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Spectral interference fringes in chirped large-mode-area fiber Bragg gratings

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ABSTRACT

Spectral interference fringes were experimentally observed in chirped large mode area fiber Bragg grating (CFBG) in the overlapping region of the reflected spectrum of fiber modes by a high resolution spectrometer. It was demonstrated that the interference is due to optical path difference of the reflected modes in slight chirped FBGs. By assuming chirped fiber Bragg gratings as a Fabry–Perot (FP) cavity, free spectral range (FSR) of FP was calculated 0.08 nm which is matched with measurement very well. Furthermore, the experiments show that axial tension and temperature changes of the CFBG do not have observable effects on the magnitude of FSR, however coiling of the fiber deceases spectral interference fringe amplitude without sensible effect on FSR magnitude. The results of this work can be utilized in bending sensors.

1. Introduction

Large Mode Area (LMA) fiber Bragg gratings (FBGs) are widely used in fiber laser systems for different purposes such as fiber laser reflectors, dispersion compensators, spectral filters, etc. Output characteristics of fiber laser systems depend on spectral responses of LMA FBGs [1,2]. Therefore it is important to understand spectral responses of these types of FBGs. Toru Mizunami et al. presented experimental characterization of reflection spectrum of FBG in multimode fibers. They observed number of reflection peaks in reflection spectrum for low and high mode excitation conditions. These peaks were explained by phase-matching condition for different modes [3]. In their work, number of peaks is directly proportional to propagating modes. Aarni et al. presented a method to characterize modal coupling in LMA FBGs [4]. Jens U. Thomas et al. used pure mode excitation approach to investigate FBG spectra fiber modes and mode coupling in LMA FBGs inscribed in Yb-doped LMA fibers [5]. Waleed Mohammad and XijiaGu presented a simulation and spectral measurement on non-chirped LMA FBG. They reported a single fringe of interference in the middle of spectrum in their simulation and spectral measurement and explained it as the overlap of the two modes [6]. However, in all works on LMA FBGs, spectral interference fringes have not been observed in the reflection spectrum.

In this work, we characterized chirped fiber Bragg gratings (CFBGs) spectrum with high resolution in cases of one-mode and two-mode operations. We observed spectral interference fringes in the overlapping region of the reflected spectrum of the fiber modes. This interference was appeared in the reflection spectrum because of a large overlapping region of the reflected spectrum of fiber modes in LMA CFBGs. To explain it, we assumed CFBG in two-mode operation acts as FP cavity. Then we obtained free spectral range by analyzing FP cavity in the two-mode operation.

The calculated FSR of the CFBG FP is in complete accordance with experimental measurements. Furthermore, the experiments show that axial tension and temperature changes of the CFBG do not have observable effects on the magnitude of FSR however coiling of the fiber deceases spectral interference fringe amplitude without sensible effect on FSR magnitude. Change in spectral interference amplitude due to coiling diameter can be used in bending sensors.

2. Experimental setup

Schematic diagram of the experimental setup for measurement of reflected spectrum is shown in Fig. 1. An ASE (Amplified spontaneous emission) light source with 60 nm spectral width around 1050 nm is connected to a circulator input port via an APC connector. The other retuned port is connected to an optical spectrum

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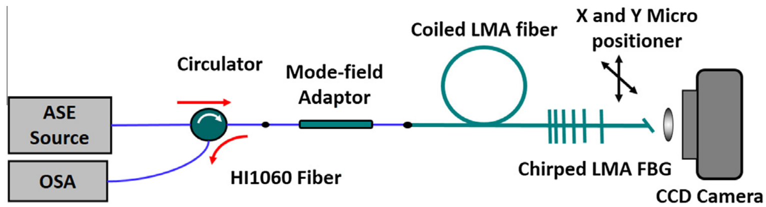

Fig. 1. Schematic diagram of the experimental setup.

analyzer (Bristol, model 721) which has an accuracy of 10 pm at 1000 nm for the bandwidth of 10–100 GHz. Transmitted port of circulator is spliced to a mode field adaptor which has an HI1060 input fiber and a 20/400 (core/cladding diameter) output fiber. The output of the mode-field adaptor is spliced to a Chirped LMA FBG (20/400, NA = 0.06, Nufern) at the short period side. The FBG has a period of 366.25 nm with 0.5 nm total chirp in the length of 10 mm which has Super-Gaussian apodization. The other side of the FBGs is cleaved at angle of 8° and placed in front of an objective lens for collimating the beam. To avoid any back reflection lights from fiber ends, APC connectors are used and CFBG end is cleaved at angle of 8°. Moreover the fiber end was immersed in index matching gel to ensure no light reflects from it. We did not see any changes in the reflection spectrum when we used the index matching gel. We monitor the profile of the output light using a CCD camera, by adjusting the angle cleaved fiber in *X* and *Y* directions.

