Cavities based on bound states in the continuum compatible with standard semiconductor technology*

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Bound states in the continuum (BICs) were predicted on the basis of quantum mechanics nearly a century ago by von Neuman and Wigner [1]. However, they have received most attention in the field of optics, beginning with [2], as they enable electromagnetic wave confinement to subwavelength dimensions with an infinite quality factor. BICs are nonradiating electromagnetic resonant states localized in open photonic systems (above the light line), although they can coexist with a continuous spectrum of unbounded states [3].
BIC can be achieved in photonic periodic structure when the following conditions are met:
1) The structure is embedded in low enough refractive index surroundings.
2) The period of the structure enables single diffraction order emitted toward substrate (below the structure) and superstrate (above the structure).
3) Substrate and superstrate are of the same refractive index (vertical symmetry).
Those conditions make BIC-based cavities technologically challenging and therefore real-world realizations use the membrane configuration or require to be covered by the material of the same refractive index as the refractive index of the substrate to ensure vertical symmetry. Such designs make it difficult to fabricate electrically driven devices, since the air or low refractive index materials (typically dielectrics) are nonconducting.
Here we demonstrate by numerical analysis that judiciously designed distributed Bragg reflector (DBR) enables reflection of higher diffraction orders produced by the periodic structure toward DBR and enables BIC creation in configuration with broken vertical symmetry which contradicts condition 3. Moreover, the effective refractive index of the periodic structure can be lower than the refractive indices of the materials composing the DBR on which the periodic structure is implemented that contradicts condition 1. Such a configuration is fundamentally different from any configuration in which BICs have been reported in the past. This work will be concluded with examples of arsenide-based configurations of finite dimensions enabling very high quality factor in the case of symmetry-protected as well as resonance-trapped BICs.
Our design opens the way for implementation of BIC-based devices in mature technology of semiconductor epitaxy, becoming an universal platform for the implementation of all possible periodic structures enabling BIC, gives promise for realization of electrically driven BIC-based devices and as our calculations show, the configuration greatly relaxes the requirements on the fabrication of the periodic structure, which can be made from almost any material used in optoelectronics.

[1] J. von Neumann, E. P. Wigner, "Über das Verhalten von Eigenwerten bei adiabatischen Prozessen," Phys. Z. 30, 467 (1929)
[2] P. Vincent, M. Nevière, "Corrugated dielectric waveguides: a numerical study of the second-order stop bands," Appl. Phys. 20, 345 (1979)
[3] D. C. Marinica, A.G. Borisov, S. V. Shabanov, "Bound states in the continuum in photonics," Phys. Rev. Lett. 100, 1 (2008)

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