Generalized Scattering-Matrix Approach for the Description of Wave Propagation in Nanostructured Magneto-Plasmonic Systems

B. Caballero[1,2], A. García-Martín[1], J.C. Cuevas[2]

[1]Instituto de Microelectrónica de Madrid (CNM-CSIC), Isaac Newton 8, PTM, 28760 Tres Cantos, Madrid, Spain; [2]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain.

blanca.caballero@uam.es

In recent years a lot of attention has been paid to the study of the optical properties of nanostructured materials with both plasmonic and magneto-optic activity [1]. Here the key idea is to use hybrid nanostructures contaning both noble metals, which exhibit plasmon resonances, and ferromagnetic materials, which provide the magneto-optical activity, to profit from the best of the worlds of plasmonics and magneto-optics. In these hybrid structures one can make use of the excitation of the plasmons supported by the noble metals to enhance the magneto-optical signals (Kerr effect, Faraday effect, etc.), which can be of great importance, in particular, for sensing applications [2].

The nanostructuring in these magneto-plasmonic structures plays a fundamental role for several reasons. First of all, it provides a convenient way to couple the light of an external source to the plasmons supported by these hybrid systems, avoiding so the typical wave vector mismatch in unstructured systems. On the other hand, by nanostructuring these hybrid systems one can manipulate light at the nanometer scale in several ways. In particular, one can concentrate light in reduced volumes with the subsequent enhancement of the electric field. This fact leads in turn to the enhancement of the different magneto-optical properties of these hybrid systems.

In view of the relevance of these novel hybrid structures, and in order to guide their design, it is crucial to have theoretical methods that are able to describe the wave propagation in nanostructured magneto-plasmonic systems. A powerful approach, which is widely used to describe nanostructed systems without magneto-optical activity, is the so-called *scattering matrix formalism* [3]. In recent years, this method has been extended to describe also different magneto-optical effects in magneto-plasmonic systems [4]. However, there are still basic situations and problems that lie out of the scope of the existent implementations of the scattering formalism. As an example, the Kerr and the Farady effect in nanostructured multilayer systems in the transverse configuration cannot be addressed with the existent theoretical methods. In this context, we present in this work a generalization of the scattering-matrix approach to describe the magneto-optics of hybrid nanostructured systems which is able to handle any combination of materials and to describe the magneto-optical effects in any configuration. We illustrate the power of the method by addressing a recent experiment where the Transverse Magneto-Optical Kerr Effect (TMOKE) was measured in a periodically perforated Fe film [5]. We show that, in excellent agreement with the experimental results, the excitation of plasmon-like modes in these structures enhances the TMOKE signal (see Fig. 1). More importantly, our theoretical method paves the way for studying the interplay between emblematic plasmon-driven effects, like the extraordinary optical transmission [6], and the magneto-optics in a wide variety of hybrid nanostructures.

References

[1] G. Armelles, A. Cebollada, A. García-Martín, J.M. García-Martín, M.U. González, J.B. González-Díaz, E. Ferreiro-Vila, and J.F. Torrado, J. Opt. A: Pure Appl. Opt., **11** (2009) 114023.
[2] A.G. Brolo, R. Gordon, B. Leathem, and K.L.. Kavanagh *et al.*, Langmuir, **20** (2004) 4813.
[3] D.M. Whittaker and I.S. Culshaw, Phys. Rev. B, **60** (1999) 2610.
[4] A. García-Martín, G. Armelles and S. Pereira, Phys. Rev. B, **71** (2005) 205116.
[5] J.F. Torrado, E. Th. Papaioannou, G. Ctistis, P. Patoka, M. Giersig, G. Armelles, and A. García-Martín, Phys. Status Solidi (RRL), **4** (2010) 271.
[6] F.J. García-Vidal, L. Martín-Moreno, T.W. Ebbesen, and L. Kuipers, Rev. Mod. Phys., **82** (2010), 729.

Figures

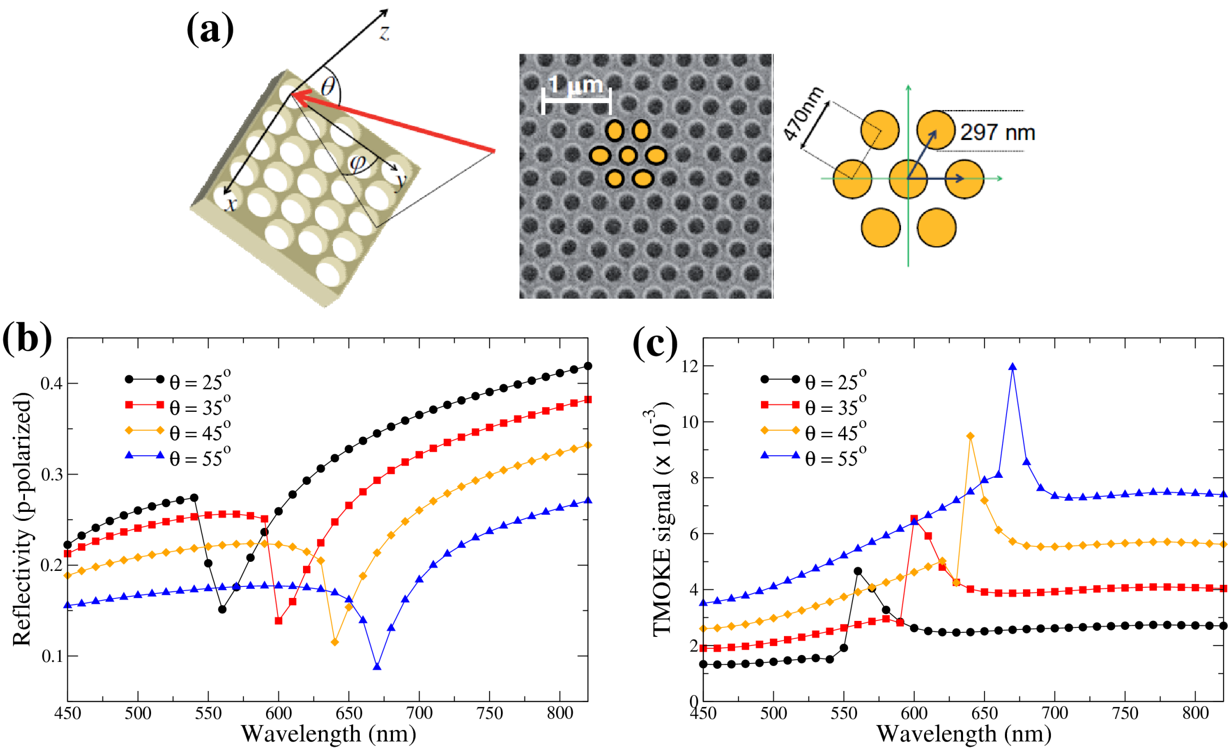

Fig. 1: **(a)** The left figure shows a schematic view of the periodically perforated Fe film studied experimentally in Ref. [5] and considered here in our theoretical work. Here, one can also see the angles defining the direction of the incident light. The central figure shows a SEM micrograph of the structure [5], and on the right hand side one can see the relevant dimensions of the system (lattice constant and radius of the holes). **(b)** Calculated reflectivity for p-polarized light for different incidence angles along the line φ = 30°. **(c)** Calculated TMOKE signal as a function of the wavelength and incidence angle θ for the crystal orientation φ = 30°.