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Characteristic Analysis of Polarization States in Magneto – Optic Fiber Bragg Grating and its Application

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ABSTRACT: Fiber Bragg Gratings have been widely used in optical fiber communication and sensing purposes. Fiber Bragg gratings are the periodic perturbation in refractive index along the core of the optical fiber. It has an important role in optical communication system especially in designing optical amplifiers and filters. Strain, temperature, pressure etc, can be sensed by the shift in Bragg's wavelength of fiber Bragg grating. Magneto Optic Fiber Bragg Grating (MFBG) is a class of fiber Bragg gratings with magneto optical effects. It has some applications such as current or magnetic field sensors, nonlinear magneto - optic switches, tunable dispersion compensation module. The transmission characteristics of the non-uniform magneto - optic fiber Bragg grating are analyzed. Measurement of magnetic field of the magneto - optic fiber Bragg grating is analyzed in terms of polarization dependent loss. Polarization dependent loss (PDL) is associated with fiber type polarization controller and this MFBGs can be used in Sagnac interferometer. Polarization Dependent Loss is wavelength dependent. Polarization properties of MFBG are related to the applied magnetic field. PDL is an effective method for magnetic field measurement. So MFBGs can be used in magnetic field sensing.

KEYWORDS: Fiber Bragg Grating, Magnetic Field sensing, Magneto – Optic Fiber Bragg Grating, Polarization, Polarization Dependent Loss,

I. INTRODUCTION

The exposure of the core of the optic fiber to periodic pattern of intense ultra violet light causes permanent change in the refractive index of the core of the fiber. This short length fiber with refractive index modulation is called as fiber Bragg grating (FBG). In fiber Bragg grating a small amount of incident light is reflected at each periodic refractive index change and the entire reflected light waves are combined into one large reflection at a particular wavelength when the strongest mode coupling occurs. This is referred to as the Bragg condition and the wavelength at which this reflection occurs is called Bragg wavelength. Only those wavelengths that satisfy the Bragg condition are affected and strongly reflected. The reflectivity of the input light reaches a peak at the Bragg wavelength. Bragg wavelength depends on the grating period and effective refractive index of the core.

FBG sensors are based on the fact that the Bragg wavelength changes with change in the pitch of the grating and the change in the refractive index. Thus any physical parameter like temperature, stress, strain which causes change in the above mentioned parameters can be sensed using FBG, by measuring the shift in the Bragg wavelength or the change in reflection coefficient of a particular wavelength. FBG sensors provide significant advantages such as small size, geometric flexibility, wavelength multiplexing, simplicity of fabrication and distributed detection. Different types of magnetic sensors have been reported based on the Faraday Effect, the Lorentzian force, and magnetostrictive effects. These magnetic sensors uses external methods for sensing magnetic field and minute changes in current and temperature and this additional step introduces thermal and mechanical influences. To avoid this, a new method is introduced which is to couple the magnetic and optical behaviours in a FBG. The direct coupling of the external field to the electromagnetic wave propagating in the FBG containing fiber offers greater sensitivity, compactness, and signal resolution. Polarization dependent loss method is used to analyse the polarization properties in magneto-optic fiber Bragg grating. Polarization dependent loss is the measure of the peak-to-peak difference in transmission of an optical component or system across all possible states of polarization. The peak of polarization dependent loss is directly proportional to the induced magnetic field. Magneto - Optic fiber Bragg gratings can also be used as optical switches, filters and in tunable dispersion compensation modules. The main advantage of MFBG is that, it is an in-fiber component therefore it can be readily integrated into optical circuits. They are lighter and more compact than conventional electromagnetic field devices.

II. RELATED WORKS

Xiao Liu and Kun Qiu [2] discuss the characteristics of magneto - optic fiber Bragg grating in optical signal processing. It is a kind of flexible and tunable polarization converted grating structure and the adjustable control of photonic band gaps by introducing the polarization-mode conversion effect. The shift of spectral lines along with the photonic semitransparent frequency band dependent on the magneto optic coupling intensity helps to design high resolution magnetic field sensors for the Bragg wavelength of 1550 nm. The mode conversion resulting from the Faraday effect is easily illustrated by means of magnetically induced circular birefringence, the nonlinear coupled-mode equations in the MFBG can be simplified from the point of view of circularly polarized light. On the basis of it, the equivalence relationship between the nonlinear effects and the magneto optic mode conversion is analyzed. It is expected that a new class of flexible and controllable photonic signal processing devices such as nonlinear MO switches may be achieved by integrating the adjustable MO bias with light-by-light effects of nonlinear photonic crystals.

