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Topology Transitions of Anisotropy Induced Bound States in the Continuum

Samyobrata Mukherjee[1], Jordi Gomis-Bresco[1], Pilar Pujol-Closa[1], David Artigas[1,2], Lluis Torner[1,2]
[1]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Av. Carl Friedrich Gauss, 3, 08860 Castelldefels (Barcelona), Spain.
[2]Department of Signal Theory and Communications, Universitat Politècnica de Catalunya, Jordi Girona 1-3, 08034 Barcelona, Spain.
E-mail: Samyobrata.mukherjee@icfo.es

Abstract: We demonstrate that Bound states In the Continuum (BICs) are supported in planar anisotropic structures where the optic axes are arbitrarily oriented. Moreover, we reveal fundamental new topological properties of these BICs that depend on the relative orientation of the optic axes in the core and substrate.
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Bound states in the continuum (BICs), first predicted in the field of quantum physics [1], are localized radiationless states existing in the part of the parameter space that corresponds to radiative modes. BICs were first demonstrated in acoustic systems and recently in photonic systems [2]. They coexisted in symmetric photonic structures with guided modes as almost-pure transverse-electric (TE) or transverse-magnetic (TM) states, at fixed frequencies and propagation directions [3]. Recently, we have proposed planar waveguiding structures containing anisotropic birefringent materials that support a fundamentally new kind of BIC with unique properties [4]. In particular, anisotropy-induced BICs exist with pure transverse-electric, pure transverse-magnetic or full-vector hybrid polarization. They change propagation direction with frequency and are supported by symmetric and asymmetric geometries. Interestingly, anisotropy-induced BICs may be the only possible bound states in properly designed structures, thus appearing as a discrete, isolated oasis in a desert of radiative states.

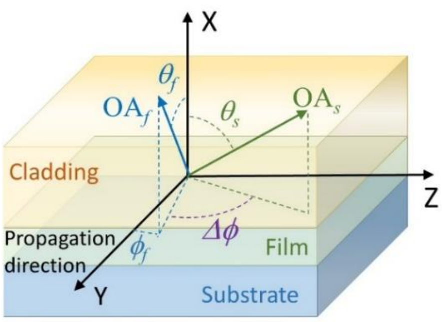

Figure 1. Layout of the System: A generic layered waveguide system comprising isotropic cladding, positive birefringent film and negative birefringent substrate. Light propagates along the Y direction. The green and the blue arrows indicate the substrate and film optical axis (OA), respectively. Structure parameters are as follows: {n_{of}=1.5, n_{ef}=1.75, n_{os}=2, n_{es}=1.25, n_c=1}

The structure we study is shown in Figure 1. BICs are formed when the radiation channel (usually in the substrate) is suppressed, resulting in the mode being decoupled from the continuum. This suppression of the radiation channel can result from polarization separability or destructive interference. The interference BICs are fully vectorial modes. Moving the optic axes of the core and substrate independently in the interference plane and even outside it, gives us new parameters to explore the structure. These parameters give rise to three distinct regimes: (a) core and substrate optic axes in plane and both aligned in the same direction, (b) both optic axes in interface plane, but de-aligned, and (c) one or both optic axes out of the interface plane. Traversing these regimes affects the dispersion of the BICs as shown in Figure 2.

In the regime where one of the optic axes is taken out of the interface plane (Figure 2c), we see that the dispersion line of the BIC collapses to a point on the leaky mode branche. We study this transition by inspecting the phase of the radiation channel around BICs, which is shown in Figure 3. We see that BIC dispersion lines correspond to a phase discontinuity. However in the third regime, when the BIC dispersion line collapses to a point, we see a screwing of the phase around the BIC that allows us to assign it a topological charge of +1 or -1. This topological transition results in a state similar to that of BICs existing in photonic crystals, which show vortex-like features and exist at a single frequency and direction [2,3].

