# Wavelength dependence of the SPP wavevector magnetic modulation in Au/Co/Au films

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Surface plasmons polaritons (SPP) are evanescent waves that propagate along a dielectric-metal interface. They can be confined in subwavelength metal structures, i.e. below the diffraction limit, which leads to many possible applications, including miniaturized optical devices. Within that context, the development of active plasmonics is important to achieve nanophotonic devices with advanced functionalities. This requires a system where the plasmon properties can be manipulated using an external agent. Among the different control agents considered so far, the magnetic field seems a promising candidate, since it is able to modify the dispersion relation of SPP [1] at reasonable magnetic field strengths, and with a high switching speed. This modulation comes from the non-diagonal elements of the dielectric tensor, $\varepsilon_{ij}$, appearing when the magnetic field is turned on. For noble metals, the ones typically used in plasmonics, these elements are proportional to the applied magnetic field but, unfortunately, very small at field values reasonable for developing applications. On the other hand, ferromagnetic metals have sizeable $\varepsilon_{ij}$ values at small magnetic fields (proportional to their magnetization), but are optically too absorbent. A smart system to develop magnetic field tunable plasmonic devices is the use of multilayers of noble and ferromagnetic metals [2, 3].
That is the framework of the present work, where we analyze the magnetic field induced SPP wavevector modulation (□k) 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, □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 (see optical interferogram in Fig. 2), 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, we measure the variation of intensity associated with this pattern shift, $I_{MP}$, with a lock-in amplifier. This constitutes the magnetoplasmonic interferogram, also shown in Fig. 2. 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 $\Delta k_{SP}$ represents the $k_{SP}$ modulation with the sample magnetization and it is defined as $\Delta k_{SP} = k_{SP}(M) - k_{SP}(-M)$. As we can see in the equation, the modulation of $k^r{}_{SP}$ (□$k^r{}_{SP}$) is related to the amplitude of the magnetoplasmonic signal, while the modulation of $k^i{}_{SP}$ (□$k^i{}_{SP}$) induces a phase shift (□) between the optical and the magnetoplasmonic signal. We would like to notice here that for □$k^i{}_{SP}=0$; 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 $\Phi$ is zero in that case.

Thus, through the analysis 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 3 shows the behaviour of □$k^r_{SP}$ as a function of Co depth for three different wavelengths.

We have observed that $\Delta k^r_{SP}$ 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]. Regarding the wavelength dependence, □$k^r_{SP}$ decreases as the wavelength increases. We associate this behaviour with the dispersion relation of the plasmon, since the higher the wavelength, the closer the plasmon is to the light line, and the more its electromagnetic field is spread on the dielectric. For lower wavelengths, on the other contrary, the SPP electromagnetic field appears more squeezed at the interface, probing more inside the metal layer, where the magnetic activity lies.

The behaviour of the imaginary part is not so directly related with the extension of the SPP electromagnetic field in the interface, and the value of the □$_{ij}$ and its dependence with the wavelength seem to be the relevant parameters in this case.

**References:**

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**Figures:**

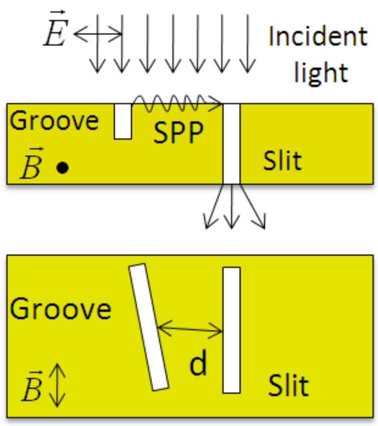


**Figure 1**: Interference pattern and sketch of the magnetoplasmonic micro-interferometer.

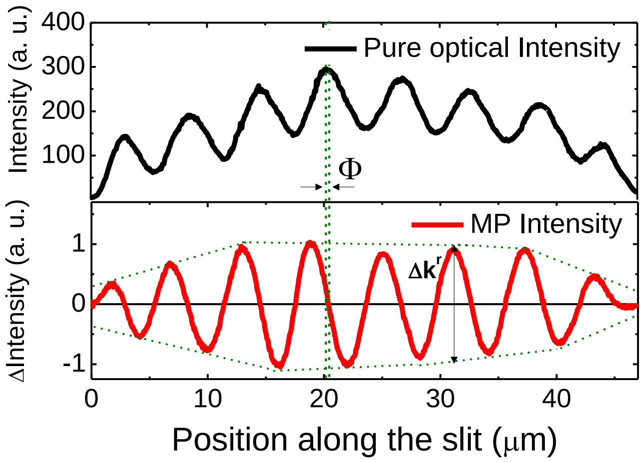


**Figure 2**: Optical and magnetoplasmonic interferogram

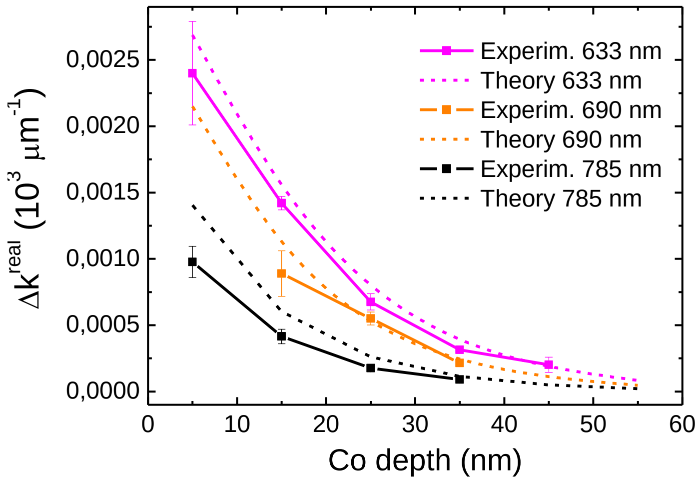


**Figure 3**: Dependence of the modulation of the real part of $k_{SP}$ with the position of the cobalt layer and the incident wavelength.