MEASUREMENT OF BIREFRINGENCE IN EXTERNALLY STRAINED MAGNETO-OPTICAL WAVEGUIDES

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ABSTRACT

This paper presents a method for measuring the birefringence in magneto-optical waveguides. A holographic grating on the waveguide surface is used to couple light to and from the waveguide. Since no mechanical contact is necessary for the light coupling the method is well suited for studies of how the birefringence is affected by environmental parameters.

As an example of possible applications for this method we present measurements showing how the linear birefringence is affected by an externally applied stress. It is shown that in a specific YIG:Gd,Ga waveguide the linear birefringence is changed 300 rad/m, i.e. 180°/cm, for a strain of about 10^{-4} .

INTRODUCTION

By using photolithography and holographic techniques it is possible to fabricate a grating in photoresist on the surface of a planar waveguide. This grating then provides a non-destructive means of measuring several waveguide properties, [1]. The grating is used both for coupling light into and out from the waveguide. If a laser beam is coupled into the waveguide, light will be coupled out at every point along the light propagation path. When linearly polarized light is used to excite the TE- and TM-mode simultaneously, the intensity along the light path will vary when viewed through a polarizer. This variation is due to the beating arising from the birefringence. Moreover, it is possible to determine the birefringence in the waveguide from this intensity distribution.

Now assume that the plane of polarization is oriented so that the TE- and TM-mode are equally excited. If the output light is viewed through a polarizer, with its transmission axis perpendicular to the input polarization plane, the intensity will vary according to:

$$I_1 = I_0 f_g(z) e^{-\alpha z} \sin^2 \left[\left(\frac{\Delta\beta}{2} \right)^2 + \Theta_F^2 \right]^{\frac{1}{2}} \cdot z \quad (1)$$

where z is the direction of propagation. If the polarizer is rotated 90° the intensity distribution will be phase shifted, fig. 1, and thus

$$I_2 = I_0 f_g(z) e^{-\alpha z} \cos^2 \left[\left(\frac{\Delta\beta}{2} \right)^2 + \Theta_F^2 \right]^{\frac{1}{2}} \cdot z \quad (2)$$

$f_g(z)$ = grating efficiency along the light propagation path

$\Delta\beta$ = total linear birefringence

Θ_F = magnetic circular birefringence
(the Faraday effect)

$e^{-\alpha z}$ = exponential decay of the light in the waveguide due to losses in the guide, and also to the fact that light is coupled out from the guide. In the case of YIG-waveguides, the refractive indices of the grating and the guide are far apart, leading to a very small grating efficiency. Thus the α -coefficient is almost solely due to waveguide losses.

Fig 1. Intensity distributions measured with two perpendicular orientations of the polarizer.

Measuring these two intensity distributions and calculating the sum at every point gives:

$$I_1 + I_2 = I_0 f_g(z) e^{-\alpha z} \quad (3)$$

This function can be used to normalize I_1 and I_2 , fig. 2:

$$I_1^{norm} = \frac{I_1}{I_1 + I_2} = \sin^2 \left[\left(\frac{\Delta\beta}{2} \right)^2 + \Theta_F^2 \right]^{\frac{1}{2}} \cdot z \quad (4)$$

By fitting a sine-square function to this measured and normalized function we can estimate the argument $\left[\left(\frac{\Delta\beta}{2} \right)^2 + \Theta_F^2 \right]^{\frac{1}{2}}$ with good accuracy. A separate determination of $\Delta\beta$ and Θ_F can be made by using functions measured with different orientations of the magnetic field, [1].

The function $I_0 f_g(z) e^{-\alpha z}$ can also be used to determine the loss in the guide as the grating efficiency is small. This will not be demonstrated here.

Fig 2. One of the intensity distributions from fig. 1, normalized by dividing by the sum of the two distributions.

EXPERIMENTAL SETUP

The experimental setup is sketched in fig. 3; The light-source is a He-Ne laser at 1152 nm. The quarter-wave plate makes the light circularly polarized, making it possible to choose any direction of the polarization plane with the polarizer. The light coupler is a holographic grating made of photoresist on the sample surface, and covers the whole sample. The grating is fabricated by exposure of an argon laser two beam interference pattern. The grating periodicity is chosen so that the 'center' of the mode spectrum is excited at normal incidence of the laser beam. The light coupled out from the waveguide is detected by a linear photodiode array after passing another polarizer. The array consists of 1024 elements with a $13\mu\text{m}$ center-to-center spacing.

Fig.3. Experimental setup.

In order to produce a uniform stress in the waveguiding layer, the substrate was mounted as one wall of a small vacuum-chamber. The opposite wall was made of ordinary glass. A lowering of the pressure in this chamber produces a deformation of the substrate which in the first approximation gives a uniform strain in the layer. When lowering the pressure to 0,1 atm the strain will be about 10^{-4} .

The deformation of the substrate also affects the measured intensity distribution due to geometrical changes of the light propagation. This effect must be taken into account when the change of $\Delta\beta$ is to be determined. This could be done in either of two ways. One way is to measure the deformation and calculate the correction. The other way is to turn the holder and make another measurement from the other side of the substrate, as this will reverse the sign of the geometric change.

EXPERIMENTAL RESULTS

The curves in fig. 4 show how a normalized intensity distribution changes when the waveguide is strained. The curves represent differences in the birefringence of about 300 rad/m, i. e. $180^\circ/\text{cm}$. The waveguide is a $8\text{ }\mu\text{m}$ thick YIG:Gd,Ga film grown on a GGG-substrate and the strain is about 10^{-4} . When the substrate is turned in the holder so that the stress in the guide is changed from tensile to compressive and hence the sign of the strain is changed, the change of the birefringence also reverses its sign. Fig. 4 shows the case for the fourth mode, but the measured change of the birefringence has shown to be independent of mode number.

Fig.4. Normalized intensity distribution for the fourth mode, when the waveguide is under tension (dotted line), under compression (dashed line) and relaxed (solid line)

Experimental accuracy

The periodicity of the energy distribution falling on the photodiode array, will be the same as the one emanating from the waveguide, including the geometrical modification as discussed above. This is due to the fact that the system does not contain any imaging optics, which implies that no calibration procedure is needed.

The accuracy of the measurements and the calculations can only be estimated from the misfit of Eq. (4) to the respective curves of fig4. The misfit is mainly caused by scattered laserlight that is added to the 'true' signal. As the distribution of the stray light cannot be unambiguously determined it cannot be totally compensated for.

A variation of the waveguide thickness, which affects $\Delta\beta$, also adds to the uncertainty of the measurements. In the high quality films used in the reported measurements, however, such a thickness variation could barely be seen.

To summarize, the estimated overall accuracy of the birefringence determinations, including the lack of reproducibility, was about 0,1 %.

CONCLUSIONS

We have reported a method suitable for measuring the birefringence of magneto-optical as well as other waveguiding films. The method utilizes a holographic grating on the film surface for the coupling of light to and from the film, implying an absence of mechanical influence. This fact makes it possible to conveniently perform experiments where environmental influences on the film are to be measured, e.g. dependence upon pressure or temperature.

As the light coupler is distributed over the whole sample surface it is also possible to make 'mappings' of the whole sample simultaneously.

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