Magnetoplasmonic design rules for active magneto-optics

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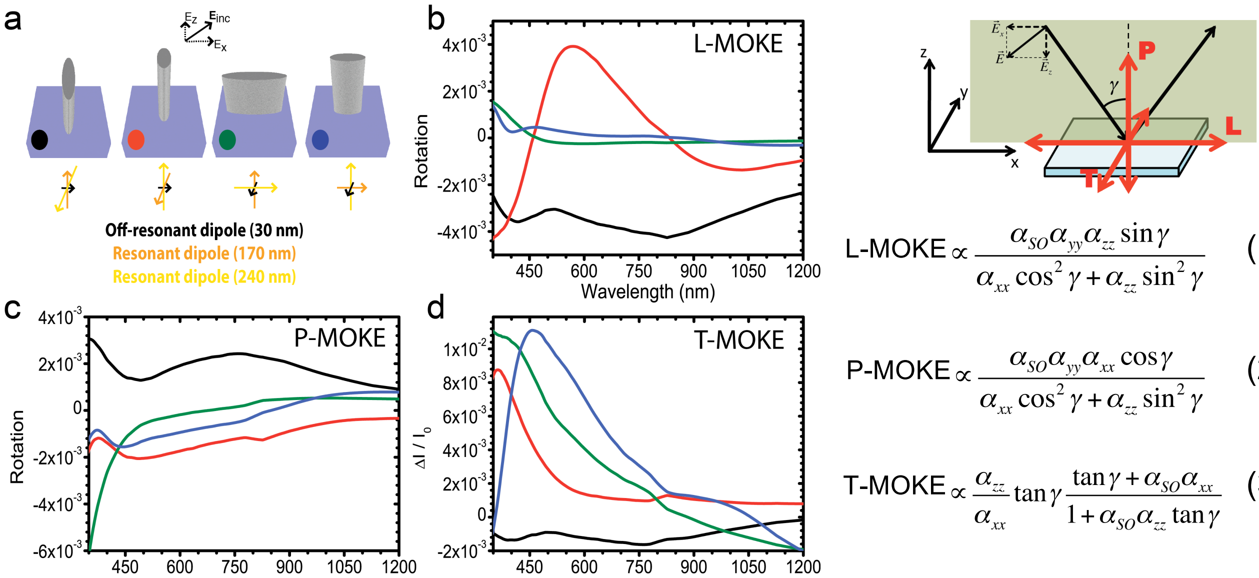
Abstract: Magnetoplasmonics offers a versatile smart toolbox in the quest for actively tunable metasurfaces. Here we present design rules for metasurfaces based on magnetoplasmonic nanoantennas that allow for advanced control of light polarization states.

Magneto-optical materials are often used to control the polarization state of propagating waves in integrated optical circuits. The polarization control originates from the off-diagonal terms in the dielectric tensor of these materials that can be activated by applying an external magnetic field. This gives rise to tunable non-reciprocal propagation of the light waves, an effect that has been intensively studied in optical insulators. Similar effects can be obtained in magnetoplasmonic nanoantennas, where the localized near-field enhancement at the plasmon resonance amplifies the intrinsic magneto-optical effects and allows tailoring it by means of the nanoantenna design. Here we derive simple design rules that can be exploited for fully 3D magnetoplasmonic nanoantennas in order to obtain magnetically tunable active metasurfaces.

We investigated the magnetoplasmonic response of 2D and 3D nanoantennas in all three conventional magneto-optical Kerr effect (MOKE) geometries, namely longitudinal (L), polar (P) and transversal (T). In the former two cases, the polarization state of a transmitted wave is changed, resulting in a Kerr rotation and ellipticity, while in the latter case the intensity is modulated by the applied magnetic field. In figure 1 we illustrate the broadband tunability of the Kerr response for different orientations of elliptical nanoantennas that support three mutually orthogonal plasmon modes. The magnitude of the modulation and its sign can be predicted based on the polarizabilities of the nanostructures along their different symmetry axes, as illustrated by the formulas 1-3.



$$\text{L-MOKE} \propto \frac{\alpha_{SO}\alpha_{yy}\alpha_{zz}\sin\gamma}{\alpha_{xx}\cos^2\gamma+\alpha_{zz}\sin^2\gamma} \quad (1)$$

$$\text{P-MOKE} \propto \frac{\alpha_{SO}\alpha_{yy}\alpha_{xx}\cos\gamma}{\alpha_{xx}\cos^2\gamma+\alpha_{zz}\sin^2\gamma} \quad (2)$$

$$\text{T-MOKE} \propto \frac{\alpha_{zz}}{\alpha_{xx}}\tan\gamma\,\frac{\tan\gamma+\alpha_{SO}\alpha_{xx}}{1+\alpha_{SO}\alpha_{zz}\tan\gamma} \quad (3)$$

Figure 1: Calculated MOKE signals [1, 2] for p-polarized light in different 3D nanoellipses (a) and different Kerr geometries. (b) Longitudinal, (c) Polar and (d) Transversal. Equations 1-3 show the scaling of MOKE signals for the respective geometries with the polarizabilities along the symmetry axes of the nanoantennas and the incident angle γ.

For the selected case (incident angle 25°) we can observe how the magnitude of the Kerr signal scales according to the design rules in equation 1-3. Irrespective of the Kerr configuration, the largest signals are obtained when two plasmon modes in the numerator exhibit a simultaneous resonant behaviour (see vectors in a, black and red lines in panel b, equations 1). For non-perpendicular incidence, two plasmon modes are directly excited by the incident wave (α_{xx} and α_{zz}), while the third one can be activated through the spin-orbit interaction (α_{yy}) for the L- and P-configurations. In the T-MOKE case both the directly excited plasmon modes (α_{xx} and α_{zz}) are coupled by the spin-orbit interaction, allowing unprecedented and versatile H-modulated control of the light intensity.

References

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