Demodulation System Intensity Coded for Fiber Bragg Grating Sensors

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***Abstract*— We report an optical system to be used for the interrogation of fiber Bragg grating based sensors. The demodulation system is intensity coded and its low cost is the main advantage when compared with the traditional wavelength coded systems. Eventual changes in the source intensity are compensated by splitting the interrogating beam in two components and taking the ratio between them. The splitting is accomplished with the combined use of a high-birefringence fiber Bragg grating with two bands centered at 1549.7 and 1550.2 nm and a polarizing cube beamsplitter, besides photo-detectors are used as transducers devices. The system performance was tested by the analysis of a fiber Bragg grating response mounted in a sensing head subjected to a mechanical stress. A linear response of the sensing head was observed, with a sensitivity of 0.36 nm per screw turn that corresponds to a FBG sensitivity of 0.8 pm/με a maximum sensitivity of 0.02/με was measured to the applied stress ranging from 225 to 452 με.**

***Index Terms*—** Bragg grating, demodulation system, fiber sensor.

I. INTRODUCTION

The technology for fiber Bragg gratings (FBG) production in optical fibers was greatly developed since Hill et al [1] discovered the photosensitivity of this type of waveguides. Along the last years, an intensive research has been devoted to the application of such photorefractive devices in both optical communication systems and optical sensors [2]-[5]. In the sensing field, the electromagnetic immunity and the electrical passivity make the FBG a very attractive option for sensors that must work in inflammable environments. Besides these features, its reduced size and the possibility for integration in optical links make them a versatile choice for fast and remote monitoring. Although FBG sensors can be designed to measure a range of physical parameters (e.g. temperature, mechanical stress, curvature and pressure), almost all of the interrogation systems relate the change in the measurand to the Bragg wavelength reflected by the Bragg grating [6]-[7]. The majority of these interrogation systems is based on tunable Fabry-Perot and acousto-optic filters or other interferometer systems, and so requires expensive components and equipments to the measurements. To overcome this drawback, some demodulation systems that relate the measurand with the optical power were proposed [8]-[11]. This work shows an alternative optical interrogation system intensity coded for

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Bragg gratings based sensors that employs a Bragg grating written in a high birefringence fiber (HiBi-FBG). The light intensities reflected by the two bands of the HiBi-FBG, associated with the slow and fast axis of the fiber, are measured with two optical detectors and related to the parameter under measurement.

II. EXPERIMENTAL SETUP

In the experiment, a sensing head that uses the response of a fiber Bragg grating under an applied longitudinal stress is employed to analyze the demodulation system performance. The set-up employed two sensing FBG, both engraved in a hydrogen loaded (100 atm for 14 days) standard telecommunication optical fiber. The experimental set-up used for writing FBG uses a phase-mask interferometer with a Nd-YAG laser (266 nm) as the radiation source. One of the gratings, hereby called grating 1, presents a bandwidth of 0.11 nm and Bragg wavelength of 1548.9 nm at 21 °C and the other one, named grating 2, presents a bandwidth of 0.15 nm and Bragg wavelength of 1549.24 nm at 21 °C. Figure 1 shows a picture of the constructed sensing head. In this apparatus, a FBG is bonded with a cyanoacrylate ester on a steel sheet that can be bent with the aid of a screw. By turning the screw a stress is applied to the FBG, resulting in wavelengths shifts of the grating reflection peak due to the applied force. This sensing apparatus was firstly characterized with an OSA (Anritsu, MS9710B, 0.1 nm resolution, ±5 pm of wavelength stability) to verify its wavelength response to the applied stress, so that the data could be compared to the ones obtained with the proposed intensity coded interrogation system.

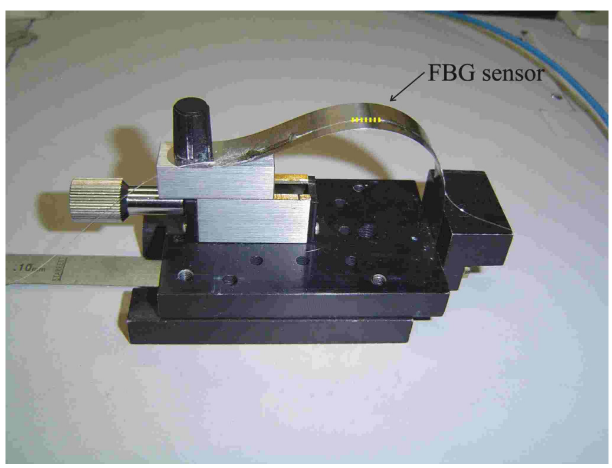

Fig. 1. FBG (λ= 1548.9 nm, $\Delta\lambda$= 0.11 nm at 21°C) assembled in the sensing head.

