Magnetic fluid filled to detect the magnetic field based on Fabre-Perot cavity tube

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Abstract— **Magnetic field was been studied through so many processes from decades. In this paper, we have aimed to report about the magnetic fluid to fill into the cavity tube based on Fabre-Perot interferometer to find the magnetic field. The magnetic fluid is filled into the cavity tube by using the syringe injection. This magnetic fluid sensor has the properties to detect the weak magnetic field. When an external magnetic field is applied on this sensor' the refractive index would be changed accordingly. By the outcome of experiment, the result illustrates the magnetic field sensitivity with the ratio percentage of 0.00113nm/Gs, where the filling cavity tube has 0.3 mm in size and BBL method has range of 1520 nm to 1610 nm. The sensor has the advantage of simple structure, compact size and easy fabrication.**

Index Terms— **Optical fiber Coupler; magnetic fluid; cavity tube sensor; Fabre-Perot interferometer; magnetic field.**

I. Introduction

The measurement of the magnetic field is of great importance in many applications, such as military, industrial, health, and energy **(1)**. Special emphasis in the electric power field where new technologies capable to characterize in real time the energy flow in the grid are needed to better understand its operation and to enable the development of sustainable energy management systems **(2)**. Fiber magnetic field sensors have been proposed for over 30 years **(3)** and have always been widely studied because of their advantages such as lightweight, resistance to electromagnetic interference, small size and capability of remote operation **(4)**. In these sensors, a magnetic functional material is an important element since it interacts with light parameters such as intensity, phase or polarization **(5)**. In recent years, magnetic fluids (MF) as a kind of promising magneto optical **(6)** and Nano materials **(7)** have attracted extensive attention for serving as crucial sensing elements of optical fiber magnetometer due to their advantages of fiber compatibility **(8)**, fluidity **(4)**, and high sensitivity **(9)**. So far, various of efforts on MF-based fiber-optic magnetometers designing with different structures have been demonstrated by utilizing the excellent magneto-optical effects of MF **(10)**, such as birefringence **(11)**, tunable refractive index **(12)**, tunable transmission loss **(7)** and so on. Among previously reported magnetometers, there were two kinds of the most popular structures, which can be categorized into MF coating based and MF filling based ones **(3)**. The combination of magnetic fluid and the optical fiber is one important direction **(6)**. The fiber Fabry–Pérot interferometers **(13)**, which is widely used as a sensor for the measurements of many physical and chemical parameters is a good choice to combine with MF **(14)**. Various structures have been employed to realize the sensing function, for example, fiber structures with up-tapered joints **(11)**. Dai et al. reported an MF infiltrated fiber Bragg grating magnetic field sensor **(15)**. Sagnac interferometer and Mach-Zehnder interferometer were employed to enhance the acutance of the spectra and the magnetic field sensitivity **(16)**. In 2006, the magnetic field sensor base on magnetic fluid-filled photonic crystal fibers **(17)**. In 2010, a hollow-core photonic crystal fiber Fabry–Pérot **(13)** sensor for magnetic field measurement based on magnetic fluid was proposed by Candiani et.al **(18)** and it adopted the coating technology and reflection mirror to increase the reflectivity of the two interfaces to enhance the power of the signal. But it was not easy to fabricate and also very expensive **(19)**.

In this paper, a fiber optic F–P magnetic field sensor **(20)** has proposed, based on the tunable refractive index property of MF **(21)**, and a fiber cavity tube **(16)** was used to effect on the sensor. Magnetic fluid is a kind of sensitive medium **(11)**, was filled into the cavity tube of the Fabry–Pérot **(13)** sensor by using the injection syringe method based on the magneto-optical characteristics of MF **(22)**. The structure and measuring principle of the sensing system has introduced. Preliminary experiments such as the relations between wavelength and magnetic field were done. Compared with other magnetic field sensors, the sensor proposed in this letter has many features, such as simple structure, compact, easy fabrication, low cost, high sensitivity, and stability **(23)**.

The remaining part of the paper is analyzed in three parts. First part will talk about the 'operations of sensor' **(24)** with properties and principles, second part will present the 'proposed results of conducted experiment' and the last part will discuss about the 'conclusion and future work'.

