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Birefringent optical fibers axial positioning technique for fiber Bragg gratings writing

Sergei V. Arkhipov[1] · Vladimir E. Strigalev[1] · Sergey V. Varzhel[1] · Yulia D. Smirnova[1] · Nadezhda S. Soldatova[1] · David A. Palanjyan[1] · Anna S. Munko[1] · Andrey A. Petrov[1]

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Abstract An experimental setup for fiber Bragg gratings writing with preliminary optical fiber orientation has been described in this paper. The writing efficiency results of Bragg gratings of type I in birefringent optical fiber with an elliptical stress cladding at two extreme positions of the stress ellipse were presented. These results were compared to the similar data, received after the fiber Bragg gratings inscription in PANDA carried out in the same way.

Keywords Scattering interference pattern · Fiber Bragg grating · Phase mask · Excimer laser · Writing efficiency · Birefringence · Stress applying parts · Anisotropic optical fiber

1 Introduction

Fiber Bragg gratings (FBGs) are currently one of the most important elements in a variety of fiber optics devices and measurement systems of various physical quantities.

The possibility of material optical refractive index (RI) modulation by the radiation is widely used in various elements production including FBGs. From the coupling-mode theory it is known that the FBG reflection coefficient depends on the induced RI change inside the waveguide (Kashyap 1999). The induced RI in its turn is proportional to the laser beam density.

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✉ Sergei V. Arkhipov
thinkingcreature@yandex.ru

[1] Saint-Petersburg National Research University of Information Technologies, Mechanics and Optics, Kronverkskiy pr. 49, 197101 Saint-Petersburg, Russia

FBGs have several advantages compared with other reflective elements (for example, interference mirrors and bulk diffraction gratings)—wide variety of spectral and dispersion characteristics, all-fiber design, ease of fabrication, low loss, and others.

One of the FBGs' applications is to use them in different systems that measure temperature, humidity, pressure, deformation, chemicals concentration (Kukushkin et al. 2006). Using of FBGs inscribed in polarization maintaining specialty anisotropic single-mode optical fibers allows to fabricate high-precision phase interferometric sensors (Meshkovskiy et al. 2013).

The anisotropy of lightguide optical properties and, as a result, birefringence is usually achieved using the photoelastic effect by adding in the optical fiber structure stress applying parts (SAP) that create mechanical stresses. The fibers with elliptical stress cladding used in this work are an example of such structures. In optical fibers of such design the slow birefringence axis (BA) matches the long stressing ellipse axis.

Some SAP properties as material radiation absorption, its form and RI influence the efficiency of structures inscription in fiber. Hence, the optical fiber parts position is to be taken into account during the FBG writing.

Today there are several ways to determine the optical fiber parts position and consequently the position of BA. It can be accomplished by the observation of cleaved and polished endfacet with a microscope with strong magnification which, however, is hard to implement in the FBG inscription area, in addition this method is destructive. There are other ways to determine the SAP position which include the application of the tensile stress to the investigated fiber part followed by the pattern change study in fiber output (Carrara et al. 1986); fiber lateral side illumination by the white source followed by processing of the resulting fiber endfacet image obtained from the camera (Fujikura Ltd. 1990).

The method used in this work is based on the observation of the interference pattern of scattered light while illuminating the lateral surface of the optical fiber with coherent radiation source such as He–Ne laser (Aniano 1994; Watkins 1974; Smithgall et al. 1977).

2 Experimental setup

In the present work for the FBG inscription the modified for SAP positioning setup described in the papers (Varzhel' et al. 2011; Varzhel' et al. 2012) (Fig. 1) was used.

In this study the excimer laser COMPexPro 102 F made by Coherent with the gas mixture KrF was used. The laser generates 20 ns pulses with the central wavelength of 248 nm. The "Coherent" attenuator allows to set the laser beam density. Laser beam passes through the cylindrical lens mounted on the linear stage. The cylindrical lens with the focal length of 500 mm focuses the laser beam to reach the required energy density. The slit allows to change the size of radiated fiber part thus to set the FBG length.