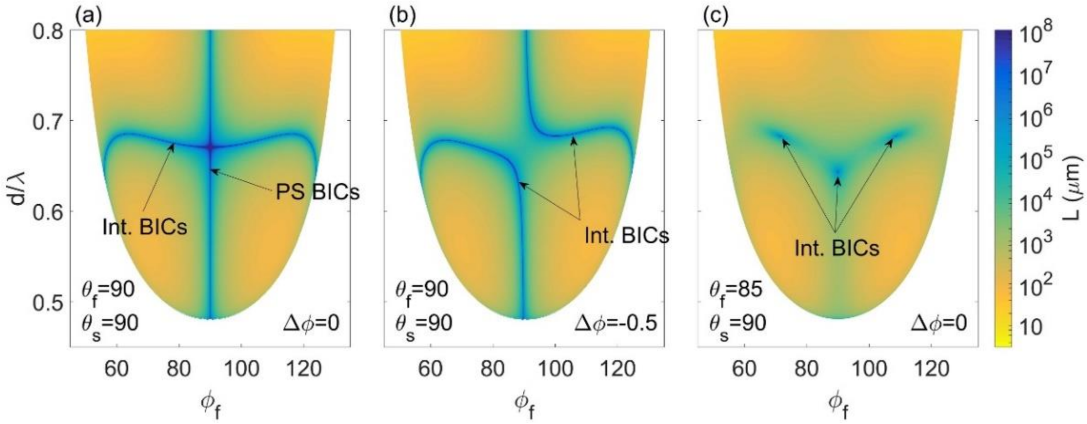

Figure 1. Existence loci of BICs in structures with broken anisotropy-symmetry. The colored area in the figures shows the decay length of the leaky modes in the $\phi_f - d/\lambda$ plane, where BICs appear as blue lines. The transition from the colored to the white area is the cut-off for the leaky modes.

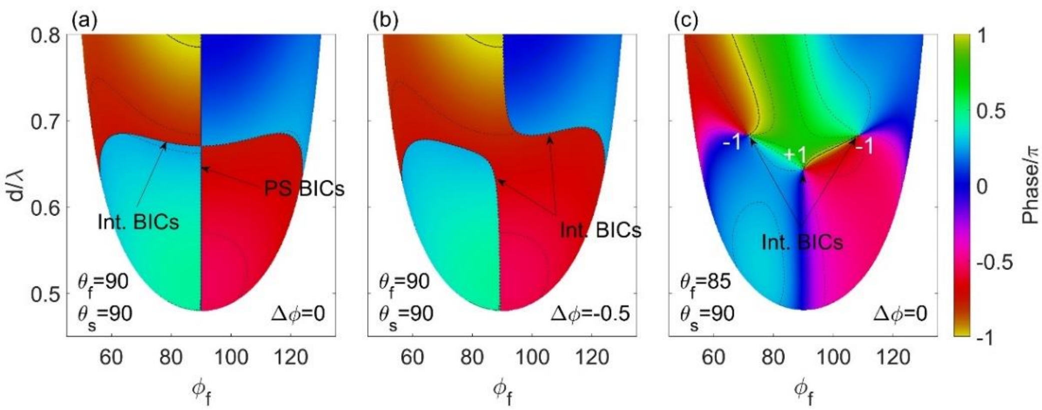

Figure 3. Transformation from simple phase dislocation to screw phase dislocations. The representation corresponds to Fig. 2. The color stands for the phase difference of the ordinary radiative channel with respect to the phase of the extraordinary confined wave in the substrate.

We have revealed that BICs are strongly related with the relative orientation of the optic axes in the film and the substrate. In addition we show that the transition of the dispersion line of BICs corresponds to a transition in the phase signature of BICs from phase discontinuitites to screw phase dislocations. Moreover, the fact that the BIC changes propagation direction with frequency suggests that the structure gives itself to potential applications as spatial and spectral filters.

References

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