Editorial

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The science of harnessing light's darkness

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Nonradiative sources of light such as *anapoles* and *bound states in the continuum* (BICs) were initially proposed in quantum mechanics and astrophysics, and they did not attract much attention in photonics for a long time. However, primarily due to the rapid development of metamaterials and metaphotonics, it was recognized that such states are very prospective for efficient trapping of light, amplification of local fields, control of scattering, and also nonlinear manipulation of light at the nanoscale. Metaphotonics provides a broad variety of resonant dielectric structures, including optical gratings, metasurfaces, photonic crystals, and single resonators for a precise engineering of high values of quality factor (Q-factor) of the resonant states and their optical response. In the last ten years, nonradiating states matured from pure conceptual fundamental works to experimental demonstrations and original applications in photonics and radiophysics. They promised functional tools for controlling electromagnetic radiation of different spectral ranges from visible light to microwaves.

The special issue collects the 20 research articles and two review papers devoted to the cutting-edge results and recent progress in nonradiating metaphotonics, focusing on anapole states, supercavity modes, bound states in the continuum, and related scattering phenomena. Figure 1 shows a graphical summary of all the published papers sorted by nonradiative area of research.

The review by Joseph [1] and coauthors provide the detailed classification of BICs and their evolution in various plasmonic and dielectric structures along with their application, including nonlinear harmonic generation, sensing, imaging, lasing, low loss on-chip communication, and photodetection. The review by Carletti [2] focuses on the nonlinear response of high-Q dielectric and semiconductor metasurfaces and physical phenomena that enable the dynamic control of the nonlinear response. Complementary to this review, Abujetas and coauthors suggest using a class of metasurface in which the magnetic field dynamically controls BICs and quasi-BICs [3].

Photonic structures with nonradiative states dramatically change conventional views on well-known effects. Nonradiative systems support, for example, a vanishing conversion from the fundamental frequency to the second harmonic even when the phase-matching condition is satisfied. The work by Jin et al. [4] predicts this novel effect and baptizes it "*resonance-forbidden second-harmonic generation*". Longhi predicts another fundamental effect in [5]. He suggests that a crystal made of BICs, composed of an array of BICs indirectly coupled via a common continuum of states, results in a tight-binding dispersive energy miniband embedded in the spectrum of radiating waves. Such designs have a potentially high impact on quantum electrodynamics. Leonforte et al. develops a theory that sets an analogy between the impurity problem in condensed matter and a quantum emitter coupled to a homogeneous photonic reservoir [6]. They derive a general expression of dissipationless effective Hamiltonians explicitly featuring the overlap of single-emitter dressed bound states.

In [7], the authors study theoretically the enhanced efficiency of second-harmonic generation and degenerate four-wave mixing in GaP metasurface possessing quasi-BICs states. The work [8] demonstrates experimentally such enhanced efficiency of second-harmonic generation in the ultraviolet range from the Mie resonant $LiNbO_3$ nanoantennas.

Along with enhancing nonlinear effects, BICs provide a set of fundamental advantages for ultrasensitive biosensing, bridging the gap of high effective mode volumes with prominent experimental quality factors. The article of [9] shows experimentally how BIC-based photonic structures can act label-free DNA biosensors with facile interrogation and low-cost optical setup. The work of [10] studies the quasi-BICs in high-contrast gratings for protein detection.

