Increasing the modulation depth in Au/Co/Au magnetoplasmonic interferometers

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The ability of surface plasmon polaritons (SPP) to confine optical fields beyond the diffraction limit makes them very attractive for the development of miniaturized optical devices. Several passive plasmonic systems have been successfully demonstrated in the last decade, but the achievement of nanophotonic devices with advanced functionalities requires the implementation of active configurations. This necessitates the capability to manipulate the surface plasmon polaritons with an external agent. Among the different control agents considered so far, the magnetic field holds a robust promise since it is able to directly modify the dispersion relation of SPPs [1]. This modification lies on the non-diagonal elements of the dielectric tensor, ε_{ij}. For noble metals, the ones typically used in plasmonics, these elements are unfortunately very small at reasonable field values. On the other hand, ferromagnetic metals have sizeable ε_{ij} values at small magnetic fields (proportional to their magnetization), but they are optically too absorbent. Thereby, a smart system to develop magnetic field sensitive plasmonic devices could be multilayers of noble and ferromagnetic metals [2, 3].

Based on these hybrid multilayers, magnetoplasmonic modulation has been recently demonstrated [4]. The implementation of these modulators has been performed through micro-interferometers consisting on a slit paired with a tilted groove, as sketched in Fig. 1. Illumination with a *p*-polarized laser beam at normal incidence results in the excitation of SPPs at the groove, which propagate towards the slit, where they are reconverted into free-space radiation (I_{SP}) and interfere with light directly transmitted through the slit (I_r). The interference term is given by $\sqrt{I_{SP}}\sqrt{I_r}\cos(k_{SP}\, d+\phi_0)$, with k_{SP} the SPP wavevector and d the groove-slit distance. In our tilted groove configuration, d varies for each slit position, creating a pattern of maxima and minima in the light transmitted through the slit (see optical image in Fig. 1). When we apply an external periodic magnetic field high enough to saturate the sample (about 20 mT) in the direction parallel to the slit axis, k_{SP} is modified therefore shifting the interference pattern. Thus, at each slit position we detect a variation of the intensity synchronous with the applied magnetic field (see graph in Fig. 1). The full intensity modulation depth of the system is given by the product $\Delta k \times d$, where Δk is the SPP wavevector modification induced by the magnetic field.

The modulation obtained in this basic configuration of the magnetoplasmonic interferometers made of Au/Co/Au multilayers in air is of the order of 2% at a wavelength of λ_0 = 800 nm and for a mean slit-groove distance of 20 µm, corresponding to $\Delta k \sim 0.5\text{x}10^{-3}$ µm^{-1} [4]. This modulation value is reasonable although slightly low for practical applications, and thus the optimization of the geometrical parameters to increase the modulation of the surface plasmon wavevector will provide a higher flexibility in the design of the magnetoplasmonic active devices. A straightforward approach entails the coverage of the metallic multilayer with a dielectric media with higher ε_d, since the modulation Δk is proportional to $(\varepsilon_d)^2$. We have then covered our magnetoplasmonic interferometers with a thin layer of PMMA (ε_d = 2.22). Figure 2 shows the measured Δk for systems with 60 nm PMMA at λ_0 = 633 nm as compared to identical reference samples without PMMA. A fourfold enhancement of the Δk value, in excellent agreement with the theoretical predictions, has been obtained. Nevertheless, the propagation distance of the plasmon, L_{SP}, decreases with the addition of dielectric overlayers, which will prevent the use of interferometers with large d and the intensity modulation depth will then be limited. Thus, a compromise between the Δk enhancement and the SPP propagation distance has to be achieved. The relevant figure of merit in this case is the product $\Delta k \times L_{SP}$. Our theoretical results show that, with the right thickness of polymer cover, this product can be almost doubled. A detailed analysis of the behaviour of the magnetoplasmonic interferometers when covered with dielectric overlayers, both in terms of modulation enhancement and propagation distance, will be presented. The dependence of these two parameters with the thickness of the dielectric overlayer allows us to obtain information on the SPP electromagnetic field distribution in our system.

