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Study of the magneto-optical interaction in a hybrid non-reciprocal mode converter

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Abstract: In this paper, we aim at determining the magneto-optical (MO) behavior of a TE-TM mode converter. This last is based on an hybrid interaction between a MO layer and a waveguide obtained by ion exchanged technology on glass. Comparison between measurements and theoretical behavior can be applied to give some clues for a better understanding of the MO measurements.

Introduction

In the framework of the development of optical telecommunication, lots of optical functionalities have to be integrated and, at this time, this has been achieved [1-2] for most of them. Nevertheless, optical isolation is still missing because its integration comes up against a material problem: classical MO materials, such as YIG or (Ce or Bi) substituted YIG, need high crystallization temperature (750-800°C) [3] and close lattice substrate (GGG), which make this kind of material incompatible with integration technologies. To overcome this, different approaches have been carried out, and among them the use of magnetic cobalt ferrite ($CoFe_2O_4$) nanoparticles embedded in a sol gel matrix [4]. This composite material can be coated on ion exchanged waveguides [5], and a MO mode conversion, which is a major step in the integration of an optical isolator, has been demonstrated [4]. In the following sections, we will focus on the mechanism of the MO interaction in such a hybrid structure.

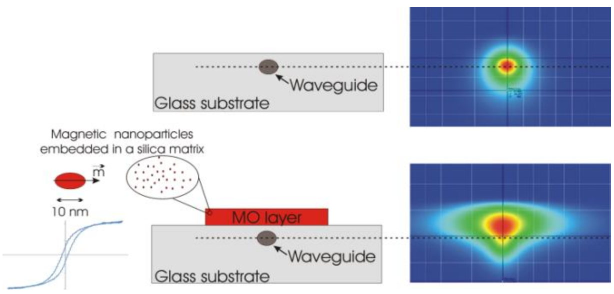

Fig. 1: Hybrid magneto-optic mode converter

Magneto-optical interaction

Free space Faraday rotation leads to a rotation of the polarization plane proportional to the magnetization of the sample. In guided configuration, as only TE and TM modes can propagate, the Faraday rotation leads to a TE-TM modal conversion which magnitude is limited by the difference between their propagation constant Δβ. According to the coupled mode theory [6], this conversion can be expressed as:

$$\frac{dA_{TE}}{dz} = iK(z).A_{TM}\, exp(i\Delta\beta z)$$
$$\frac{dA_{TM}}{dz} = iK^*(z).A_{TE}\, exp(-i\Delta\beta z) \quad (1)$$

Where: A_{TE} and A_{TM} are respectively the magnitude of the TE and TM modes. The coupling coefficient K(z) is proportional to the amount of modes energy confined in the MO layer, and to the magnetization of the layer through the off-diagonal element in the dielectric tensor which is determined experimentally by the measurement of the free space Faraday rotation.

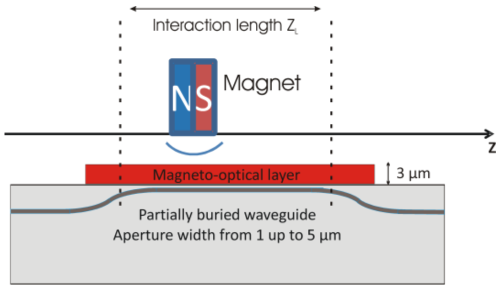

Fig. 2: partially buried waveguide

Sample preparation and characterization

Magnetic nanoparticles, issued from a magnetic liquid, are added to a sol gel solution [4]. Then, using dip coating technique, a thin film, with a specific Faraday rotation of 140°.cm^{-1}, is coated on a glass substrate containing partially buried channel waveguides made by a silver/sodium ion exchange process and followed by a selective burying process [7-8]. This last step allows both the delimitation of the interaction length Z_L and the reduction of the reflection losses due to the change of the effective index in the MO area thanks to an adiabatic transition (Fig. 2). The characterization of the MO waveguide is made via the analysis, with a lab-built polarimeter [8], of the emerging polarization under the influence of a longitudinal magnetic field. This polarization is characterized by its azimuth γ, and its ellipticity ε, with respect to the waveguide axis. A permanent neodymium magnet is moved along the whole waveguide, and the emerging polarization is recorded as a function of its position (fig. 3). At first, we can observe oscillations whose period L_B is related to the modal birefringence ($\Delta\beta = \frac{2\pi}{L_B}$) [9]. We can notice also that these oscillations exceed the interaction length: this is due to the fact that the magnetic field created by the magnet is spreading along the z axis. Thus, modeling the behavior of such MO converter, using numerically integration of the differential equations system (eq.1), requires taking into account all of these parameters by the introduction of a z dependent term in the coupling coefficient K. This will lead to the determination of the amount of power confined in the MO layer. It is, mainly due to the adiabatic transition, z dependent. Typical result is shown in fig. 3 for a 0.5mm thick neodymium magnet. The global shape of the simulated curves is globally the same as the experimental points, even if some details differ in the magnitude of the polarization angles.

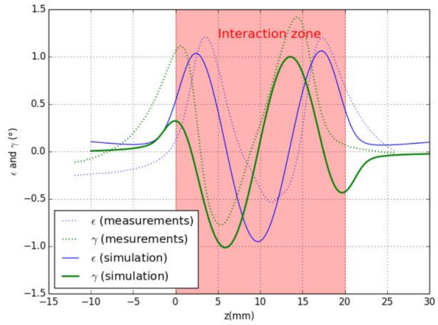

Fig.3: simulated and measured sample emerging polarization

Conclusion

Based on MO measurements, we have modelized the behavior of a MO mode converter in order to extract some information such as MO confinement in a hybrid configuration. These first results from our simulations are rather in good agreement with our measurements. Further improvements of the model will allow us to better understand all the mechanisms underlying the mode conversion in guided configuration**.**

References

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