

Optical sensor based on fiber grating for hydrocarbon detection in aquatic environment

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Abstract

This work shows the application of a long period grating LPG as a sensor device to detect the presence of several types of commercial petroleum hydrocarbons (e.g. gasoline, kerosene, turpentine, paint thinner, diesel) in water environments. The LPG was written in a standard telecommunication optical fiber applying a point-to-point electrical arc discharge from a fusion splicer. In order to detect the pollutant presence in the water environment, the LPG was kept into a stream of water under constant longitudinal stress and a hydrocarbon sample was added to it. Once the LPG is also sensitive to temperature changes, a fiber Bragg grating (FBG) was employed to correct the sensor response. Furthermore, the information from the LPG and the FBG are wavelength coded, which allows to integrate several sensors spread out over a large area around the place of interest, each point being associated with a specific wavelength.

Introduction

In the past years were related a lot of results concerning to the use of optical sensors [1] based on fiber optic gratings to measure physical parameters like temperature, mechanical stress and refractive index. A particular type of fiber grating named LPG (long period grating) has taken great attention once its present more sensitivity to the changes in the external medium refractive index than the FBG (fiber Bragg grating). This characteristic makes possible the use of LPG sensor in petroleum and natural gas fields [2] and environment control [3].

The LPG are a periodic modulation in the fiber optical properties with long special periods (100-700 μ m), which couples light from the fundamental core propagation mode to co-propagating cladding modes. This mode coupling results in attenuation dips in the fiber transmission spectrum [4], centered in wavelengths given by:

$$\lambda_m = (n_{co} - n_{cl}^m) \Lambda \quad (1)$$

where λ_m is the dip resonance wavelength, n_{co} and n_{cl}^m are the effective refractive indexes of the core and cladding modes and Λ is the grating period. Mechanical stress and temperature changes modify both the grating period and the modes effective index. Moreover, external medium index changes also lead to alteration in the cladding modes effective index. Such changes result in the wavelength shift of the attenuation dip (see equation 1). The most interesting features of LPG for sensing application are the possibility of real time response, quasi-distributed monitoring system with the use of more than one LPG in the same link, and information wavelength coded.

Along the last years, several accidents have been caused by petroleum hydrocarbon leakage in the environment. The resulting harms can take a long time to be repaired with high monetary costs and impairments to the involved industry. The most common places where these accidents can occur are the refineries, harbors and pipelines neighborhoods, which are often near to rivers, swamps, oceans and dams increasing the problem due to the high water flow. The present leakage detection systems are based on pressure and flow monitoring besides the visual human observation, what account for the long detection time.

In the field of environment preservation, LPG are very attractive as sensors once it is possible to use several sensors that spread out over a large area covering a place of interest. In this way, the area around petroleum refineries, harbors and pipelines, which are subjected to leakage, can be monitored in real time. The harms of an ecological accident can be drastically reduced if the petroleum is quickly detected. The LPG based sensors can provide this fast detection without the human assistance, being possible its operation with no interruption.

This work shows the employed of a LPG sensing device to detect the presence of several kind of petroleum hydrocarbons in water environments. To correct the LPG temperature response we used a FBG to make the sensor insensitive to temperature changes.

Experimental Setup

The LPG was produced by the use a point-to-point writing method, applying on a bare fiber an electrical arc discharge from a fusion splicer (Siemens, model S46999-M7A-71) [5]. The electrical parameters are 12 m-A current and 0.5-s discharge time, producing a LPG with 65 interaction points and a pitch of 595 μm .

The characterization set-up is shown in figure 1. The optical fiber with the LPG is inserted through a glass recipient, where the sample with the pollutants can be placed. In one of the sides, out of the recipient, the fiber is fixed on a holder. After passing a pulley, the opposite fiber side is bound to a small box with a 20 g weight to keep the LPG under a constant longitudinal stress during the measurements. The optical source is a superluminescent LED with a 1550 nm central wavelength, and the reading system uses an optical spectrum analyzer (OSA) with a 0.1-nm resolution and a PC. A Bragg grating (FBG) is inserted in the optical system with two 3-dB couplers to monitor the water temperature. These data are used to correct the LPG temperature sensitivity response.