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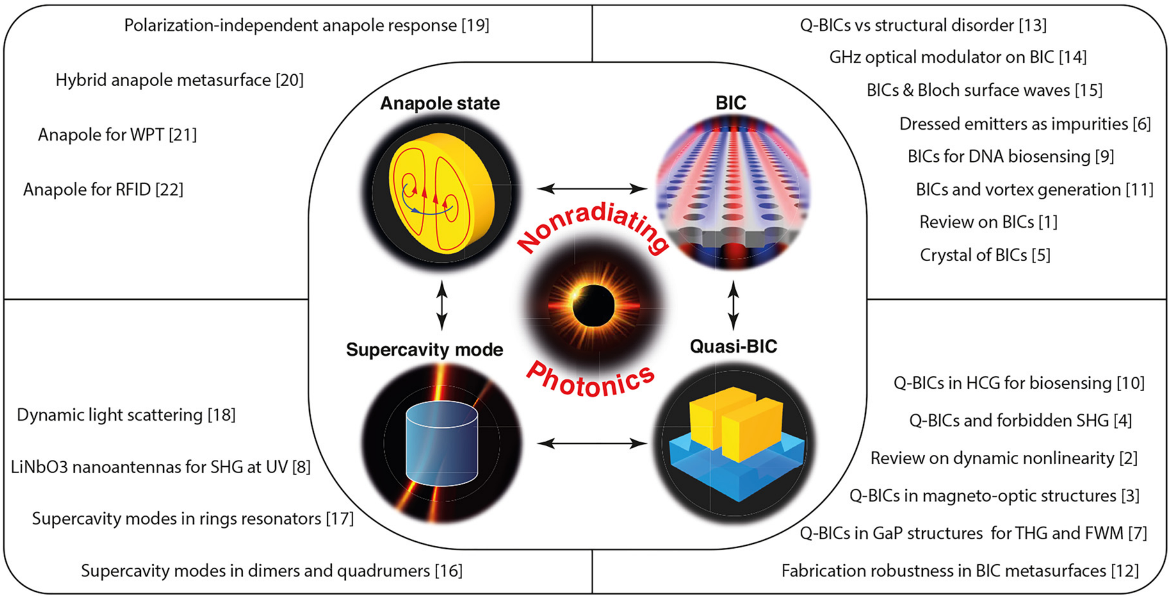

Figure 1: Chart of all papers included into this special issue on nonradiating resonant dielectric nanostructures.

The authors suggest two novel grating configurations to improve the performances of traditional biosensors.

BICs also open new avenues in light generation with on-demand properties. In [11], the authors propose a new approach based on the dual resonances to improve the cross-polarization efficiency of nonlocal vortex beam generation. While BICs typically originate as a collective destructive interference that suppresses far-field radiation, the structural disorder can play an essential role in altering this effect. The works [12, 13] analyze theoretically and experimentally this issue for both BICs and quasi-BICs.

Recent work reveals that the well-known "*magic width*" of ridge waveguides, i.e., the specific width of a ridge waveguide in which the radiative losses into the substrate suppress, is a manifestation of a BIC nonradiative state. In [14], the authors show experimentally that such BICs can be used for the efficient on-chip GHz acousto-optic modulation at near-visible wavelengths on a lithium-niobate-on-insulator platform. Moreover, this BIC concept allows the design of effective acousto-optic modulators from low-refractive-index materials like polymers directly on a lithium niobate platform without the need for etching $LiNbO_3$. The work [15] further explores the idea of loss suppression via the "magic width", proposing a new type of BIC in subwavelength and near-subwavelength integrated diffraction gratings.

Quasi-BICs can also exist in single dielectric resonators in the form of supercavity modes. In [16], the authors extend the concept of ultrahigh supercavity modes to the case of a finite array consisting of three and four different coaxial disks predicting the Q factor up to 10^6. The work [17] provides a generalization of supercavity modes to the case of ring resonators. In [18], the authors develop a two-mode analytical model for the description of non-steady Fano resonances and sharp peaks in the scattering spectra that appear under pulse excitation of resonant structures.

Anapole represents a nonradiating configuration of currents (polarization) induced by incident light. It manifests itself as a sharp dip in the scattering spectra that strongly depends on the configuration of the incident field. In [19], the author provides a comprehensive study of metasurfaces composed of dielectric clusters supporting polarization-independent anapole states. The work of [20] proposes a novel concept of hybrid-anapole based metasurface for phase control of the transmitted light. In [21], the authors demonstrate the efficiency of a hybrid anapole state with strong suppression of far-field radiation for near-field wireless power transfer. In [22], the work studies how anapole-based radio-frequency tags can provide hardware secure for radio-frequency identification, prohibiting far-field attacks.

In summary, we believe this special issue provides an overview of the state-of-the-art research activities in nonradiating photonics, collecting original research articles and review papers on BICs, quasi-BICs, anapoles, and supercavity modes. We hope this collection could stimulate further development of progress in experimental metaphotonics and attract more scientists to this rapidly developing research area.

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