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Application of Permanent Magnetic Powder for Magnetic Field Sensing Elements

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A multimode optical fiber with a composite polymer-magnetic coating was investigated as an optical fiber magnetic sensing element (OFMSE) for detecting external magnetic fields. The coating was formed by dispersing the magnetic powder Nd-Fe-B in poly-(ethylene-co-vinyl acetate)-EVA solution in toluene. The influence of an applied magnetic field on the change in intensity of a light signal propagated through the OFMSE constructed was investigated. In this study, the influence of the magnetic powder concentration in the composite coating on optical propagation characteristics of the modified optical fiber with the composite polymer-magnetic coating was investigated.

1. Introduction

Measuring magnetic fields has been a critical task in different technical areas. The introduction of optical fibers has changed the methods of telecommunications and related fields. Optical fibers provide a large band width, and have a low cost of mass production and a low transmission loss in communication channels.[(1–3)] Optical fibers coated with a composite polymer-magnetic powder coating can be used as an optical fiber magnetic sensing element (OFMSE) (see Fig. 1). OFMSE can be used in areas that are too harsh to measure with conventional systems because its optical fiber is usually made of dielectric material that has high resistances to vibration, electromagnetic interference, thermal shock and corrosion.

The OFMSE presented in this paper was constructed on the basis of intensity-based optical fiber vibrating sensors (OFVS) which are used in damage monitoring of fiber-reinforced plastics, vibration sensing, and the location of impacts.[(4,5)] The resonse of OFMSE would be different if vibration is present. Because vibrating sensors are defined to respond to vibrations and impacts, those responses have different shapes. The presence of magnetic field is visible with a rapid change in signal, compared with that of the vibrating

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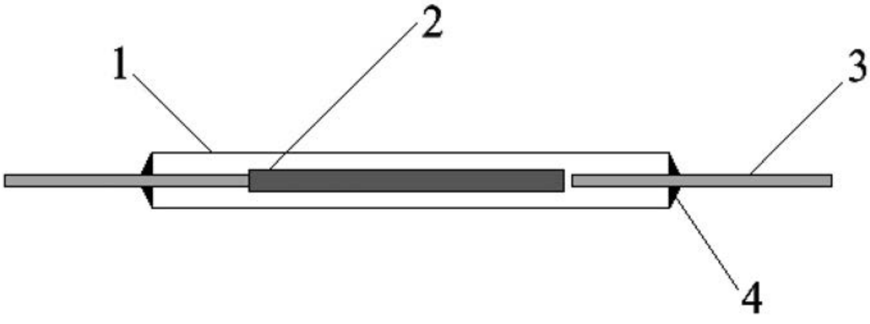


Fig. 1. Magnetic field sensing element based on modified optical fiber with composite polymer-magnetic coating. 1, capillary tube; 2, coated optical fiber; 3, optical fiber without composite coating; 4, glue.

sensor. The only function of OFMSE is detecting magnetic fields not to measuring them; thus, signal attenuation successfully fulfills this task. The sensing element consists of two optical fibers held in close proximity to each other and is based on the principle of intensity modulation. One fiber is coated with a composite polymer-magnetic coating and cantilevered on a plastic plate. The cantilevered section moves in the opposite direction to the rest of the sensor in response to an applied magnetic field, and the amount of light coupled between the two fibers is modulated. The composite coating can be made by adapting the existing process of manufacturing optical fibers in stages in which a polymer coating is applied to the drawn fiber.(6–8) Instead of a coating of solely polymer, a coating with magnetic powder particles can be used. Appropriate composite coatings are homogenous and thus enable reliable magnetic detection, while minimizing side effects. A copolymer of ethylene and vinyl-acetate (EVA) was chosen for the polymer component of the composite coating because of its good adhesive properties. Using EVA, it is possible to produce a coating without the application of UV or thermal curing; hence, the number of process parameters is reduced. The magnetic component of composite coatings can be selected from a variety of permanent ferromagnetic powders (e.g., hard ferrite, Sm-Co and Nd-Fe-B).(6,7) Nd-Fe-B magnetic powder has shown better results than $SmCo_5$, so it was chosen for investigation.(9–11) In this report, the influence of the concentration of magnetic powder in a composite coating on the sensitivity of OFMSE is discussed.

