Direct near-field study of generation, coupling, propagation and design of surface plasmons polaritons in the mid-infrared.

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Scattering-type near-field optical microscopy (sNSOM) uses the tip of an atomic force microscope to scatter the electromagnetic near-field towards a detector located in the far-field. Recording the scattered near-field as a function of the position of the tip while it is scanned over the sample surface, allows one to obtain an optical image of the scanned area with subwavelength resolution, at the same time as its topography is recorded. As the scattered light propagates in free space, sNSOM can be applied at any wavelength. Application of sNSOMs at low photon energies such as mid-infrared and terahertz wavelengths is the nanoscale observation of the dielectric contrast between materials [1], or the mapping of the spatial distribution of evanescent waves at the surface of waveguides or devices [2].

Surface plasmons polaritons (SPPs) are propagating electromagnetic modes bound at the interface between a metal and a dielectric, which originate from electron oscillation in the metal. These electromagnetic waves are evanescent in the direction perpendicular to the interface, while they can propagate in a direction parallel to it. sNSOM is a unique tool to perform direct imaging with subwavelength resolution of SPPs propagating on metal surfaces. In this talk, we will give an overview of our recent sNSOM investigations of various types of plasmonic devices which are active, in the sense that they use a mid infrared (midIR) quantum cascade laser (QCL) as an electrical generator of SPPs [3,4].

Due to their dispersion relation, the generation of SPPs generally requires the use of a prism or a grating combined with an external laser source. In situ generation is clearly required to produce compact integrated SPPs devices. We have achieved this goal in a device operating at □≈7.5 µm which includes all the building blocks required for a fully integrated plasmonic active source: an electrical generator of SPPs based on a 1st order distributed feed-back (DFB) metal grating at the surface of the laser cavity, a grating coupler, and a passive metallic waveguide. We have demonstrated the operation of the device by reproducing the analogue in the near-field of the slit-doublet experiment, using the sNSOM to observe directly the standing wave pattern which is formed in the near-field on the passive section of the device, due to the interference of two counter-propagating SPPs [3]. An alternative method to inject SPPs on a passive waveguide is end-fire coupling, which we have used to generate SPPs on a flat metallic strip from the end facet of a QCL at □≈7.5 µm. We demonstrate the propagation of SPPs at distances of several hundreds of micrometers from the end facet of the laser via both far-field and near-field imaging techniques [4]. At midIR wavelength, SPPs propagating on a flat gold surface have a decay-length (perpendicular to the gold surface) of tens of micrometers [4]. The "designer's" or spoof SPPs allow one to dramatically change this behavior by artificially designing the dispersion relation using structured surfaces [5]. The idea is to mimic at IR wavelengths features which in principle are observed at shorter wavelength, and which result in an enhanced confinement of the

SPPs at the surface [5,6]. We have achieved this by replacing the flat surface of the SPPs waveguide by a properly designed sub-wavelength metallic groove grating. Increasing the groove depth results in an increased in-plane wavevector and, therefore, long wavelength spoof SPPs have a shorter decay-length and can be manipulated just as their short wavelength counterpart. Based on sNSOM imaging, we demonstrate curved spoof SPPs trajectories and we present our progress towards the realization of a sub-wavelength-sized “hot spot” where local field enhancement occurs (7).

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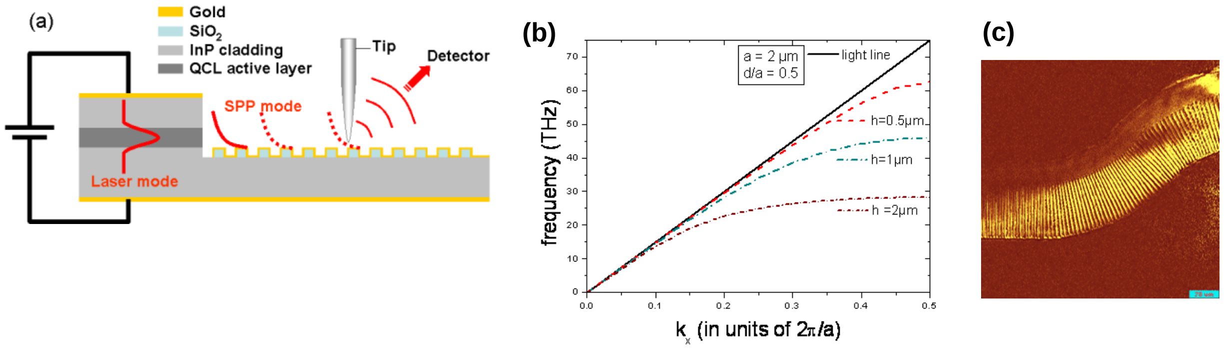

Figure 1: (a) Schematic cross section of a spoof SPPs device using a mid IR QCL as generator, and schematic view of the sNSOM detection; (b) Dispersion relation of spoof SPPs corresponding to a metal grating with a pitch of 2µm, duty cycle 0.5, and depth h ; (c) sNSOM image measured on a curved spoof SPPs waveguide.

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