B. J.Wu and X. Lu [3] demonstrate the coupled mode theory for magneto – optic fiber bragg grating. According to the perturbation theory, the coupled-mode equations for guided optical waves in the magneto-optical fiber Bragg gratings under non-uniform magnetic field are derived. The equivalent relation between the magnetically induced non-uniform fiber Bragg grating and the corresponding non-magnetic chirped grating is expressed and verified by the piecewise-uniform MFBG model under linear magnetic field. By analyzing the coupled-mode equations of guided optical waves in the MnFBG, the equivalent relation between the MnFBG and the non-magnetic chirped FBG is derived for the first time, which is also validated by comparison with the results calculated from the piecewise-uniform MFBG model. They also describe the application of magneto optic fiber bragg grating which is useful for dispersion compensation and comb filtering.

F. Wen and S. Perumal [4] describes the magnetic field response of erbium doped magneto optic fiber brag grating. The spectrum shift of Er-MFBG induced by the magnetic field is determined by the direct edge detection, and then the effective Verdet constant of erbium-doped silica fiber is known. According to the nonmagnetic equivalent model of MFBG, they theoretically analyze the magnetic field response of Er-MFBG.

III. SYSTEM MODEL

Magneto – Optic Fiber Bragg Grating is a class of Magneto - Optical fiber Bragg gratings which couples the magnetic and optical effects in a FBG [5]. The MFBG is used as a sensor for sensing magnetic field. A longitudinal magnetic field is applied to the fiber grating. The transmitted signal from the grating is directed to a polarization analyzer which characterizes the polarization properties [6] of the transmitted signal. These polarization properties contain the information about the magnetic field. The Polarization Dependent Loss of MFBG can be defined in terms of dB as

$$PDL = 10 \log |T_{max}/T_{min}| \quad (1)$$

where T_{max} and T_{min} are the maximum and minimum transmission spectra of MFBG.

In a single mode magneto optic (MO) fiber there exist two orthogonal eigen modes left and right handed circularly polarized light. When an isotropic perturbation of refractive grating independent of the eigen modes is added to the magneto optic fiber, the identically polarized guided waves propagating forward and backward coupled each other. To extract these right and left handed polarized light (RCP, LCP), circular polarizers are used. Figure 2.1 shows the simulation setup of nonmagnetic equivalent model of MFBG. These components are given as the input to individual nonmagnetic equivalent FBG. Optical adders are used to combine the two transmitted or reflected optical fields into the output. Transmission and reflection spectra are analyzed using the optical spectrum analyser.

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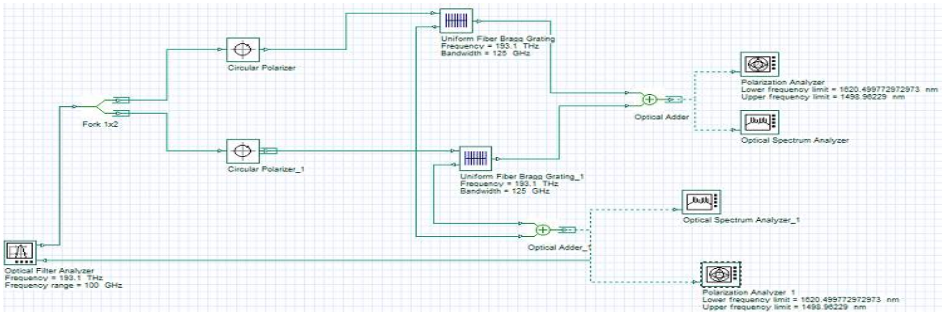

Figure 2.1: Simulation Setup for MFBG

Magnetically induced polarization dependent loss [3] is defined as the ratio of transmission spectra for input right and left circularly polarized light.

