Tailoring the modulation depth in Au/Co/Au magnetoplasmonic switches

D. Martín-Becerra‡,1, J. B. González-Díaz[1], V. V. Temnov[2], A. Cebollada[1], 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

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 requires 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 SPP [1]. This modulation 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, a magnetoplasmonic switch has been recently demonstrated [4]. The switch has been implemented through a micro-interferometer consisting on a slit paired with a tilted groove (see figure 1). Illumination with a *p*-polarized laser beam at normal incidence results in the excitation of SPPs at the groove, which propagates 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 $\sqrt{I_{SP}}\sqrt{I_r}\cos(k_{SP}\, d+\lambda_0)$, 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 (optical interferogram, see 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 (magnetoplasmonic interferogram, see graph in fig. 1). The analysis of both interferograms allows us to extract the SPP wavevector modulation, Δk. The full intensity modulation depth of the system is given by the product $\Delta k \times d$.

The modulation obtained in this basic configuration of the magnetoplasmonic switch, Au/Co/Au multilayers in air, is $\Delta k \sim 0.5\text{x}10^{-3}\ \mu\text{m}^{-1}$ for a wavelength of λ_0 = 800 nm, reasonable although slightly low for practical applications. Optimization of the geometrical parameters to achieve the maximum possible modulation of the surface plasmon wavevector will provide a higher flexibility in the design of the magneto-plasmonic optical switches. A straightforward approach consists on the coverage of the metallic switch with a dielectric media with high ε_d, since the modulation Δk is proportional to $(\varepsilon_d)^2$ [4]. We have then covered our magnetoplasmonic switches 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 modulation, in excellent agreement with the theoretical predictions, has been obtained. Nevertheless, the propagation distance of the plasmon decreases with the addition of 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 modulation enhancement and the propagation distance of the SPP has to be achieved. The relevant figure of merit in this case is the product $\Delta k \times L_{SP}$. In fact, our theoretical results show that, adding the polymer cover, we can actually almost double that product. A detailed analysis of the behaviour of the magnetoplasmonic switches when covered with dielectric overlayers, both in terms of modulation enhancement and propagation distance, will be presented.

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:

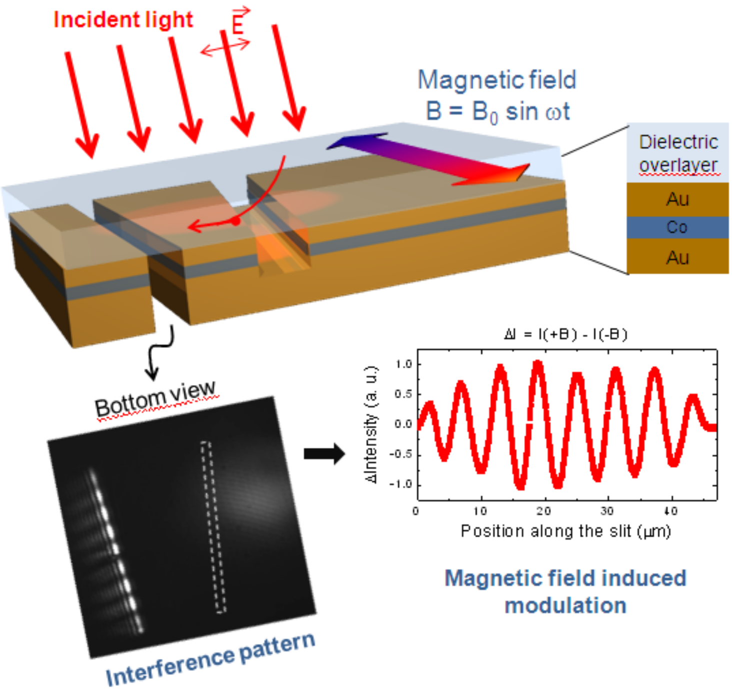

Figure 1: Sketch of the magneto-plasmonic micro-interferometer.

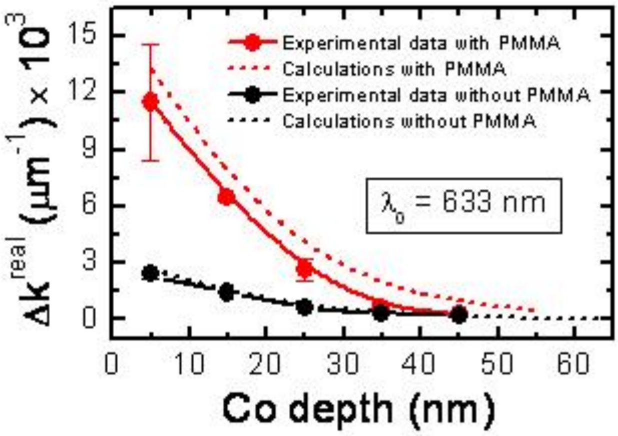

Figure 2: Comparison of the SPP wavevector modulation as a function of the Co layer position for Au/Co/Au micro-interferometers without dielectric overlayer and with 60 nm PMMA overlayer. The values correspond to $\lambda_0 = 633$ nm.