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Spectral characteristics of draw-tower step-chirped fiber Bragg gratings

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ABSTRACT

This paper presents research results on the spectral properties of step-chirped fiber Bragg grating arrays written during the fiber drawing process into a birefringent optical fiber with an elliptical stress cladding. The dependences of resonance shift of the step-chirped fiber Bragg grating on bending, on applied tensile stress and on temperature have been investigated. A usage of such step-chirped fiber Bragg gratings in fiber-optic sensing elements creation has been considered.

1. Introduction

The first fiber Bragg grating (FBG) had been obtained in 1978 [1]. About ten years later, for the first time, FBGs were written through a lateral surface of optical fiber [2]. Nowadays such gratings find more and more applications in fiber optic systems [3–5].

The small reflection spectrum bandwidth of such FBGs can be extended by using chirped gratings. The temporal dispersion of light pulses in modern fiber optic communication links can be compensated by means of gratings with the resonance wavelength changing continuously or stepwise along their length in a specified way [6]. Such chirped gratings have a broad reflection spectrum (broader than 100 nm) or large dispersion (more than 1000 ps/nm). Such gratings may be written by changing the modulation period of the induced refractive index or effective index of the fundamental mode over the fiber length [7]. Such structures are applied, e.g., as dispersion compensators in fiber optic communication [6] and also in sensing elements of fiber optic measuring systems. The concept of distributed fiber optic phase interferometric sensors based on FBGs requires gratings with a specified reflection coefficient and a large full width at half-maximum [8–11].

FBGs of type I could be written with almost any reflection coefficient and full width at half-maximum; however, they require a special writing technique with long exposure time (10–20 min) [12], for example, the scanned phase mask interferometer or point-by-point writing [13]. That is not possible for grating inscription during the fiber drawing process of an optical fiber. FBGs of type II allow using an inscription technology with single pulses and provide FBGs with reflection coefficient values up to 100% and a full width at half-maximum of about 1 nm [14]. However, FBGs of type II are characterized by a strong dependence of the induced refractive index modulation in optical fiber on the excimer laser pulse energy density [15]. This feature complicates producing the gratings with the required reflection coefficients; moreover, the FBGs of type II suffer from reduced mechanical stability [7].

Therefore, we have investigated the possibility of using arrays of so-called step-chirped gratings of type I [13]. These arrays consist of several single pulse FBGs inscribed at different positions along a fiber with varying reflection wavelengths. The overall reflection of all gratings corresponds to the effect of a chirped grating. Such gratings can be produced during the fiber drawing process, and they do not damage the silica glass structure or reduce the mechanical stability of the fiber. They could provide the reflection characteristics required to create sensing elements for a phase interferometric sensor with sufficient full width at half-maximum of the grating spectrum. In order to maintain the

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polarization properties in an interferometric system, optical fibers with stress-induced birefringence have been used.

2. FBG writing

The step-chirped FBGs were written during the fiber drawing process of the optical fiber by means of a Talbot interferometer and a Lambda Physik Compex 150 T excimer laser system [16]. We used an excimer laser working on a gas mixture of KrF (248 nm) with a pulse energy of about 200 mJ at a beam size of approximately $8 \times 22\ mm^2$. The FBG writing scheme is shown in Fig. 1 [17].

The drawing speed of the optical fiber was about 10 m/min. The fiber passes the interference pattern, while the laser generates 25 ns pulses at a wavelength of 248 nm with a frequency of 20 Hz. From pulse to pulse, the tilt angle (φ) of the dielectric mirrors (Fig. 1) mounted on rotary stages was changed by 1.6 arcsec. The quality and reproducibility of such draw-tower gratings strongly depends on the pulse energy stability and on the beam coherence (spatial and temporal). The laser was modified to improve its beam quality, e.g. keeping high pulse energy, pulse stability and homogeneous energy distribution [16].

The Bragg wavelength (λ_{Bragg}) related to the tilt angle (φ) of the dielectric mirrors mounted on rotary stages can be calculated as shown below

$$\lambda_{Bragg} = \frac{n_{eff}\,\lambda_{laser}}{\sin(\alpha + 2\varphi)},$$

where n_{eff} is the effective refractive index of the fiber, λ_{laser} is the laser wavelength and $\sin(\alpha)=\lambda_{laser}/\Lambda_{pm}$ (Λ_{pm} – phase mask period).

