Hyperspectral Plasmonics

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***Abstract*- The concepts of uncollimated and broadband plasmonics are introduced into a novel approach of 3D plasmonics, where the whole dispersion relation of scattered light can be monitored directly. This is experimentally achieved by a hyperspectral imaging technique. We illustrate how these ideas are enabled by nanophotonics and applied to biosensing.**

I. INTRODUCTION

The intrinsic surficial sensitivity of the surface plasmon resonance (SPR) effect is a well known consequence of the spatial localization of the electromagnetic fields and charge coupled mode. As a result, multiple commercial and research apparatus exploit the advantageous properties of the SPR for biochemical analysis and imagery of processes localized on metal surfaces. Conventionally, SPR consists in tracking the intensity modulations (I) over the dispersion relation E(**k**) of the charge coupled electromagnetic (EM) wave, under a predetermined condition of resonance in either energy E (fixed incident energy) or in wavevector **k** (fixed incident coupling angle). A more global approach would be to directly monitor the general dispersion relation of any light emitted or diffracted by the architecture, providing a complete map in I(E,**k**), thus describing the whole system's state. The complete mapping of the dispersion relation of EM signals presents great technological advantages, but its full characterization is a convoluted experiment given the fundamental intertwinement of the variables involved. We propose a solution to this problem through the use of a hyperspectral imaging technology, which allows the measurement and storage of the dispersion relation properties of any EM waves in quasi real-time with scalable resolution. We present the application of this technology to carry out SPR analyses of integrated quantum semiconductor (QS) devices.

II. UNCOLLIMATED SPR

The SPR event takes place in the 3D space of the intensity distribution of the dispersion E(**k**). It can be induced optically where an EM wave meets a metal-dielectric interface [1]. At a given energy, E, the resonance is achieved when the projected in-plane wavevector of the incoming EM wave has a wavevector of norm $k_{II}^2 = k_x^2 + k_y^2 = k_{SPR}^2$, as illustrated in Fig.1 a). This resonance can be met for various energies and values of $\mathbf{k_{SPR}}$, following a SPR dispersion relation E(k_x, k_y) distributed in a 3D Fourier space, as caricatured in Fig.1 b). Following the time-dependent modulations of such SPR surfaces can be employed for high sensitivity spectroscopic tracking of the biochemical events occurring within the SPs evanescent EM fields.

A practical way of generating the conditions where SPR is coupled in an uncollimated and broadband manner is by integrating the light source and metallic layer in a single nanostructure. Bringing a light emitter, such as quantum dots, quantum wells (QW), LED and even LD in proximity of the metal interface, produces the conditions where multiple **k** and E are emitted. Consequently, all the photonic modes supported by the architecture are coupled, including SPR. These SPR modes, thus occurring at a wide range of E and **k**, can interact with any biochemical event and provide a precise picture of the refractive index within their evanescent field, typically 100 to 200nm. A straightforward method of extracting the surface plasmons (SPs) into free-propagating light is through the diffraction of a grating: a periodic dielectric corrugation within the SPs evanescent EM field. The result is an integrated nanoctructure emitting a broadband cone of light, which contains a complete picture of the SPR surficial conditions, in both energy and wavevector dependent intensity modulations I(E,**k**).

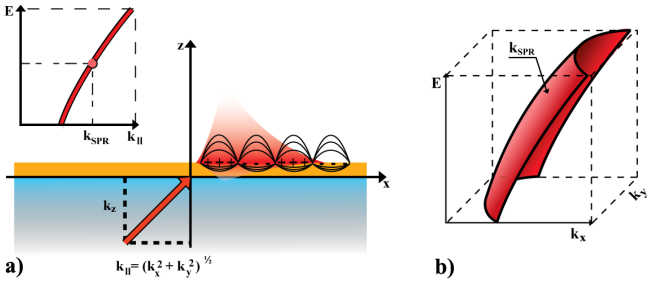

Figure 1a) SPR tracking consists in probing the resonance phenomena across the dispersion relation E(**k**) of the charge coupled EM wave under fixed conditions in either energy, E, or in wavevector $\mathbf{k_{II}}$, function of the coupling angles. b) Under specific circumstances, SPR can be induced at any energies where $\mathbf{k_{II}}$=$\mathbf{k_{SPR}}$(E). The resulting surfaces in E(**k**) can be employed for high sensitivity spectro-angular SPR tracking.