The experimental setup used for the intensity measurements is shown in Fig. 2. A LED (Superlum Pilot 2) is coupled to port 1 of an optical circulator and illuminates the sensing FBG at port 2. Light reflected from this grating illuminates, via port 1 of a 2x2 optical coupler, a HiBi-FBG at port 4. This grating presents two bands centered at 1549.7 nm and 1550.2 nm, each of one with a bandwidth of approximately 0.13 nm. Light reflected from this FBG is coupled, via port 2, to a fiber polarizer controller (Thorlabs FPC031) and then is split in two beams with a cube beamspliter (Thorlabs

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PBS3). By means of a careful adjust of the polarization state, each of these two beams becomes associated to the light reflected by one of the HiBi-FBG bands and is measured by the photo-detectors PD1 or PD2, as these two beams present polarization states mutually perpendicular. A lock-in amplifier (SR830 Stanford Research Systems) is employed to improve the signal quality and to transfer the signal data to a personal computer [12]. When the sensing FBG evolves towards higher wavelengths between the two HiBi-FBG peaks, the transmitted beam intensity (associated with the lower-wavelength HiBi-FBG peak, for example) experiences a decrease, while the reflected beam intensity (associated with the higher-wavelength HiBi-FBG peak) experiences an increase. For a specific screw angle position, the ratio of the two intensities is uniquely related to this position, and consequently to the stress applied on the sensing FBG.

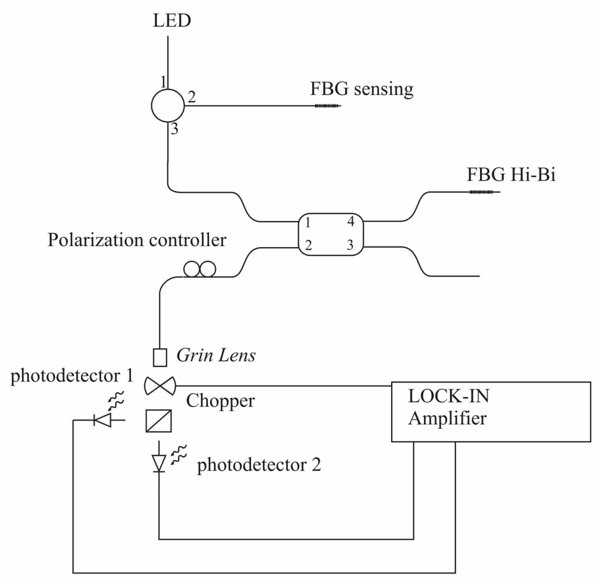

Fig. 2. Diagram of the interrogation system intensity coded experimental setup.

III. RESULTS AND DISCUSSION

In order to verify the sensing head response as the screw was turned, the central wavelength of the sensing FBG reflection band is measured with the OSA for several screw angle positions, and the results are shown in Fig. 3. Both sensing FBG were previously characterized and showed a strain sensitivity of 0.8 pm/με. To minimize errors in the analysis of the sensing head response, the FBG central wavelength was determined by fitting a Gaussian curve to the experimental spectrum. In the whole dynamical range of the sensing head the device presents a linear behavior of the wavelength shift, with a sensitivity of 0.36 nm/turn. This linear behavior also shows that the sensor head is not inducing a chirp in the grating by bending the sensing FBG. Furthermore, neither the bandwidth nor the reflectivity of the sensing grating suffered changes during the whole experiment.

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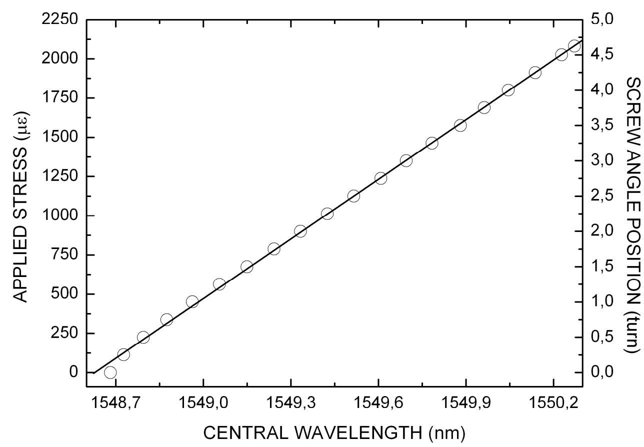

Fig. 3. Wavelength response of the sensing FBG (grating 1, bandwidth of 0.11 nm and Bragg wavelength of 1548.9 nm at 21°C) mounted in the sensor head.