The step-chirped FBGs were written during the drawing process into a birefringent optical fiber with an elliptical stress cladding, obtained by means of the technology as described in [18,19]. In order to enhance the photosensitivity of the fiber, the concentration of GeO_2 in its core was increased to 12 mol%. Enhancing the photosensitivity at the stage of the preform formation allows writing the FBG arrays during the fiber drawing process. A disadvantage of this method is an increase in the linear optical losses of a fiber. The attenuation of birefringent optical fibers with an elliptical stress cladding with 12 mol% GeO_2, as used in this work, is about 3.5 dB/km at 1550 nm. This is higher than the loss of a birefringent optical fiber with an elliptical stress cladding and with 4 mol% of GeO_2, which is produced with the same technology [18,19] and which achieves losses less than 1 dB/km at a wavelength of 1550 nm.

The necessity of using this birefringent optical fiber is due to the fact that, on its basis, a phase interferometric sensor is intended, where it is necessary to keep the polarization state of optical radiation.

The full width at half-maximum of the grating spectrum and, thus, the number of steps required for writing step-chirped FBG arrays is chosen according to the desired operating conditions. There is a condition of quasi-continuity of the step-chirped FBG spectrum [13], which allows calculating the number of sections of step-chirped grating for obtaining a continuous spectrum according to

$$\frac{N}{L} = \frac{2n_{eff}\,\Delta\lambda_{chirp}}{\pi\lambda_{Bragg}^2},$$

where N is the number of sections of step-chirped gratings for obtaining a quasi-continuous spectrum, L is the length of the optical fiber with inscribed diffraction structure, $\Delta\lambda_{chirp}$ is the full width at half-maximum of the whole diffraction structure spectrum, and λ_{Bragg} is the central wavelength of the complex spectrum.

A typical spectrum of a step-chirped FBG, which was written during the drawing process in the birefringent optical fiber with an elliptical stress cladding, is presented in Fig. 2. This diffraction structure consists of 5 FBGs with a length of each grating of 9 mm, a space between gratings of 1 mm and a Bragg resonance shift between each pair of neighboring gratings of about 0.1 nm. The reflection coefficient of each grating is approximately 4%, the total length of the diffraction structure is about 50 mm, and the full width at half maximum of the step-chirped FBG array is about 0.5 nm for each polarization axis of birefringent optical fiber.

For stable operation of a distributed phase interferometric sensor array, one should have quasi-continuous spectra of such step-chirped FBGs. In our case, a wider wavelength distance (0.1 nm) had been chosen to make possible effects of temperature and bending on the single gratings better visible for this investigation. For a more continuous reflection spectrum, the Bragg resonance shift from grating to grating should be reduced to half the initial value, so it should be 0.05 nm.

3. Spectral characteristics of the step-chirped fiber Bragg grating array

In order to evaluate the applicability of such step-chirped FBGs in a distributed fiber optic phase interferometric sensor, it is necessary to study the influence of temperature and mechanical stresses on the spectral characteristics of the grating array.

The fiber with such an induced step-chirped fiber Bragg grating array has typically a length of about 50 mm, unlike common single gratings, which have a typical length of only 1–15 mm. This extended length of the grating array may have a negative effect on its spectral characteristics through temperature and mechanical stress and bending. Therefore we investigated these effects for the step-chirped grating array.

At first, we studied the influence of bending on the grating spectrum of the 50 mm long optical fiber section. We used different winding diameters in a range between 50 and 10 mm with a

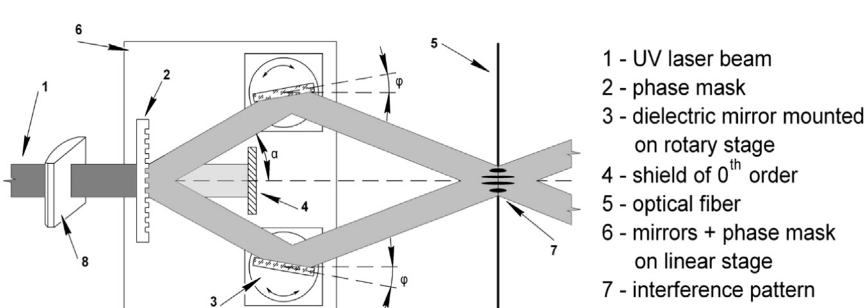

Fig. 1. Talbot interferometer for recording draw-tower step-chirped fiber Bragg gratings.