2. Experimental

For the beginning of the experiment, following materials were chosen:

- Multimode optical fiber with acrilate coating, produced by Alcatel
- Polymer poly(ethylene-co-vinyl-acetate) produced by DuPont under commercial name ELVAX 265
- Magnetic powder of hard magnetic material Nd-Fe-B

Properties of the optical fiber are shown in Table 1.

Table 1
Properties of multimode optical fiber.

Optical properties		
Signal attenuation	λ=850 nm λ=1300 nm	2.87 dB/km 0.66dB/km
Frequency range	λ=850 nm λ=1300 nm	522 MHz 748 MHz
Geometrical properties		
Core diameter	62.5 μm	
Cladding diameter	125 μm	
Optical fiber diameter	250 μm	

A magnetic powder of $Nd_2Fe_{14}B$ was milled for 2 h under the protecting fluid toluene. The characterization of the magnetic powder was done before and after milling. After milling, the magnetic powder was measured using SEM and optical microscope with reflected light. Images were analyzed on " Leica" equipment with the software package Qwin.

The polymer-magnetic composite coating consisted of a mixture of the permanent magnetic powder and poly-(ethylene-co-vinyl acetate) produced by DuPont under the commercial name ELVAX 265. The polymer was used in a toluene solution with a 33.33 mass% polymer. The polymer was dissolved in toluene for 2 h at a temperature of 60˚C. After dissolving EVA in toluene, the magnetic powder was dispersed in the solution. Samples with four different concentrations of magnetic powder in the composite coating were made. The amount of magnetic powder in each sample is presented in Table 2.

The original coating of the optical fiber was removed and the polymer-magnetic composite coating was applied. The end of fiber without original coating was immersed in the solution of composite material. The end of the fiber was slurred around the solution, and left for 24 h to dry in air. A drop that formed at the end was cut off. The thickness of optical fibers with composite magnetic coating depends on the amount of magnetic powder. It was between 0.34 mm (sample with 50 mass% magnetic powder) and 0.39 mm (sample with 20 mass% magnetic powder).

To avoid any influences of positioning and connecting on the sensitivity of the OFMSE in the capillary tube, a plate for simulation has been constructed (Fig. 2). The simulation plate consisted of one plastic plate with an incision and a round hole in the middle. The diameter of the hole was 2 cm and the depth of the incision was 1 mm. The optical fiber, which received signals, had a larger diameter to avoid problems with positioning and cantilevering fibers.

The equipment for measuring signal attenuation is shown in Fig. 3. The light from a light emitting diode (λ=849 nm) was launched into an optical fiber with a deposited composite polymer-magnetic coating. The intensity and wave length of the light emitted through the optical fiber were constant during the experiment. The light signal was

Table 2
Mass percent data of Nd-Fe-B powder in different samples.

Sample number	Mass% of Nd-Fe-B powder
1	50
2	40
3	30
4	20

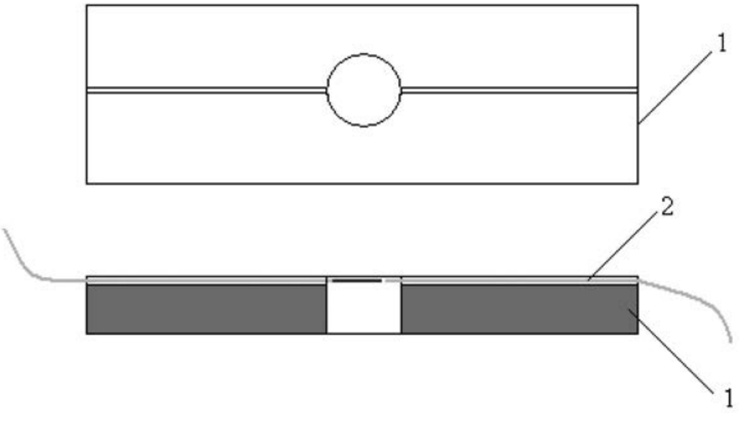


Fig. 2. Simulation plate for measuring signal attenuation of optical fibers with composite coating: 1, plastic plate; 2, optical fiber.

