Magneto-refractive characteristics and mechanism of erbium-doped silica fiber

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Abstract

The magneto-refractive characteristics of erbium-doped silica fiber (EDF) are of great significance in magnetic field sensing. The fiber doped with rare earth Er^{3+} has a large magnetic moment and spin splitting, which makes a major contribution to the magnetic properties of the fiber. The refractive index of EDF in different magnetic fields was measured. The experimental results show that the refractive index of EDF decreases linearly with the increase of magnetic field. The magneto-refractive sensitivity of EDF is 3.21×10^{-5} RI /mT, which is about 20 times higher than that of single-mode fiber. The magneto-refractive properties of silica fiber are enhanced by rare earth element Er^{3+}.

I. INTRODUCTION

Compared with traditional magnetic field sensors, optical fiber magnetic field sensors have higher sensitivity, stability and miniaturization potential. At present, optical fiber magnetic field sensors are mainly based on the magnetic fluid field refractive index adjustable characteristics, magneto-optical Faraday effect and magneto-strictive effect [1,2]. The rare earth doped fiber magnetic field sensing is more stable and corrosion resistant and can work in complex environments such as underwater. Secondly, the rare earth doped fiber has a large Verdet constant and is used in the sensing field. Among them, EDF has high refractive index, excellent near-infrared transmission and optical transparency, and is easy to fabricate [3] and other optical properties, thus EDF is widely used, such as erbium-doped laser, erbium-doped fiber amplifier [4,5] and current sensing [6].

As an important parameter to measure the sensing response of optical fiber, the refractive index can reflect the characteristics of optical fiber such as dispersion, loss and optical transmission mode. It is a relatively intuitive test method. Erbium, as a rare earth paramagnetic material, has a responsive refractive index to external magnetic field. Under the external magnetic field, the refractive index of EDF changes significantly. Using doped fiber as the sensing unit has the advantages of strong stability, small volume, flexible design structure, easy networking and integration, etc., which has great potential in optical fiber magnetic field sensing [7].

Our work focuses on the magnetic refractive properties of EDF. The refractive index of optical fiber under the action of magnetic field is measured by digital holography technology. The feasibility of EDF magnetic field sensor is discussed.

II. EXPERIMENT AND RESULTS

To study the magnetic refractive characteristics of EDF, an experimental system was established. The system is based on the method of digital holography technology [8,9]. In the optical fiber region, the strength of the magnetic field can be changed by adjusting the electromagnet. The holograms of different magnetic field intensities are obtained, and the refractive index curve of the fiber varies with the intensity of external magnetic field.

An EDF was fabricated by the combined technology of modified chemical vapor deposition (MCVD) and atomic layer deposition (ALD) [10]. The cladding diameter of EDF is about 121.3μm, and the core diameter is about 16.8μm, as shown in Figure. 1.

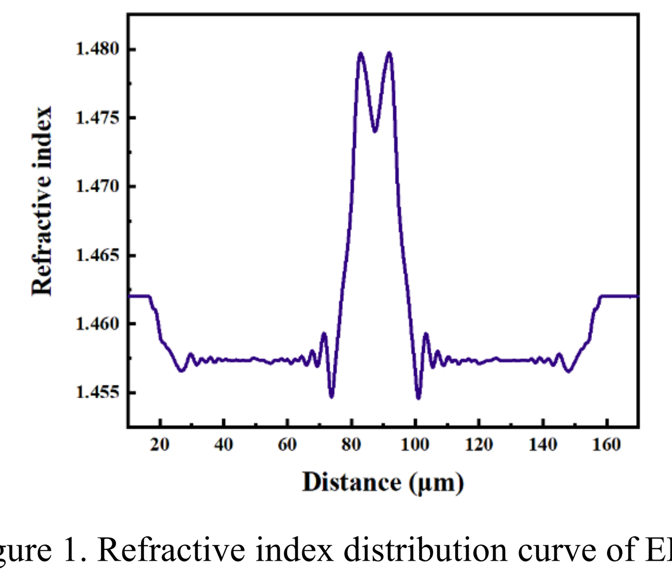

Figure 1. Refractive index distribution curve of EDF

The composition and content of the EDF were analyzed by Electron probe X-ray microanalyzer (EPMA-8050G, Shimadzu, Japan), as shown in Table I, among them, Er doping accounted for 2.9%, which proved that Er was successfully doped into the fiber.

TABLE I. WEIGHT PERCENTAGE LIST OF THE EDF

Element	Wt%
O	60.5
Si	27.1
Al	1.7
Ge	7.8
Er	2.9

EDF refractive index distribution curves under different magnetic fields were measured experimentally, as shown in Fig. 2. With the increase of the magnetic field, the change of the refractive index of the fiber core decreased significantly, and the refractive index distribution of the single-mode fiber under different magnetic fields was measured.