$$MCDL = 10 \log|T_{RCP}(\lambda) / T_{LCP}(\lambda)| \qquad (2)$$

For the extraction of RCP and LCP components for a linearly birefringent fiber an elliptical polarization extractor is needed. But the elliptical polarization extractor is unavailable in the software. So a new scheme capable of simultaneously extracting two eigen SOP components is used. The elliptical polarization extractor is unavailable in the software. So a new scheme capable of simultaneously extracting two eigen SOP components is used. The elliptical polarization extractor consists of a polarization splitter, a polarization rotator, a coupler, a phase shift, and a couple of polarization controllers. Two output ports of this extractor respectively correspond to right- and left-handed elliptically polarized light. Simulation setup is shown in figure 2.2 and experimental setup for MCDL measurement of an erbium doped MFBG is shown in figure 2.3.

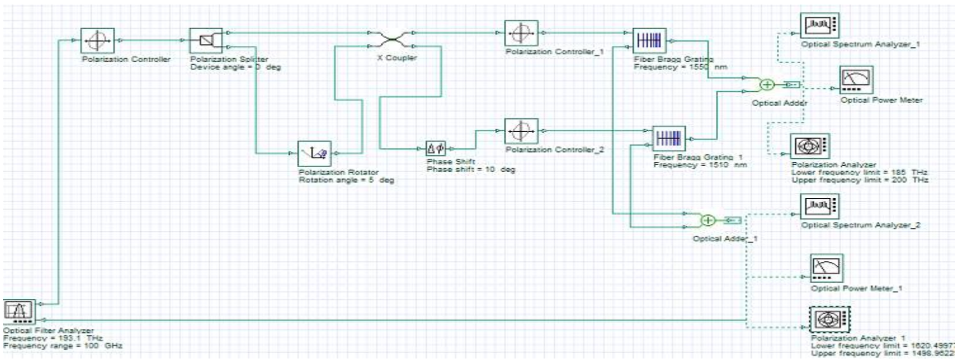

Figure 2.2: Simulation setup for linearly birefringent fiber

Tunable Laser source (TLS) is used to generate the continuous wave (CW) probe light. The light beam is split into two branches, and then the RCP or LCP light can be obtained by adjusting the corresponding polarization controller and an optical switch. The insertion losses of the OS are, respectively, 1 dB and 1.42 dB for two branches. The MCDL for the Erbium doped MFBG can be measured by using a Polarization Synthesizer/Analyzer.

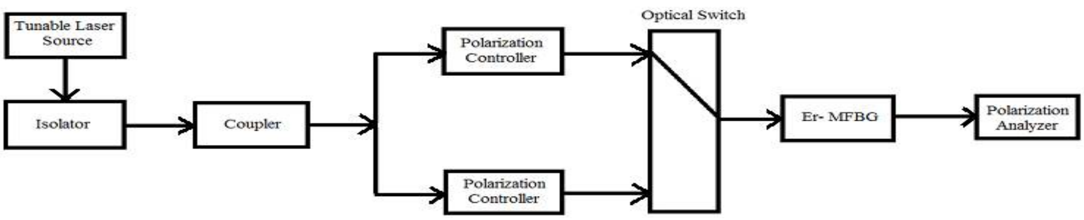

Figure 2.3: Block Diagram for MCDL measurement

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The MFBG can be used in Sagnac interferometer. It involves bidirectional transmission of light. Figure 2.3 shows the block diagram for MFBG based Sagnac Interferometer (MSI) system. A coupler is used to split the input optical field Ei into two optical paths and then simultaneously injected into the MFBG clockwise and counter-clockwise. E_r and E_t are the reflected and transmitted optical fields, respectively. The polarization controllers (PCs) in the MSI system are used to compensate for the linear birefringence in the fiber loop. The magnetic field B is applied along the MFBG of length L.

