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Mechanically induced long-period fiber gratings on tapered fibers

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ABSTRACT

The characteristics of a mechanically induced long-period fiber grating (MLPFG) made by pressing a pair of grooved plates over single-mode fiber tapers are analyzed. Fiber tapers with a waist length of 80 mm and diameter ranging from 90 to 125 μm, fabricated using the heating and puling method, were used. We observed that the resonance wavelengths shift toward shorter wavelengths as the fiber taper waist diameter is reduced. A maximum shift of 254 nm in the position of the resonance peaks was observed when the fiber diameter was reduced to 90 μm. This technique is particularly suitable for tuning the resonance wavelengths to shorter wavelengths below the limit imposed by the grooved plate period.

1. Introduction

Spectral filtering properties of the long-period fiber gratings (LPFGs) can be exploited to develop attractive all-fiber devices for optical fiber communication and sensing systems [1]. In a LPFG, the LP_{01} core mode is coupled to forward-propagating cladding modes of order m. The resonance wavelength λ_m of the LPG is defined by the phase-matching condition [1,2]:

$$\lambda_m = (neff_{core} - neff^{m}_{clad})\Lambda \tag{1}$$

where Λ is the grating period, $neff_{core}$ and $neff^{m}_{cladd}$ are the effective index of the LP_{01} fundamental mode and the mth cladding mode, respectively. In general, for a given period Λ several cladding modes satisfy this condition, each one at a different λ_m that increases with m. The transmission spectrum of the LPFG thus exhibits a series of attenuation bands. The resonance wavelengths λ_m depend on the fiber characteristics through the effective indices of the core and cladding, which instead depend on the core and cladding dimensions and their refractive indices. Hence, a change in dimensions of the core and cladding diameter will affect the position of the resonance wavelengths.

One of the key characteristics of the LPFG, that makes it more attractive, is the great variety of methods to generate it, due to the fact that the period can be as large as hundreds of micrometers. For example, the mechanical induced long-period fiber gratings (MLPFGs) can be created through the application of periodical load microbend which couples the LP_{01} core mode to antisymmetric LP_{1m} cladding modes [3]. The fabricated MLPFGs are also reversible and their attenuation loss can be controlled in real time that makes them very promising for spectral filtering or gain equalization in fiber amplifiers [4,5]. In addition, gratings can be induced practically in any kind of conventional single-mode fibers [6] or even in holey fibers [7] with the advantage that the experimental setup not needs to be modified. Recently, interest has been focused on finding methods for tuning the resonant wavelengths of MLPFGs in order to expand their applications. The tuning mechanism proposed so far include: grating period variations [8,9], etching of the fiber cladding [6], heating the corrugated structure that induces the grating [10] , or twisting the fiber [11]. Motivated by the unique advantages of the MLPFGs of being erasable and reconfigurable, in this paper we propose and also demonstrate the use of single-mode fiber tapers with a uniform waist for tuning the resonant peaks to shorter wavelengths.

2. Tapered long-period fiber grating

One of the simplest methods to generate a LPFG is based on microbending deformation induced on fiber by two plates, where at least one of the plates has a grooved pattern, which induces periodical microbending when the mechanical pressure is applied. The gratings studied here were produced using this method. In Fig. 1 we show the schematic representation of the experimental setup used to generate and analyze the transmission spectra of the MLPFG. We used two identical aluminum blocks of 24 × 70 × 25 mm ($L \times W \times T$) which have rectangular grooves of 306 μm in depth, a duty cycle of 60–40 and a period of 470 μm. The period, depth and duty cycle were measured by optical microscope integrated in an Atomic Force Microscope (AFM) (Digital Instruments, Dimension 3100) and trough software included in the AFM we got images and measurements for each plate. Blocks were mounted and fixed in a mechanical system, designed and fabricated in our

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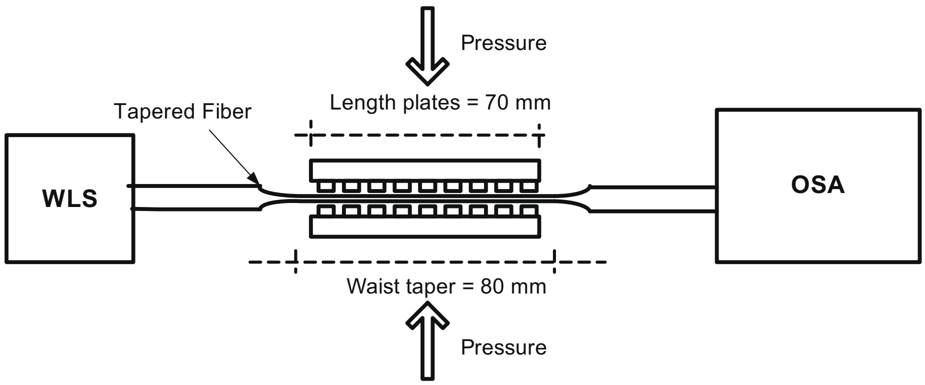

Fig. 1. Schematic diagram of the experimental setup used to generate and interrogate the MLPFG over a fiber taper.