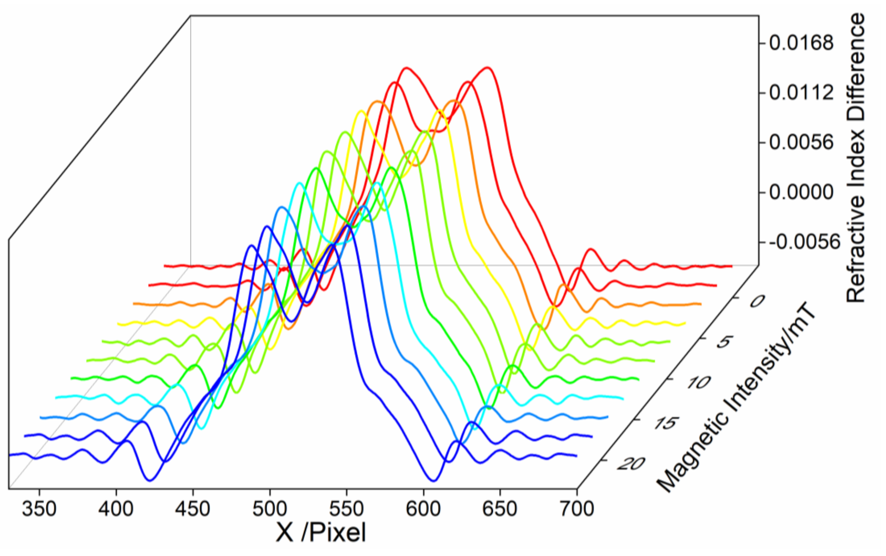

Figure 2. Refractive index distribution curve of EDF in different magnetic fields

The linear relationship between the specific magnetic field and the refractive index is shown in Fig. 3. With the increase of magnetic field intensity, the refractive index of single-mode fiber has little change, and the magneto-refractive sensitivity is 1.42×10^{-6} RI/mT, while the refractive index of EDF decreases linearly with the increase of magnetic field, and the magneto-refractive sensitivity is 3.21×10^{-5} RI/mT. The single-mode fiber does not have spin lone pair electrons and has weak magnetism, the magneto-refractive effect cannot be observed in the single-mode fiber. The addition of Er improves the magnetic characteristics of the fiber, such as magnetic moment and susceptibility, to improve the magneto-refractive characteristics of EDF. Therefore, significant magneto-refractive phenomenon is observed in the doped region of the EDF.

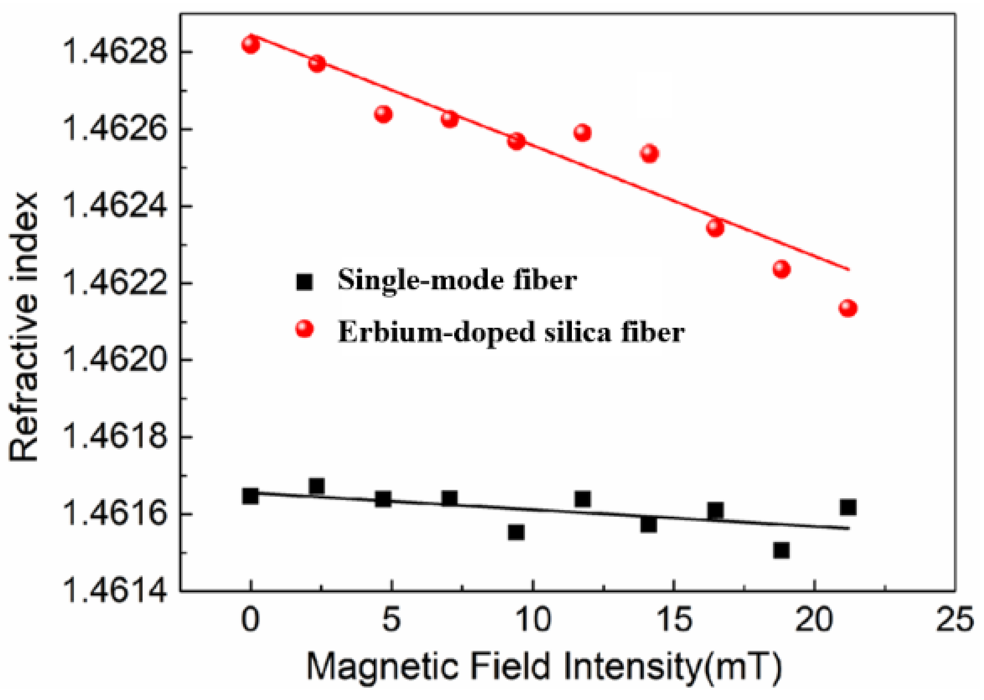

Figure 3. Relationship between the refractive index of fiber and magnetic field intensity

III. CONCLUSION

The mechanism of magnetic refractive of EDF is analyzed in this paper. The refractive index of EDF and single-mode fiber in different magnetic fields is measured experimentally. The refractive index of EDF changes significantly with the external magnetic field, showing a linear downward trend, and the magnetic refractive index sensitivity reaches 3.21×10^{-5} RI /mT. The sensitivity of the magneto-refractive properties of the fiber is closely related to the magnetic moment and susceptibility of the doped materials. It is expected that the magneto-refractive properties of the fiber can be further improved by studying other rare earth materials or co-doped fibers.

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