New perspectives in nanophotonic based quantum technologies: from theory to applications

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Nanophotonics provides a unique platform for creating quantum systems by confining and enhancing electromagnetic fields at sub-wavelength levels. Bound states in the continuum (BICs) are a paradigmatic example of an idea developed in early quantum theory, which challenged the traditional understanding that bound states could not exist in the same energy range as free states, and became an experimental reality in nanophotonic structures.
We present our recent contributions to the emerging field of BICs, which have attracted considerable interest in nanophotonics for their potential to enhance light-matter interactions, a cornerstone of quantum information processing, sensing and communication.
The design of BICs into nanophotonic structures, such as photonic crystals, metasurfaces and nanocavities, offers unprecedented control over photon dynamics. This can lead to enhanced spontaneous emission rates, upconversion[1], high-quality factor resonances and robust, loss-resistant photonic states. The uniqueness of photonic BICs can be understood within the framework of topological photonics, where the properties of the system play a crucial role in the formation and stability of these states. We explored the origin of the topological charges[2] that ensure the robustness of BICs to perturbations, making them highly stable and less sensitive to fabrication imperfections, which is crucial for the development of reliable quantum devices, enhancing the performance of single-photon sources and quantum emitters by providing a stable and high-quality optical mode for emission. We have also investigated the spin-orbit coupling (SOC) effect supported by BICs[3], which allows control of the propagation and polarisation state of light, leading to more efficient quantum gates and memories.
Finally, we present the ARTEMIS HORIZON-EIC Pathfinder project, coordinated by CNR-ISASI[4], which aims to propose new concepts for the development of quantum materials that can be used as single and entangled photon sources on command. This would provide a disruptive advantage for metrology and integrated photonics. To reach this ambitious high-risk, high-gain goal, ARTEMIS aims at investigating an integrable quantum photon source by resorting to metal d and f ions-based molecular materials with organic moieties. Finally, we present the ARTEMIS HORIZON-EIC Pathfinder project, coordinated by CNR-ISASI[4], which aims to propose new concepts for the development of quantum materials that can be used as single and entangled photon sources on command. This would provide a disruptive advantage for metrology and integrated photonics. To reach this ambitious high-risk, high-gain goal, ARTEMIS aims at investigating an integrable quantum photon source by resorting to metal d and f ions-based molecular materials with organic moieties.

[1]Schiattarella, C, et al. Directive giant upconversion by supercritical bound states in the continuum. Nature 626, 765–771 (2024).
[2]De Tommasi, E. et al. Half-Integer Topological Charge Polarization of Quasi-Dirac Bound States in the Continuum. Adv. Opt. Mater. 11, (2023).

[3]Zito, G. et al, Observation of spin-polarized directive coupling of light at bound states in the continuum, Optica 6, 1305-1312 (2019).
[4]https://www.artemis-quantumproject.eu/

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