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Bragg gratings inscription in weakly-doped fibers

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ABSTRACT

The results of an investigation of the Bragg gratings inscription processes in weakly-doped fibers with different dopants without preliminary hydrogen-loading are presented in this work. The Bragg grating inscription in nitrogen weakly-doped fibers is demonstrated for the first time. The features of the inscription dynamics in this type of fiber are presented in comparison with the germanosilicate analogue—the Corning SMF-28e telecommunication fiber.

Introduction

Nowadays, fiber Bragg gratings are widely used as optical filters and mirrors for fiber lasers as well as sensors of physical quantities. The inscription of Bragg structures in the core of optical fibers is usually carried out by means of ultraviolet (UV) laser irradiation and spatial interferometers or phase masks, which create the necessary periodic pattern in the core of the optical fiber. For efficient inscription of such gratings, the fiber should have the photosensitive property, which can be achieved by incorporating an additional amount of dopants, such as germanium and boron, in the core [1,2]. However, such a method leads to a change in the waveguiding properties of the optical fiber and can cause additional unwanted losses when combining Bragg sensors into arrays using a standard telecommunications optical fiber. Another widely used way to increase photosensitivity, applicable to weakly germanium-doped fibers, including standard telecommunication ones, is to load them with molecular hydrogen [3]. Such a method of Bragg grating fabrication is in some cases more preferable. When the sensors connected to the telecommunication extension line, no additional loss arises in the splice point. However, this method has its drawbacks. The Bragg gratings inscribed in hydrogen-loaded fibers have low stability and are unable to work under elevated temperatures [4]. In addition, during the fabrication process, additional procedures are required, such as saturating the fibers with molecular hydrogen and stabilizing the grating parameters after inscribing. In some cases, the optimal solution for the fabrication of Bragg gratings is their direct inscribing in standard telecommunication fibers with a low doping level or in fibers close to them in waveguiding properties. Such properties are satisfied by Corning's standard fiber SMF-28e or its analogues from other manufacturers. The possibility of inscribing Bragg gratings in such fibers without the use of molecular hydrogen was previously shown [5]. In addition, such gratings showed greater stability of their parameters at elevated temperatures [6].

However, for a number of tasks, special sensors and fibers with high radiation and thermal resistance are required [7]. Fibers with a germanium-doped core, which include standard telecommunication fibers, do not meet these requirements. An alternative to them can be optical fibers with a nitrogen-doped core [8]. Such fibers were previously shown to have increased ionizing radiation resistance [9,10], and Bragg gratings based on them are able to withstand high temperatures [11–13] and ionizing radiation dose [14,15]. However, the inscription of Bragg gratings in nitrosilicate fibers is possible only with the help of high-energy UV radiation with a photon energy of about 6.4 eV and higher. This requirement is satisfied by an ArF-excimer laser with a wavelength radiation of 193 nm. Nitrogen-doped optical fibers exhibit relatively low photosensitivity, so the Bragg gratings are usually inscribed in heavily-doped fibers, which obviously have poor field matching with standard telecommunication fibers.

In this paper, we show for the first time the possibility of Bragg gratings inscription in weakly-doped nitrosilicate optical fibers. A two-step inscribing mechanism has been discovered in this kind of fiber. The Bragg gratings inscription dynamics for a nitrogen-doped optical fiber and its germanosilicate analogue—the Corning SMF-28e telecommunication optical fiber—are compared.

Experiment and samples

In this work, two fibers with the closest parameters were investigated, namely, a fiber with a germanium-doped silica core Corning SMF-28e and a nitrogen-doped fiber with a similar core diameter and aperture. The difference in the refractive indices of the core and the cladding in both fibers was approximately 0.005, and the core diameter was about 9 µm. The preform for the nitrogen-doped fiber was synthesized by Surface plasma chemical vapor deposition (SPCVD)