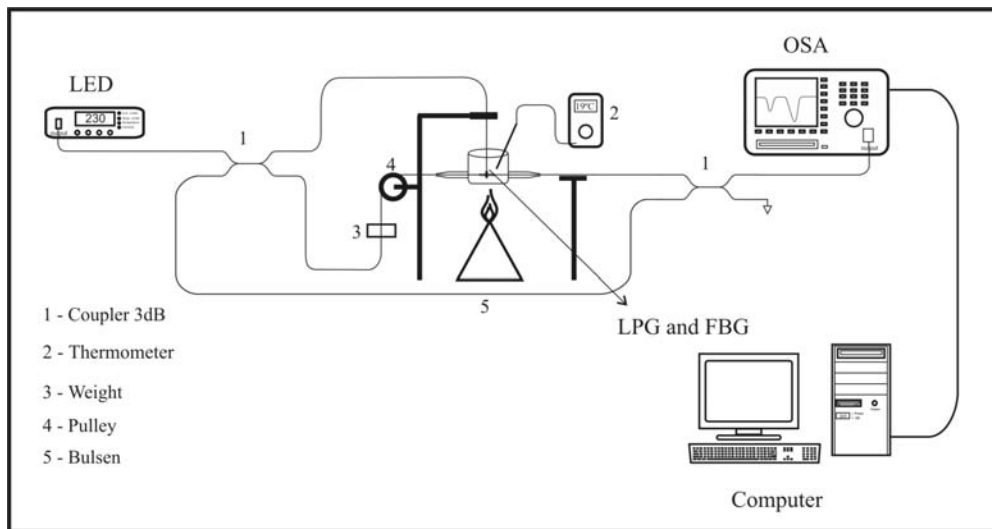


Figure 1: Experimental set-up employed for the characterization of the LPG as hydrocarbon detector.

The temperature gratings sensibilities are analyzed warming up the water in the recipient from 20 °C to 60 °C. During the heating process, the temperature and the transmission spectra (LPG plus FBG) are measured in temperature intervals of 5 °C. The coefficients of thermal sensibility of LPG (α_{LPG}) and FBG (α_{FBG}) are employed in the equation (2) to correct the LPG spectral shift caused only by the temperature change.

$$\lambda_c = \lambda_m + \alpha_{LPG} \frac{(\lambda_f - \lambda_i)}{\alpha_{FBG}} \quad (2)$$

In this equation, λ_c is the LPG corrected wavelength position, λ_m is the LPG measured dip wavelength for the temperature T, λ_f and λ_i are respectively the FBG measured wavelength for the temperature T and 20 °C.

To detect the pollutant presence, the LPG is immersed in water and its transmission spectrum is monitored. After the pollutant addition, the bottom drain valve in the recipient is opened and a transmission spectrum is measured in time intervals of 10 seconds. In this way, the pollutant flows through the recipient and is detected by the LPG. After that, a new amount of water is injected in the recipient so that the level sample increases until the water covers the sensor again. Five different types of hydrocarbon are used: gasoline, kerosene, paint thinner, turpentine and diesel.

Results and Discussions

Figure 2 shows the thermal behavior for LPG (full circles) and FBG (open circles) attenuation dips. The results show a maximum wavelength shift about 3nm in the LPG attenuation dip for temperatures between 20 °C and 60 °C. The coefficients of thermal sensibility obtained from the best fit of a linear function to the experimental data are $\alpha_{LPG} = (0,07 \pm 0,002) \text{ nm/}^\circ\text{C}$ and $\alpha_{FBG} = (0,01 \pm 0,0003) \text{ nm/}^\circ\text{C}$ for the LPG and FBG gratings, respectively. To validate the correction method, the λ_m and λ_f values are measured for several temperatures from 20 °C to 60 °C and then the results from equation (2) are compared with the λ_c values measured for 20 °C.

