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A linear fiber laser temperature sensor based on a fiber Bragg grating

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Abstract

In this work, a linear fiber laser temperature sensor based on a fiber Bragg grating (FBG) is presented. Here, a microchip Q-switched laser working at 1064 nm is used. Additionally, a fiber Bragg grating is used as head sensing and its wavelength is centered at 1550 nm. Moreover, the linear laser can be tunable from 1548 to 1553 nm when the temperature is varied, and a sensitivity of 58.33 °C/nm is achieved in a range from 3 to 200 °C. The supercontinuum (SC) generation was achieved by means of the pulsed laser and bending of SMF-28 fiber in a cylindrical tube.

Sensors, Fiber Bragg Grating, Supercontinuum Generation

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Introduction

Optical fiber sensors have been studied in the past few decades due to their immunity to electromagnetic interference, high sensitivity and capability of measure in situations where conventional electronic or electro-mechanical sensors would be affected by, for example, a harsh environment (Grattan & Sun, 2000). One way to approach optical fiber temperature sensors is by means of interferometric sensors, such as the proposed by Martinez-Rios et al. whose experimental setup presents an Erbium-doped fiber ring laser with a Mach-Zehnder interferometer as sensing element placed in different solutions of glycerol and water, showing a maximum sensitivity of 1089 pm/°C in a temperature range from 55 to 70 °C (Martinez-Rios et al., 2015).

Other temperature sensors have been studied by using other kind of optical devices, such as Fabry-Perot interferometers (Pinto et al., 2010), multimode interference (Nguyen et al., 2008) and photonic crystal fiber (PCF) (Yang, Lu, Liu & Yao, 2017). Fiber grating sensors are commonly used because of their high sensitivity, which can be increased with the use of an interferometer. As an example, the experimental setup proposed by Gonzalez-Reyna et al. (2015) presented a sensitivity of 18.8 pm/°C within the range from 220 to 90 °C. Another advantage fiber grating sensors present is their multiplexing capability (Kersey et al., 1997; Mandal et al., 2006). Furthermore, supercontinuum is the nonlinear process of spectral broadening of light and has found applications in telecommunications, sensing and spectroscopy.

Supercontinuum generation can be produced through the interaction of linear effects such as dispersion, and nonlinear propagation effects such as self-phase modulation (SPM), cross-phase modulation (XPM), Raman scattering, four-wave mixing (FWM), modulation instability (MI) and others (Dudley & Taylor, 2010). Efficient SC can be achieved by using pulses in the order of femtoseconds and a peak power of kW through optical fiber.

A well-known feature that optical fibers have, is the nullification of dispersion in a specific wavelength. This wavelength is named zero-dispersion wavelength and is denoted as λ_0. Above this wavelength $(D > 0, \beta_2 < 0)$ the optical fiber presents an anomalous dispersion regime, while below this wavelength $(D > 0, \beta_2 > 0)$ propagation takes place in the normal dispersion regime. In past works, it has been demonstrated that depending on the characteristics of the pumping beam employed in the supercontinuum generation, is the contribution of the nonlinear effects involved (Gutierrez-Gutierrez et al., 2009; Estudillo-Ayala et al., 2012). In this work, we are using standard SMF-28 optical fiber with a zero-dispersion wavelength at 1310 nm and a pumping source operating at 1064 nm. Therefore, the experiment happens in the normal dispersion regime, thus, the linear and nonlinear effects involved in the supercontinuum generation are: group velocity dispersion (GVD), self-phase modulation (SPM), modulation instability (MI) and stimulated Raman scattering (SRS).

The objective of this study was to develop a simple, reliable and cost-efficient fiber laser configuration using only a FBG as the sensing and tuning element.

Experimental setup

The proposed laser configuration is shown in Figure 1. A microchip Q-switched laser operating at 1064 nm with a peak power of 10 kW, pulses of 700 ps and 9kHz repetition frequency (Teem Photonics, microchip model: MNP-06E-100) was coupled to the port 1 of a four-port 99/1 coupler by means of a mirror and a 10X microscope objective mounted on a manual XYZ stage. Port 3, with 99% of laser's power is connected to 100 m of SMF-28 fiber wrapped to a 5.4 cm diameter cylindrical tube. Additionally, the bending of SMF-28 fiber through the cylindrical tube acted as our nonlinear medium. This section was spliced to the FBG which represents one end of the configuration and whose Bragg wavelength is centered at 1550 nm. On port 2 of the coupler, a circulator is connected, completing the laser cavity. The output power was measured with an optical spectrum analyzer (OSA, Yokogawa AQ6370B) through a 90/10 coupler placed on the circulator loop. Additionaly, OSA resolution used was 0.1 nm.

From below 24 °C, the FBG was placed on a Peltier cell and from above 24 °C, the FBG was placed on an electric oven. Temperature was monitored by means of a thermocouple and a multimeter (Tektronix TX-DMM TX3 digital multimeter) in both cases.