3. Results and discussions

Fig. 2(a) shows a high resolution reflected spectrum of the LMA-CFBG for two cases. In the first one, both LP_{01} and LP_{11} modes are present but the LP_{01} is the dominant mode. As, it is observed, reflected spectrum is modulated by 0.08 nm FSR. In the second one, when the CFBG input fiber is coiled at diameter of 10 cm to remove LP_{11} mode, amplitude of the interference fringes decreases significantly and the reflected spectrum becomes nearly uniform. In Fig. 2(b), these spectra are shown with low resolution for the comparison. As it was seen spectral fringes are vanished in the first one and a dip is appeared in the middle of spectrum. To present modal content of LMA-CFBG qualitatively, spatial profiles of the both cases are illustrated in Fig. 3. Profile of output is rather elliptical before coiling that indicates presence of LP_{11} mode. In two-mode fibers, intensity profile is obtained from superposition of electric field of fundamental and second modes. They have the intensity profiles of nearly Gaussian and two-lobe respectively. Moreover superposition profile depends on the percentage of energy for each mode and their total phase difference. Therefore, profile of intensity of two-mode fiber becomes nearly elliptical when the fundamental mode is dominant [7].

The experiments show that the appearance of the spectral interference in the reflection spectrum of LMA-CFBG is the result of the presence of LP_{11} mode. The origin of spectral interference can be due to the different propagation constant of modes which causes modes to have different optical paths in LMA-CFBG. Assuming that LMA fibers have circular core symmetry and slight birefringence, LP_{01} and LP_{11} modes will be modal content of the fiber. Since the LMA fibers possess small numerical aperture (NA = 0.06), effective index of LP_{01} and LP_{11} modes are close to each other, there is a large overlapping reflectivity region between the two modes in the chirped fiber Bragg gratings [6]. As a consequence, spectral interference occurs between LP_{01} and LP_{11} modes in this region due to different phases they gain after reflection from Bragg layers of the CFBGs. When the fiber is coiled the LP_{11} mode leaks into the cladding due to low NA of LMA fibers. As a consequence, the portion of LP_{11} mode in the interference drastically decreases and therefore, interference fringes get vanished.

For simplicity, it can be assumed that LP_{01} and LP_{11} modes are reflected from two given positions in LMA-CFBG because of different effective index of modes. Therefore, these two positions can be considered as reflector positions of a FP cavity that difference of them is cavity length. Fig. 4 shows a schematic diagram of CFBGs FP.

As it was shown in Fig. 4 the length of the FP cavity, Δz is the difference between reflection positions ($z_i(\lambda)$) of the two modes. In a linearly periodic chirped FBG, the dependence of the refractive modulation period upon the axial position and Bragg condition relation can be expressed as Eqs. (1) and (2), respectively:

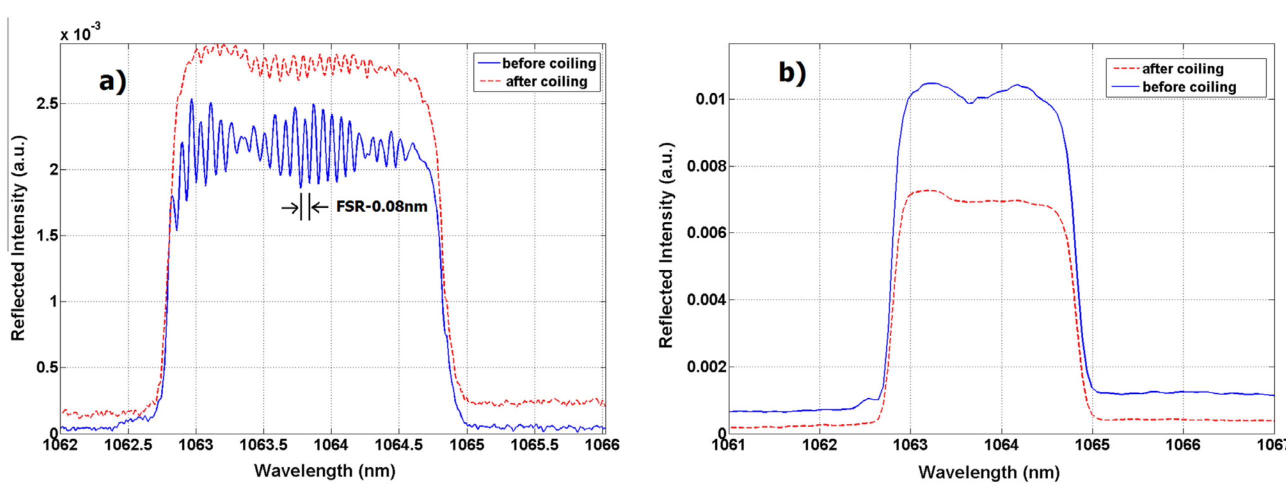

Fig. 2. (a) Reflected spectra of LMA-CFBG with high resolution for the two cases: Both modes are present but LP_{01} mode is dominant (blue line), LP_{01} mode is present but LP_{11} mode is removed by coiling (Red line), (b) Spectra of LMA-CFBG with low resolution. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)