facilities, where the fiber was placed between the blocks and aligned along the normal to the groove lines. A loading system [12] locally exerts a controlled pressure on blocks and therefore grooves induce a microbending deformation in the fiber. Also the system allows us to adjust the grating period to higher values by changing the angle between the fiber axis and grooves. Standard step-index telecommunications fiber SMF-28e fabricated by corning was used in this analysis. The characterization of the attenuation bands was carried out by observing the transmission spectrum with an Optical Spectrum Analyzer (OSA) (ANDO AQ-6315A) with a spectral resolution of 0.1 nm and a White Light Source (WLS) (ANDO AQ-4303B). The transmission spectra of a MLPFG induced over untapered fiber with (continuous line) and without (dotted line) the protective polymer coating is shown in Fig. 2 where four mayor notches can be observed. In the jacketed fiber the resonant peaks occur at 1470, 1500, 1550 and 1640 labeled as first, second, third and fourth notch, respectively. As we can see, for uncoated fiber the notches are blue-shifted and slightly broad, and the depth of the fourth notch decreases 1 dB reaching a maximum attenuation of −11 dB. A possible explanation is that the deformation is applied directly over the cladding.

Some studies have analyzed the effects of the cladding diameter reduction over the spectral behavior of a recorded LPFG [4,13–15]. Mainly, the cladding etching process has been employed for tuning the resonant wavelength of the LPFGs or to increase the sensitivity of the device toward the refractive index of the external medium. However, the characteristics of a LPG recorded over an optical fiber taper in which both the core and cladding has been tapered have not been sufficiently studied [16]. Actually, this is the first time, to our knowledge, that spectral behavior of MLPFGs induced on a fiber taper is analyzed. In Fig. 3 we show the shape of the fiber taper proposed. It consists of a cladded single-mode fiber with a section of length L_0 and constant diameter ρ, also known as waist. The fabrication of such structure is carried out with the heating and pulling process described in Refs. [17,18]. An oscillating flame torch produced by a controlled mixture of butane and oxygen is used to soft the fiber while it is gently pulled. Since the cladding is not removed the tapering process is easier and more controllable than etching. It is important to notice that in a tapered fiber the core and cladding diameter have decreased simultaneously and in the same proportion. A collection of samples with a waist length (L_0) of 80 mm were fabricated. We first analyzed the losses introduced by the tapering process. The measurements were carried out with a LD, with peak emission at 1550 nm, and a single photodetector. We found that the maximum losses were below 0.1 dB, and they can be considered negligible in practical situations. Losses are lower since the tapered fiber transition satisfies the adiabatic criteria [19,20]. In Fig. 4a and b we show the profile of two tapered fibers with a normalized taper waist diameter (ρ/ρ_0) of 0.92 and 0.72, respectively. The profiles were measured along the tapers with steps of 1 mm using an optical fiber diameter measuring system (M551A, Anritsu). As we can see in Fig. 4, the shapes of tapered fibers had a biconic structure and the taper length depends on the waist diameter. In the wider taper (a) the whole transition has a length of about 100 mm and in the case of (b) is approximately 150 mm, in both cases the uniform waist length were 80 mm.

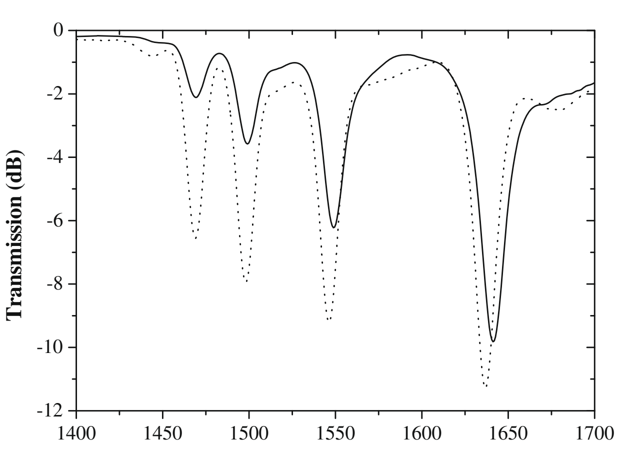

Fig. 2. Measured transmission spectra of a MLPFG over an untapered optical fiber with (continuous line) and without (dashed line) coating jacket.

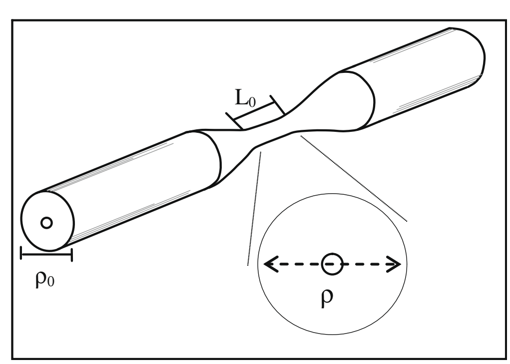

Fig. 3. Diagram of the fiber taper shape. ρ_0 represents the original diameter of the fiber, L_0 and ρ represents the length and diameter of the fiber taper waist, respectively.