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Research Article

Bragg Gratings Induced in Birefringent Optical Fiber with an Elliptical Stress Cladding

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The paper presents the results of writing of type I and high-performance type II fiber Bragg gratings in birefringent optical fiber with an elliptical stress cladding by a single 20 ns pulse of KrF excimer laser (248 nm). The gratings' efficiency produced by a single pulse was up to 100%. Experimental results on visualization of these gratings are presented.

1. Introduction

The first fiber Bragg grating (FBG) was obtained in 1978 [1]. About ten years later, FBG was written through a lateral surface of optical fiber for the first time [2]. Nowadays, gratings are becoming more and more widely used.

Fiber Bragg gratings written in birefringent optical fibers can be used in creation of sensors for measuring physical quantities [3, 4]. To date, FBGs have been induced in birefringent optical fibers of different types: with elliptical core [5], bow-tie [6], PANDA [7], and internal elliptical cladding [8]. Here we demonstrate the results of FBG writing by a single 20 ns KrF excimer laser pulse in birefringent optical fiber with an elliptical stress cladding, obtained using the technology [9, 10].

This birefringent optical fiber due to its unique properties [11] is being used to create precision interferometric sensors, such as a fiber-optic gyroscope [12]. Special quadrupole winding is used in a fiber-optic gyroscope with the class of accuracy below 0.01 deg/h for temperature drift compensation in the fiber loop, which is the main source of phase noise [12].

To create a fiber-optic gyroscope with class of accuracy 0.01 deg/h and higher, the development of an active system of temperature gradients compensation in the fiber loop is required.

Refractive index gratings are being widely used in temperature sensors [13, 14]. So, it is possible to measure temperature gradients inside the gyroscope fiber loop using FBGs array.

For creating FBGs array, this birefringent optical fiber with an elliptical stress cladding, obtained using the technology [9, 10] with complex structure [15], which includes a core, a circular isolating cladding, an elliptical stress cladding, and a circular outer cladding, was selected. To enhance the photosensitivity of the fiber the concentration of GeO_2 in its core was increased to 16 mol. %. Enhancing the photosensitivity at the stage of preform formation allows you to write the FBG arrays during the drawing process of optical fiber. The disadvantage of this method is an increase in linear optical losses of the fiber. Losses of birefringent optical fiber with an elliptical stress cladding with 16 mol. % GeO_2, used in this work, are ~18 dB/km at 1550 nm. But losses of birefringent optical fiber with an elliptical stress cladding with 4 mol. % GeO_2, produced using the same technology [9, 10], are less than 1 dB/km at a wavelength of 1550 nm.

2. Experimental Setup

We used an excimer laser Lambda Physik Compex 102 with pulse energy ~150 mJ using a gas mixture of KrF. FBG writing

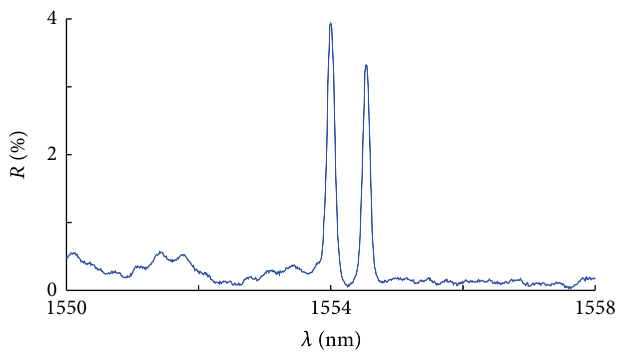
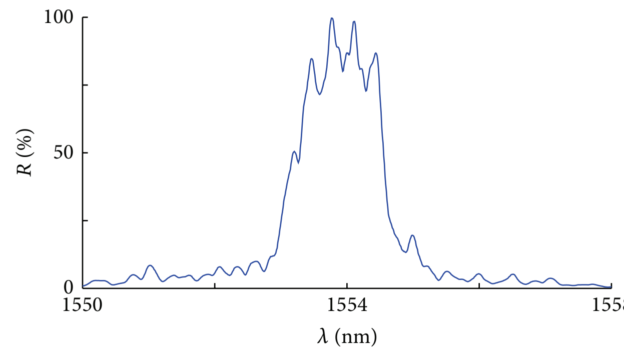
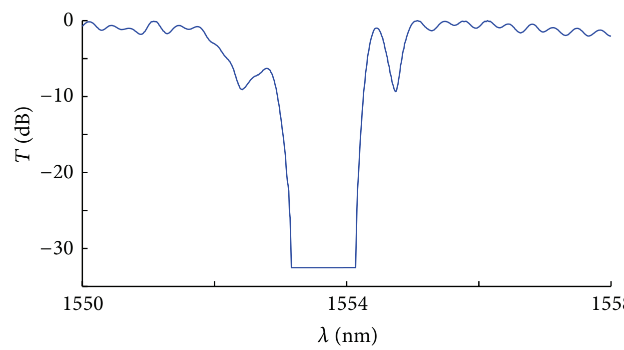


Figure 1: Type I FBG reflection spectrum.



