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Regular Articles

Tunable overlapping long-period fiber grating and its bending vector sensing application

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ABSTRACT

A novel overlapping long-period fiber grating (OLPFG) is proposed and experimentally demonstrated in this paper. The OLPFG is composed of two partially overlapping long-period fiber gratings (LPFG). Based on the coupled model theory and transfer matrix method, it is found that the phase shift LPFG and LPFGs interference are two special situations of the proposed OLPFG. Moreover, the confirmation experiments verified that the proposed OLPFG has a high bending sensitivity in opposite directions, and the temperature crosstalk can be compensated spontaneously.

1. Introduction

Phase shift long period fiber grating (LPFG) and LPFG pair interference are two different physical phenomena, which are widely used in the design of optical fiber sensors, bandpass/notch filters and all-optical processing elements. Some unique spectral properties can be achieved, such as increased number or narrow bandwidth for the resonance peaks, when the phase shift is introduced. The aforementioned advantages make it attractive to research in the last decade. Ke et al. analyzed phase-shifted LPFGs and highlighted the effects of introducing multiple phase shifts at various locations along a LPFG [1]. Liu et al. theoretically studied phase shifted and cascaded LPFGs [2]. A bandpass filter based on mechanically induced multi-π-shifted LPFGs is proposed by Zhou et al. [3]. Gao et al. designed a temperature-insensitive optical fiber twist sensor based on multi-phase-shifted helical LPFG [4]. Wang et al. used high-repetitionrate CO_2 laser to fabricate phase-shifted LPFG, where both the grating and the inserted phase shift are simultaneously produced [5].

LPFG pair interference also has attracted a number of researches because of their high stability and repeatability. The Mach-Zehnder interferometer (MZI) composed by a pair of LPFGs fabricated in silica microfiber was demonstrated by Tan et al., which was used for the measurement of surrounding refractive index [6]. Fu et al. proposed a liquid-level sensor based on a pair of LPFG interferometer [7]. Fan et al. designed a refractive index sensor based on a fiber MZI formed by two cascaded special LPFGs with rotary refractive index modulation [8]. Zhou et al. fabricated an optical grating vector bending sensor by tilting the grating planes at increasing angles, as moving away from the center grid of the structure [9]. Li et al. devised a bending vector sensor based on a pair of opposite tilted LPFGs [10].

So far, two different models are proposed to study phase shift LPFG and LPFG pair interference, but these two structures have one topological and the only difference is the gap of gratings. In this paper, we propose one united model that can describe both the phase shift LPFG and the LPFG pair interference. The confirmation experiments are carried out in the overlapping long-period fiber grating (OLPFG) system, which consists of two partially overlapping identical LPFGs. By controlling the length of the overlapping area, phase shift LPFG and LPFGs interference can be transformed into each other. Moreover, the confirmation experiments verify that the proposed OLPFG has a high bending sensitivity in opposite directions, and the temperature cross sensitivity can be spontaneously compensated.

2. Structure, principle and simulation

The schematic diagram of the proposed model we designed is shown in Fig. 1. The OLPFG consists of two same gratings, some of which are overlapping. We define the direction of the CO_2 laser exposure as the −y direction, whereas the opposite direction is the +y direction.

The principle of the proposed OLPFG can be explained by the coupled model theory and transfer matrix method. The transmission spectra of the proposed OLPFG are simulated with the values of Λ, Δn_{eff}

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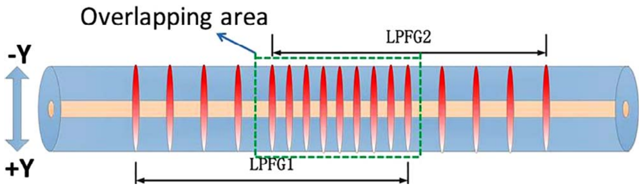

Fig. 1. Schematic diagram of the OLPFG.

and δn_{eff} are 600 μm, 2.4×10^{-3} and 2.1×10^{-5} respectively. Λ is the period of LPFG, Δn_{eff} is the effective refractive index difference between the core mode and cladding modes, and δn_{eff} is the modulation depth.

Fig. 2 manifests the simulated transmission spectra of the OLPFG with different overlapping lengths. Fig. 2(a) shows the spectrum of the OLPFG with the overlapping length of 0 period, which is same as the ordinary LPFG. When the overlapping length is adjusted to 1 period, these dips respectively split into two dips as shown in Fig. 2(b). Because of the overlapping section between these LPFG pair, a phase shift has occurred. Fig. 2(c) and (d) show the spectra when the overlapping length are 2 periods and 5 periods, respectively. With the increase of overlapping length, the number of dips are also increasing, as shown in Fig. 2(e) and (f). In addition, the interference peaks emerge. This phenomenon can be explained as follows: when the overlapping length is increasing, the phase shift changes into interference. Fig. 3 shows the spectra of the OLPFG change with the continuous change of overlapping periods obviously. With the increase of overlapping length, the intensity of the dips decrease and the number of the dips increase.

