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Bragg gratings and BIO-Bragg-gratings in tapered optical fibers

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Abstract. Tapered optical fibres are well-established devices for different applications, in order to exploit nonlinear effects, manage dispersion, excite azimuthal resonances in microresonators (so-called Whispering Gallery Modes). Also, the micro- or nanofibres guide optical-fields with large evanescent fields. In this talk, we will focus on the combination of tapers and Bragg gratings to perform novel optical devices. We will present two applications: the first, the fabrication of single-mode Bragg gratings in commercial multimode or few-mode tapered fibres by means of UV-photoinscription. The result is a grating that exhibits a single-mode reflection band and low insertion loss. The second application is the fabrication of Bio Bragg Gratings in micrometric tapers of single-mode fibres. In this case, the Bragg Grating is formed by a periodic pattern of biomolecules microstamped on the surface of the taper waist. As the molecules binds to its specific antibody, the reflectivity of this Bio Bragg Grating will increase, allowing quantification of the antibody concentration.

1 Introduction

A tapered waveguide is that which dimensions are tailored in a gradual way along its length, usually diminishing its diameter. This leads to a continuous variation of different guiding parameters, such as effective modal index, dispersion or modal area. The transitions from the pristine fibre section to the waist of the taper can be designed to be adiabatic even for subwavelength diameters, which ensure low insertion losses for these devices.

In the context of optical fibres, one of the first uses of tapered ones was the study of nonlinear phenomena. León Saval *et al.* fabricated submicrometric tapers (below 300 mm for the diameter waist) from conventional telecom fibre, for the generation of supercontinuum[1]. Also, a fine tuning of the core size of microstructured fibres can be performed by means of tapering techniques to match the pump wavelength to the zero dispersion wavelength of the fibre and, hence, optimize the supercontinuum spectrum[2]. Other phenomena, such as third- or second-harmonic generation via intermodal coupling has been reported using submicrometric fibers[3]. Micrometric tapers are also used for exciting Whispering Gallery Modes (WGM) thanks to their large evanescent optical field, with coupling efficiencies close to 100%[4]. Tapered capillaries with submicrometric thickness of the walls can be used as microfluidic channels, using WGM for their optical interrogation[4]. The combination of tapers and Fibre Bragg Gratings (FBG) have been exploited to fabricate tunable delay lines[6] and chirped gratings using a uniform phase mask for the photoinscription process[7]. In this talk we are going to present two examples of devices that combine gratings and tapered fibres to produce novel components with unique properties: (1) singlemode gratings (SMG) inscribed in multimode fibers (MMF)[8], and (2) Bragg gratings composed of molecules microstamped in a periodic fashion over the surface of a microtaper, BIO-Bragg-gratings (BBG)[9].

2 Singlemode gratings in multimode fibres

High power fibre lasers require of large mode area, hence multimode fibres, to prevent nonlinear effects in the laser cavity. This can lead to a poor quality of the beam and multiwavelength operation. The use of SMG can avoid these two drawbacks, thus there is an interest to offer methods that allow fabricating such gratings in MMF.

In this work, we present the fabrication of SMG in two commercial fibres:
- a four-modes step-index fibre from OFS (FMF), V-number ~ 5 @ 1550 nm, and
- the MM 50/125 graded index multimode fibre (GMMF) from Spectran Corporation, V-number ~ 14 @ 1550 nm.
According to the calculations, the FMF showed SM operation for tapered diameters below 55 μm, while GMMF was SM below 25 μm of clad-diameter.
The gratings were inscribed using a uniform phase mask (pitch: 1076.25 nm) and a doubled-argon UV laser. The different fibres were hydrogenated in a 30-bar atmosphere for 15 days to improve their photosensitivity. Figure 1 shows an example of a FBG written in a GMMF that was previously tapered down to 20 μm in diameter. The technique used for tapering was the fuse-and-pull technique; waist length: 4 cm, taper transition length: 5 cm with an exponential profile. The loss introduced ng the tapering was less than 0.1 dB. Several reflection bands are observed in the red curve, correspondent to the spectrum measured with the fibre in air. When a thin film

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of oil-index-matching was applied to the fibre, the two reflection bands at shorter wavelengths disappeared, while that correspondent to the Bragg wavelength for LP_{01} mode remained intact, see green curve. This indicates that these reflection bands are cladding modes which are excited at the taper transition, interact with the grating in the waist region, and are coupled back to the counter-propagating cladding modes. Nevertheless, the energy carried by these modes is below 5%, value estimated from the measurement of the transmission spectrum. Thus, we demonstrated that SM gratings can be inscribed in a MMF with a large V-number.