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II. OPERATION PRINCIPLE OF SENSOR

A. Properties of Magnetic fluid

Magnetic fluids have many properties as listed in Kotov et.al article's **(25)**. The magnetic fluid is a kind of highly stable colloidal material with single-domain ferromagnetic nanoparticles dispersing in a suitable carrier liquid. It exhibits features of both the fluidity of liquid and the magnetic property of solid magnetic materials **(26)**. The relationship between the refractive index and the magnetic field was studied in the letter **(27)**. With the increase or decrease magnetic field a change in the optical spectrum can be observed.

The relationship between wavelength and the transmission loss has been shown in "Fig.1". At zero magnetic field strength H, this spectrum has been obtained in the initial experiment. As we will increase the magnetic field, change has occurred in the spectrum.

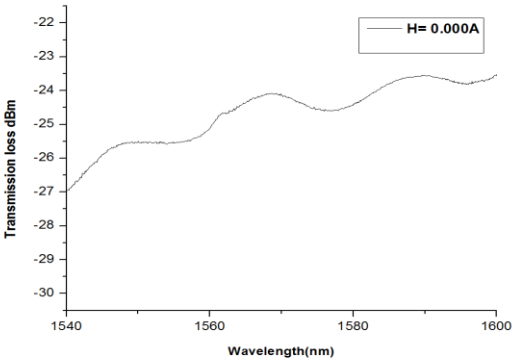

Figure 1: Initial optical spectrum

B. Sensor structure and Principles

The magnetic fluid filling structure is suggested in this paper is shown in "Fig.2". This sensor structure consists of two single-mode fibers with coupler, Magnetic fluid, and a fiber cavity tube. The size of the tube is very small and open to both ends. One SMF is connected to one end of the tube and the SMF is connected with the other end of the cavity tube. There is a line hole at the upper side of the cavity tube. The size of the cavity tube can be adjusted by moving to and fro of the connected pigtail of the SMF. The magnetic fluid is filled into the cavity tube using the syringe injection method **(28)**.

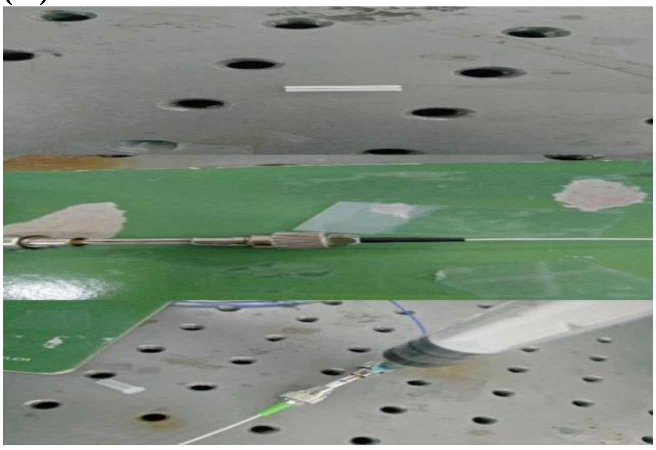

Figure 2: Filling process of Cavity tube

The experimental sensing structure has been shown in "Fig.3". This system consists of a Broadband light source, two single mode fiber coupler, sensing system, magnetic field, power supply, Tesla meter, and an optical spectrum analyzer OSA. The light from the broadband light source entered into the coupler and then went to the sensing system strike with Fabry-Perot (13) cavity tube and then reflected back and received by the OSA' where we can see some optical spectrum.

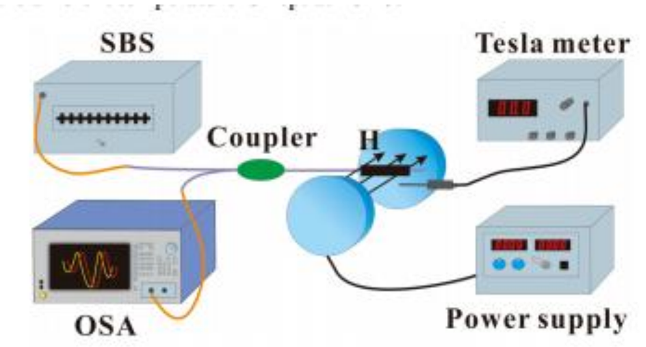

Figure 3: Process structure of optical Fabry-Perot cavity tube and sensing system of our model