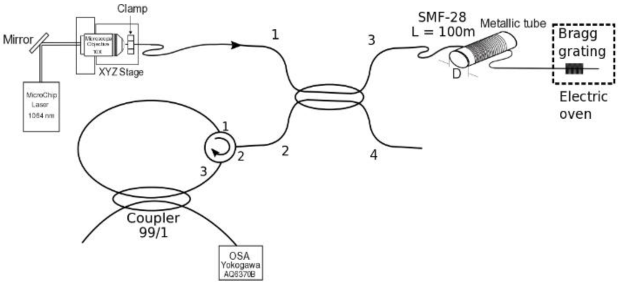

Figure 1 Experimental setup of the temperature sensor.

It is important to point out that the diameter selection of the cylindrical tube was due to good stability response and sufficient spectral broadening for our experiment (Rojas-Laguna et al., 2015).

Results and discussion

Broad spectral fiber laser due to supercontinuum generation observed between the 100 m of SMF-28 and the FBG is shown in Figure 2. The SC spectra goes from 1064 nm to 1660 nm. Fiber laser output spectral responses to temperature changes are shown in Figure 3. Wavelength shifts as well as a slight variation of the output power can be observed. Wavelength displacement can be explained by the temperature dependence of the refractive index of the FBG. In addition, Figure 4 shows the maximum output power wavelength, or peak wavelength, at different temperatures. Note how the Bragg wavelength is centered on 1550 nm at 24 °C, as mentioned before. Moreover, the wavelength shift of the sensor shows a quasi linear response to the temperature changes in a range from 3 to 200 °C with a sensitivity of 58.33 °C/nm. Comparing Figure 3 and Figure 4, temperature sensors show a wavelength displacement from left to right.

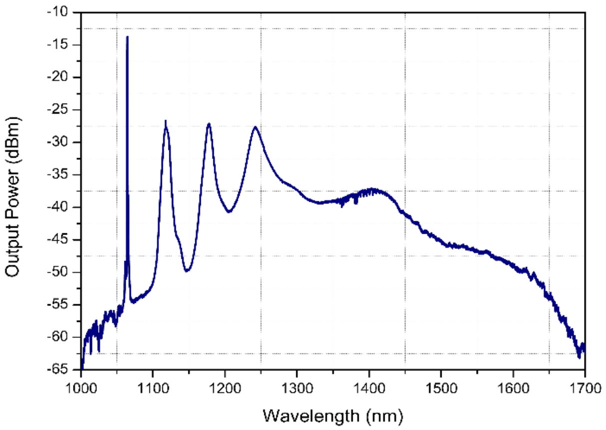

Figure 2 Supercontinuum spectra generated.

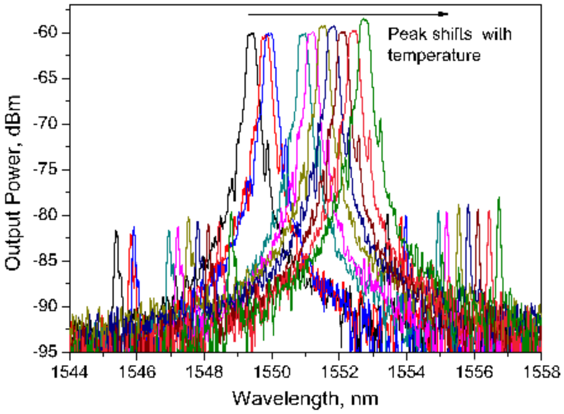

Figure 3 Output laser spectrum at different temperatures.

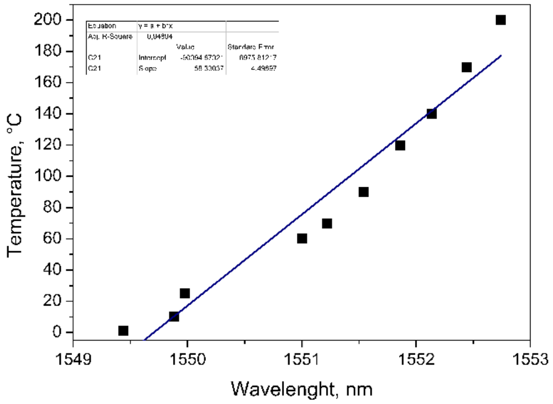

Figure 4 Output laser spectral peaks at different temperatures.

Conclusions

In this paper, a linear fiber laser temperature sensor based on fiber Bragg grating with a SC source has been demonstrated. A linearly sensitivity of 58.33 °C/nm in the ranges from 3 to 200 °C demonstrates a high sensitivity and stability at room temperature considering the experimental setup proposed. SC generation was achieved by means of a pulsed microchip Q-switched laser and bending 100 m of the SMF-28 fiber on the cylindrical tube.

Finally, due to the lack of use of special optical fiber components such as rare-earth-doped fiber, photonic crystal fiber and interferometers, the temperature sensor has a low cost and a simple fabrication process.

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