Enhanced Magnetic field modulation of surface Plasmon wavevector in ultraflat Au/Fe/Au trilayers

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A crucial aspect for the advance of plasmonics is the development of active elements, i.e., systems whose plasmonic properties can be modified by an external agent. Magnetoplasmonic structures combine materials with magneto-optical (MO) activity (usually ferromagnetic metals such as Fe or Co) and materials with plasmonic properties (typically Au [1] or Ag [2,3]). This kind of structures allows for a magnetic field control of the plasmonic characteristics of the system. On the other hand, obtaining ultrasmooth metallic structures is a crucial point for the implementation of active, high performance plasmonic devices[4,5]. Therefore, the elucidation of the influence on the magnetoplasmonic properties of the morphology of the structure to be used in those devices is of major interest.

Two series of 10 nm Au/X nm Fe/10 nm Au structures, with Fe thickness varying between 0nm and 6nm, have been grown on MgO substrates. Buffer layers, namely 1 nm Fe and 2 nm Cr, were used to fabricate the otherwise equivalent series of samples. The Fe buffer layers were grown by PLD whereas the Cr ones and Au layers were deposited by MBE.

Representative AFM images of the topmost surface of two equivalent samples (4.5 nm and 5 nm of Fe interlayer thickness, respectively) of the series grown on top of PLD and MBE buffers are shown in Fig. 1 (a). It is interesting to remark that both AFM images are displayed with the same scales for better comparison. As it can be observed, the PLD sample exhibits an ultraflat surface with global differences in height of around 0.5 nm over the scanned area. On the other hand, the equivalent MBE sample shows a rougher surface including granular structures around 7 nm in height, correlated to the different buffer growth technique. In Fig. 1 (b) we have plotted the Fe interlayer thickness dependence of the RMS roughness of the topmost layer for both series of samples, which is systematically at least a factor of two larger in the MBE samples than in the PLD ones for every Fe interlayer thickness. To extract quantitative information about the roughness of this Fe interlayer, x-ray reflectometry is a very suitable tool, since it allows quantifying, not only the roughness of the topmost layer in a multilayered system, but also the roughness of buried interfaces. The obtained results for the Fe interlayer – top Au layer interface from XRR measurements are also shown in figure 1 (b). A similar trend to that mentioned in the case of AFM results is observed.

The experimental SPP wavevector modulation $(\square k/k)_{SPP}$ was extracted from the Reflectivity and Transverse Kerr signals measured both under SPP excitation (Kretschmann configuration) by means of the formalism detailed in ref. [2]. In Fig 2 we present in symbols the experimentally obtained modulation as a function of the Fe interlayer thickness for both series of samples. As it can be seen, $\square k/k$ increases with Fe interlayer thickness for both series of samples, with systematically larger values for the PLD samples, specially for Fe thickness above 2.5 nm, whereas the observed modulation is similar for both series below this value. Besides, experimental values are in agreement with the simulated $(\square k/k)_{SPP}$ (lines) using the Transfer Matrix Method and the actual MO constants from 6 nm Fe layers of both PLD and MBE sets of samples. The most relevant result is the magnitude of the SPP wavevector modulation obtained in the PLD series, which doubles that measured in the MBE ones for the samples having a Fe thickness above 2.5 nm. This difference is ascribable to the reduced effective MO constants of the Fe interlayer for the MBE series. This reduction of the effective MO constant can be mainly explained in two ways. On the one hand, a system with a rough interface can be optically considered as an effective medium composed by Fe and Au, and therefore with effective MO constants lower than those of bulk Fe. On the other hand, a purely interfacial effect where the properties of the Fe and Au atoms at this interface are different from bulk; structures with rough interfaces, and as a consequence of it with a larger interfacial area than equivalent structures with sharper interfaces, would exhibit reduced MO constants as it has actually been reported. In our specific case, this would explain the reduced SPP wavevector modulation in the MBE samples, with rougher interface, with respect to the PLD ones. The use of deposition techniques that allow fabricating ultraflat magneto-plasmonic structures will facilitate obtaining novel devices whose plasmonic properties will be largely modulated by the application of a magnetic field.

References

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Figures

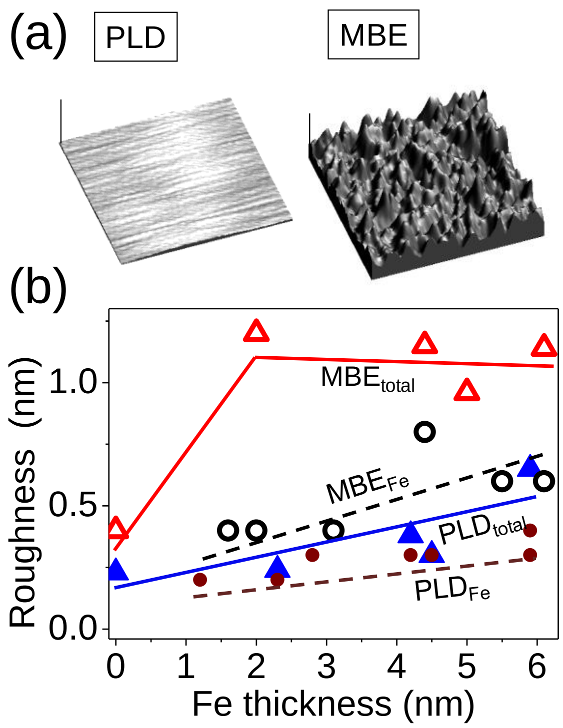

Figure 1: *(a) AFM images for representative 4.5 nm and 5 nm Fe thickness of the PLD (left column) and MBE (right column) structures respectively. The AFM images have the same scale (7 nm vertical and 400 nm lateral). (b) Evolution of the surface (triangles) and Fe interlayer (circles) roughness, measured by AFM and XRR, respectively, with the Fe interlayer thickness for PLD (full symbols) and MBE (empty symbols) structures.*

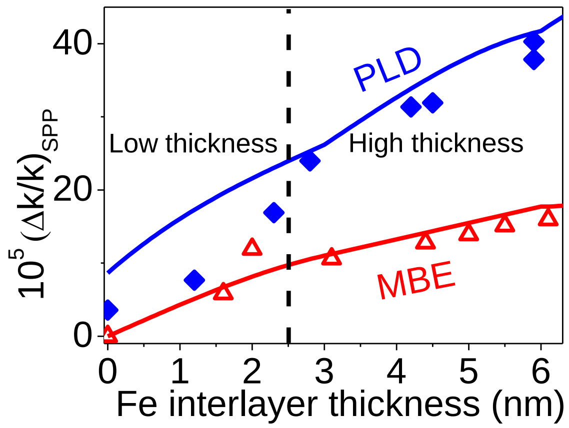

Figure 2: *In the two remarked low (<2.5nmFe) and high (>2.5nmFe) thickness regions, Fe interlayer dependence of experimentally (symbols) and simulated (continuous lines) (□k/k)$_{SPP}$ with actual MO constants from PLD (diamonds) and MBE (triangles) sets are shown.*