Large enhancement of longitudinal magneto-optical effect with an
all-dielectric resonant guided-mode grating

Student Paper

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ABSTRACT

An integrated device with high magneto-optical response is currently required since there is a high demand on photonic devices employing magneto-optical effects like optical isolators and magnetic field sensors. Thus, we experimentally and numerically demonstrate a significant enhancement of the longitudinal magneto-optical response in transmission and for small angles of incidence, in a subwavelength resonant structure consisting of a dielectric grating and a magneto-optic waveguide.

Keywords: magneto-optics, Faraday effect, Kerr effects, magneto-plasmonic, resonant guided-mode grating.

1 INTRODUCTION

Most of magneto-optical (MO) effects can be described by a rotation of the plane of polarization through a magnetized MO material, which are named the Faraday effect in transmission geometry and Kerr effect in reflection geometry[1]. In recent years, these effects attract much attention due to their possible applications in optic isolators, which are important elements in laser systems. They can be used also in magnetic field sensors, MO data storage and optical modulation[1].

The enhancement of MO response can be achieved by subwavelength magneto-plasmonic structures: MO dielectric material surrounded by metallic grating. They are based on the phenomenon of an extraordinary optical transmission (EOT), where an unusual high transmission spectra can be observed[7]. Both waveguide mode and extended surface plasmon polaritons (SPPs)[3] are responsible for this exceptional behavior. Belotelov et al.[4] succeeded in increasing theoretically the Faraday and Kerr rotations in polar configuration[1] by a factor of 9 in comparison to a single Bi:YIG film, with 2D magneto-plasmonic structure. While the Faraday rotation measured by Floess et al.[5] for a 1D magneto-plasmonic structure is enhanced by a factor of 14 in comparison to a single EuS film.

Another way to excel the MO effects is by using the all-dielectric resonant guided-mode gratings: dielectric MO waveguide surrounded by a dielectric grating. These structures are based on the phenomenon of the waveguide mode resonance[6], where a diffracted wave is coupled into the waveguide. The condition of the coupling is given by:

\[ n_1 \sin \theta_{inc} + m \frac{\lambda_0}{\Lambda} = n_{eff} \]  

Where \( n_{eff} \) is the effective index of the waveguide mode, \( n_1 \) is the refractive index of the incidence medium, \( \theta_{inc} \) is the incident angle, \( m \) is the diffraction order, \( \Lambda \) is the period of the dielectric grating and \( \lambda_0 \) is the vacuum wavelength for the incident light.

At resonance, a destructive interference occurs between transmitted and diffracted wave fronts[7]. Therefore, contrary to the magneto-plasmonic structure, a deep in transmittance and consequently a peak in reflectance are obtained. In these structures, a considerable MO effects can be achieved with high reflectivity which is important for applications in 3D imaging and magneto-optic data storage[1]. An enhancement of Faraday and Kerr effects has been theoretically demonstrated by Gamet el al.[8] through 1D subwavelength all-dielectric structure. An improvement by a factor of 100 and 700 in comparison to the off-resonance is obtained respectively for Faraday and Kerr effects in the polar configuration. While for the Kerr rotation in the longitudinal configuration[1], an enhancement of 10^5 was achieved.

Here, a numerical and experimental large MO response in the longitudinal configuration and in transmission, is presented for small angles of incidence (AOI) by a simple 1D all-dielectric resonant guided-mode grating.

2 FABRICATION AND CHARACTERIZATION

Our structure geometry is illustrated by Fig.1. It consists of a photoresist (PR) grating deposits on a thin layer of our MO composite sol-gel. The structure was fabricated as it follows: first a layer of MO composite with thickness \( t_{MO} \) was deposited on a glass substrate (BK7) by dip coating then treated thermally at 90°C for
values of $14$ incident light. While, for the Faraday rotation, Floess et al.[5] have theoretically and experimentally demonstrated of $0$ perforated gold with hole arrays deposited on a uniform Bi:YIG film. They theoretically demonstrated values higher than that obtained by Belotelov et al.[4] with more complex structure, made by 2D structure (not shown here).

These values are higher than that by increasing the AOI the resonance wavelength increases, this dependency is verified by (1). The presence of the large opposite rotation peaks is linked to the both transmission resonances for both polarizations (TE and TM). As seen in this figure, the measured rotations reach values of $1.1^\circ$ and $-0.8^\circ$ as highest values for the different AOI except the normal incidence (there is no resonant MO effects). Whereas for a simple layer of our MO material without grating ($t_{MO} = 440 \text{ nm}$), the MO effects are zeros for these small AOI (see inset Fig.2(b) and Fig.2(d)). Therefore, a big enhancement was achieved with our resonant dielectric structure. The advantage here is that the resonant MO effects coincides with high transmittance, greater than 60% for the different AOI. The large detected MO effect ($\theta = 1.1^\circ$) is related to the fact that at AOI= $0.45^\circ$ the propagative TE mode (order $m = 1$) and the anti-propagative TM mode (order $m = -1$), resonate at the same wavelength (as seen in Fig.2(a) and Fig.2(c)). Thus, at the exit of the structure, the rotations of these two modes add up and give an important MO response. Such enhancement could be applicable in the non-destructive control or in a magnetic field sensor based on this type of structure. A good agreement can be seen between the simulations and the measurements, and the wavelength shift can be explained by the imperfection of the fabricated structure. Furthermore, for TM polarized incident light, same order of polarization rotation was not achieved (see shown structure).

These values are higher than that obtained by Belotelov et al.[4] with more complex structure, made by 2D perforated gold with hole arrays deposited on a uniform Bi:YIG film. They theoretically demonstrated values of $0.78^\circ$ and $0.63^\circ$ for Faraday and Kerr effects respectively in the polar configuration and for TM polarized incident light. While, for the Faraday rotation, Floess et al.[5] have theoretically and experimentally demonstrated values of $14^\circ$ and $8^\circ$ for TE and TM polarizations respectively, with 1D magneto-plasmonic structure made by
Figure 2. The left-hand column displays the measured transmittance (a) and polarization rotation (b) for TE-polarized incident light and for different angles of incident. The experimental data agree with the performed simulation shown in the right-hand column (c),(d). The inset curves in (b) and (d) represent respectively the measured and simulated polarization rotations, for our resonant structure at normal incident (AOI=0°) and for the MO film.

an embedded gold nanowires in a EuS film. But, the measurements were taken at a very low temperature of 20K since the EuS material has a maximum of MO effects at this temperature.

4 CONCLUSION

In this work, a significant enhancement of MO effect in the longitudinal configuration was experimentally and numerically demonstrated at small angles of incidence, with 1D all-dielectric resonant grating. This latter consists of a uniform MO dielectric film with a dielectric grating on the top. This structure is easily fabricated which extends its application as a magnetic field sensor or in the non-destructive testing.

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REFERENCES