(a)



(b)

Figure 2: Type II FBG spectra: reflection (a) and transmission (b).

scheme is shown in [16] and the attenuator with a built-in shutter was added at the laser output.

The laser generates 20 ns pulses at a wavelength of 248 nm with a frequency of 1 Hz. The attenuator with a built-in shutter allows you to allocate a single pulse from their order, when the laser is launched into a stationary mode. The cylindrical lens focuses the laser beam on one axis to achieve the required energy density. The aperture allows changing the length of the grating.

A single 20 ns laser pulse, passing through a phase mask (PM) with a period Λ_{PM} = 1065.3 nm and suppression of the zero-order diffraction (<3%) at a wavelength of 248 nm, is diffracted in +1 and −1 orders. The interference pattern of +1 and −1 orders writes the refractive index grating in the fiber core, fixed in the magnetic holder at the distance of several microns from the PM.

3. Results

Figure 1 shows the reflection spectrum of FBG, written with a single pulse in birefringent optical fiber with an elliptical stress cladding with 16 mol. % GeO_2. Presented FBG was written with the energy of 75.9 mJ at the attenuator output. The resulting FBG is a type I grating [17].

The presence of two reflection peaks in Figure 1 is due to the fact that the grating is induced in birefringent optical fiber. Since the effective refractive index for each of the selected axes of birefringent optical fiber is different, the wavelength of the Bragg resonance is different for the light traveling along the fast and slow axes of the fiber.

With a slight increase in energy at the attenuator output to 79.3 mJ, so that the energy density on optical fiber is closer to 1 J/cm^2, type II grating [18] was written in the same fiber with a single excimer laser pulse. Figure 2 shows the spectra of the type II FBG: reflection (a) and transmission (b).

Type II FBG has about 100% reflection and the spectral width at half maximum over 1 nm. Due to the broadening of the spectrum, reflection peaks of the two orthogonal polarizations are merged.

Investigation of the thermal stability and visualization of this FBG confirm that this is grating of type II, which can withstand high temperatures (up to 1000°C) in contrast to the grating of type I. As shown by the authors in [19], type II FBG annealing begins only at 900°C, which is consistent with the data presented in [13, 20].

Also the observed dependence of the induced grating type on the pulse energy is consistent with the experimental data presented in [20, 21].

4. Visualization of Type II Fiber Bragg Gratings

Visualization of type II FBGs induced in birefringent bow-tie optical fiber was presented in [6].

Experimental results on visualization of type II FBGs induced in birefringent optical fiber with an elliptical stress cladding with 12 and 18 mol. % GeO_2 were presented in the previous work [22]. Here, we demonstrate visualization of type II FBG induced in birefringent optical fiber with an elliptical stress cladding with 16 mol. % GeO_2 (Figure 3).

The FBG image was obtained by the optical microscope Zeiss AxioImager Z1 by the differential interference contrast (DIC) technique with a diode laser (405 nm). DIC measurements can be successfully used to obtain the refractive index profile of optical fiber [23]. The DIC technique is also used to get images of type I gratings [24].

The obtained images show that a single pulse recording of type II FBGs creates a periodical structure in optical fiber, the spatial period of which corresponds to the PM period, optimized for +1/−1 diffraction orders. The measured period of the grating is about 1.06 μm. As seen in Figure 3, grating is not localized in the core of the optical fiber but

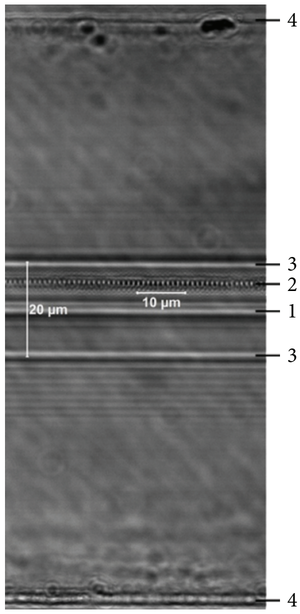


Figure 3: FBG image in birefringent optical fiber with an elliptical stress cladding with 16 mol. % GeO_2, where 1 is core, 2 is heterogeneous periodical structure, 3 is boundary between 20 μm cladding and stress cladding, and 4 is outer boundary of the fiber.

near the boundary between the core and the 20 μm cladding. However, despite the fact that this should lead to a lower efficiency of the FBG, this grating has an almost 100% reflection (Figure 2). Perhaps this is due to energy transfer from the fundamental core mode into the modes of elliptical cladding, but the exact explanation of this fact requires further research.

5. Conclusion

Type I and type II FBGs were written in birefringent optical fiber with an elliptical stress cladding by a single 20 ns pulse of KrF excimer laser (248 nm). The gratings' efficiency produced by a single pulse was up to 100%. Experimental results on visualization of type II FBGs show the localization of these gratings in this fiber type.

The obtained FBGs can be used not only in temperature sensors but also in creation of a new generation of measurement systems, such as fiber-optic hydrophone or monitoring system of extent objects (pipelines, railways, and borders). Distinctive features of these systems are the extension of controlled areas, speed, and unique information capabilities.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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