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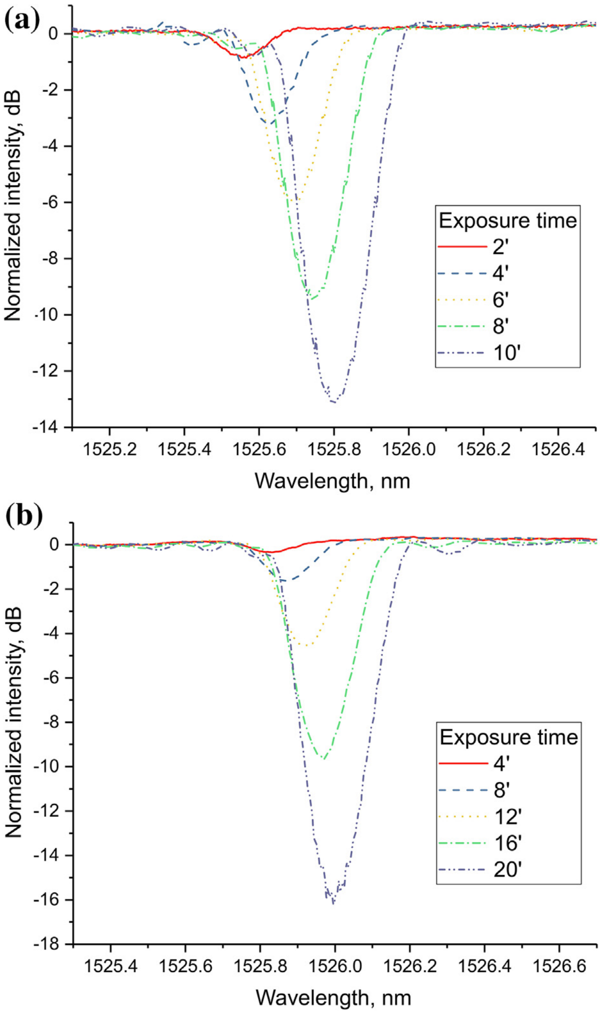

Fig. 1. Dynamics of the Bragg gratings' spectrum change during their inscription in germanium-doped (a) and nitrogen-doped (b) fibers.

technology [8,16,17].

The fabrication of the gratings was carried out by means of the well-known phase mask technology using the radiation of an ArF-excimer laser with a radiation wavelength of 193 nm and a pulse duration of about 14 ns. All samples of Bragg gratings were inscribed under absolutely identical conditions; only the laser pulse energy was varied. The period of the phase mask used in the experiment was 1054 nm. The length of the Bragg gratings was 5 mm. The laser pulse repetition rate was 50 Hz.

Results and discussions

Fig. 1 shows the dynamics of the changes in the spectrum during the grating inscription in the SMF-28e fiber (Fig. 1a) and in its nitrosilicate analogue (Fig. 1b). The gratings were inscribed at the same energy density of 250 mJ/cm^2. From the graphs we can see that the grating inscription dynamics of fibers with different dopants differ greatly. Thus, in the germanosilicate fiber, the level of the grating's reflection increases almost proportionally to the exposure time, whereas in the case of the nitrogen-doped sample, a significant nonlinearity of growth dependence is observed.

More clearly, data on the Bragg gratings formation dynamics can be represented as the dependence of the photoinduced magnitude of the refractive index modulation on the exposed dose. The magnitude of the refractive index modulation Δn in the grating of length L and with the reflection coefficient R can be calculated with formula (1):

