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Quest for an Optical Circuit Probe

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What is common in near field optics and the electronic circuit probe techniques? Typical electronic test probes are conveniently used to connect test equipment such as oscilloscopes to an RF integrated circuit. Likewise in near field optics, it is highly desirable if we have similar precision test probes with both high spatial and spectral resolution to study the optical phenomena. Such light-matter interaction in nanostructures involving single and collective emitters can enhance our understanding and design for cavity quantum electrodynamics.

Recently, low-energy excitation by swift electrons has been applied to explore the optical response of nanostructured materials with unmatched spatial resolution. For example, the measurement of photon emission rate using cathodo-luminescence techniques can provide a direct quantification of local radiative energy transfer from electron to photons at spot size close to 10 nanometers, which compliment other experimental techniques such as photoluminescence. Such tightly localized excitation source and a high-resolution mapping technique is particularly suited to study the spontaneous emission rate of a plasmonic nanostructure with sub-wavelength mode volume.

In this invited talk, we will discuss our effort of developing near field optical and electron probes for characterizing optical nanstructures for light trapping, mixing and extraction. A fundamental research in the physics of metamaterials is the interaction between electron and the cavity plasmon [1], which plays an important role in many applications such as nanolasers [2] and nanoantennas [3]. Dark plasmonic modes, which lead to “forbidden” photon transition, are of particular interest as they promise to controllable stimulated emission at nanoscale. Recently, many novel phenomena associated with dark modes are also observed. For instance, it has been shown that the Fano resonances associated with the coupling between dark and bright modes can lead to extraordinary far-field phenomena [4]. Our preliminary research show that photon emission of bright and dark modes in single metal bowtie nanoantenna can be selectively excited using a focused electron spot as shown in Fig. 1. The measured high resolution spectrum shows unexpected high photon counts associated with signatures of the dark modes, in contrast to common wisdom that such dark modes only couple weakly to the far field. With an eigendecomposition response theory [5], we successfully explained the phenomena as a result of hybridization between localized plasmons. These probes could provide brand new insight of quantum metamaterials with unprecedented fine spectral and spatial resolution.

In the second part of this talk, we present a potential application of local electron energy loss spectroscopy as a quantitative optical probe for photon emission rate engineering. For example, optical excitation on hexagonal boron nitride (hBN) nanostructures has sparked remarkable research interests, since such materials could accommodates highly dispersive surface phonon-polariton modes. Our theoretical model on graphene-hBN heterostructures suggests that the graphene plasmon couples differently with the phonons of the two Reststrahlen bands in the mid-

IR, owing to their different hyperbolicity. This also leads to distinctively different interaction between an external quantum emitter and the plasmon-phonon modes in the two bands, leading to substantial modification of its spectrum. The coupling to graphene plasmons allows for additional gate tunability in the Purcell factor, and an induced transparency in its emission spectra.

References:
[1] F. J. G. de Abajo, Rev. Mod. Phys. 82, 209–275 (2010).
[2] D. J. Bergman, and M. I. Stockman, Phys. Rev. Lett. 90, 027402 (2003).
[3] P. Chaturvedi, et al., ACS Nano 3, 2965–2974 (2009).
[4] V. A. Markel, *J. Opt. Soc. Am. B* **12,** 1783–1791 (1995).
[5] K. H. Fung, et al, Phys Rev. B, 89, 045408(2014).
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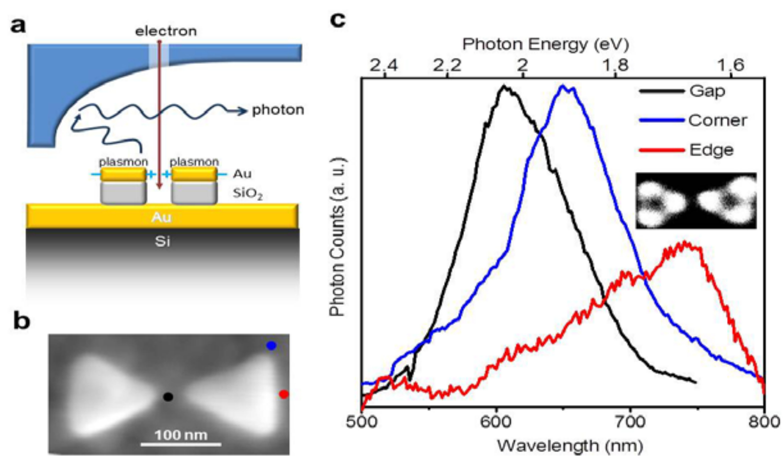

Figure 1. Cathodoluminescence spectroscopy of plasmonic nanoantennas. (a), Schematic diagram of the setup and the process of photon generation by electron beam. Electrons are incident from top of the sample. Photons emitted from the nanoantenna are collected collimated by a parabolic mirror before detection. (b) SEM picture of a fabricated bowtie antenna. (c) Measured CL spectra at three locations indicated as colored dots in b. The inset shows a panchromatic spatial image collected for the whole spectrum detected by the photodetector. Bright color corresponds to high photon counts.