Designer magnetoplasmonics in ferromagnetic nanoparticles through symmetry breaking

Kristof Lodewijks[1], Irina Zubritskaya[1], Randy Dumas[2], Johan Åkerman[2], Alexandre Dmitriev[1]

Applied Physics, Chalmers University of Technology, Fysikgränd 3, 412 96 Göteborg, Sweden
Physics Deparment, Gothenburg University, Fysikgränd 3, 412 96 Göteborg, Sweden
kristof.lodewijks@chalmers.se

Abstract

The interaction between magnetic materials and plasmon resonances has been extensively studied in the field of magnetoplasmonics. It was recently shown that ferromagnetic nickel nanoparticles support localized surface plasmon resonances that can be exploited to modify the magneto-optical behavior at will [1]. As such, the magnetization loops that are measured in spectroscopic Magneto-Optical Kerr Effect (MOKE) experiments can show changes both in sign and magnitude depending on the excitation wavelength and its relative position with respect to the localized surface plasmon resonance (LSPR) frequency. The large phase change between both spectral sides of the LSPR and the intrinsic phase shift that the magnetization of the ferromagnetic material induces allows tuning of the magnetization loops by means of the plasmon resonance. Here we show that symmetry breaking adds one more degree of freedom by modifying both the magnetic and optical behavior of the nanoparticles. We studied the magnetization behavior of round and elliptical nickel nanoparticles in longitudinal spectral MOKE, measuring along the different symmetry axes of the system, as illustrated in figure 1.

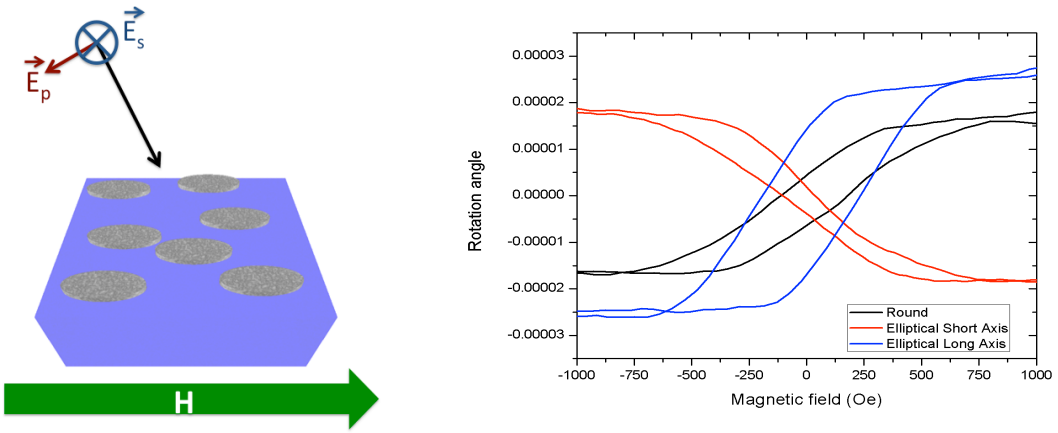

Figure 1: Schematic overview of the measurement configuration in L-MOKE (left) and magnetization loops measured with 800nm wavelength along the different symmetry axis of round (170nm) and elliptical (170/240nm) particles in P-polarization.

From the loops in figure 1, it can be seen directly that the short and long axis of the nanoparticles behave as a hard- (red) and easy (blue) axis for the magnetization, which severely alters the magnetization behavior compared to simple round disks (black). When we compare the coercivity between the different particles we see that it is increased (decreased) along the long (short) axis with respect to the values for round nanoparticles. Moreover, the particles also support 2 pronounced localized plasmon resonances along the 2 symmetry axes of the system, which adds one more degree of freedom that can be exploited to tailor the magnetoplasmonic response of the system. It was already shown for round disks that a reversal of the sign of the magnetization loops can be achieved by properly designing the size of the nanoparticles and choosing the appropriate measurement wavelength in spectroscopic MOKE measurements. The tunability of the magnetoplasmonic response originates in the intrinsic phase change induced by the magnetization of the nickel and the interplay with the polarizability of the nanoparticles and the associated phase change between the two spectral sides of the LSPR mode.

