Gap-Mode Plasmonic Cavities: Engineering Light-Matter Interactions in Metallic Structures

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Optical cavities can tightly confine light in the vicinity of optical emitters, enhancing the interaction of light and matter. The modes or optical states of the cavity can be precisely designed and engineered, and in recent years there has been remarkable progress in demonstrations of 'cavity quantum electrodynamics (cQED)' in solid state platforms. Such progress has been primarily for cavities fabricated in dielectric materials, with a steady improvement in cavity quality, with quality factors, Q, in excess of $10^4 – 10^6$ realized for cavities with coupled emitters [1],[2]. These high Q-coupled emitter systems have demonstrated heralded single photon emission [3], ultra-low threshold lasing [4] and strong light-matter coupling [5],[6].

Metal-based optical cavities would have inherently lower Q's (and greater loss) than dielectrics; however, metal cavities utilizing surface plasmon polaritons (SPPs) can have sufficiently small mode volume to produce a substantial Q/V, the quantity relevant for high Purcell factors, a measure of the light-matter interaction. This talk will focus on such *plasmonic cavities*, with optical modes formed within the gap of the two metal layers which defined the cavity [7]. Initial structures comprised silver (Ag) nanowires (NW), 70 nm in diameter and 1 - 3 μm in length, placed into close proximity to a Ag thin film substrate, with the NW axis parallel to the substrate surface. Optically active material was interposed between the nanowire and the Ag substrate: this comprised one to two monolayers of PbS colloidal quantum dots, clad on top and bottom by thin dielectric layers of varying composition and thickness. A representation of the cavity geometry is shown in Figure 1.

The fluorescence spectrum of PbS quantum dots within the gap was strongly modified by the cavity mode, with peak position in quantitative agreement with numerical calculations, and demonstrating Q values of ~ 60. Figure 2 shows the different modal signatures as a function of nanowire length.

The ability to tune the optical modes into resonance with the emitters is important in achieving the optimal light-matter coupling, and geometry of these cavities lends itself to a relatively simple and straightforward tuning approach. Carefully controlled deposition of dielectric layers formed by Atomic Layer Deposition (ALD) resulted in the systematic shift of the optical modes, as shown in Figure 3.

The high Q/V possible for these cavities, and the range of organic and nanocrystalline emitters they can accommodate make these important building blocks for the exploration of light-matter interaction in the solid state.

References

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Figures

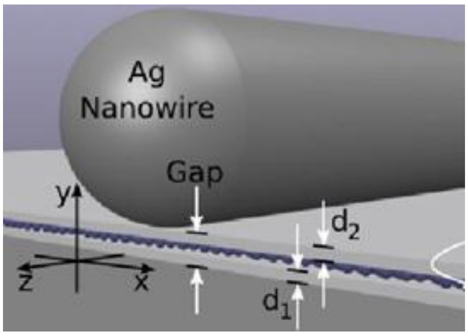

Figure 1. Schematic diagram of plasmonic nanocavity with quantum dot optical emitters (not to scale).

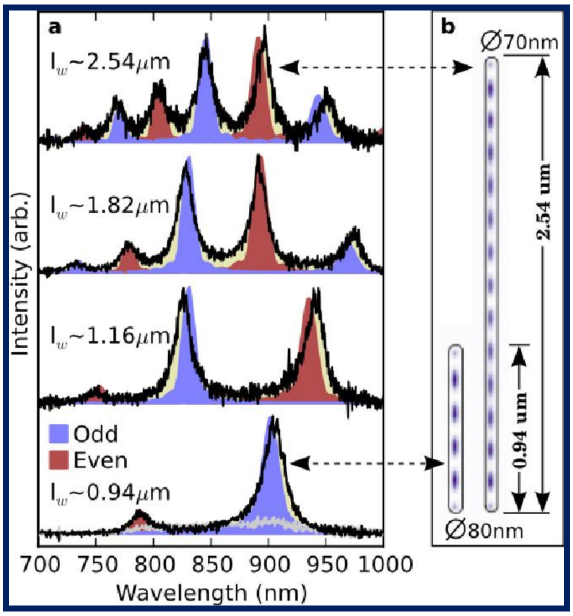

Figure 2. (a) Measured (lines) modes and FDTD calculated resonances (filled curves) from four cavities of different lengths , indicated in (b) Calculated modal profile for the two indicated cavities. The cavity lengths are indicated by the numbers on the upper-left of each spectrum.

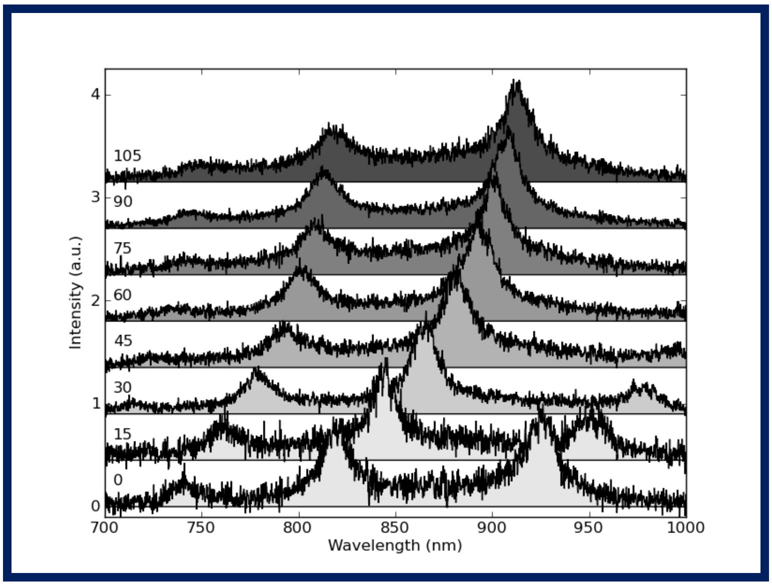

Figure 3. Systematic shift in modes with increased dielectric deposition on cavity.Numbers on the upper left of each spectrum indicate the number of ‘cycles’ of atomic layer deposition. Approximately 1 nm/cycle of Al_2O_3 is deposited.