Enhanced transverse magneto-optical Kerr effect in multilayered one-dimensional magnetoplasmonic crystals with narrow slits

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Abstract: Transverse magneto-optical Kerr effect enhancement in the transmittance geometry driven by surface plasmon-polariton resonances with different quality factors was experimentally observed in one-dimensional multilayered magnetoplasmonic gratings with narrow slits.

1. Introduction

Transverse magneto-optical Kerr effect (TMOKE) is an effect that manifests itself as changes of intensity and phase of linearly polarized light reflected from a sample when the external magnetic field is applied to the sample perpendicularly to the plane of the light incidence [1]. For the visible, the TMOKE values of ferromagnetic metals are conventionally less than 1.5%. The coupling of the incident light with surface plasmon-polaritons (SPPs) can significantly enhances the TMOKE of thin ferromagnetic metal films. That appears due to the modulation of the SPP wave vector in the external transverse magnetic field. One-dimensional (1D) metal gratings, in combination with ferromagnetic metals, are often used for the SPP-induced TMOKE. In the reflectance geometry, the TMOKE enhancement was found in all-ferromagnetic gratings [2,3], in the gratings that consist of a combination of ferromagnetic and noble metals [4] in order to decrease large optical losses of SPPs in ferromagnetic metals.

The transmittance geometry is more convenient for the practical applications of the TMOKE enhancement driven by SPPs, i.e., for magneto-optical shutters. It also allows tuning the wavelength of enhancement without changing the light beam direction. Magnetoplasmonic films and gratings without slits or holes have transmittance too low for this purpose. Therefore, metal gratings with narrow slits present a good candidate to modulate the intensity of the light propagating in the transmittance geometry. These structures reveal resonant transmittance due to the excitation of SPPs. The TMOKE enhancement in the transmittance geometry induced by SPPs was studied in the 1D array of gold bars on the magnetic dielectric substrate [5]. However, the TMOKE enhancement in the transmittance geometry in magnetoplasmonic gratings with slits perforated in all-ferromagnetic films or ferromagnetic films with noble metal layers has not been investigated. In this work, the TMOKE enhancement in the transmittance geometry has been experimentally studied in the 1D multilayered magnetoplasmonic grating with narrow slits. This structure combines the SPP-induced resonances of transmittance, large sensitivity of SPPs to the transverse magnetization of the ferromagnetic layer and the reduced absorbance by inclusion of noble-metal layers.

2. Sample and methods

The magnetoplasmonic 1D grating under study is a one-dimensional array of three-layer Au(10nm)/ Ni(10nm)/Au(100nm) stripes which are arranged on a transparent sapphire (Al_2O_3) substrate. The period of the grating d = 440 nm, and the width of slits is 70 nm. The grating was fabricated using focused ion beam technique. The size of the total area of the grating is 100x100 μm^2.

The magneto-optical micro-spectroscopy experimental setup was used to measure the TMOKE in the transmittance geometry. The ac magnetic field was generated by electromagnetic coils. The differential transmittance $\Delta T = T(H) - T(-H)$ was detected by the lock-in detection technique at the frequency of the ac magnetic field of f = 87 Hz. The TMOKE was defined as $\delta=\Delta T/T$, where T is the transmittance without presence of the magnetic field.

3. Results and discussion

The wavelength-angular 2D map of transmittance shows that SPPs of the $+1^{st}$ and -1^{st} order are excited at the Au/air and Au/Al_2O_3 interface and the localized plasmon in multilayered stripes is also excited in the magnetoplasmonic gratings. The transmittance spectra are in good agreement with finite-difference time-domain (FDTD) simulations.

The transmittance TMOKE was measured at angles of the light incidence (θ) of 0°, 3°, 5°, 10°, 15°, and 20°. The TMOKE enhancement was found only at the excitation of SPPs of the $+1^{st}$ and -1^{st} order at the Au/Al_2O_3 interface. The TMOKE isn't enhanced at the excitation of SPPs of the $+1^{st}$ and -1^{st} order at the Au/air interface. The maximum value of the TMOKE at the excitation of the SPP of the -1^{st} order is larger than the one at the excitation of the SPP of the $+1^{st}$ order (Fig.1). The maximum value of the TMOKE in the transmittance geometry at θ=5° is $\delta = -0{,}275\%$ at $\lambda = 830$ nm at the excitation of the SPP of the -1^{st} order and $\delta = 0{,}1\%$ at $\lambda = 760$ nm at the excitation of the SPP of the $+1^{st}$ order (Fig. 1). The difference of the maximum value of the TMOKE at the excitation of SPPs of the $+1^{st}$ and -1^{st} order was also found at other angles of the light incidence.

