QMETA: Realising Quantum METAsurfaces with quantum dot arrays

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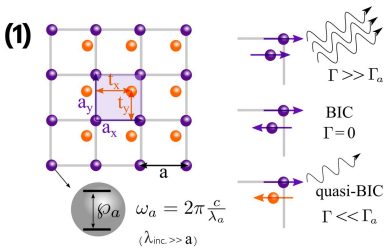
Nanotechnologies

Quantum metasurfaces

- Metasurfaces are artificial media composed of specifically designed nanomaterials that allow to tailor the interaction with light beyond what can be achieved with natural materials. Metasurfaces can enter the quantum realm by designing collections of quantum emitters, whose collective interactions result in *subradiant states* with reduced coupling to the environment that can be used as quantum memories, among other prospects.
- Quantum metasurfaces have been realised with cold atom arrays, but these of complex setups and cryogenic temperatures. In contrast, QMETA searches the realisation of *solid state quantum metasurfaces by exploiting ordered arrays of quantum dots*. This will result in compact quantum metasurfaces operating at room temperature, with applications in photonic quantum communications and quantum information.
- Here we present a theoretical proposal of a quantum metasurface supporting subradiant optical states whose lifetime can be controlled through the array geometry.

Bound states in the continuum in quantum metasurfaces

(1)

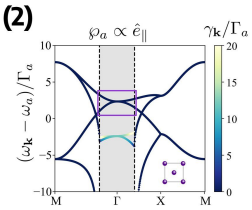


$$\frac{H}{\hbar} = \sum_{j=1}^{N_A} \left(\omega_j - i\frac{\Gamma_j}{2}\right) \sigma_{ee}^j - \sum_{\substack{j=1 \\ i \neq j}}^{N_A} \frac{\omega_{eG}^2}{\epsilon_0 c^2} [\wp_i^* \cdot \mathbf{G}_{ij}] \wp_j] \sigma_{eg}^i \sigma_{ge}^j$$

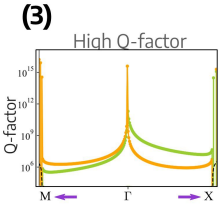
Quantum non-hermitian Hamiltonian

Green's function: dipole-dipole interaction

(2)

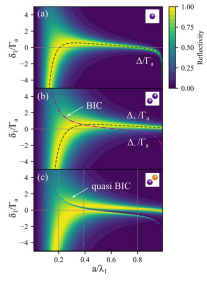


(3)



Optical response at normal incidence

(4)



Reflectivity

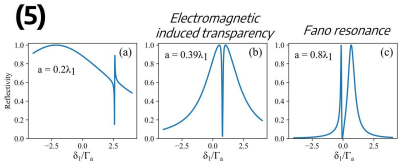
$$R_{\sigma\sigma'}(\mathbf{k}_{\parallel}) = \frac{|\mathbf{e}_{\sigma} \cdot \hat{\boldsymbol{\alpha}}_{\text{eff}} \cdot \mathbf{e}_{\sigma'}|^2}{(A\lambda\varepsilon_0/\pi)^2}$$

- *BIC modes cannot couple to the far field*
- *Symmetry breaking leads to quasi-BIC with controllable line-width*

Symmetric Antisymmetric

$$\alpha_{\text{eff}}^{\sigma\sigma}(\omega, \mathbf{k}_{\parallel}) = \alpha_0 \Gamma_1 \left[\frac{\Sigma_+(\mathbf{k}_{\parallel})}{\delta_+(\omega) - \Omega_+(\mathbf{k}_{\parallel})} + \frac{\Sigma_-(\mathbf{k}_{\parallel})}{\delta_+(\omega) - \Omega_-(\mathbf{k}_{\parallel})}\right]$$

(5)



Highlights & perspectives

- QMetasurfaces can support Bound states in the continuum: perfectly subradiant states with infinite lifetime and quality factor, useful for information storage.
- Non-perfect arrays support Quasi-BICs with long and controllable lifetimes, and a very rich spectrum.
- Quantum metasurfaces with Quasi-BICs also serve as optical elements: act as extremely narrow bandwidth polarisers and phase changers
- Experimental realisation in the solid state with arrays of quantum dots promises compact quantum metasurfaces operating at room temperature

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