The excimer laser pulse passes through the phase mask Ibsen Photonics with the period of 1065.3 nm, optimized for the 248 nm wavelength and diffracts to the +1 and −1 orders. This interference pattern modulates the RI in the fiber placed at a short distance from the phase mask. The He–Ne laser presented in the Fig. 1 generates the radiation of 5 mW power and is used to get the scattered light interference pattern from the illuminated fiber area.

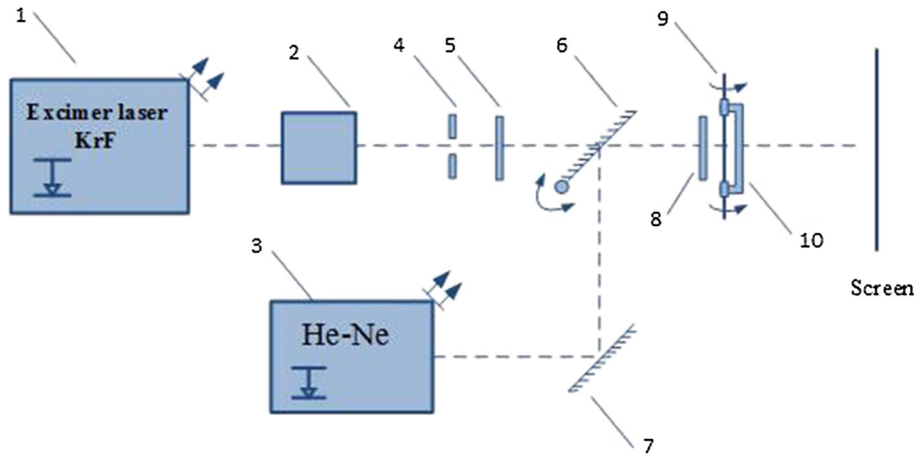

Fig. 1 FBG inscription setup: *1* KrF excimer laser, *2* attenuator, *3* He–Ne laser, *4* slit, *5* cylindrical lens, *6* flip mirror, *7* mirror, *8* phase mask, *9* optical fiber, *10* angular micropositioner

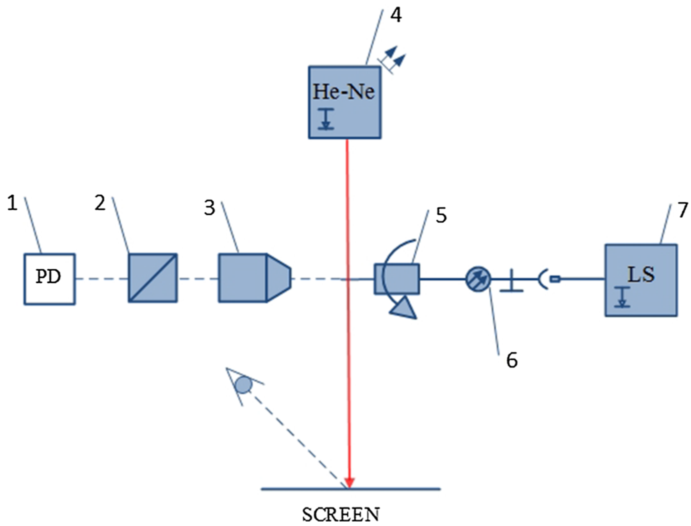

Fig. 2 Scattering interference pattern observation scheme: *1* photodetector, *2* polarizer, *3* objective, *4* He–Ne laser, *5* angular micropositioner, *6* optical fiber sample, *7* polarized light source with FC connector which key is oriented along the slow BA

3 The preliminary fiber testing

The birefringent optical fibers with elliptical stress cladding with 4 mol% (ESC-4) and 12 mol% (ESC-12) of GeO_2 in its core are the subjects of study. These anisotropic lightguides are fabricated using the technology described in the papers (Eron'yan 2000; Bureev et al. 2007). PANDA fiber was studied for comparison as well.

The scheme shown in the Fig. 2 was used for the preliminary fiber test.

After the irradiation coupling to the slow BA the fiber was set with polarizer position and the photodetector readings in such way that the slow fiber axis was directed perpendicularly to the He–Ne laser beam propagation direction. Then the pictures of the scattered light interference pattern had been taken at different SAP angular positions by the rotation of the micropositioner 5 (Fig. 2). In the Fig. 3a the schematic position of the studied fiber with respect to the He–Ne laser beam propagation direction.