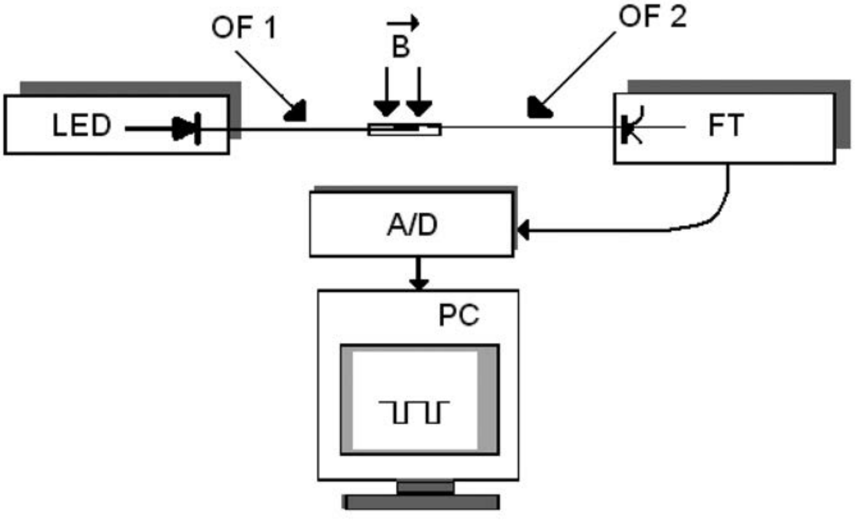


Fig. 3. Equipment for measuring signal attenuation of OFMSE.

received by the optical fiber that was fixed at the opposite end of the plate. The intensity of the light from this fiber was detected by a photodetector. The amplified output signal from this fiber was connected to a data acquisition system consisting of an A/D card, a personal computer and a specially developed software in Pascal.

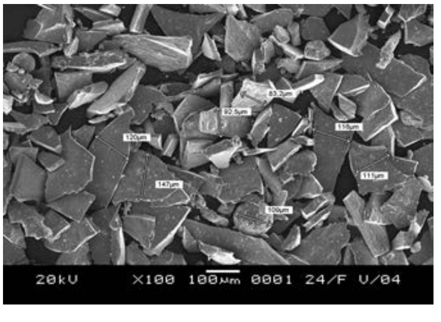
If the OFMSE is not in the magnetic field, the ends of the optical fibers are collinear and the intensity of the propagated light is maximal. If a permanent magnet approaches the sensing element, light intensity decreases. In the first part of the experiment, the magnetic field was increased from 0 to the induction of about 200 mT and was then decreased to 0. In the second part of the experiment, the sensing element was positioned in an oscillating magnetic field. The magnetic field oscillated with a frequency of 1 Hz. The maximum induction of the oscillating magnetic field was 200 mT.

3. Results and Discussion

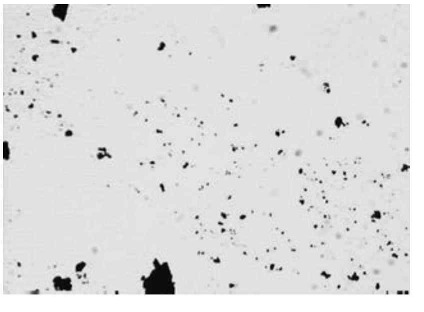
To be used as a magnetic component, Nd-Fe-B powder must be milled to the appropriate size. Previous research has shown that the optimal size of particles is between 1 and 5 μm.[10] (see Fig. 4)

In this study, the dependence of the response of the OFMSE with different concentrations of magnetic powder on the external magnetic field was investigated. Figure 5 refers to the first part of experiment.

Every sample reacted in the external magnetic field. The parts of recorded responses have been measured at approximately equal maximum magnetic field strengths (maximum induction was around 200 mT). Depending on concentration, signal attenuation is different for different samples. The highest attenuation was observed for the sample number one, which had the largest amount of magnetic powder. If the amount of magnetic powder in the composite coating decreases, signal attenuation in the external magnetic field decreases. The sample with 20 mass% of magnetic powder in the composite coating showed good sensitivity, but in the opposite direction (with increased magnetic field strength, the intensity of the signal increased).



(a)



(b)

Fig. 4. Magnetic powder (a) before and (b) after milling in toluene for 2 h.

