پژوهشکده لیزر و پلاسما

اولین کنفرانس ملی حسگرهای فیبر نوری - ۶ آبان ۱۴۰۰

ICOFS 2021

1st Iranian Conference on Optical Fiber Sensors

October 28, 2021

Mach-Zehnder interferometric fiber optic sensor for measuring methyl orange dye concentration in water

Hamid Reza Solaimany Nazar[1], Vahid Ahmadi[1,*], Ali Reza Solaimany Nazar[2]

[1]Dept. of Electronics, Faculty of ECE, Tarbiat Modares University, Tehran, Iran
[2]Chemical Engineering Dept., Faculty of Engineering, University of Isfahan, Isfahan, Iran
*Corresponding author: v_ahmadi@modares.ac.ir

Abstract- An intensity-based Mach-Zehnder interferometric fiber optic sensor using multimode–single-mode–multimode configuration is developed to measure methyl orange concentration in water. The transmission spectrum of the sensor is monitored at 460 nm while subjected to different concentrations of methyl orange (MO) solutions. The transmitted light intensity percent is proportional to the methyl orange concentration. This sensor shows a sensitivity of -37.2 and -37.9 dBm/ppm for the measurement of MO concentration in DI and Tehran tap water, respectively. This sensor offers easy fabrication, fast response, online monitoring, and proper linear response at low concentrations beside other advantages of fiber optic sensors.

Keywords: Fiber optic sensor; Mach-Zehnder interferometric; Methyl orange dye; Water pollution

1. Introduction

Worldwide environmental pollution is on the rise due to human population growth and industrial developments. Organic dyes are cases in point which are found in various manufacturing sectors like plastics, printing, textiles, and papers [1]. These dyes are the main contaminants of water that can cause chronic disease in living creatures based on their concentration and exposure time [2]. Methyl orange (MO) which is an anionic dye is an example of organic dyes that is harmful to human beings and can induce diarrhea, headaches, and skin irritation [3].

Over the last few decades, fiber optic sensors have been used to detect many parameters [4] by assessing the changes in wavelength, intensity, polarization, and phase of the light passing through the sensor [5]. In-line Mach-Zehnder interferometric (MZI) fiber optic sensors are one commonly used type of these sensors that have attracted significant attention owing to their superb features such as, low cost, simple structure, flexibility, and high sensitivity [6]. These sensors utilize various fabrication techniques including core mismatch [7], lateral offset [8], small core [9], and tapering [10]. Among these techniques, core mismatch multimode–single-mode–multimode (MSM) optical fiber sensors are frequently used because they exhibit very high sensitivity and are easy to assemble [11]. This sensor is composed of a single-mode (SM) fiber spliced between two multimode (MM) fibers wherein the SM fiber acts as the sensing part.

In this paper, a core mismatched multimode–single-mode–multimode (MM-SM-MM) in-line MZI fiber optic sensor is proposed to measure the concentration of MO in the range of 5 to 45 ppm in both deionized (DI) and Tehran tap water for the first time. The variations of transmitted light intensity are monitored in terms of the concentration of MO solution and the calibration curves for both experiments are presented.

2. Theory

As shown in Fig.1, when light passing through the multimode fiber (MMF) reaches the entrance of spliced single-mode fiber (SMF), owing to the core diameter mismatch some higher order modes of different effective refractive indices are generated and guided by the cladding of the SMF. Also, these modes can penetrate the external medium, creatingevanescent waves that have interaction with the surrounding medium of SMF. Consequently, the change in RI of the surrounding medium induces a phase shift. After propagating through cladding of the SMF, these higher order modes reach the second MMF and recouple back to interfere with the copropagating fundamental mode whereby turning the phases of guides into the change of light's intensity. The intensity of light after interference can be written as

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi \tag{1}$$

where I_1 and I_2 are the intensity of propagating light and the phase difference can be calculated as

$$\phi = \frac{2\pi}{\lambda}(\Delta n_{eff})L \tag{2}$$

where L is the sensing length and Δn_{eff} is the effective RI between the core and cladding of the fiber.

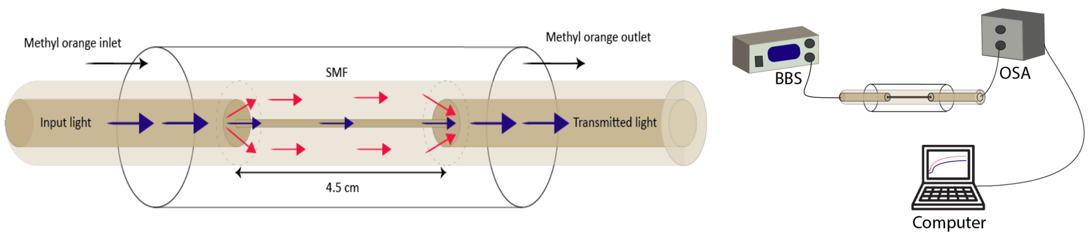

Figure 1. The schematic structure of the in-line MZI base on core mismatch and diagram of the experimental setup.