Figures 3b and 4b show the collages of the scattered by ESC-12 and PANDA light pattern pictures taken at different SAP positions with a 5 degrees step. The screen was at a distance of 140 cm from the optical fiber. From the figures one can see that the intensity and the interference pattern orders angular coordinates depend on the BA angular position.

By observing the intensity and orders angular position in scattering interference pattern, the required angle of fiber angular micropositioner rotation is determined before inscription. The FBG writing had been carried out at two optical fiber positions:

1. position at which the slow fiber axis is perpendicular to the He–Ne laser beam propagation direction;
2. position at which the slow fiber axis is parallel to the He–Ne laser beam propagation direction;

The first position corresponds to the angle $\varphi = 90°$ in Figs. 3 and 4, the second to $\varphi = 0°$.

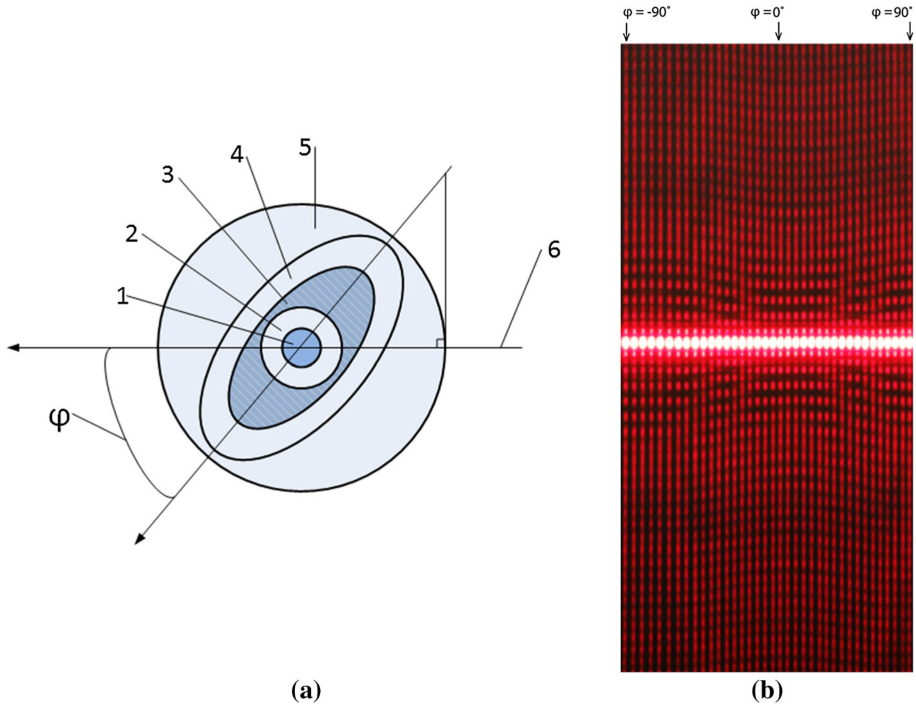

Fig. 3 Optical fiber ESC-4 cross-section scheme (**a**): *1* core, *2* isolating cladding, *3* stress cladding, *4* protection cladding, *5* constructive cladding, *6* He–Ne laser beam propagation direction. φ angle between the He–Ne laser beam propagation direction and slow optical fiber BA. The collage (**b**) comprised of 37 scattering interference patterns which are vertically oriented sets of minimum and maximum values, the φ value corresponds to the fiber position in (**a**)