To simulate the performance of the interrogation system, both the sensing (grating 1) and the HiBi-FBG gratings were connected to ports 3 and 4 of a 2x2 coupler with the LED in the port 1, and the resultant spectrum for each angle position of the screw was recorded with the OSA in port 2. For each spectrum, three Gaussians curves were adjusted to the experimental points to fit the measured spectral shapes of the FBG bands [4]. A typical spectrum obtained is shown in Fig. 4, where it also can be seen a diagram of the assembly in the inset. As it can see from figure, the fitted Gaussian curves provide an efficient adjust to the FBG reflection bands. By turning the screw of the sensing head, the sensing FBG covers the whole wavelength range where the HiBi-FBG operates.

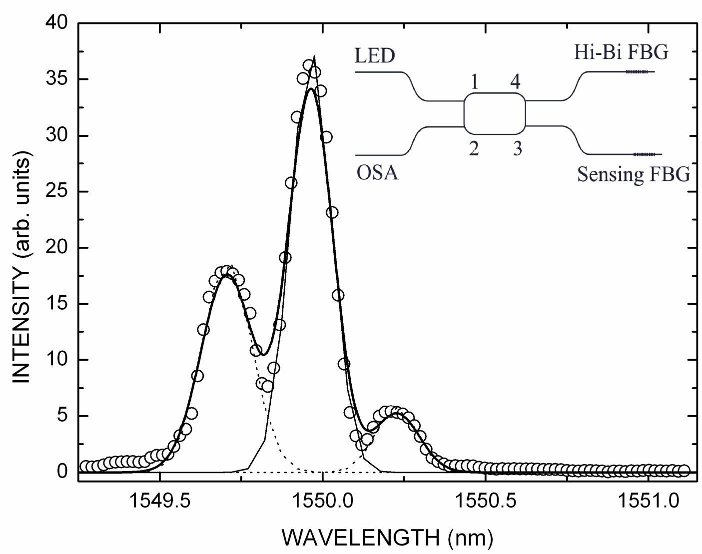

Fig. 4. Superimposed Hi-Bi and FBG sensing spectra obtained for a specific screw angle position. The experimental points (open circles) were adjusted by three Gaussians curves (HiBi-FBG: doted, sensing: solid lines), and the bold solid line represents the resultant fitted curve.

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For the HiBi-FBG, all the adjusting parameters (off-set, central wavelength, bandwidth and area under the curve) were determined and kept constant for each screw angle position. For the sensing FBG the only variable parameter was the central wavelength for each screw angle position. The adjusted equation for the sensing FBG was then multiplied by each equation that represents each one of the HiBi-FBG bands, and the area under the two resulting curves was calculated. These areas are associated with the beam intensities IR and IT reaching the photo-detectors PD1 and PD2, which correspond to the light reflected by each one of the HiBi-FBG bands, when the complete setup shown in Fig. 2 is used. The resultant intensities ratio IT/ IR is shown in Fig. 5 for several screw angle positions and consequently different values of stress applied to the FBG sensor. As it can be seen from that figure, to a particular value of stress applied to the FBG sensor, there is a characteristic ratio value that can be used to calibrate the instrument. However, this unique association only occurs when the sensing FBG central wavelength is in the spectral range between the central wavelengths of the HiBi-FBG reflection bands (indicated by the two vertical lines in the figure). The fit of the graph by two straight lines allows finding the low and high average values of sensitivity in the spectral range between the central wavelengths of the HiBi-FBG reflection bands. In the high sensitivity range the correspondent value is 0.03/με while in the low sensitivity range is 0.003/με.

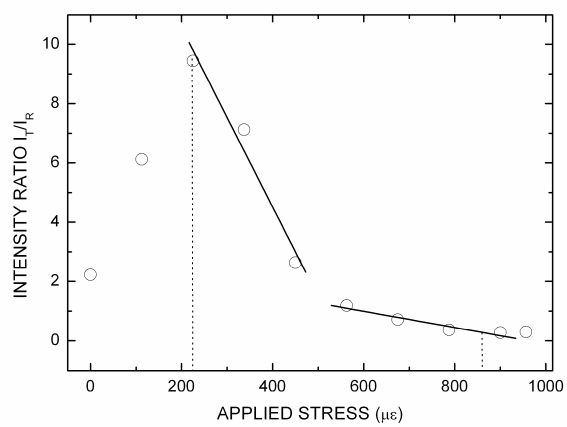

Fig. 5. Ratio of the areas obtained in the simulation of beams for several screw angle positions in the sensing head and the sensing FBG (grating 1, bandwidth of 0.11 nm and Bragg wavelength of 1548.9 nm at 21 °C).

