Optical method to measure peroxides: A setup for edible oils sensing using a core-offset Mach-Zehnder Interferometer

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Abstract

Peroxide value is the index to follow the primary oxidative rancidity in fats and oils. Peroxides increase in fats and oils used for repeated frying. A peroxide sensing setup based in the Mach-Zehnder Interferometer (MZI) was fabricated. The MZI had the connection of three sections of optical fiber of Single Mode Fiber (SMF) implemented by splicing standard single mode fiber segments (SMF, Single Mode fiber) by the technique of misalignment of the fiber axes. A change in the output spectrum was induced by applying different samples of edible oil with different times of usage for repeated frying on the interferometer. Finally, the experimental results showed a sensitivity of 0.80461 nm/meq/kg for edible oils. The sensor fabrication process is very simple and low cost.

Interferometry, Mach- Zehnder, Edible Oil Sensing, Optical Fiber

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Introduction

Although frying is a relatively simple process of immersing the food product in hot oil, it involves different factors that directly affect the rate of oil degradation and the final product properties. Some of these factors are the type of food, degree of saturation of the oil, oil temperature, and frying time, among others (Enriquez-Fernández et al., 2012). In practice, for repeated frying of foods, the oil remains regularly in the fryer for days at high temperatures, which, along with other aspects such as presence of oxygen environment and water from foods being fried, causes alterations to the oil properties (Flores-Álvarez et al., 2012).

The peroxide value indicates the milliequivalents of oxygen in the form of peroxide by kilogram of fat or oil, this peroxide value (PV) is determined according to the Mexican standard (NMX-F-154-SCFI-2010). Its maximum value is 20 meq/kg; otherwise, the fat/oil must be discarded, as peroxides have been recognized as toxic for the human.

Optical fiber sensors have attracted great attentions in the applications of biological, chemical and environmental industries, including the measurements of the liquid level, refractive index (RI), temperature and strain (Li et al., 2012). Compared to other techniques based on the mechanical, chemical and electrical methods, the optical fiber sensors have several advantages, such as electromagnetic immunity, high sensitivity, capability of remote sensing and low cost.

In this paper, a sensing setup based on a core-offset Mach-Zehnder interferometer was achieved by core-offset fusion splicing of a segment of a single mode fiber between two pieces of single-mode fibers.

Taking into account the characteristics of the fiber optics in different applications, this work refers to the sensing of indices of degradation of edible oils based on an interferometer type Mach-Zehnder fiber optic, where the change of edible oil sample over the MZI, the output power spectrum can be measured.

Methodology

Several types of optical sensors have been proposed to develop Mach-Zehnder interferometers as well as there are several ways to fabricate a MZI along a single-mode fiber (SMF). The commonly used method is to induce and recombine the core mode and cladding modes of a SMF by using core-offset splicing (Zhang et al., 2011; Duan et al., 2011). Figure 1 shows the schematic diagram to implement the Mach-Zehnder Interferometer.

The sensor was formed by fusion splicing a section of 6 cm of single-mode fiber (SMF-28) between two sections of single-mode fibers, which functions as a detection sensor for the peroxide levels present when making direct contact with the sample. The core and cladding are considered as the arms of the MZI, while the offset act as optical fiber couples, for this case, the axes of a conventional single-mode fiber (SMF-28) were misaligned by 20 µm (offset).

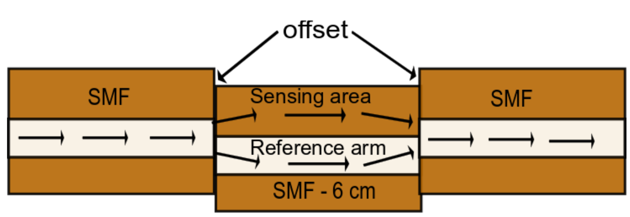

Figure 1 The schematic diagram of a typical Mach-Zehnder interferometer (MZI) by the technique of misalignment of the fiber axes.

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Once the single-mode fiber has an effective refractive index difference between the core section n_c = 1.4598 and the coating section n_{cl} = 1.4458, a phase difference can occur through the physical length of the interferometer. Since the fiber used has a core with a diameter of 8 μm and the coating with a diameter of 125 μm, each one will behave as an optical path with different refractive index. Therefore, upon reaching the light beam at the first coupling, it is diffracted by the two optical paths, and then, the core modes and the modes of the coating are returned to the mode of the nucleus at the second junction. By the phase difference and the strips of separation, which are dependent on the wavelength, the optical power transmitted by the interferometer will be maximum at a certain wavelength. The experimental setup used to characterize Mach-Zehnder interferometer as the degradation of edible oils sensor is shown in Figure 2. A semiconductor laser diode (Qphotonics, model QFBGLD-980-500, MI, USA) with a peak centered at 980 nm was used as a source of pumping. The pumping source is connected to the 3.8 m erbium doped fiber (EDF, Thorlabs, model M5-980-125, Newton, New Jersey, USA) using a wavelength division multiplexer (WDM) and the output of the EDF is spliced with the Mach-Zehnder interferometer.

The output power of the sensing setup was monitored by an optical spectrum analyzer (OSA, Yokogawa AQ6370C, Tokyo, Japan) with a resolution of 20 pm.

