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New Optical Glasses with High Refractive Indices for Applications in Optical Current Sensors

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The paper concentrates on the optical fibre sensors of electric current intensity. The specially elaborated glasses with high values of refractive indices were investigated in the prepared testing stand. The glasses have possessed the refractive index values n in the range $1.6 \leq n \leq 2.2$. For the glasses the values of the Verdet constants for two waveguides: $\lambda_1 = 635$ nm and $\lambda_2 = 1550$ nm were determined. The obtained results showed that the elaborated on the base of new glasses optical fibres are much more sensitive on the action of magnetic field than the silica fibres.

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1. Introduction

In power industry, in control and safety systems of power supply lines there are often used current measuring transformers. The very attractive alternative for current measuring transformers may occur in near future optical fibre current sensors (OFCSs) often named optical current transducers (OCTs) [1–9].

In the sensors of this kind, parameters of the light wave have changed which propagates in an optical fibre located near a power supply line [10–12].

Physical phenomenon, which is utilized in optical fibre sensors of magnetic field and electric current, is the magnetooptic Faraday effect [10–18].

The Faraday effect consists in arising a circular birefringence in a material medium induced in it by external magnetic field.

In result of this induced birefringence the transmitted in the medium polarized light changes its state of polarization (SOP), practically the angle α of azimuth of polarization changes itself. The twisting of the angle of polarization is customary named as the Faraday rotation

$$\alpha = VBl\cos\Theta,$$

where V — so-called the Verdet constant, B — induction of the magnetic field, l — length of light propagation in the magnetic field, Θ — angle between a direction of light and a direction of magnetic field vector.

The important features of the Faraday effect are:

- its linearity (in relatively wide range of magnetic field) [12];
- its evenness (the torsion rises even if the light propagates in opposite direction) [8, 9];
- very short time of response of a medium on magnetic field action (about 10^{-9} s) [9].

In Fig. 1 the idea of construction of the optical sensor of magnetic field based on an optical fibre is presented. The conductor with electric current is located inside a spool of measuring optical fibre. Induced magnetic field by flowed electric current is concentric to rolls of an optical fibre. Thanks to the circular symmetry of the sensor, the Faraday effect is the greatest and the interaction between magnetic field and light is the most effective.

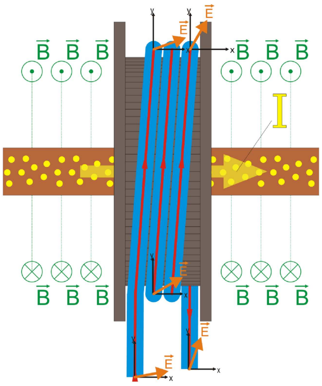

Fig. 1. Optical fibre current sensor scheme.

To the main advantages of the optical fibre sensor of magnetic field belong:

- safety of services because the optical fibres are made by very good isolators,

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- good insulating power all elements applied in the measuring system,
- insensitiveness to electromagnetic interference,
- very short response time (because the Faraday effect is very prompt), which makes possible applying these sensors in protection systems.

In practical realization of the optical measurements of magnetic field with using of the optical fibres very important is minimization of own linear birefringence of the optical fibre and particularly — restriction of random changes of the birefringence, which induces noises of the SOP. The noises disturb information about the measured magnetic field (or intensity of electric current) [3–7].

In this paper, its authors present results of investigations concerning elaboration of the optical fibre sensor of magnetic field based on glasses with the high value of refractive indices. Additionally, the obtained optical fibres are characterized by small internal mechanical stresses and high values of the Verdet constants. At first step, the investigations have focused on finding suitable glasses for production of sensing optical fibres [8, 9].

2. High refractive index glasses for sensing fibres

Prospecting of glasses for elaboration of the sensing optical fibres were led in the group of multicomponent glasses. For this objective inDepartment of Optical Radiation at the Białystok Technical University in cooperation with Department of Optoelectronics at Silesian University of Technology in Gliwice, Poland many glass samples were made, which characterized high values of refractive indices and possessed various interesting physical and chemical properties. One can find detailed information concerning elaborated glasses in the paper [8]. Four glasses were selected for their future applications in production of the sensing optical fibres. The selected glasses have possessed the refractive index values n in a range: $1.6 \leq n \leq 2.2$. The glasses were tested in the magnetooptic research stand. For the all glasses the values of the Verdet constants for two wavelengths: $\lambda_1 = 635$ nm and $\lambda_2 = 1550$ nm were determined. The obtained results are presented in Fig. 2 and in Table.

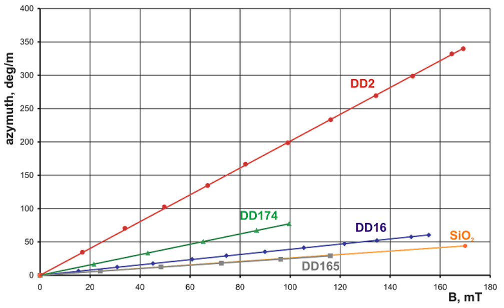

Fig. 2. Magnetooptic sensitivity of the elaborated glasses.