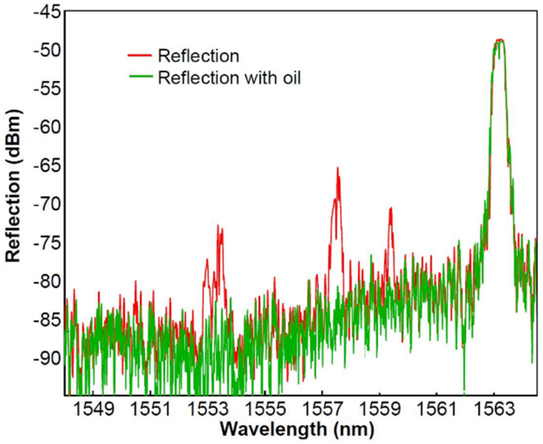

Fig. 1. Reflection spectra of a grating in a GMMF.

3 BIO-Bragg gratings in tapered fibres

In this section we present a label-free biosensor based on the combination of two techniques: first, the microstamping of molecules on glass surfaces[10] and, second, the use of micrometric tapered fibres that is, guiding modes with large evanescent fields.

A grooved PDMS stamp with a pitch of 555 nm was used for the microstamping of molecules over the taper surface (waist diameter: 3 µm, waist length: 2 cm; parameters were optimized for the best results). The stamp was incubated with BSA molecules; after two hours they were microstamped in the taper waist by applying mechanical pressure between the stamp and the microfibre. At this point, a periodic network of BSA molecules covers a section of the taper surface and interacts with the evanescent field of its fundamental mode. The reflectivity of such grating will be determined by the modulation depth, that is, the size of the molecules forming the pattern. Thus, an incipient, weak reflection band is observed at the correspondent Bragg wavelength. The device is rinsed in deionized water and then immersed in a solution containing a given concentration of the antibody, IgGs in this case. When BSA and IgGs bind each other, the modulation depth of the BBG increases and so does its reflectivity. By measuring the variation of the BBG the reflectivity, it is possible to quantify the concentration of the IgG in the solution.

Figure 2 shows an experimental immunoassay (dots), and their fit to a sigmoidal regression. Each concentration was measured at least three times in air, to ensure reproducibility. From the date, experimental detection and quantification limits were determined: 0.1 µg/mL and 0.4 µg/mL, respectively.

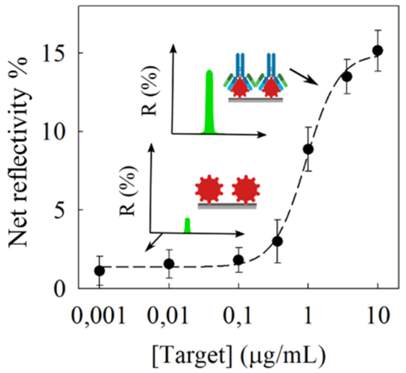

Fig. 2. Experimental immunoassay using BSA-IgG.

4 Conclusions

Two examples of the combination between two well developed devices, fibre tapers and fibre gratings, have been demonstrated. In the first case, it is shown how tapering a MMF fibre allow inscribing single mode gratings in them. The taper transitions make the role of impedance adapters for symmetric modes of the MMF, thus the insertion losses of these devices is below 0.1 dB. Some cladding modes can lead to additional reflection bands apart from that of the fundamental mode that can be easily eliminated with a thin film of index-matching oil. The second example consists on a label-free biosensor based on the microstamping of molecules (BSA) over the surface of a fibre taper. The measurement of the reflectivitiy of the BBG allows quantifying the concentration of the antibody. Detection and quantification limits comparable or better to other reported in the literature are obtained.

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