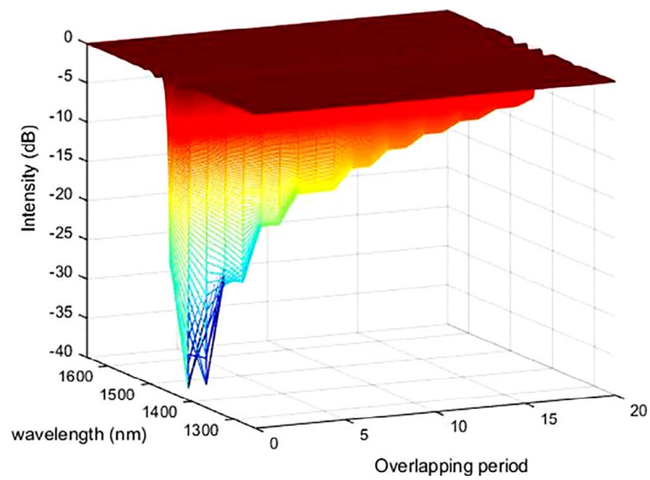

Fig. 3. Simulation of transmission spectra with continuous change overlapping periods.

Based on the aforementioned analysis, the phase shift LPFG and LPFGs interference are two special situations of the proposed OLPFG. When the overlapping length is small, it is similar to the shift LPFG. While the overlapping length increases, it is similar to the LPFGs interference.

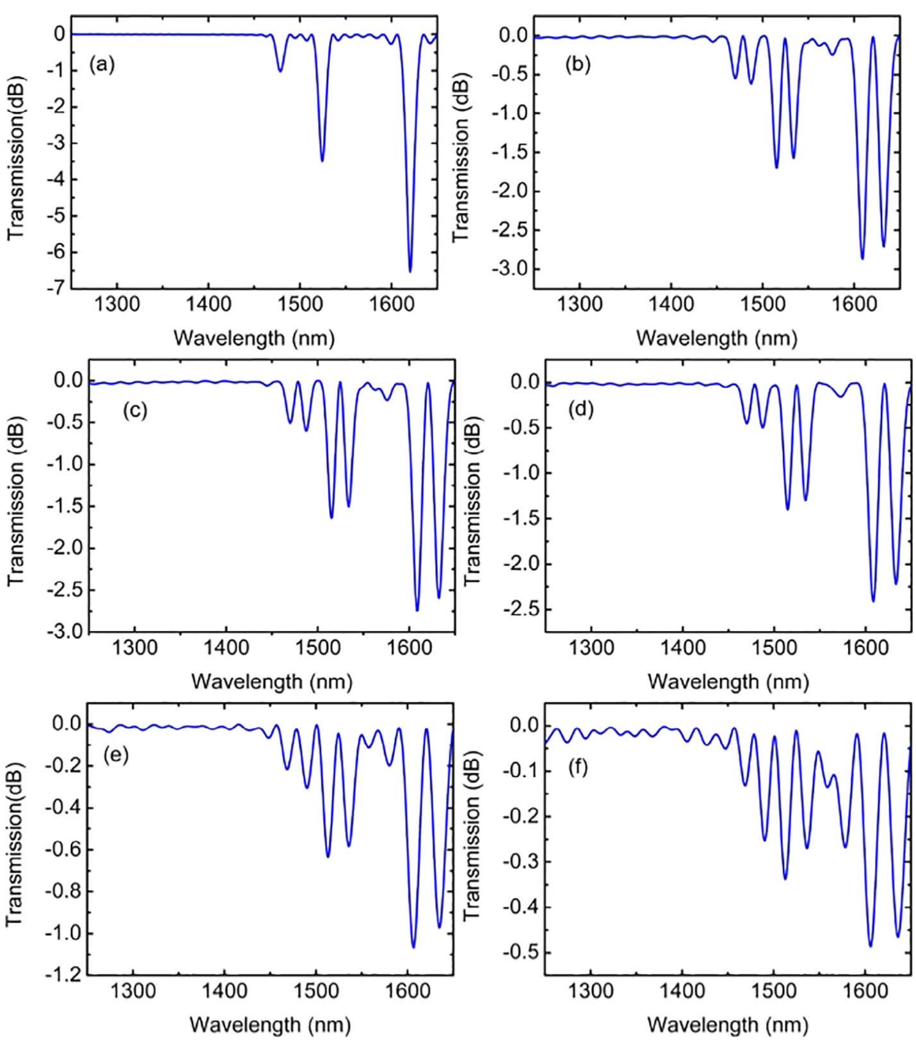

Fig. 2. Simulation of transmission spectra with different overlapping lengths. (a) 0-Periods; (b) 1-periods; (c) 2-periods; (d) 5- periods; (e) 10-periods; (f) 15-periods.