The TMOKE enhancement is connected to the sensitivity of the electromagnetic field of the SPP to the magnetization of the Ni layer. The spectral dependence of the electric field localization into the Ni layer was calculated by FDTD technique (Fig.2). The considerable enhancement of the electric field localization was observed at the excitation of SPPs of the $+1^{st}$ and -1^{st} order at the interface Au/Al_2O_3 and at the excitation of the localized plasmon in stripes. Quality factors of SPPs of the $+1^{st}$ and -1^{st} order depending on the angle of the light incidence were calculated by Lorentz-line fitting of the electric field localization spectra. The quality factor of the SPP of the -1^{st} order is larger than the one of the SPP of the $+1^{st}$ order. The quality factor of the SPP of the $+1^{st}$ order is 16 and the one of the SPP of the -1^{st} order is 26 at $\theta = 5°$. The difference of the TMOKE maximum values at the excitation of SPPs of the $+1^{st}$ and -1^{st} order is associated with the difference of the quality factors of SPPs.

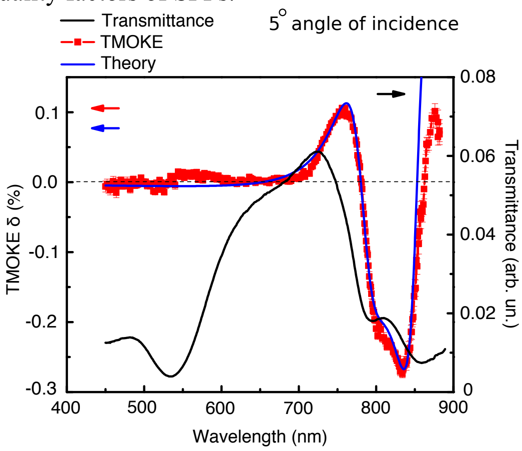

Figure 1. Black line: the transmittance of the magnetoplasmonic grating. Red dots: the TMOKE. Blue line: the calculation of the TMOKE by using Lorentz-line shape of the grating transmittance. The angle of the light incidence is 5°.

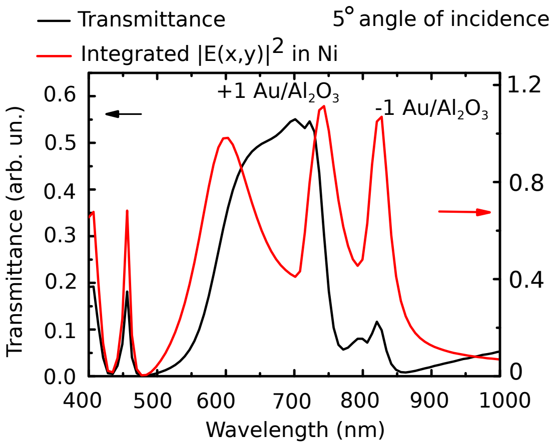

Figure 2. Black line: simulated transmittance of the magnetoplasmoinic grating by the FDTD technique. Red line: the spectrum of the integrated value of the electric field intensity localized into the Ni-layer. The angle of the light incidence is 5°.

4. Conclusion

We found that the excitation of the surface plasmon-polaritons (SPPs) in the multilayered (noble metal/ ferromagnet/ noble metal) 1D grating with narrow slits leads to the significantly enhancement of the transverse magneto-optical Kerr effect (TMOKE) in the transmittance geometry. The maximum observed value of the TMOKE is 0.275% at the SPP excitation and it is approximately 0.0% at the non-resonant case. The difference of the maximum values of the TMOKE enhancement at the excitation of the SPPs of the $+1^{st}$ and -1^{st} order was found and associated with different values of the SPPs quality factors.

Acknowledgment

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