Spectral evolution of the SPP wavevector magnetic modulation in Au/Co/Au films

D. Martín-Becerra[‡,1], J. B. González-Díaz[1], V. V. Temnov[2], G. Armelles[1], T. Thomay[3], A. Leitenstorfer[3], R. Bratschitsch[3], A. García-Martín[1], M. U. González[1]

[1]IMM-Instituto de Microelectrónica de Madrid (CNM-CSIC), Isaac Newton 8, PTM, E-28760 Tres Cantos, Madrid, Spain.
[2]Department of Chemistry, Massachusetts Institute of Technology, Cambridge (MA), USA
[3]Department of Physics and Center for Applied Photonics, University of Konstanz, Germany
[‡]diana.martin@imm.cnm.csic.es

Surface plasmon polaritons (SPPs) are quasi-two-dimensional electromagnetic excitations that propagate along a dielectric-metal interface. They have field components decaying exponentially into both neighboring media, which makes them suitable for many possible applications, including miniaturized optical devices. For this reason, it is essential the development of "active" plasmonic configurations, which requires a system where we are able to manipulate plasmon properties with an external agent. Thereby, magnetic field seems a promising choice to play that role, since it is able to modify the dispersion relation of SPP at reasonable values and at a high switching speed [1]. In fact, when we apply the magnetic field, both the real and the imaginary part of the SPP wavevector k_{SP} are modified. This effect is related to the non-diagonal elements of the dielectric tensor, ε_{ij} that appear when applying a magnetic field. Those are too small for noble metals (the ones typically used in plasmonics), while for ferromagnetic metals (whose optical losses are however larger), they are much higher at easily achievable magnetic field magnitudes. Therefore a compromise can be achieved by using multilayers of noble and ferromagnetic metals [2, 3].

In the present work, we analyze the magnetic field induced SPP wavevector modulation (Δk) in Au/Co/Au films as a function of the wavelength and the position of the Co layer inside the trilayer.

The experimental analysis of the SPP wavevector modulation has been performed via surface plasmon interferometry with tilted slit-groove microinterferometers [4]. A sketch of a magneto-plasmonic interferometer is shown in Fig. 1. Illumination with a p-polarized laser beam at normal incidence results in the excitation of SPPs at the groove that propagate towards the slit, where they are reconverted back into free-space radiation (I_{SP}) and interfere with light directly transmitted through the slit (I_r).The total intensity collected from the slit is:

$$I_{DC} = I_r + I_{SP} e^{-2k^i{}_{SP} d} + 2\sqrt{I_{SP}}\, e^{-k^i{}_{SP} d} \sqrt{I_r} \cdot cos(k_{sp}{}^r \cdot d + \varphi_0),$$

where k^r_{SP} and k^i_{SP} are the real and imaginary part of the SPP wavevector respectively, φ_0 is an arbitrary phase, and *d* is the groove-slit distance.

When the light intensity transmitted through the slit is recorded by scanning a photodiode along the slit axis, a series of maxima and minima appears as a consequence of the different slit-groove distance for each slit position. To detect the magnetic modulation, we apply an external periodic magnetic field high enough to saturate the sample (about 20 mT) in the direction parallel to the slit axis. This generates a variation in the SPP wavevector, therefore shifting the interference pattern. Then, at each point of the slit, with a lock-in amplifier we measure the variation of intensity associated with this pattern shift, I_{MP}, which constitutes the magnetoplasmonic interferogram. Actually, when applying the magnetic field, both the real and the imaginary part of the SPP wavevector k_{SP} are modified and the I_{MP} signal can be expressed, up to a first order approximation, as:

$$I_{MP} = I(M) - I(-M) \approx (-2 \cdot \Delta k_{sp}{}^r \cdot d)\sqrt{I_{SP}}\, e^{-k^i_{SP} d} \sqrt{I_r} \cdot sin(k_{sp}{}^r \cdot d + \varphi_0 + \Phi), \text{ with } \tan\Phi = \frac{\Delta k^i_{sp}}{\Delta k^r_{sp}}$$

Here Δk_{SP} represents the k_{SP} modulation with the sample magnetization and it is defined as Δk_{SP} $=k_{SP}(M)-k_{SP}(-M)$. As we can see in the equation, the modulation of k^r_{SP} (Δk^r_{SP}) is related to the amplitude of the magnetoplasmonic signal, while the modulation of k^i_{SP} (Δk^i_{SP}) induces a phase shift (Φ) between the optical and the magnetoplasmonic signal. We would like to notice here that for Δk^i_{SP}=0 the optical and magnetoplasmonic interferograms are shifted by exactly 90º due to the cosine and sine dependence of each magnitude, and according to our definition Φ is zero in that case.

Thus, through the comparison of both interferograms we are able to determine the modulation of both the real and imaginary part of k^r_{SP}. We have performed this analysis as a function of the wavelength and Co position. Figure 2 shows the spectral evolution of Δk^r_{SP} and Δk^i_{SP} for three different Co positions. As can be shown, Δk^r_{SP} decays exponentially as the position of the cobalt layer goes deeper in the trilayer, a behaviour that can be correlated with the exponential decay of the SPP field inside the metal [4, 5]. Regarding the wavelength dependence, Δk^r_{SP} decreases as the wavelength increases. This behaviour is related to the dispersion relation of the plasmon, which is associated with the electromagnetic field inside the metal layer. The higher the wavelength, the closer the plasmon is to the light line, and the more its electromagnetic field is spread on the dielectric. On the other hand, for lower wavelengths, the SPP electromagnetic field appears more confined at the interface, probing more inside the metal layer, where the magnetic activity lies.

References:

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Figures:

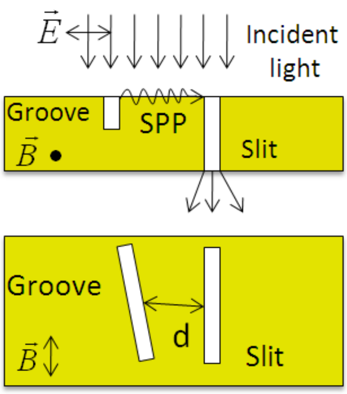

Figure 1: Sketch of the magneto-plasmonic micro-interferometer.

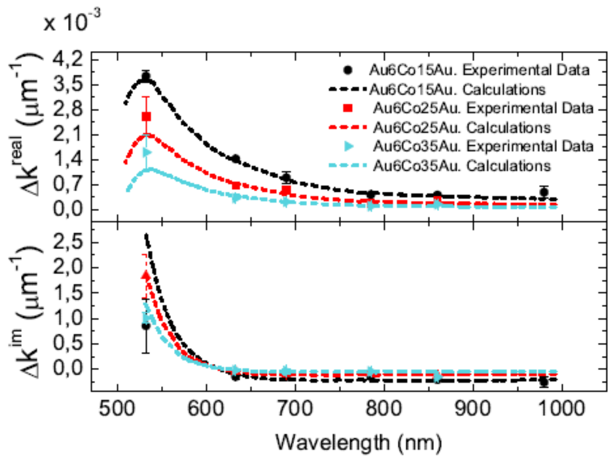

Figure 2: Spectral evolution of the magnetic modulation of real and imaginary part Δk^r_{SP} and Δk^i_{SP} *the real part of* k_{SP} *with the position of the cobalt layer and the incident wavelength.*