Longitudinal spatial characterisation of optical fibre erbium distributed feedback laser under the motion of steady magnetic field

Yuan Yao*[a,b], Gordon M.H. Flockhart[b]

[a] College of Physical Science and Technology, Central China Normal University, Wuhan, Hubei, P.R.China, 430079; [b] Centre for Microsystems and Photonics, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, UK

ABSTRACT

The spatial sensitivity of an erbium doped optical fibre distributed feedback (DFB) laser to an external magnetic field is reported. Intrinsic birefringence of the laser cavity allows lasing in two orthogonal modes. The polarisation beat frequency between these modes is sensitive to magnetic fields aligned along the axis of the optical fibre due to the Faraday effect. The interaction of magnetic field, generated by a permanent magnet, with the spatial mode profile of the laser is investigated. Experimental measurements show a 3.82 MHz change in the beat frequency when a permanent magnet is scanned along the fibre laser.

Keywords: magnetic sensing, DFB fibre laser, beat frequency, Faraday effect

1. Introduction

Magnetic field measurement is widely used in data storage, aircraft manufacturing, mobile communications and modern industrial fields. Magnetic field sensors have been widely used for navigation, vehicle detection, current sensing, and spatial and geophysical research[1]. Fibre magnetic field sensors are desirable because of their immunity to electromagnetic interference, low weight, small size, multiplexing, and long-distance signal transmission for remote operation. In recent years, many fibre-optic magnetic field sensors have been explored, using Faraday effect[2,3], magnetostrictive effect[4], magnetic force[5,6], Lorentzian force[7], magneto fluid material[8,9]. A silica fibre sensor based on Faraday effect can be used to measure magnetic fields directly[10], but the sensitivities are low because the Verdet constant of silica fibres is small. Fibre Bragg grating magnetic field sensors with wavelength interrogation have been proposed[11,12]. Recently, dual-polarization fibre grating laser based sensors have been reported for DC magnetic fields[3], but this method measures the uniform magnetic field of a solenoid.

In this paper, we report the spatial sensitivity of an erbium doped optical fibre distributed feedback (DFB) laser to an external magnetic field. A magnetic field is generated by a permanent magnet and then the permanent magnet is displaced along the axis of the DFB fibre laser, thus the beat signal frequency will shift.

2. Principle of DFB fibre laser to magnet sensing based on beat frequency demodulation

General axisymmetric single-mode fibre can transmit two linear polarization modes or two circular polarization modes. If the fibre is completely axisymmetric, the two linear polarization modes, or two circular polarization modes, have the same

*yaoyuan@mail.ccnu.edu.cn; phone +44 141 548 2899; www.strath.ac.uk/eee/research/cmp/

23rd International Conference on Optical Fibre Sensors, edited by José Miguel López-Higuera, Julian Jones, Manuel López-Amo, José Luis Santos, Proc. of SPIE Vol. 9157, 91571T
 · doi: 10.1117/12.2059679

effective refractive index, and the polarization mode does not change in the transmission process. However, due to non axisymmetric structures, residual internal stress and UV induced refractive index changes from the fibre laser fabrication, birefringence will be produced. Therefore, the output of the DFB fibre laser will typically generate a beat frequency signal between orthogonal polarisation modes. This beat frequency is given by[14]:

$$\Delta\nu = \frac{c}{n_0\lambda_0}B \tag{1}$$

Where c is the light speed in vacuum, λ_0 is the laser wavelength, n_0 is the average effective refractive index, B is the birefringence of the optical fibre.

A polarisation controller is used to optimally align the orthogonal polarisation outputs of the DFB laser at 45° to the transmission axis of an in-line fibre polariser. The transmitted components produce a beat frequency when detected using a high-speed photodetector. This demodulation method has high speed, high sensitivity and low cost characteristics.

Normally, the intrinsic linear birefringence of the DFB fibre laser is present in a fibre laser cavity, and the fibre laser cavity has two linear polarization modes, when the fibre laser cavity is placed in an axial magnetic field, a circular birefringence will be generated in the fibre cavity because of Faraday rotation effect. This results in elliptical birefringence due to the combination of circular and linear birefringence. The beat frequency is related to the magnetic field by[3]:

$$\Delta\nu \approx \frac{1}{2\pi}\frac{c}{n_0}\left[\beta + \frac{2}{\beta}(\nu H)^2\right] \tag{2}$$

where ν is the Verdet constant, H is the axial magnetic field, β is the intrinsic linear birefringence of the optical fibre.