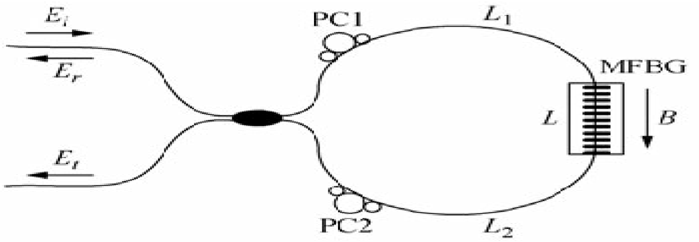

Figure 2.4: Block Diagram for MFBG based Sagnac Interferometer

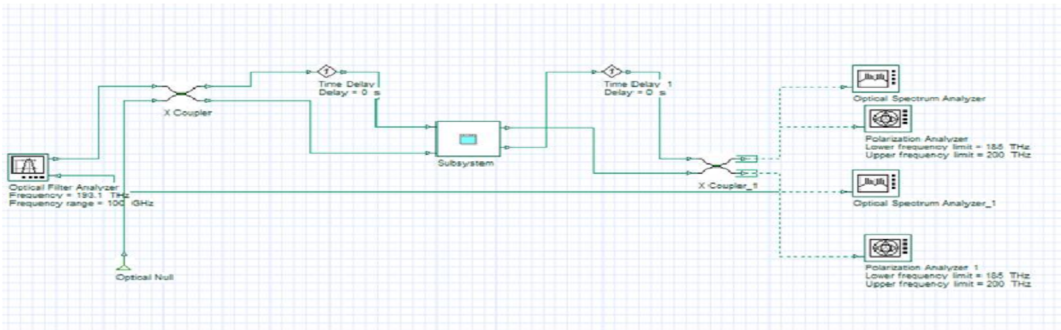

Figure 2.5: Simulation setup for MSI system

For the simulation of MSI system bidirectional injection of light is used. The linearly polarized light by the optical filter analyzer is launched into the MSI system. The reflected and transmitted optical spectra of the MSI system are displayed by the OSA of 0.1nm resolution.

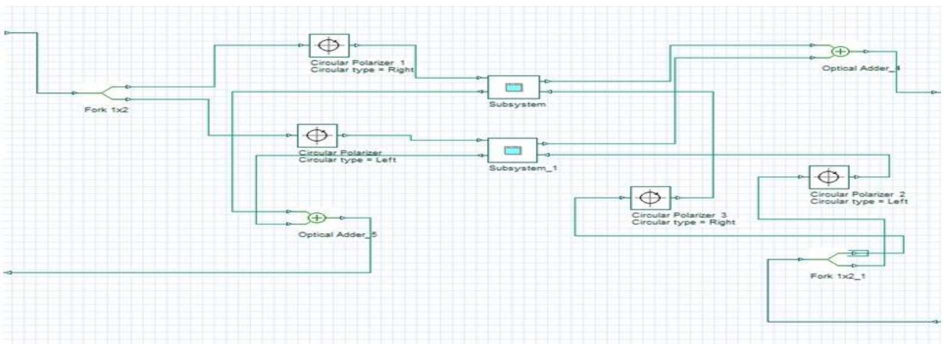

Figure 2.6: Simulation model of MFBG with bidirectional injection of light

IV. RESULT AND DISCUSSION

Obtained reflection spectrum of MFBG is shown in Figure 3. Range of frequency given to MFBG is 1545 nm to 1555 nm and the central wavelength is 1550 nm.

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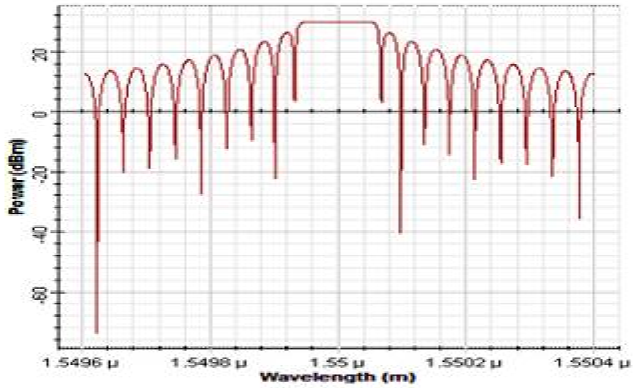

Figure 3.1: Reflection spectrum

From the reflection spectrum it is clear that, as the grating length increases the side lobes get increased. thus the power is wasted through the side lobes. The wastage of power through side lobes can be minimized by applying different refractive index profiles.

