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Regular Articles

Wide-range magnetic field sensor based on magnetic fluid coated polymer optical fiber: The influence of concentration

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ABSTRACT

A simple design of a wide-range magnetic field sensor is proposed employing a tapered polymer optical fiber (POF) coated with magnetic fluid (MF). This sensor operates based on intensity modulation of the evanescent field technique. In order to expose the evanescent field to the surrounding environment, the middle segment of POF was tapered to the diameter of 0.5 mm and surrounded with MF. Output light intensity is modulated through magnetic field owing to the refractive index variation of MF as new cladding of the POF. In order to evaluate the effect of concentration on the sensing performance, experimental comparative studies were performed with incorporating different concentrated synthesized MF as well as the one provided by a commercial MF. The prepared nanoparticles were characterized by X-Ray diffraction pattern (XRD), scanning electron microscopy (SEM), vibrating sample magnetometer (VSM) and atomic force microscopy (AFM). Characteristic results confirm the formation of Fe_3O_4 crystallite nanoparticles size of less than 10 nm and cubic spinel structure with high saturation magnetization of 68.34 emu/gr. Results reveal that the proposed sensor is capable of detecting magnetic field with linear response of more than 99% in the wide range of 2.5–125 mT measurements.

1. Introduction

The subject of sensors has emerged as a very fascinating topic in basic sciences in recent times due to their important applications in physics, chemistry and engineering. Among the sensors, polymer optical fibers (POFs) have attracted wide attentions in constructing various sensor devices which have versatile features. These sensors have higher flexibility, less brittleness and larger core diameter than silica based-optical fibers. Thus, the sensors present a wide range of applications for optical fiber based-detection techniques [1–5]. In recent years, many scientists have studied fiber sensors because the sensors have many potential applications in chemistry, mechanic, medical analysis, and especially diagnostics techniques during testing and therapy stages [6]. The demand for optical fiber sensors has appreciably increased due to their immunity to electromagnetic waves as transferring sensed data, electrical insulation, lightweight, small sizes and high selectivity and sensitivity [7–11]. Among these advantages, the most important one is their safety of service and insulating power which make it able to perform measurements at precise locations that are often hard to reach in body towards magnetic resonance (MR) diagnostics applications. Since optical fiber conducts light in a sealed dielectric environment, it becomes immune from electromagnetic fields and so does not perturb magnetic fields inside the MR-scanner, not affecting image quality, which is crucial factor for the preservation of the quality of diagnostic information. Moreover, when it takes the sensing information of remote location, as a target region, the information would be safe to pass the conducting way to the monitoring point. These two versatile features further show the potential role of optical fiber sensors in medicine and thereby they are especially attractive to exposure the magnetic resonance scanner and develop “MR-compatible” sensors. The improvement of this kind of sensors as an important topic has been performed by an efficient and popular technique of decorating optical fiber with a proper nanostructure. It causes to employ different sensing applications such as ions [12], temperature [13], biomolecules [6], gases [14,15] and magnetic fields [16]. Although considerable research has been devoted to the pressure, temperature and gases sensors, up to my knowledge only few works has paid to the magnetic field strength sensor based on nanostructure-coated fiber in different environments. Regarding that, in this work, we have developed a compact and simple magnetic field sensing configuration with employing magnetic fluid. Magnetic fluid (MF), known as Ferro-fluid, is a type of stable colloidal material including magnetic nanoparticles dispersed steadily in an appropriate liquid carrier such as water, oleic acid and ester which undergoes directed aggregation into clusters under the applied magnetic field [17]. MFs have been widely used in magnetic field sensors due to their interest magneto-optical

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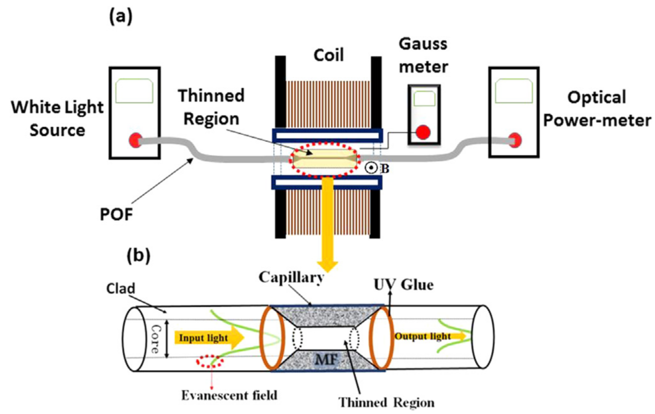

Fig. 1. (a) Experimental setup for magnetic field measurements, (b) magnified sensing region.