3. Experimental setup and results

3.1 Experimental setup

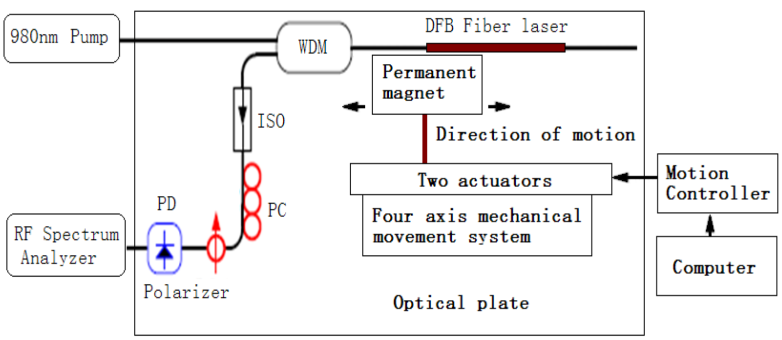


Figure 1 Experimental system of DFB fibre laser for magnetic field sensing

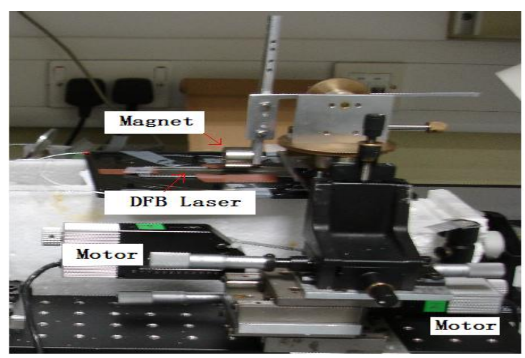


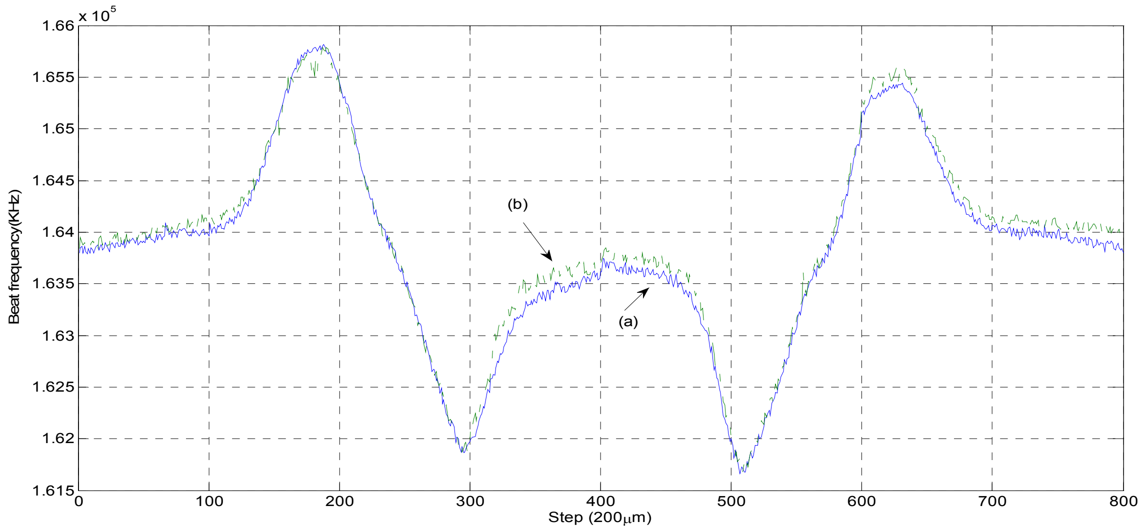
Figure 2 Permanent magnet movement system

To investigate the longitudinal spatial characterisation of optical fibre erbium distributed feedback laser to magnetic field, a DFB fibre laser magnetic field sensing system is shown in Fig 1. The optical setup is constructed on an active vibration isolation table (Halcyonics, Micro 60) to reduce external vibrations. A 45mm π-phase shifted grating fibre laser is pumped using a 980 nm pump laser and the backward propagating laser emission is separated using a 980/1550nm WDM. A high speed (3 GHz) photodetector (LBR-10M3G-10-15-10) and an electronic spectrum analyser (Agilent, E4404b) is used to measure the polarisation beat frequency. Two DC motor actuators (Newport, 850F) are mechanically combined to allow a permanent magnet (Magnet Expert, F4MLM52N, 25mm diameter x 45mm thick) to be scanned along the axis direction of DFB fibre laser using motor driver (Newport, MM4005). A multi-axis mechanical movement system is used to align the magnet and position it in close proximity to the DFB laser. The movement control software of the two actuators is programmed by LabView, which can set the range and step distance of the two actuators, and the time interval between movement steps.

The permanent magnet movement system is shown in Fig 2. The permanent magnet has a maximum magnetic flux density of 0.625 T on the surface; however the magnetic field at the location of the laser was measured using a magnetic field probe to be 0.02T.

3.2 Experimental results

The environmental temperature is 24°C and remains stable. The fibre laser output power is -50.54 dBm. The total scan length is 80 mm and the magnet is moved from one side A to the other side B and back again along the axial direction of the DFB laser. The step size is 0.2 mm and the time interval between steps is 4 seconds. The laser beat frequency is measured using an electronic spectrum analyzer at each step.