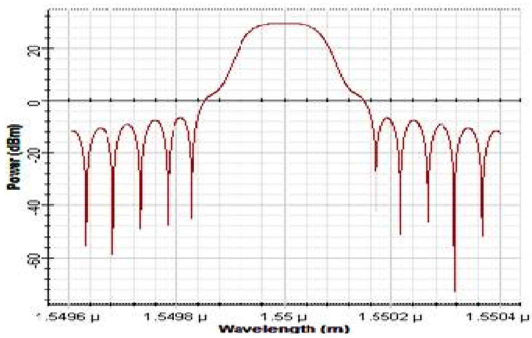

Figure 3.2: Reflection spectrum of Guassian apodized MFBG

Variation of refractive index profile is known as apodization. Different apodization functions can be used such as gaussian, rectangular etc. Figure 3.2 shows the output spectrum of gaussian apodized MFBG.

In figure 3.3, variation of Polarization Dependent Loss (PDL) with different grating length. As the grating length increases the polarization dependent loss gets increased.

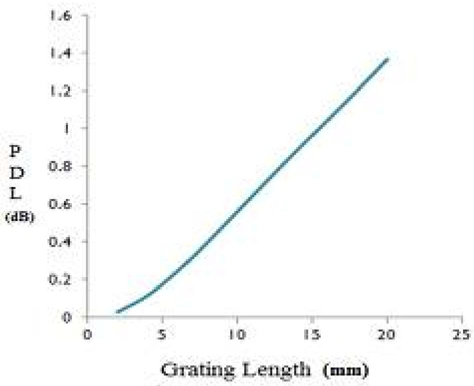

Figure: 3.3: Variation of PDL with grating length and wavelength

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Polarization properties of MFBG are analyzed using polarization analyzer. The polarization properties of the transmitted and reflected light are analyzed in terms of azimuth and ellipticity angles.

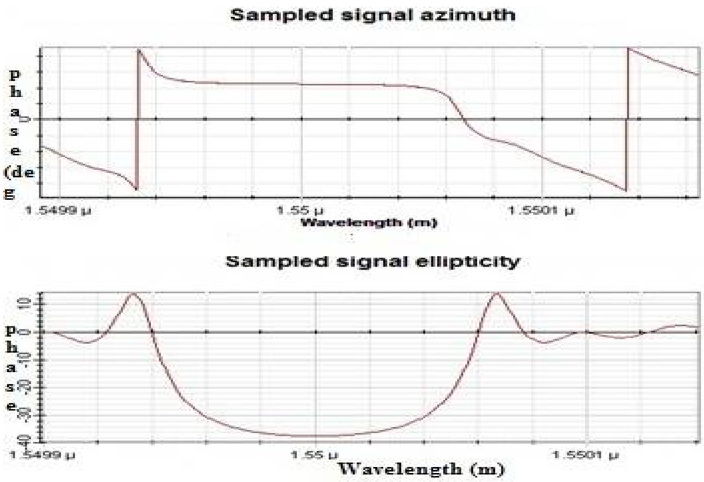

Figure 3.4: Transmitted polarization state of MFBG

At the wavelength of large transmittivity, the maximal azimuth and ellipticity angles occurs. If the azimuth angle of incident linearly polarized light is taken as zero then the frequency dependence of the transmitted azimuth angle is known as the Faraday rotation spectrum which is shown in figure 3.4.

IV.CONCLUSION

In optical communication systems fiber Bragg gratings are extensively used for sensing purposes. Sensing is mainly based on the shift in Bragg's wavelength. This Bragg wavelength depends on effective refractive index, grating length birefringence etc. The minute changes in temperature and magnetic field, detected by a new class of fiber grating which couples the multiferroic and optic effects in FBG. These fiber Bragg gratings are known as magneto optic fiber Bragg gratings. Polarization properties of this Magneto - Optic FBGs are analyzed using Polarization dependent loss. Polarization Dependent loss of FBG is the peak to peak throughput variation of power for all the possible input polarization states. Polarization dependent loss for MFBG is wavelength dependent and is increased as the grating length increases. One of the advantage of MFBG is it does not change the polarization state of transmission and reflection, which is analyzed using polarization ellipse. Due to this, MFBG can be effectively used for magnetic field measurement. MFBGs can also be used in tunable dispersion compensation modules, optical switches and Sagnac interferometer.

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