Flow cell for strain- and temperature-compensated refractometric measurements by means of cascaded optical fiber long period and Bragg gratings as promising label-free biosensing system

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Introduction

Refractometric measurements in biological fluids have been used for many years in the quantitative measurements of analytes, by employing chemical/biochemical recognition layers deposited on substrates. Chemical/biochemical recognition layers with these layers lead to changes in the refractive index of the layer which can be detected by means of optical methods, and which depends on the concentration of the interacting analyte. This approach is known as the label-free approach [1,2], in contrast with the methodology that makes use of luminescent markers chemically bound to recognition elements. Within the optical approach, optical fiber long period gratings (LPGs) have been recently proposed for chemical/biochemical sensing [3]. These sensors show a high sensitivity to the refractive index of the medium surrounding the fiber and thus a number of refractometric measurement systems have been proposed in the past [4-7]. However, LPGs have great sensitivity not only to the refractive index, but also to temperature, strain and fiber bending. A number of techniques have been proposed in order to get rid of the influence of these cross-sensitivities [8,9], which can be critical when an accurate refractometric measurement is carried out with the investigated sample flowing within a flow cell, as generally occurs in the chemical/biochemical sensing. In this scenario our goal is to describe the design and characterization of a thermo-stabilized flow cell of low volume (tens of µL) for accurate refractometric measurements using LPG and a methodology for measuring and correcting all the LPG cross-sensitivity, by means of a fiber Bragg grating (FBG) written on the same fiber and an accurate temperature measurement system [10-13].

Theory and methodology

Definition: an optical fiber grating is a permanent periodic modulation of the fiber core refractive index.

Classification (according to the grating period, λ, which sets out a specific coupling of light):
- Short period or fiber Bragg gratings (FBGs):
  - Grating period in the range of hundreds of nanometers;
  - Coupling between the fundamental core mode and its respective counter propagating mode;
  - Characteristic equation [14]
  \[ \lambda_{FBG} = 2\Delta n_{eff} L \] \hspace{1cm} \( \Delta n_{eff} \) is the effective index change and L is the grating period.

Methodology:

- Theoretical expressions:
  \[ \Delta \lambda_{FBG} = k \Delta n_{eff} L \]
  \[ \Delta \lambda_{LPG} = k \Delta n_{eff} L \]
  \[ \Delta \lambda_{LPG} = \frac{2\pi}{\Lambda} \Delta n_{eff} L \]
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- Once the four coefficients in the foregoing equations are determined experimentally, and by measuring the wavelength shift of the two gratings and the temperature, the value of the nonlinear function \[ \frac{\Delta \lambda_{LPG}}{\Delta \lambda_{FBG}} \] can be attained.

Experimental setup

1. Flow cell: the sketch of the flow cell, its picture, and the block diagram of the experimental setup are shown in the three figures below.

2. Fabrication of the gratings

- FBGs: by irradiating a photomixing B-Ge co-doped optical fiber (Fiberoptic PS1290/1550) through a rectangular phase mask (1059.9 nm period) with an Excimer KrF laser [14].
- LPGs: by irradiating the same fiber through an appropriately shaped and focused laser spot; the ad hoc developed fabrication setup is made up of a motorized translation stage and a control/management program for choosing both the grating period and the number of shots for each step (point-to-point technique).

3. Introdugtion system: for each measurement step, the software routine centers at the resonance wavelength, fixes the λ-plate (LPG: 25 mm; FBG: 2 mm), acquires the spectrum and extrapolates the minimum wavelength by means of a Lorentzian data fitting (first for the LPG and then for the FBG).

4. Fluids system and chemicals

- Solutions at a different refractive index (1.334 – 1.467) were prepared by mixing glycerol and water in different ratios, and the refractive index was measured by means of a hand-held refractometer.
- Measurement protocol: flow rate of about 0.5 mL/min for 4 minutes, afterwards halting the pump and acquisition of FBG and LPG minima for 10 minutes.

References