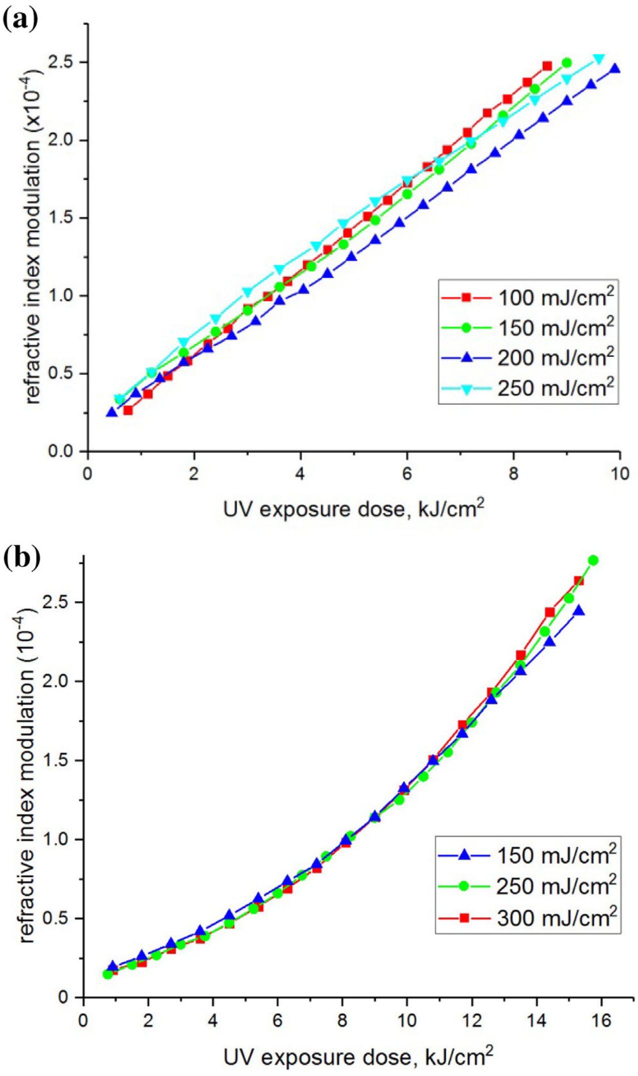

Fig. 2. Dynamics of the effective refractive index modulation change during UV irradiation with different radiation densities in germanium-doped (a) and nitrogen-doped (b) fibers.

$$R = \tanh^2(\pi \Delta n_{\text{mod}}\, \eta L/\lambda_B) \tag{1}$$

where λ_B represents the Bragg grating's wavelength and η represents the so-called overlap integral, which determines the overlap of the guiding (fundamental) mode and a fiber core ($\eta < 1$). In the case of fibers with identical waveguide properties, we can consider the modulation of the effective refractive index $\Delta n_{eff} = \Delta n_{mod} \cdot \eta$:

$$\Delta n_{eff} = \frac{\lambda_B \tanh^{-1}\sqrt{R}}{\pi L} \tag{2}$$

Fig. 2 shows the inscription dynamics at different radiation densities for the germanium-doped sample (a) and the nitrosilicate fiber (b).

For an optical fiber with a nitrogen-doped core, there is no dependence of the grating's inscription dynamics on the pulse energy density. But, it can be seen that at the initial irradiation stage, the photoinduced changes in the refractive index modulation occurs more slowly, clearly demonstrating a two-step mechanism in the grating's formation. A similar two-step mechanism was observed earlier during the inscribing of gratings in fibers with a hydrogen-loaded, phosphorus-doped core [18,19]. At the initial irradiation stage, there is, in fact, a "preparation" of the glass network in which, in the future, significant photo-induced changes occur. It is obvious that photoinduced defects are associated with the presence of nitrogen atoms in the silica glass network, which induces the initial absorption of UV radiation [20].

In the case of the germanosilicate analogue, a “classical” recording dynamic is observed. Note, however, that under our irradiation conditions, no significant dependence of the grating’s formation dynamics on the energy density per pulse was observed, in contrast to work [6]. This may be due to a different range of energy densities used in which two-photon processes in this type of glass are negligible. We note, however, that a relatively low exposure dose density is used to fabricate effective gratings with a high reflection level in an SMF-28e optical fiber. Therefore, this technique can be used for the mass production of sensors in this type of optical fiber without first loading it with molecular hydrogen.

Conclusion

In this paper, the Bragg gratings inscription in nitrogen weakly-doped silica fibers is demonstrated for the first time. The two-step recording mechanism is demonstrated. A comparison is carried out with the grating’s inscription dynamics in a hydrogen-free standard germanium-doped telecommunications optical fiber Corning SMF-28e.

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