TABLE

The Verdet constants of the elaborated glasses.

Symbol	Refractive index	Verdet's constants [rad/(T m)]	
		$\lambda_1 = 635$ nm	$\lambda_2 = 1550$ nm
DD16	1.6	6.58	1.28
DD165	1.65	4.34	–
DD174	1.74	13.85	–
DD2	2.2	35.70	8.57

3. Investigations of magnetooptic efect in sensing fibres

For elaboration of the optical fibre sensor of magnetic field from the glass DD16 (production name) the optical fibre was made (Table). The cut wavelength of this fibre amounts to 632.8 nm. The elaborated optical fibre was tested in a measuring stand presented in Fig. 3. In experiments the laser light with 635 nm wavelength was applied. As a source of the external magnetic field the air coil of 80 cm length was used with a direct current. At the end of optical fibre the SOPs in the function of the magnetic induction B (produced by the air coil) were registered.

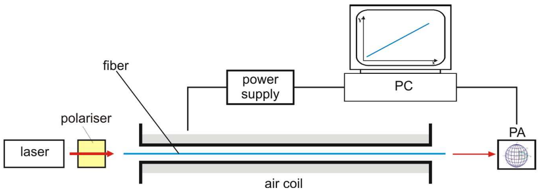

Fig. 3. Scheme of the measuring stand.

Figure 4 presents the results of investigations of the sensing optical fibre (DD16). For comparison, in Fig. 4 the results of testing the silica single mode optical fibre of step-index type have performed in the same stand were presented, too.

For the optical fibre sensor two configurations of work were elaborated. The measuring configurations in Fig. 5 are presented. In the first configuration (Fig. 5a) the light is directed to the measuring head by a single mode polarization maintained optical fibre. In the vicinity of the measuring magnetic head the light is introduced from this fibre to the sensing optical fibre. This fibre is twisted on the suitably prepared cylinder (Fig. 1).

At the end of the sensing optical fibre, the light was directed to the polarizing prism (the Wollaston prism) where it was divided in two orthogonally polarized light beams. Both beams were coupled with the multimode fibres and transmitted to the photodetectors. Each signal

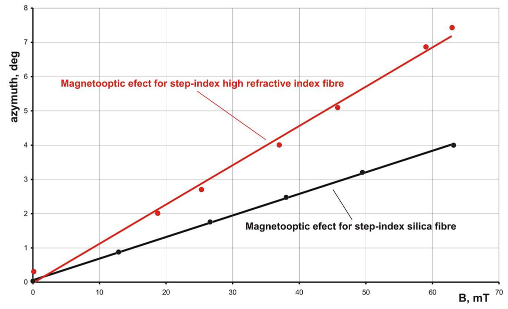

Fig. 4. Result of magnetooptic measurements in the optical fibres.

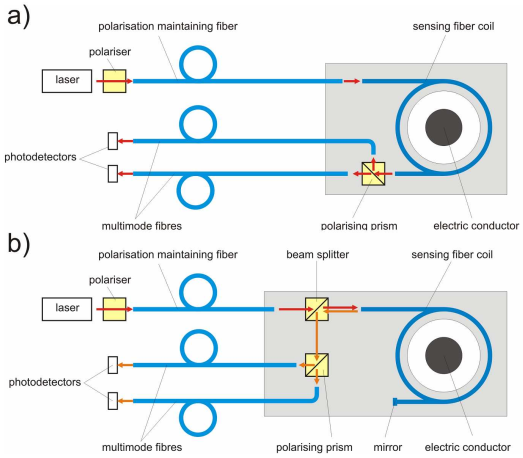

Fig. 5. Schemes of optical fibre current sensor system.

from the photodetector was proportional to a respective polarization component of incident light and it depended on the intensity of the external magnetic field. Correct action of this system was required to apply the beam splitter which should be insensitive to the state of polarization of the incident light. Signals from the photodetectors were preliminarily numerically modified according to relation

$$I = \frac{I_1 - I_2}{I_1 + I_2},$$

where I_1 and I_2 are the signals from the first and second photodetectors. Such modified signal I may be calibrated in the values of the electric current of power supply lines.

In Fig. 5b the measuring system is presented where the sensing optical fibre is ended by a reflecting mirror. The light beam propagates in the magnetic field twice — there and back. (The magnetic field is created by the electric current in the power supply line.) By means of a beam splitter the light is directed to the Wollaston prism. There, the light is divided in two orthogonally polarized light beams. Both beams were coupled into the multimode fibres and transmitted to the photodetectors. (Using the Faraday mirror one can restrict effects of changes of the state of polarization caused by existing birefringent elements in an optical path [9].)

4. Conclusions

Within the framework of operation concerning elaboration of the optical sensors of electrical current the suitable glasses were performed. Next, the single mode optical fibre based on the elaborated glass with the refractive index value $n = 1.6$ was produced. The first investigations have shown that the magnetooptic sensitivity of this fibre is much higher than for the silica fibre. In the nearest future the sensing optical fibres based on the glasses with the higher values of refractive indices will be produced.

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