Magneto-optical activity and plasmonic resonances in ferromagnetic nanostructures

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Abstract

Electromagnetic scattering from metallic nanometer-scale particles is currently a topic of huge interest. The vast majority of these studies are performed on noble-metal nanostructures and are focused on the effects on the scattered field due to the nano-confinement of electric fields caused by the excitation of localized plasmon resonances (LPRs) in single nanoparticles.

In the last years the research efforts moved to the study of magnetoplasmonic nanostructures, viz., nanostructures that combine magnetic and plasmonic functionalities [1], since they could be the building block of a new class of magnetically controllable optical nanodevices for future biotechnological and optoelectronic applications. This new research direction has brought forward numerous studies of the effects arising from the mutual interplay between magneto-optical (MO) activity and light-matter coupling in spatially confined geometries [2-5].

Moreover, very recently, it was shown how the concerted action of LPRs in single nanoparticles and magnetization can be exploited to actively manipulate the reflected light's polarization (i.e., to induce and control Kerr rotation/ellipticity reversal) of pure ferromagnetic nanostructures beyond what is offered by intrinsic material properties [6], even if plasma oscillations in ferromagnetic materials typically exhibit a stronger damping than in noble metals [7]. While most of the investigations carried out before were focused on the achievement of substantial enhancement of magneto-optical Kerr effect (MOKE) or Faraday rotation, Bonanni et al. shifted the paradigm of research on magnetoplasmonic functional materials by exploiting the phase tunability of the optical polarizability due to the excitation of LPRs in single nanoparticles and the simultaneous presence of magneto-optical activity in the same ferromagnetic nanostructures.

Driven by this recent turn of the research direction in pure ferromagnetic plasmonic nanoparticles, a formalism to compute the polarizability, as well as far-field MO spectra, of large magnetic ellipsoidal nanoelements, i.e., exceeding the Rayleigh limit (electrostatic regime) was developed [8]. This approach can be applied to real samples of optically non-interacting flat disks with circular and elliptical sections, and size up to a few hundred nanometers, as it is shown in the Scanning Electron Microscope (SEM) images in the top panel of Figure 1. The disks are modeled as ellipsoids, like the one pictured in Figure 2. The calculations performed with our formalism are in excellent quantitative agreement with the experimental measurement, as it is shown in the bottom panel of Figure 1 and in Figure 3, with no other parameters than material dielectric optical and magneto-optical constants (taken from literature), and nanostructure sizes and shapes (experimentally determined). our approach, in spite of its approximations, captures the essential physics of the interplay between magneto-optical activity and excitation of localized plasmon resonances in single magnetic nanostructures, optically non-interacting, of broad fundamental and practical interest.

References

[1] G. Armelles et al., Adv. Optical Mater. **1** (2013), 10.
[2] S. Melle et al., Appl. Phys. Lett. **83**(22) (2003), 4547.
[3] V. I. Belotelov et al., Phys. Rev. Lett. **98**(7) (2007), 077401.
[4] Z. Liu et al., Appl. Phys. Lett. **95**(3) (2009), 032502.
[5] G. Ctistis et al., Nano Lett. **9**(1) (2009), 1.
[6] V. Bonanni et al., Nano Lett. **11**(12) (2011), 5333.
[7] J. Chen et al., Small **7**(16) (2011), 2341.
[8] N. Maccaferri et al., Optics Express **21**(8) (2013), 9875.

Figures

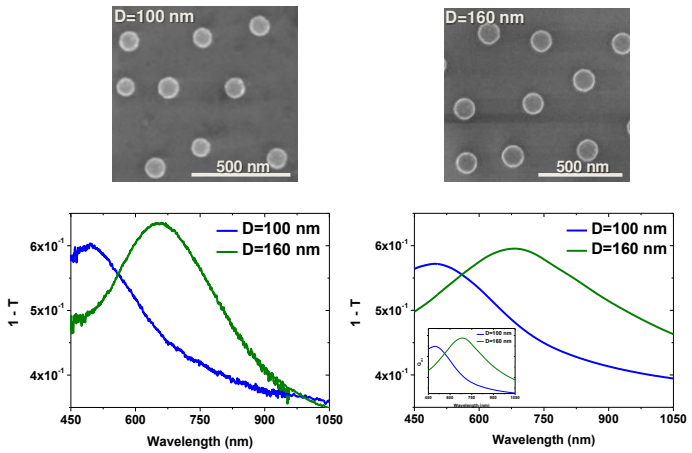

Figure 1. Top panel: Scanning Electron Micrscope images of Ni nanodisks with D = 100 (left) and 160 nm (right), 30 nm thick. Bottom panel: experimental (left) and calculated (right) transmission spectra. Inset: extinction efficiencies.

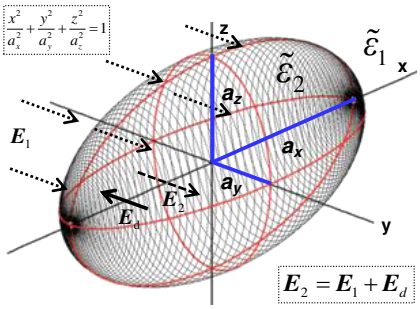

Figure 2. Scheme of a general ellipsoid embedded in a non-magnetic host medium. The ellipsoid is under the influence of an acting field $\boldsymbol{E}_1$, and, due to the induced dipole moments, the electric field $\boldsymbol{E}_2$ inside it changes.

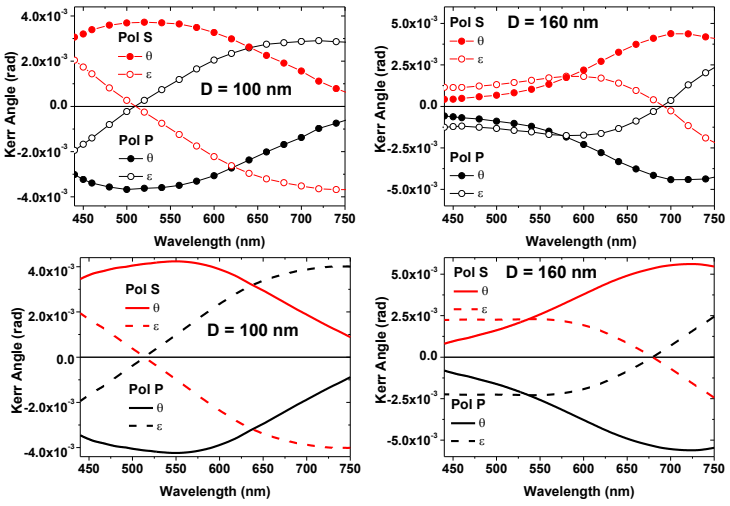

Figure 3. Top panel: experimental Kerr angle in P-MOKE configuration, of Ni nanodisks with D = 100 nm and 160 nm, 30 nm thick. Bottom panel: calculated spectra.