The intensity of the reflected light from the sensing system can be described by the equation (1):

1. $I(r) = (R1+q2-2q\sqrt{(R\_1)} \cos\delta / 1+q2-2q\sqrt{(R\_1)} \cos\delta) *I$

Where, R1 is the reflected light from the cavity tube of the sensor, q is the absorption coefficient of the magnetic fluid inside the cavity tube, and δ is the phase difference in the cavity tube, which can be described as equation (2):

2. $\delta = 4\pi nL / \lambda$

Where n is the refractive index of the magnetic fluid, L is the length of the filled cavity tube, λ is the light wavelength, because the cavity tube is filled with magnetic fluid and the refractive index n can be describes as equation (3). Where Δn MF is the change of the MF refractive index, aH –n is the magnetic field sensitivity of the magnetic fluid in the cavity tube **(29)**.

3. $\Delta n\ MF = a\ H - n\ \ \Delta H$

III. EXPERIMENT AND RESULTS

This section is divided into two parts; first part will talk about the core setup of experiment and second part will talks about the results and discussion.

A. Experimental structure

Schematic diagram of the sensor system was shown above. Water-based magnetic fluid EMG705 produced by Ferrotec Corporation was chosen to fill the cavity tube of the Fabry–Pérot interferometer using the injection syringe method. In this letter, a cavity tube with the length of 0.3mm was proposed to fill the magnetic fluid to form the extrinsic Fabry–Pérot **(13)** interferometer. The size of the cavity tube can be adjusted by connecting the SMF pigtail with both holes. At the center of the both SMF pigtails into the cavity tube magnetic fluid is entered into the center of these holes. First of all, size is fixed and then magnetic fluid is filled into the cavity tube holes. This sensor is kept into the magnetic field. An external magnetic field is applied by the current source. The BBL broadband light source is produced by the Company method with the wavelength range of 1520nm to 1610nm. For calculating the magnetic field sensitivity an optical spectrum analyzer OSA is used by the Company Youkogawa AQ6370C (the measurement range from 1200nm to 2400nm).

B. Result and discussion

The sensor system and the equipment's, which were used in this article, are mentioned in above as shown above. The sensing cavity tube was observed in above and its size is calculated. The size of the filling cavity tube was 0.3mm and the magnetic fluid-filled cavity tube fiber Fabry–Pérot **(13)** sensor was polished as shown in above section.

In the experiments, the relationship between the wavelength shift and magnetic field was shown in "Fig.4", which indicated that the wavelength shift of the peak was linear to the magnetic field strength. The measurement sensitivity of 0.00113nm/nT was obtained as shown.

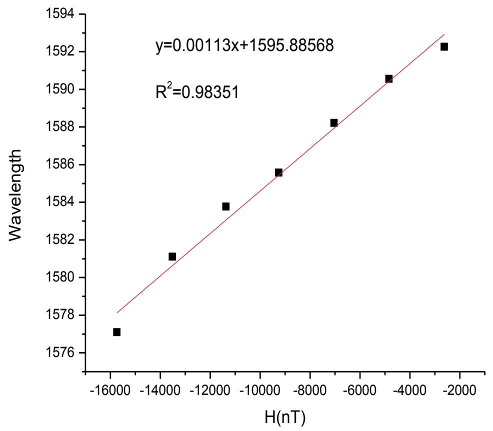

Figure 4: Relationship between wavelet and magnetic field strength

IV. CONCLUSION AND FUTURE WORK

Magnetic fluid-filled cavity tube of the fiber Fabry-Perot interferometer **(13)** is proposed. The sensing system mentioned in this article has very smooth, solid and easy fabricate. From the experimental results, we can observe that the sensor was usefulness with its sensitivity, which is measured as about 0.00113nm/nT. This experimental result was very close to the accuracy. So this kind of sensor can measure the magnetic field.

The results of this experimental setup also can be improved by changing the quantity or quality of the magnetic fluid. Some environmental conditions also influence it but it can be improved in the near future.

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