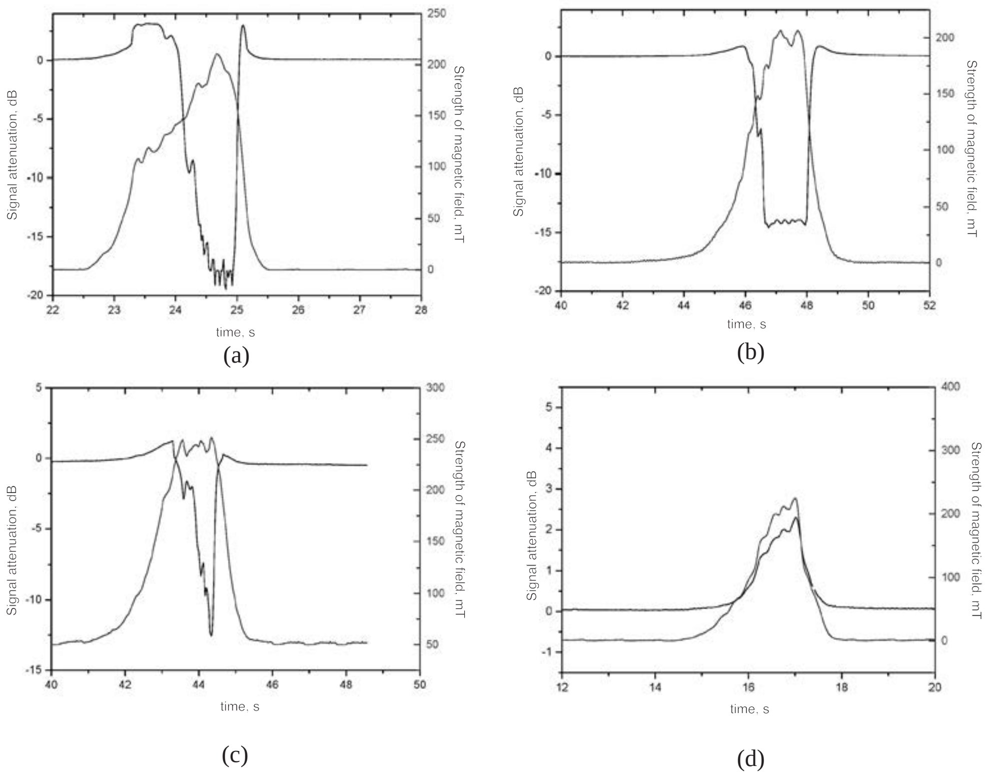


Fig. 5. Responses of samples in external magnetic field with (a) 50 mass% magnetic powder, (b) 40 mass %magnetic powder, (c) 30 mass% magnetic powder and (d) 20 mass% magnetic powder.

The larger the diameter of the receiving optical fiber the easier the signal was to receive; however, the interpretation of the results was difficult. All samples show slight at the beginning of measurement. The reasons for that are assumed to be the axes of the coated and receiving optical fibers were not completely collinear and a difference in the angle of their axes existed. When an external magnetic field was applied, the axis of the coated optical fiber passed through the axis of the receiving optical fiber with a larger diameter and at that point a maximum signal was achieved. After that, the angle between the axes increased and the intensity of the signal decreased. In the case of the sample with 20 mass% of magnetic powder, that did not occur, the maximum signal remained. In this configuration of OFMSE, the content of Nd-Fe-B was too low for the proper magnetostrictive reaction of the composite coating (see Table 3).

The second part of the experiment was conducted in an external magnetic field that oscillated with a frequency of 1 Hz. Figure 6 shows the responses of different samples in the oscillating magnetic field. This part of the experiment was also carried out with a receiving fiber of a larger diameter.

As is obvious from Fig. 6, the sample with 50 mass% magnetic powder in the composite coating shows good signalresponse and reversibility. The sample with 40 mass% magnetic powder shows good response in one response in one direction and only a slight response in

Table 3
Maximum signal attenuations and magnetic field strength.