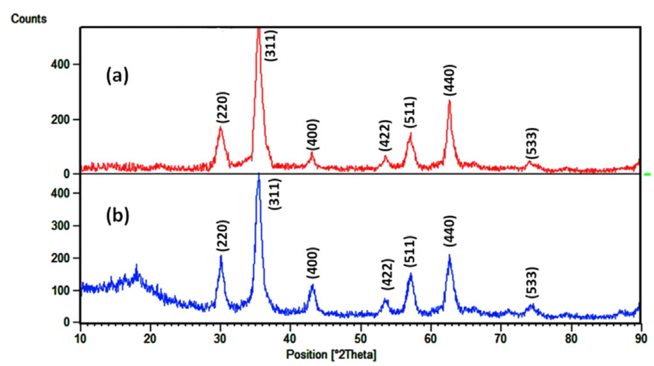

Fig. 2. XRD patterns of (a) as-synthesized and (b) commercial Fe_3O_4 nanoparticles.

properties such as Faraday effect, tunable refractive index (RI), field dependent transmission and birefringence [18–20]. To implement sensing operation, MF coated optical fiber could be exploited in the diverse optical sensing configurations like interferometers [21], fiber gratings [20], and microfiber knots [22]. The basic technique of these devices is the variation of MF refraction index (RI) in the presence of the magnetic field which was considered by Yang et al. through total reflection method [18]. Gao et al. have experimentally demonstrated measuring magnetic field using photonic crystal fiber (PCF) filled with MF [23]. They have also investigated the length of filled region and the highest sensitivity was related to the sample with 19.7 cm length in the filled region. In another study, a magnetic sensor based on singlemode-multimode-singlemode (SMS) fiber structure was fabricated [24]. The clad of the multimode fiber was corroded by HF acid and maximum sensing performances observed with corrosion time of 1620 s. They have used oil based MF with nanoparticles of around 10 nm diameter was provided by Ferrotec Company. Nancy et al. have proposed a long-period fiber grating (LPG) sensor employing commercial MF (EMG605) [16]. Reported sensor was able to measure magnetic field as low as 7.4 gauss. Another compact and low cost magnetic field sensor based on interferometry technique has also been reported employing multimode optical fiber immersed into MF (EMG605) [25]. In the aforementioned works, the sensing configuration has not been studied the influence of MF structure on the yielded results and also the reported literatures weren't able to cover wide range of sensing. In this work, MF was synthesized and was characterized in detail, and then a simple and cost-effective intensity based sensor was developed. The effects of these-prepared MF with different content on the sensing performances were experimentally studied and the results were compared with one that used commercialized MF.

2. Optical fiber based sensing setup

For this kind of sensor, the first and essential step is removing the fiber clad by tapering or etching techniques. In the experiment, a 10 mm long at the center of POF thinned to 0.5 mm mechanically employing a homemade sanding machine and then smoothed by a soft sand paper. The applied POF (series: AFBR-HUXYYYZ Avago technologies) had an overall cladding diameter of 1 mm and numerical aperture of 0.48. Thinned region was encircled trough capillary filled with MF (Fig. 1b). To maintain MF surrounding the POF both ends of capillary enclosed with UV glue. Sensing region, thinned fiber surrounded with MF, was placed in the uniform magnetic field. The magnetic field was generated via coil whose intensity adjusted by changing supply current as illustrated in Fig. 1a. In addition, to measure exerted magnetic field a gauss meter was placed next to the sensing region of POF. Intensity based sensors basically needs stable light source which was prepared thanks to the standard driver, adequate cooling system and also efficient LED light source (part No. LED-P1-DH-White). Applied LED had the highest luminance near 560 nm that coupled to the one end of POF. The light emerging from the other end of the fiber is fed to optical power meter (model: PM 20 A, Thorlabs) and output light intensity was recorded. The proposed sensor's operation is based on the modulation of the evanescent field through magnetic field on the sensing region containing MF. As the light reach sensing region some portion of light leave the fiber core providing the interaction with MF. When the external magnetic field is applied the random pattern of the

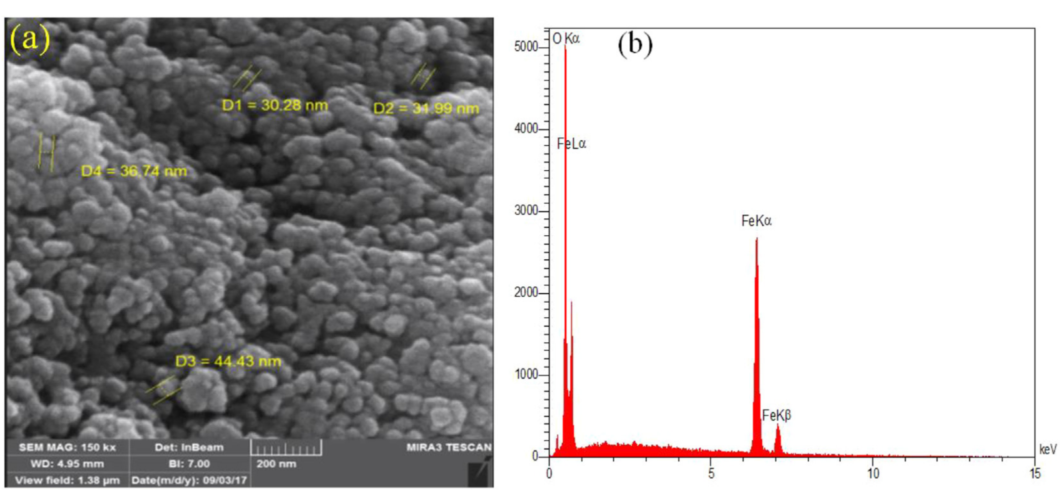

Fig. 3. (a) SEM micrographs and (b) EDS of Fe_3O_4 nanoparticles synthesized by co precipitation method.