric and shear parts of the elastic waves. Through a study of in-plane waves traversing periodic laminates, here we show that this coupling can result with unusual energy flow. Specifically, we find that the corresponding frequency spectrum contains modes which simultaneously attenuate and propagate, and demonstrate that these Bloch modes coalesce to purely propagating modes at exceptional points in the spectrum. These non-Hermitian degeneracies with propagating modes, which to date were realized by balancing energy gain and loss in systems with parity-time symmetry, are reported here in a purely elastic setting. We show that the laminate exhibits metamaterial features near these points, such as negative refraction, and beam steering and splitting. While negative refraction in laminates has been demonstrated before by considering pure shear waves impinging on an interface with multiple layers, here we realize it for coupled waves impinging on a simple single-layer interface. This feature, together with the appearance of exceptional points, are absent from the model problem of anti-plane shear waves which have no volumetric part, and hence from the mathematically identical electromagnetic waves in materials with positive refractive index. Thereby, our work paves the way for future applications such as asymmetric mode switches using a tangible elastic apparatus.