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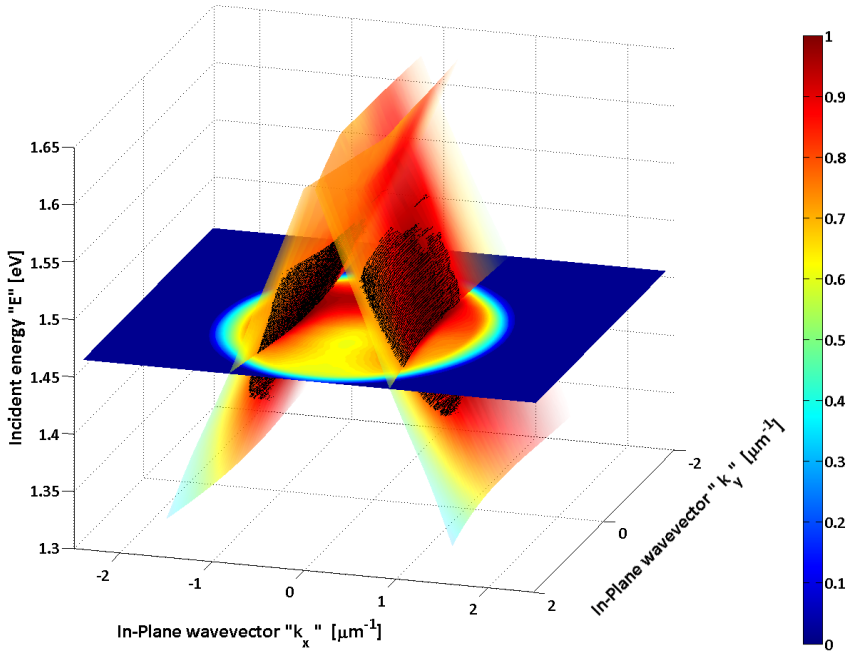

Figure 2 Measured SPR dispersion in I(E,kx,ky) for an integrated QW-SPR architecture. The 3D SPR is extracted from the hyperspectral cube as local maxima, as exemplified by the black dots. The displacement of the 3D SPR in time should provide highly precise spectro-angular information on the biochemical perturbations within the SPs evanescent fields.

III. HYPERSPECTRAL MEASUREMENTS

To completely monitor the dispersion relation E(**k**) of the emitted light cone, we have developed a hyperspectral technology capable of directly mapping the light scattering, in quasi real-time. The result is a 3D mapping of the dispersion relation of the emitted light in I(E, kx, ky). A specific and direct application of this instrument is the mapping of the diffraction of the light emitted by an embedded QW semiconductor in a SPR architecture [2-3]. An example of measurement is presented in Fig.2, where the SPR architecture consisted in 20 nm of Au deposited atop 472 nm of SiO_2 on a GaAs-AlGaAs QW structure. On this structure, we built a 750 nm period Au grating, 20 nm in height and of a ridge to groove ratio of 0.4. The QW SPs-modulated photoluminescence is collected by the hyperspectral imager and cubes of I(E,**k**) are hence constructed from the emitted light cones. Within a single measurement, the complete E(**k**) dispersion for SPR is extracted in 3D. Fig.2 presents the extracted SPR peaks for the whole hyperspectral cube, where the two diffracted SPR, from the $\pm 1^{st}$ diffraction orders of the grating, are clearly visible. For the presented cube, each voxel has a resolution of $[0.3 \cdot k_0(\mathbf{E})/1024\ \mu m^{-1},\ 0.3 \cdot k_0(\mathbf{E})/1024\ \mu m^{-1},\ k_0(\mathbf{E})^2 \cdot c\hbar/2\pi \cdot 10^{-9}$ eV], with cube size $[0.3 \cdot k_0(\mathbf{E})\ \mu m^{-1},\ 0.3 \cdot k_0(\mathbf{E})\ \mu m^{-1},\ \mathbf{E}$ eV], with **E** denoting the set of collected energies. It is important to mention that the resolution of the instrument is fully scalable by using different collecting objectives and camera units. Measurements reported here were carried out at room temperature and under relatively uncontrolled environmental conditions. The next challenges involve the quasi real-time tracking of those SPR dispersion curves, in a 3D space, in order to accurately follow the spectroscopic SPR events taking place on the device surface.

IV. CONCLUSIONS

SPR on planar metal-dielectric interfaces is a multidimensional phenomenon with a spatially resolvable intensity expressed by I(E, k_x, k_y). The embedment of a broadband light emitter in a substrate of a biosensing architecture allows one to fully take advantage of this phenomenon in a device where many energies are inducing SPR events for a continuum of planar wavevectors. . In the presented case, we showed the particular application for the measurement of SPR and tracking of the peak in a 3D space. The additional dimensions of the SPR effect, measured with scalable precision, allow increasing the precision of the tracking, reveals anisotropic surface interactions and provides spectroscopic response of the SPR effect. Future work will involve the further improvement of the experimental setup, acquisition methods and sensitivity calibrations for biochemical agents.

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