Figure 2 shows the overview of the spectral dependence of the magneto-optical response of round and elliptical nickel nanoparticles for P- and S-polarization and different sample orientations. The axis along which the magnetization was applied is indicated in the different graphs (LA = long axis / SA = short axis). This implies that in P-polarization the LSPR is excited along the same axis, while for the S-polarization the LSPR is excited along the perpendicular axis.

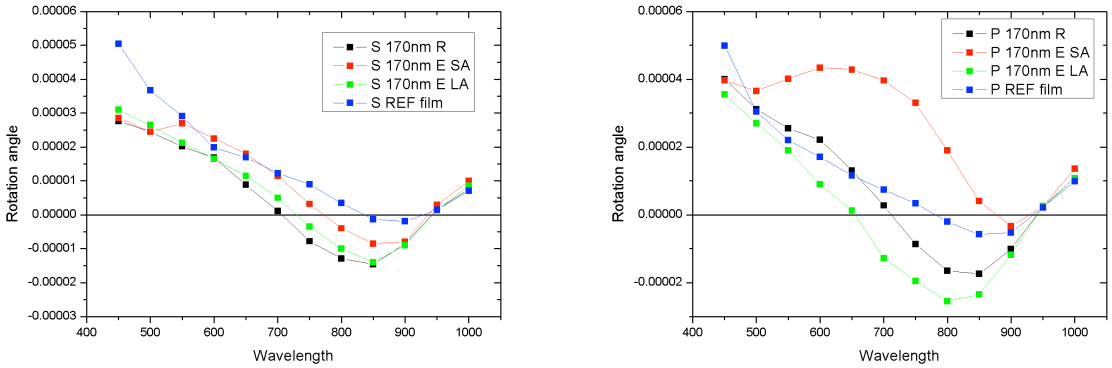

Figure 2: Spectroscopic dependence of the rotation angle in L-MOKE for P- and S-polarization and different sample orientation

For the different samples in S-polarization, the behavior looks very similar to what was observed before in round nanoparticles. The magnetization loops change sign in the vicinity of the LSPR-wavelength. The behavior of round particles and elliptical particles with the field along the long axis is almost identical, while for the elliptical particles with the field along the long axis the crossing point is red-shifted. This can easily be understood, as in the S-polarization we excite the LSPR perpendicular to the magnetic field direction, so along the short and long axis respectively. Note that with respect to the reference spectrum for a nickel film, at the LSPR the rotation value is pulled down to lower values.

In P-polarization, we observe very different behavior in the elliptical nanoparticles. When the magnetic field is applied along the long axis, the behavior is fairly similar to round disks, although the rotation angle reaches even more negative values at the LSPR along the long axis (800 nm). If the magnetic field is applied along the short axis, the magnetization behaves totally different from all other configurations. In this case, we observe that the LSPR along the short axis (650nm) pulls the rotation angles to much larger values compared to the reference film. In this particular configuration, the induced plasmon dipole is aligned along the magnetic field direction and thus should not experience any pronounced Lorentz force, which implies that this is a very surprising result. By breaking the symmetry of the nanoparticles, not only the magnetic behavior is altered, but also the polarizability along the different symmetry axes of the particles. As such, the phase difference that is picked up in MOKE between the intrinsic magnetization behavior of nickel and the LSPR mode can be tuned to an even larger extent, allowing to tailor the magneto-optical behavior of these nanoparticles at will. Future applications for such effects include amongst others magnetic memories and (bio-) chemical sensing.

References

[1] V. Bonanni et al., Nano Lett. **11** (2011) 5333