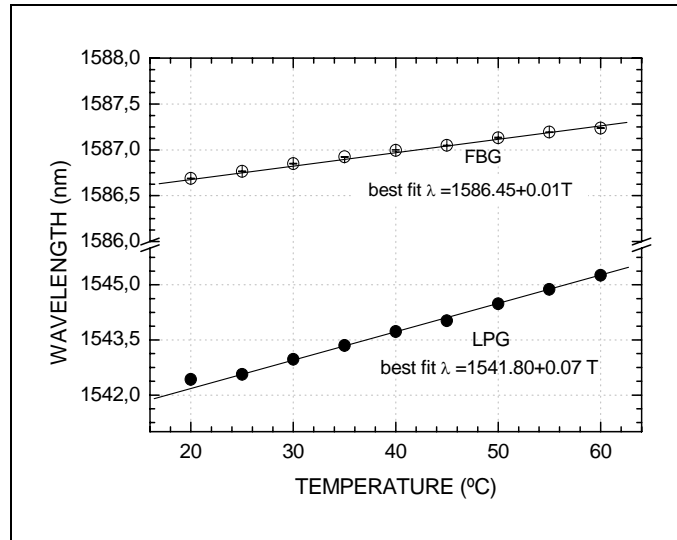


Figure 2: FBG and LPG thermal behavior.

For the different temperatures, the calculated wavelength λ_c obtained from equation (2) agrees well with the expected value (1542 nm for 20 °C). The maximum error is 0.02% (or 0.3 nm) for the temperatures of 35 °C.

In the figure 3 is shown the LPG wavelength dip measured along the time when the grating is used as a sensor device to the hydrocarbon presence in water environments, for turpentine at 20 °C. During the 300 first seconds the LPG is immersed in pure water. After this time, a wavelength shift occurs when the LPG is in contact with the turpentine sample. For $t = 450$ seconds the grating is again in contact with the water, and the wavelength shifts close to the initial value.

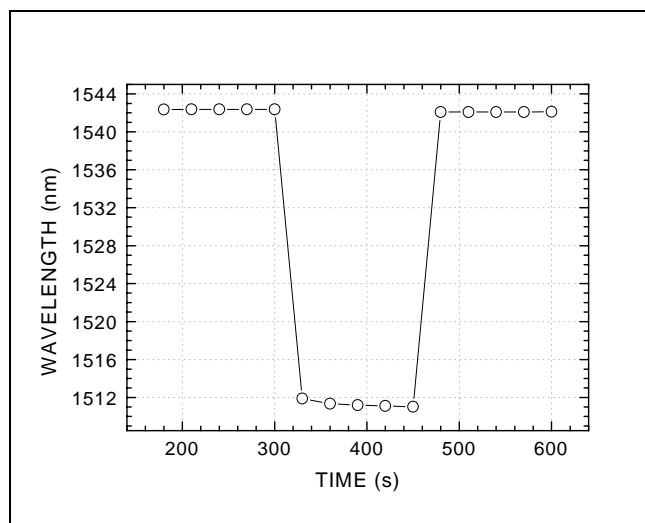


Figure 3: Characteristic behavior of the LPG resonance wavelength dip when the grating is used as presence hydrocarbon sensor in water environments.

Table 1 summarizes the results obtained for the 5 different types of hydrocarbon used in the sensor characterization.

Table 1: Measured wavelength for the LPG hydrocarbon sensor.

Hydrocarbon Sample	λ_m in water (nm)	λ_m in hydrocarbon (nm)	λ_m in water (nm) (after the contact with the hydrocarbon)
Gasoline	1542.10	1536.87	1540.74
Diesel	1542.14	1533.76	1541.71
Turpentine	1542.34	1511.34	1542.08
Kerosene	1542.38	1492.50	1539.95
Thinner	1542.56	1528.11	1543.49

Conclusions

The obtained results in this work point to prospect of using the LPG as a sensor device to detect the presence of pollutants in water environments. Wavelength shifts from 5 nm (for gasoline detection) to 49 nm (for kerosene detection) are reported, values that are easy to measure in the optical domain. An important feature is that the detection occurs at the same time that the pollutant sample is in contact with the LPG, allowing real time leakage detection. The wavelength shift due to the pollutants used in this work is higher than the shift caused by changes in the temperature sample (3 nm for temperatures between 20 – 60 °C), and the temperature correction is not important in this case. Nevertheless, the temperature correction can be necessary for lower wavelength shifts caused by the pollutant presence. The fact that the LPG dip wavelength does not recover the initial values after the hydrocarbon detection (see table 2) is not a problem, once a previous work [6] showed a non-contaminated water flow can removed the hydrocarbons adsorbed on the fiber surface.

Acknowledgements

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