Optical and magneto-optical response of magnetic nano-scale disks: size effects

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The recent rise of interest in magnetoplasmonics –materials that combine magnetic and plasmonic functionalities– has accelerated fundamental studies of the interplay of light-matter coupling and magnetism in nano-sized structures. The combination of optical and magnetic properties of nanostructurized materials has been employed to address active tuning in nanoplasmonic devices, thermal magnetization switching, and enhancement of magneto-optical Kerr effect (MOKE) [1].

The experimental exploration of the mutual relations between magnetism, magneto-optical activity and light-matter coupling in spatially confined geometries poses questions and brings a new impulse to the modeling efforts. As a first approximation, the infinite film approach has been often applied to model light interaction with finite size magnetic particles by researchers in magneto-optics. This approach worked extremely well for magnetic structures whose geometric dimensions are larger than the wavelength of the incident light (>1μm). However, the recent move to the nanometer range is expected to require a revision of the current numerical models and approximations.

In order to address the fundamental question of the limits of applicability of the infinite film approach, we have compared its predictions of the optical and magneto-optical response of ferromagnetic nano-scale disks with those by a more specific model. The latter approach considered relies on the recently developed E-DDA code, based on an extension of the discrete dipole approximation [2], which has been specifically devised to deal with nano-scale optical objects. In order to make this comparison meaningful, we worked out an equivalent discretization formulation of the infinite film approach. In doing so, we introduced the same structural discretization used for the E-DDA approach, so that the numerical specifics related to the discretization process show up in exactly the same way in the two cases. More specifically, we considered an electric dipole interacting with an infinite number of surrounding dipoles in order to get an effective polarizability expression for that reference dipole. The nano-scale particle is then built up by inserting this reference dipole in each cell of the discretization mesh (no further interaction is considered). While in this modified infinite film approach the shape of the particle only affects the scattered field through the phase of each electric dipole, in E-DDA near field interactions produce additional shape effects.

We applied these two approaches to predict the optical and magneto-optical response of Cobalt disks of several sizes illuminated with a wavelength of λ=632.8nm under normal incidence, in a typical transverse MOKE configuration (Fig. 1). The comparison of the predictions of the two methods is summarized in Fig. 2, which shows the optical and magneto-optical dipole moment distributions calculated with E-DDA and normalized to that obtained using the discretization formulation of the infinite film. Figure 3 shows the corresponding far-field intensity patterns calculated in the x-y plane.

The main conclusion we can draw from the comparison is that, for large enough disks (diameter comparable to the wavelength), both approaches provide similar results (see Fig. 3, D equal to 1000 and 600 nm), meaning that in these cases the infinite film approximation produces almost exact results. However, as the size of the disks is decreased below the wavelength, both optical and magneto-optical components show size-induced enhancement effects (see Fig. 3, D equal to 100 and 200 nm). It is worth noting that, since optical and magneto-optical contributions to the far field intensity scale nearly in the same way, the normalized magneto-optical response, which is the quantity measured in experiments, is only weakly affected even in the case of disks of sub-wavelength size.

References

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Figures

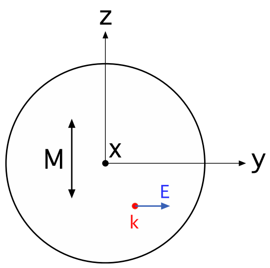

Figure 1: Transverse MOKE configuration, where the incoming light wave-vector is in the x-direction, the electric field linearly polarized along the y-direction, and the magnetization M being perpendicular to the scattering plane (considering X-Y plane).

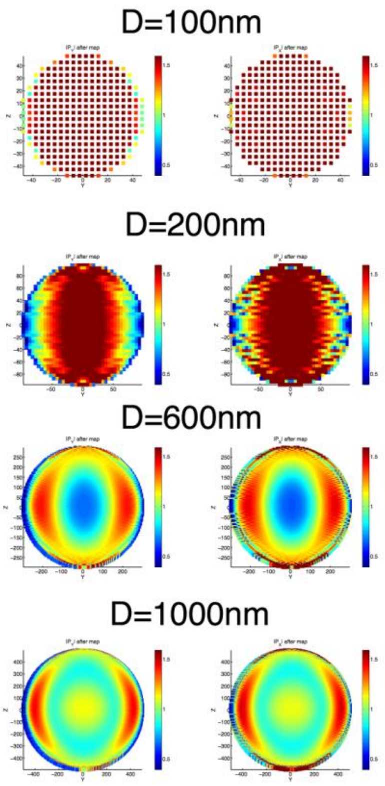

Figure 2: Absolute value of the y (left column) and x (right column) components of the induced dipole moment for several sizes normalized to the infinite film calculation. Notice that the x-component of the dipole moment is the "magneto-optically induced" component, while the y-component is the "optically induced" component.

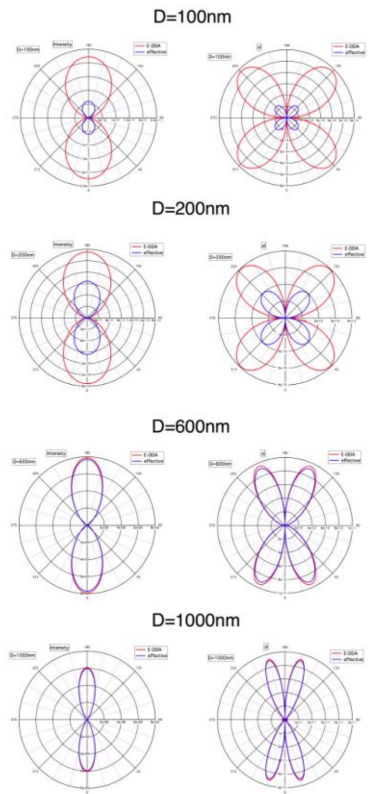

Figure 3: Far-field scattered intensity patterns and ΔI patterns for several sizes for both the E-DDA calculation and the film approach (effective). The ΔI patterns are obtained by computing the difference in scattered intensity under magnetization reversal.