Metamaterials for quantum optics

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Metamterials enable a new, unorthodox approach of enhancing the nanoscale light-matter interaction in a broad bandwidth by provide the quantum emitter with a plethora of electromagnetic states (1–2). Current nanofabrication technologies allow the engineering of the dielectric constant with metamaterials, transforming the space perceived by light to be metallic in one direction and dielectric in another. This lifts the restriction on the well-known closed spherical dispersion relation of an isotropic medium into a hyperboloid, leading to electromagnetic states unique to the metamaterial (2–3). An infinite number of metamaterial states can lie on this hyperboloid (in the low-loss, effective-medium limit), increasing the interaction with the quantum emitter while simultaneously channeling the light into a subdiffraction single-photon resonance cone (3) (see Fig. 1).

We experimentally demonstrate a broadband enhancement of emission from nitrogen-vacancy (NV) centers in nan-

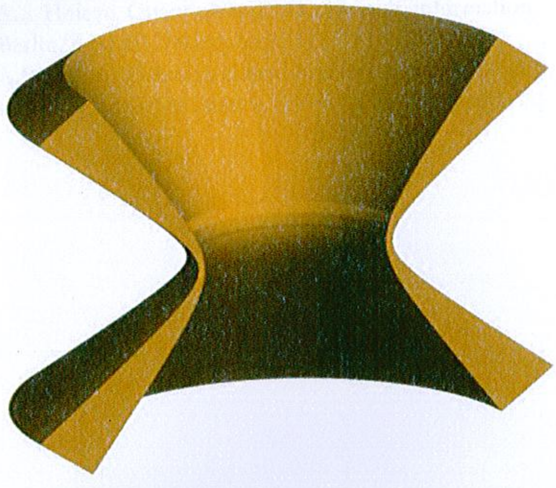

Figure 1: Unbound iso-frequency surfaces for ω and ω + δω that define the anomalously large photonic density of states in a hyperbolic metamaterial (HMM).

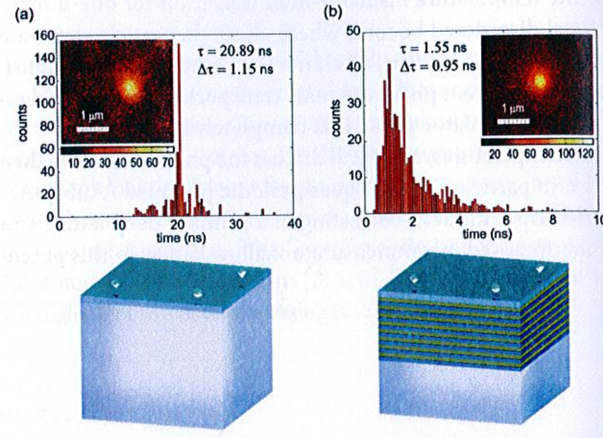

Figure 2: Experimentally measured spontaneous emission lifetimes. Histograms of the NV center lifetimes on (a) coverslip and (b) HMM. Corresponding mean values (standard deviations) of the lifetime distributions are: (a) 20.89 ns (1.15 ns), (b) 1.55 ns (0.95 ns).

odiamonds [4]. The enhancement is achieved by using a multilayer metamaterial with hyperbolic dispersion. The metamaterial is fabricated as a stack of alternating gold and alumina layers (see Fig. 2). Our approach paves the way towards the construction of efficient single-photon sources as planar on-chip devices.

In comparison to other proposed techniques for single-photon emission enhancement, this method is based on a non-resonant way of engineering the electromagnetic environment which provides enhancement across the entire emission range of NV centers. In the future, we would like to achieve higher enhancement by building HMMs based on different designs and low-loss constituent materials. Such a diamond — metamaterial device can serve as a proof of principle for more complex structures that can bring quantum optical technologies to life.

References:

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