The simulated results were experimentally verified using the complete setup shown in Fig. 2. In this experimental apparatus, light intensities reaching the photo-detectors 1 and 2 correspond to the beams reflected and transmitted by the cube beamspliter, respectively. By adjusting the light polarization state with the polarizer controller, it is possible to associate the transmitted beam with the lower wavelength band of the HiBi-FBG, and the higher wavelength band with the reflected beam. Figure 6 and 7 shows the ratio of the measured intensities for several stress values applied in the head sensing mounted with FBG sensing grating 1 and 2, respectively. The two vertical lines stand for the useful spectral range of the instrument, where each value of applied stress is uniquely associated with a

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specific ratio value of intensities. In these figures, it is possible to determine two distinct values of sensitivity, corresponding to the intensities ratio IT/ IR per applied stress. In the high sensitivity range (225 to 452 με) the obtained sensitivity was 0.02/με for the two sensing gratings.

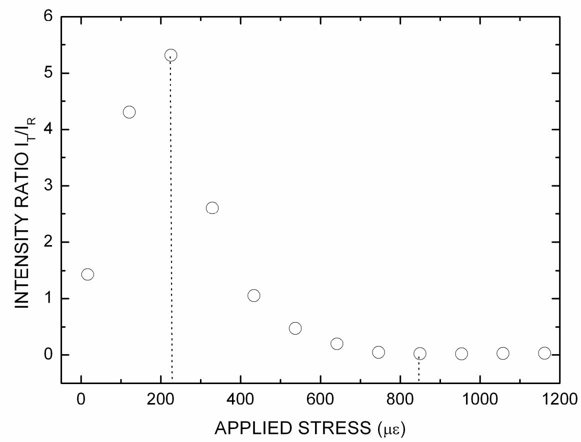

Fig. 6. Ratio of the intensities between the transmitted and reflected beams for several screw angle positions in the sensing head, obtained with the experimental setup of Fig. 2 and grating 1 (bandwidth of 0.11 nm and Bragg wavelength of 1548.9 nm at 21 °C).

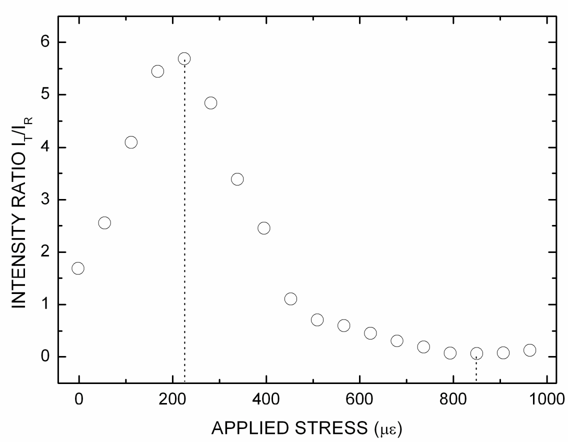

Fig. 7. Ratio of the intensities between the transmitted and reflected beams for several screw angle positions in the sensing head, obtained with the experimental setup of Fig. 2 and grating 2 (bandwidth of 0.15 nm and Bragg wavelength of 1549.24 nm at 21 °C).

IV. CONCLUSIONS

In this work, we presented an alternative interrogation system for Bragg gratings based sensors that can be used to replace the conventional more expensive systems. The system is intensity coded, and relies on the capability of a cube beamspliter to separate the two orthogonal polarization states reflected by an auxiliary Bragg grating written in a HiBi fiber. The ratio between the measured intensities of these two beams, uniquely associated to a specific value of the measurand, allows performing a calibration of the instrument. The proposed demodulation system was employed in a sensor head built with a sensing FBG that allows measuring the stress applied to the grating. The maximum operation interval of the demodulation system is limited basically by the spectral range of the HiBi-FBG employed and by the FBG sensor head sensitivity. A linear response of the sensing head to the screw turns was observed, and in the sensing head configuration the FBG showed a sensitivity of 0.36 nm/turn, for a FBG sensor sensitivity of 0.8 pm/με. In this experiment, for the employed HiBi-FBG and the sensor head characteristics, a maximum sensitivity of 0.02/με was measured to the applied stress ranging from 225 to 452 με, which corresponds to changes of 2% in the intensity ratio per με. Finally, the experimental results of this work showed that the demodulation system proposed presents a good performance for stress measurement and can be applied in other detection systems that use a FBG sensor.

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