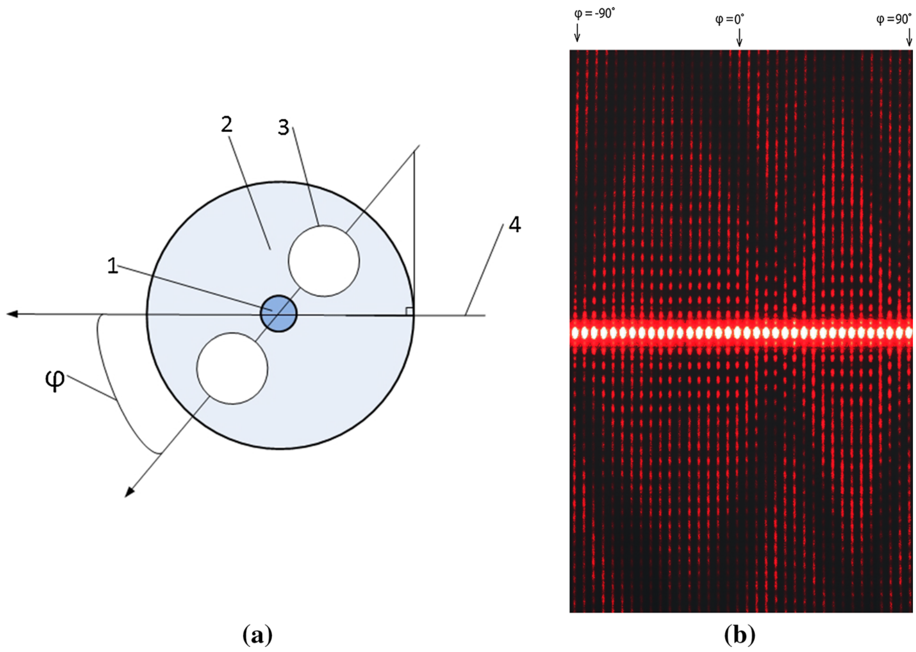

Fig. 4 Optical fiber PANDA cross-section scheme (**a**): *1* core, *2* cladding, *3* stress rod, *4* He–Ne laser beam propagation direction. φ – angle between the He–Ne laser beam propagation direction and slow optical fiber BA. The collage (**b**) comprised of 37 scattering interference patterns which are vertically oriented sets of minimum and maximum values, the φ value corresponds to the fiber position in (**a**)

4 Bragg grating inscription results

During the present investigation the type I FBGs had been inscribed in the studied fibers ESC-4, ESC-12 and PANDA with the single pulses at energy density about 140 mJ/cm^2. The average ratio of the reflection coefficients of FBGs, inscribed at slow axes orientation parallel to the writing interference fringes to reflection coefficients of FBGs, inscribed at slow axes orientation perpendicularly to the writing interference fringes in the ESC-4 was 0.628. In the ESC-12 fiber this ratio was 0.596. For PANDA that ratio was about 1.785 I.e.:

$$(R_{\varphi=90^\circ}/R_{\varphi=0^\circ})_{mean}^{ESC-4} = 0.628 \tag{1}$$

$$(R_{\varphi=90^\circ}/R_{\varphi=0^\circ})_{mean}^{ESC-12} = 0.596 \tag{2}$$

$$(R_{\varphi=90^\circ}/R_{\varphi=0^\circ})_{mean}^{PANDA} = 1.785 \tag{3}$$

The gratings' reflection coefficients were found from its reflection spectra. The spectra had been measured 3 min after the writing procedure.

This result confirms the presence of the dependence of FBG inscription efficiency on the studied fibers' SAP position.

Furthermore, in the paper (Zhao et al. 2016) it was proved that polarization mode coupling of FBG depends on the BA position with respect to the writing beam. Thus, the BA pre-positioning during the FBG writing procedure is the effective way to reduce the FBGs' cross-polarization mode coupling which are a noise source in phase interferometric sensors.

5 Conclusion

The paper presents the FBG writing scheme with preliminary optical fiber SAP orientation. The results of type I FBG inscription in anisotropic optical fibers by a single KrF excimer laser pulse with a phase mask method are presented. The reflection coefficient ratio of FBGs inscribed at two stress ellipse orientations in ESC-4 and ESC-12 was 0.628 and 0.596 that allows to estimate the dependence of the FBGs inscription efficiency on the SAP orientation in optical fibers, fabricated according to the technology described in papers (Eron'yan 2000; Bureev et al. 2007) and develop a set of recommendations for the producers of FBGs in anisotropic optical fibers used in this work. Firstly, type I FBG inscription with single pulses in the fiber with elliptical stress cladding is more effective at birefringent fiber slow axis positioning perpendicularly to writing interference fringes. At the same time, FBG incscription in PANDA fiber is more effective with the PANDA slow axis positioning parallel to writing interference fringes. Secondly, the preliminary SAP orientation during the FBG writing procedure allows to reduce the polarization mode coupling.

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