(a) Laser input model from left port of DFB laser(b) Laser input model from right port of DFB laser

Figure 3 Beat frequency result of DFB fibre laser to magnetic field sensing (Magnetic move go and return)

The measured beat frequency of the DFB fibre laser is shown in Fig 3 when the permanent magnet is scanned forwards and backwards along the laser axis. We can see the beat frequency of Fig 3 (a) and (b) have similar trend, but there are some differences in the beat frequency of Fig 3 (a) and (b). We believe this is due to small environmental disturbances.

A positive and negative shift of the beat frequency is observed as the magnet is translated along the length of the DFB laser. The experimental measurement show a maximum beat frequency of 165.710 MHz. A peak to peak shift in beat frequency of 3.815 MHz is observed when the magnet is moved from 0 to 80 mm. We believe this is due to the combined interaction of the Faraday effect with the laser mode profile and the magnetic field direction near the poles of the permanent magnet.

4. CONCLUSIONS

The spatial sensitivity of an erbium doped optical fibre distributed feedback laser to an external magnetic field is reported. The polarisation beat frequency between two orthogonal modes is sensitive to magnetic fields aligned along the axis of the optical fibre due to the Faraday effect is observed. By using a permanemt magnet we avoid potential temperature cross-sensitvity issues due to Joule heating from current flow in a solenoid. In future work, the interaction of the magnetic field and laser mode profile will be simulated and analysed.

ACKNOWLEDGEMENTS

This work is supported by China Scholarship Council (No: 201206775083), and partly supported by the Fundamental Research Funds for the Central Universities (No: CCNU13A05041).

The authors are grateful to Prof. Deepak Uttamchandani in the Centre for Microsystems and Photonics, Department of Electronic and Electrical Engineering, University of Strathclyde, UK, for his enthusiastic support for this work.

REFERENCES

[1] P Ripka, "Magnetic Sensors and Magnetometers," Artech House, Chap 6(2001).

[2] Ricardo M Silva, Hugo Martins ,Ivo Nascimento , José M Baptista ,António Lobo Ribeiro , José L Santos, Pedro Jorge and Orlando Frazão. , "Optical Current Sensors for High Power Systems: A Review," Appl Sci, 2,602-628(2012).

[3] L. Cheng, J. Han, Z. Guo, L. Jin, and B-O. Guan, " Faraday-rotation-based miniature magnetic field sensor using polarimetric heterodyning fiber grating laser," Opt Lett, 5, 688–690(2013).

[4] F. Bucholtz, et al., "Multichannel fiberoptic magnetometer system for undersea measurements," Journal of Lightwave Technology, 13,1385-1395(1995).

[5] J. Gong, C. C. Chan, M. Zhang, W. Jin, J. M. K. MacAlpine, and Y. B. Liao, "Fiber Bragg grating current sensor using linear magnetic actuator," Opt. Eng, 3, 557–558(2002).

[6] Yao Yuan, Zhou Ciming, Wang Dongli, Wu Lin, "Research on Fiber Bragg Grating Current Sensing based on Electromagnetic Force," International Symposium on Photoelectronic Detection and Imaging Proc SPIE 8191, 8191-3(2011).

[7] G. A. Cranch, G. M. H. Flockhart, and C. K. Kirkendall, "High-resolution distributed-feedback fiber laser dc magnetometer based on the Lorentzian force," Meas Sci Technol, 3, 034023(2009) .

[8] Dai J X,Yang M H, Li X B, Liu H L, Tong X L. , "Magnetic field sensor based on magnetic fluid clad etched fiber Bragg grating," Opt Fiber Technol,17,210–3(2011).

[9] Haotian Wang, Shengli Pu, Ning Wang, Shaohua Dong, and Juan Huang. , "Magnetic field sensing based on singlemode–multimode–singlemode fiber structures using magnetic fluids as cladding," OPTICS LETTERS, 19,3765-3768(2013).

[10] J. Noda, T. Hosaka, Y. Sasaki, and R. Ulrich, “Dispersion of Verdet constant in stress-birefringent silica fibre,” Electron Lett, 22, 906–907(1984).

[11] C.-L. Tien, C.-C. Hwang, H.-W. Chen, W. F. Liu, and S.-W. Lin, "Magnetic sensor based on side-polished fiber Bragg grating coated with iron film," IEEE Trans Magn, 10, 3285–3287(2006).

[12] S. Jin, H. Mavoori, R. P. Espindola, L. E. Adams, and T. A. "Strasse. Magnetically tunable fiber Bragg gratings," Proc OFC 99 San Diego CA ThJ2, 135 – 137(1999).

[13] Cheng L, Guo Z, Han J, Jin L, Guan BO. ,"Ampere force based magnetic field sensor using dual-polarization fiber laser," Opt Express, 11,13419-24(2013).

[14] B.-O. Guan, L. Jin, Y. Zhang, and H.-Y. Tam, "Polarimetric heterodyning fiber grating laser sensors," J. Lightwave Technol, 8, 1097–1112(2012).