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Theoretical developments and experimental insights of acoustic and elastic bound states in the continuum

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This paper explores recent theoretical advancements and experimental observations of bound states in the continuum (BICs) in acoustic, elastic, and optomechanical systems. We focus on three main types of BICs: symmetry-protected, Friedrich-Wintgen, and Fabry-Pérot BICs, and discuss their extensions to complex systems. Our work aims to bridge the theoretical and experimental validations of BICs, highlighting their utility and future development in mechanical wave systems.

High-quality wave localization has long been a topic of intense exploration. Recently, bound states in the continuum have garnered considerable attention due to their infinite quality factors in open resonant systems. Specifically, BICs describe a class of localized states that exists in the continuum radiation spectrum of a spatially confined open system. This is counterintuitive, because an open resonant system will inevitably couple with the external radiation state and lead to energy leakage, thus energy losses are usually unavoidable. However, due to some special conditions such as symmetry mismatch or destructive interference, certain modes are separated from the radiated waves and thus become eigenmodes with real frequencies. The resonant energy of these modes is fully localized, and their lifetimes extend to infinity, defining them as bound states in the continuum or trapped modes. BICs were first mathematically proven by von Neumann and Wigner in the field of quantum mechanics in 1929¹, and subsequently expanded by Stillinger and Herrick in atomic and molecular systems². Although the concept originated from quantum mechanics, the development of wave physics, such as electromagnetic, acoustic and elastic waves has provided simple platforms for effectively observing BICs in experiments.

It is worth mentioning that although BICs have infinite radiation quality factors in theory, they are ideal situations from pure mathematics. Due to many factors such as manufacturing errors, limited sample size, and material viscous effects, the quality factor of BICs can only be finite, which is regarded as quasi-BICs. For BICs based on symmetry mismatch, since the manufacturing structure usually does not have strict symmetry rules, the localized modes cannot be completely decoupled from the radiation continuum, resulting in leakage. For the BICs based on destructive interference, energy will leak unless the geometric parameters and frequency satisfy the

destructive interference conditions. Nevertheless, one can achieve quasi-BICs to realize compact wave functional devices such as sensors, filters, and low-threshold lasers with high quality factors. Some excellent review articles summarize the recent efforts in the field of BICs from different perspectives, including formation mechanisms of BICs^{3,4}, BICs in resonant nanostructures⁵, applications of photonic BICs^{6,7}, and acoustic resonances⁸.

In this perspective paper, we start from the introduction of types and formation mechanisms of BICs, then provide a comprehensive evaluation of the current research trends on BICs by analyzing key developments across a wide range of disciplines, including acoustics, elasticity, topology and optomechanics. This cross-disciplinary perspective enables a deeper understanding of BICs and uncovers novel opportunities for innovation and practical applications that might be overlooked when confined to a single research domain. By presenting this holistic view, the current work serves as a valuable resource for researchers looking to explore the untapped potential of BICs in emerging technologies.

Types and formation mechanisms of BICs

For the two-dimensional photonic crystals composed of periodic holes as shown in Fig. 1a, its wave vector \mathbf{k} can be decomposed into out-of-plane (k_z) and in-plane (k_x) components which are related by

$$k_z = \sqrt{\omega^2/c^2 - k_x^2} \quad (1)$$

where c is the bulk wave velocity. The corresponding momentum space is divided into two regions by $\omega = ck_x$ (solid line), as shown in Fig. 1b. Below

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