Mass% of Nd-Fe-B powder	Maximum signal attenuation, dB	Maximum magnetic field strength, mT
50	19.92	194.3
40	14.37	206.6
30	12.41	215.7
20	–2.29	223.4

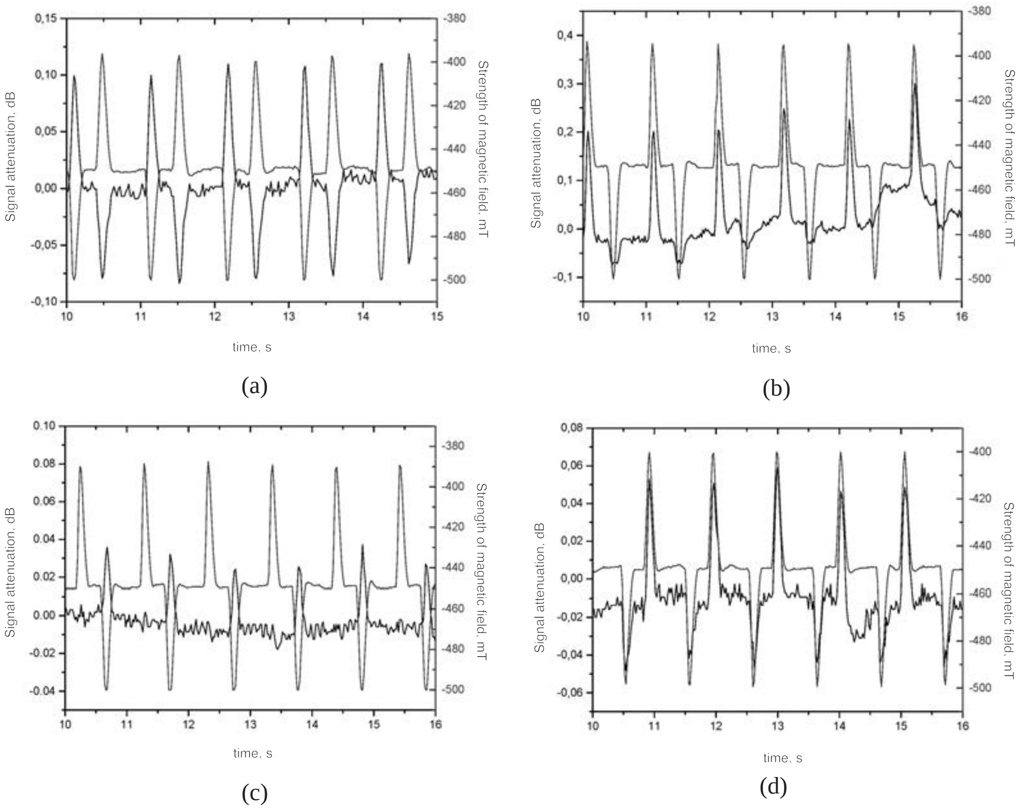


Fig. 6. Responses of samples in an oscillating magnetic field with (a) 50 mass% magnetic powder, (b) 40 mass% magnetic powder, (c) 30 mass% magnetic powder, (d) 20 mass% magnetic powder.

the opposite direction. This sample did not reverse completely between two response maximums. Samples with magnetic powder at 30 and 20mass% in the composite coating show responses in only one direction without any decrease in signal intensity in the opposite direction. The sample with 20 mass% magnetic powder does not show good reversibility. Neither of these samples show an increase in signal intensity at the beginning of measurement because the magnetic field oscillated too rapidly. A decrease in reversibility with a decrease in the amount of magnetic powder in composite coating occurs owing to a higher influence of elastic properties of the composite coating than that of its magnetic properties.

4. Conclusions

OFMSE with optical fiber coated with a composite polymer-magnetic coating has been introduced in magnetic field sensing. A composite coating is a very important part of OFMSE, and its composition has great influence on magnetic field sensitivity. As other composite materials, composition has great influence on the mechanical properties responsible for the response speed, sensitivity and reversibility of OFMSE. In this paper, the influence of the content of Nd-Fe-B powder in the composite coating of the optical fiber on the sensitivity an external magnetic field was investigated. Samples with different amounts of magnetic powder were prepared and signal attenuation in an external magnetic field was measured. Measurements were done in slowly applied and oscillating magnetic fields. If the amount of magnetic powder in the composite coating is decreased, signal attenuation decreased on both fields. The best sensitivity and reversibility were attained with samples with 50 mass% magnetic powder in the composite coating. Samples with magnetic powder at 30 and 40 mass% showed good responses to the external magnetic field. In the experimental configuration of OFMSE, 20 mass% magnetic powder was too low for a magnetostrictive reaction of composite coating, because of a high amount of polymer with a high module of elasticity. This is only a preliminary investigation, and further research in design of OFMSE should be done.

Acknowledgement

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