Superradiance, subradiance and PT-symmetry with plasmonic nanochannels

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Photonic coherent emission effects, such as superradiance and subradiance, can be achieved only when the neighboring quantum emitters are placed very closely to each other at highly subwavelength distances, which limits their practical applications. In this work, we present a new plasmonic route to obtain superradiance and subradiance effects from emitters separated by distances comparable and even larger to the operating wavelength. The superradiant and subradiant modes are stimulated by a collection of two-level emitters embedded in plasmonic nanochannels. These channels have an effective epsilon-near-zero (ENZ) response at the cutoff wavelength and Fabry-Pérot (FP) resonant behavior at lower wavelengths. The plasmonic resonant modes are able to efficiently enhance the constructive (superradiance) or destructive (subradiance) interference of several quantum emitters located inside the nanochannels.

We numerically analyze the collective emission properties of a pair of emitters and find that a directional superradiant mode exists at the ENZ wavelength that is independent of the emitters' distance. In this configuration, superradiance is no longer limited to subwavelength distances between emitters and can be extended to distances comparable to the wavelength. By increasing the number of emitters located in the elongated plasmonic nanochannel, superradiant radiation is further enhanced at the ENZ operation, leading to an ultrafast response in the collective spontaneous emission decay rate. Moreover, we can achieve dynamic tuning between superradiant and subradiant modes when the emitters operate at either the ENZ or FP resonant wavelengths, respectively. The ability to control and boost the collective emission characteristics based on a single plasmonic system can lead to fundamental implications in optical computing systems and quantum communications. Our findings can also be applied to other quantum operations, such as the efficient generation and control of long distance entanglement between qubits.

In addition, we will demonstrate a nanoscale parity-time (PT) symmetric optical device based on the aforementioned plasmonic nanochannels. This can be possible when we alternatively embed active (gain) and loss dielectric materials inside the plasmonic slits. Super scattering occurs in the vicinity of the exceptional point at the ENZ resonance of these plasmonic nanochannels just by introducing extremely small gain and loss material parameters. When we illuminate the channels with two counter-propagating plane waves, the total output power can be modulated by changing the phase difference between the two incident waves. Our findings provide a platform to investigate and design low threshold nanolasers, coherent perfect absorbers, ultrasensitive optical sensors, and new solar cell designs.