Coupling between surface plasmon polaritons and proximal InGaAs quantum dots in Au-GaAs plasmonic nanostructures

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Improving fabrication techniques now facilitate the routine fabrication of nanometer scale metallic structures, opening the way to use surface plasmon polaritons (SPPs) to guide, confine and manipulate light over lengthscales far below the diffraction limit and enhance the strength of the light-matter interaction. However, when proximal quantum emitters are brought close to such metallic nanostructures, competing radiative and non-radiative processes often complicate understanding of the precise nature of the light-matter coupling. Moreover, imaging of SPPs is non-trivial, typically calling for near field optical techniques. Here, we present investigations of lithographically defined rectangular SPP waveguides [1] and directional couplers on GaAs into which a sparse array of InGaAs quantum dot (QD) emitters is grown 25±2 nm beneath the surface [2]. Our results allow us to elucidate how the optical properties (radiative dynamics and luminescence yield) of the QDs are influenced by the proximity to the Au-GaAs interface and, furthermore, demonstrate that the QD emission can be used to directly image surface plasmon polaritons. In time resolved measurements, a highly local ~ 1.5 × enhancement of the spontaneous emission decay rate is observed close to the plasmonic nanostructures with a commensurate increase of the emission intensity of dots excited by propagating plasmons. Whilst such spatially resolved spectroscopy clearly indicates the presence of a unidirectional energy transfer mechanism from the propagating SPP modes to the dots, it also facilitates imaging of the propagating SPPs modes. For passive structures that do not contain dots we measure SPP propagation lengths ranging between 13.4 ± 1.5 μm and 27.5 ± 1.7 μm for waveguide widths of 2 μm and 5 μm, respectively [1]. In contrast, for active structures containing QDs we observe an exponential decay of the intensity of the QD emission along the waveguide with a decay length of ~5 μm, indicative of the existence of a different mode, which couples efficiently to the QDs. The local emission from QDs was used to test the operation of a plasmonic beam splitter [3] consisting of two parallel waveguides with evanescent coupling over a well-defined interaction length – L (fig 1a). By exciting plasmons in the left hand input port of the waveguide, the intensity of the QD PL in the left and right hand output ports was monitored as a function of L. Figure 1b shows the typical QD emission intensity recorded as a function of the interaction length, showing excellent agreement with the results of FDTD simulations.

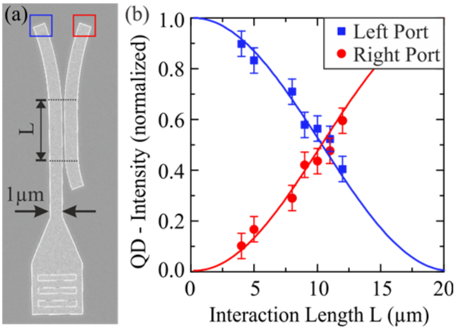

Fig. 1: (a) SEM image of a typical plasmonic beamsplitters on GaAs - Inset: Spatially resolved image of the QD emission showing the plasmonic beamsplitters (b) Splitting ratios of directional couplers: Relative intensities (scatter plot) of the two stripes plotted as a function of their interaction length. Solid lines indicate corresponding simulations of the system.

[1] Bracher et al., J. Appl. Phys. 110, 123106 (2011)
[2] Bracher et al., Proc. of SPIE 8269, 826920-1 (2012)
[3] Wahsheh et al., Optics Comm. 282,4622-4626 (2009)