References

[1] R. F. Wallis, J. J. Brion, E. Burstein, and A. Hartstein, Phys. Rev. B **9** (1974) 3424.

[2] J. B. González-Díaz, A. García-Martín, G. Armelles, J. M. García-Martín, C. Clavero, A. Cebollada, R. A. Lukaszew, J. R. Skuza, D. P. Kumah and R. Clarke, Phys. Rev. B **76** (2007) 153402.

[3] E. Ferreiro-Vila, J. B. González-Díaz, R. Fermento, M. U. González, A. García-Martín, J. M. García-Martín, A. Cebollada, G. Armelles, D. Meneses-Rodríguez and E. Muñoz-Sandoval, Phys. Rev. B **80** (2009) 125132.

[4] V. V. Temnov, G. Armelles, U. Woggon, D. Guzatov, A. Cebollada, A. Garcia-Martin, J. Garcia-Martin, T. Thomay, A. Leitenstorfer, and R. Bratschitsch, Nat. Photonics **4** (2010) 107.

Figures

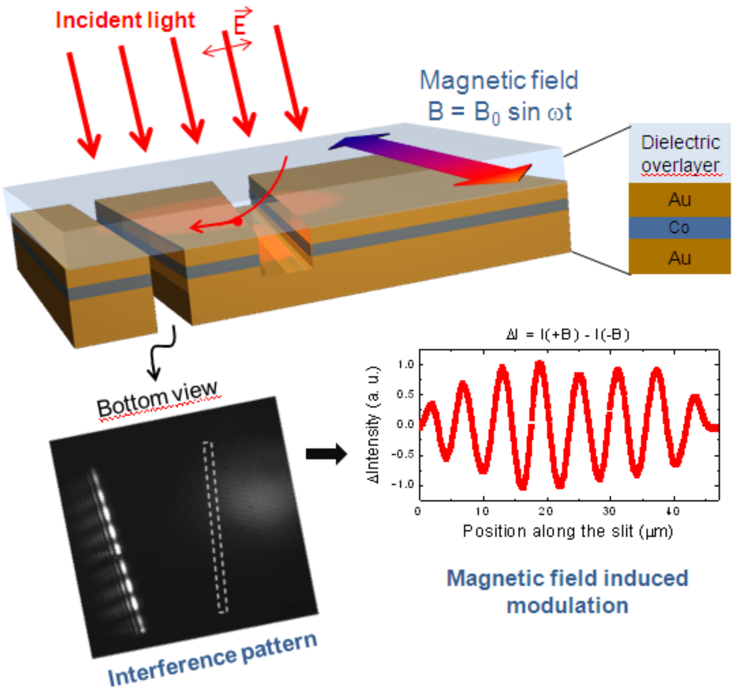

Figure 1: Sketch of the magneto-plasmonic micro-interferometer.

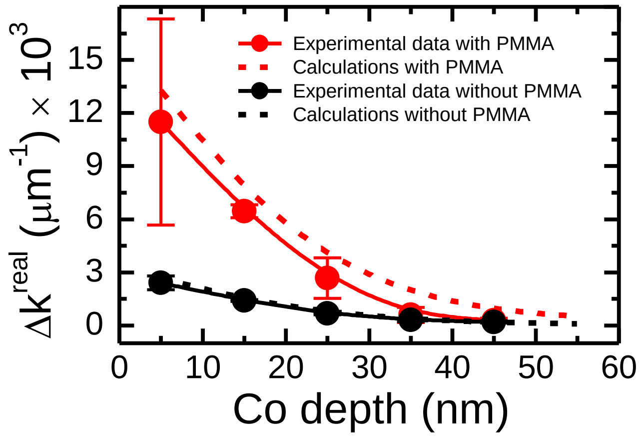

Figure 2: Comparison of the SPP wavevector modulation as a function of the Co layer position for Au/Co/Au micro-interferometers without dielectric overlayer and with 60 nm PMMA overlayer. The values correspond to λ_0 = 633 nm.