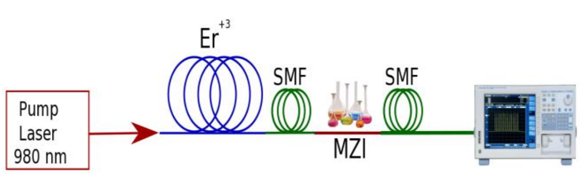

Figure 2 Experimental setup used to characterize Mach-Zehnder interferometer.

Oil samples were obtained from the repeated frying of baked fried foods (Castro-López et al., 2017). The analytical determination of peroxides was done according to the Mexican standard NMX-F-154-SCFI-2010. In a flask, 1 g of KI and 1 g of oil were placed and 30 mL of glacial acetic acid-chloroform solution (3: 2 v/ v) were added. Then, 0.5 mL of 5% KI solution and 30 mL of distilled water were added and heated in a water bath for 1 min. 2.5 ml of 2% starch solution was added and the final solution was titrated with 0.01 N sodium thiosulfate solution until get uncolored solution. Determinations were done by duplicate.

Results

When the fundamental mode being transmitted by the single-mode fiber passes through the first collapse region, the mode is diffracted and a part of the light is coupled to the core section of the SMF. Another part is coupled to the coating section as a result both the core mode and the coating modes are excited. Since both sections have different effective refractive index, a phase difference occurs and as a result, the modes are transmitted at different speeds along the entire section of the MZI.

In addition, when these modes reach the second collapse region, these are reacted back to the single mode fiber. Thus, the two regions of collapse act as optical couplers and the sections of both the core and the cladding act as arms of the interferometer. As a result of the interference between the core mode and the coating mode an interference pattern is obtained as shown in Figures 3 and 4. The separation between two consecutive stripes is given by the equation (1).

$$\Delta\lambda = \lambda^2 / \Delta n L \quad (1)$$

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Where λ is wavelength, Δn is the difference of effective refractive indices between the regions of the core and coating of the SMF and L is the length of the interferometer. At this point, it is important to mention that room temperature remained constant, in order to carry out all the experimental characterizations (Huerta-Mascotte et al., 2016).

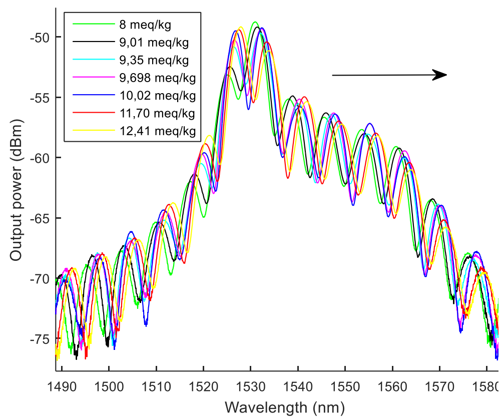

Figure 3 Transmission spectrum in edible oils.

In the Figure 3, the spectral shifting of the MZI, can be observed, under different peroxides indexes of edible oils. Futhermore, in the Figure 4, to determine the spectral changing, can be appreciated that the wavelength moves towards the right for a range from 1540 to 1548 nm.

Finally, Figure 5 was obtained from data shown in Table 1, which in making a linear trend of the corresponding data is obtained a dip of 0.88 corresponding to the sensitivity of the sensor characterized.

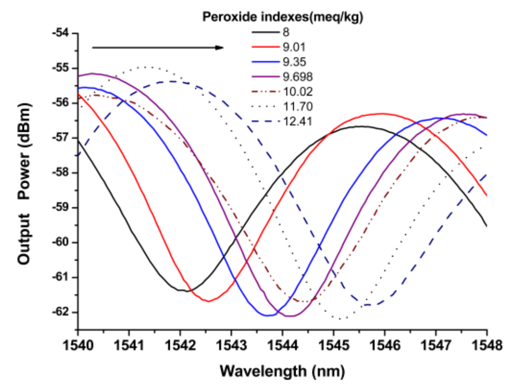

Figure 4 Spectral changing for the range of 1540 nm to 1548nm.

Wavelength(nm)	Peroxide indixes(meq/kg)
1542.037	8
1542.554	9.01
1543.677	9.35
1544.149	9.69
1544.376	10.02
1545.119	11.70
1545.699	12.41

Table 1 Values for wavelength as function of the peroxide indixes.

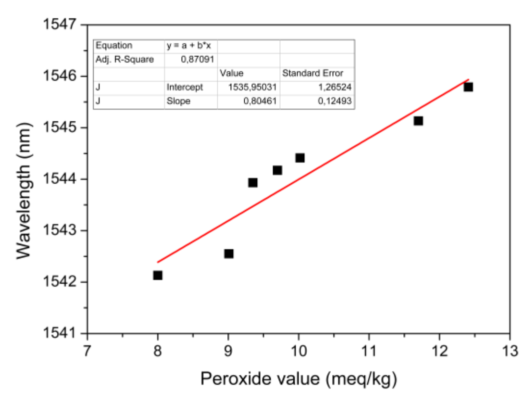

Figure 5 The interference spectrum to dip centered at 1541 nm.

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Conclusions

A sensing of the degradation in edible oils based on a core-offset Mach-Zehnder interferometer was proposed, based on a 6 cm section of SMF. The output power spectrum shift occurs between wavelengths of 1490-1580 nm with a good linearity in the dynamic range between 8 to 12.41 meq/kg for edible oils with visibility of 7.07 dBm an approximate sensitivity of 0.88 nm/meq/kg in the range of 1540 to 1548 nm. This work is starting and the instrument still needs to be detailed and tested in other range of peroxides.

Acknowledgments

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