3. Experiment

To fabricate the MZI sensor, two conventional MMFs with a core diameter of 50 microns and a segment of conventional SMF (SMF-28) are used. After removing the polymer jacket and cleaving fiber tips, a 4.5 cm SMF segment is placed in between two MMFs and fusion spliced to both using a commercial fiber fusion splicer (Sumitomo, T-55). The SMF is placed in a capillary tube with a diameter of 1.1 mm. One end of the sensor is connected to a UV-Vis broadband source with spectral range of 360 to 1500 nm and 43 µW power (Avalight-DH-S) and the other end to an optical spectrum analyzer (AvaSpec-3648). Then MO solutions using DI and Tehran tap water are prepared in the concentration from 5 to 45 ppm. Finally, the capillary tubes are sealed with epoxy adhesive. The MO solutions are injected into the capillary tube and then evacuated through needles and the output spectrum of the sensor is monitored. Also, it is worth mentioning that the sensor is fixed on plexi glass so other environmental changes would not affect the output spectrum. After each test, the sensor is washed with DI water and purged with air. All the tests are performed at room temperature.

Furthermore, the same fabrication process is employed to implement sensors with SMF lengths of 3.5 cm and 5.5 cm to compare their performances.

4. Results and discussion

The optical absorption of MO has a peak around 460 nm [12] and all three fabricated sensors (SMF lengths of 3.5, 4.5, and 5.5 cm) responded reasonably at this wavelength when subjected to different concentrations of MO solutions. Therefore, the output spectrum intensity is measured around this wavelength. The sensor with 5.5 cm SMF had a low transmission spectrum intensity (less than 12 percent) because the light absorption and leakage are proportional to the sensing length. The sensor with 3.5 cm SMF showed an acceptable transmission spectrum intensity, but the difference between the light intensities for each concentration is not as perceptible as the sensor with 4.5 cm SMF. This occurs because evanescent cladding modes do not have as much interaction with the surrounding environment as the sensor with 4.5 cm SMF. Consequently, the sensor with 4.5 cm SMF is employed to measure different concentrations of MO solutions. As it is evident from Fig.2(a) when the concentration of MO in DI water is increased the output light transmission drops, indicating that more light is being absorbed by MO molecules. Moreover, the measured data of MO concentration in Tehran tap water showed the same trend. However, the overall transmission spectrum is lower due to the presence of other contaminants in water that can increase the RI of the surrounding environment and the light absorption.

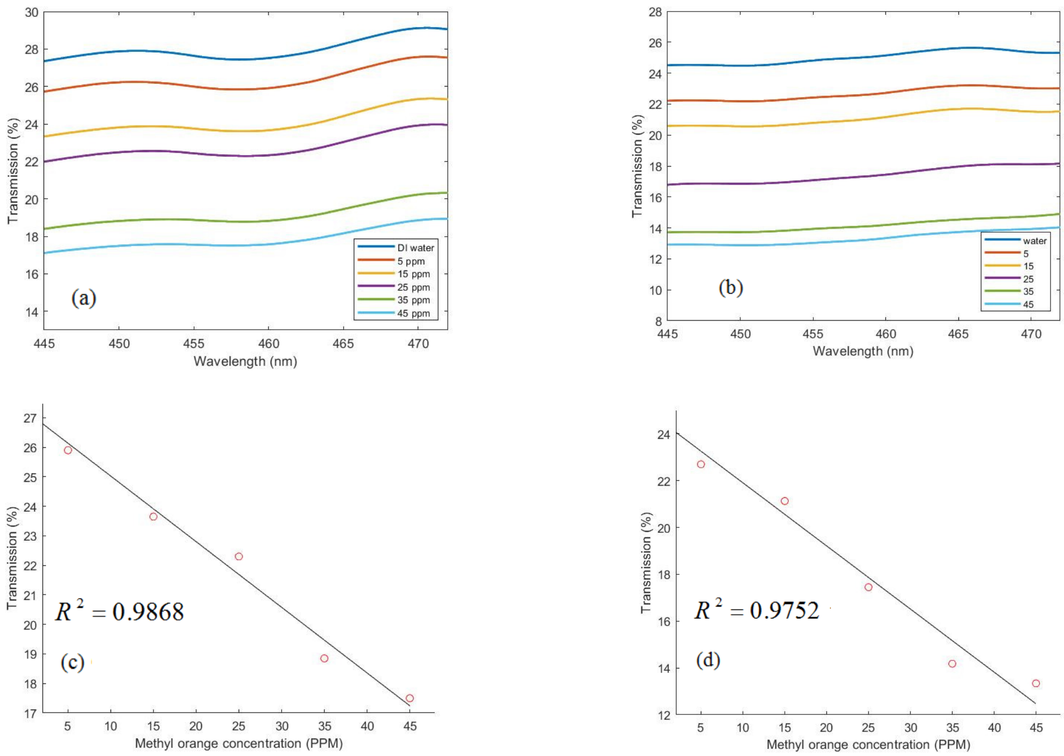

Figure 2. (a) Transmission spectrum of the MZI sensor for different concentrations of MO in DI water; b) Tehran tap water.

Change in transmission intensity at different concentrations of MO in c) DI water; d) Tehran tap water.

This sensor exhibits a sensitivity of -37.2 and -37.9 dBm/ppm for the measurement of MO concentration in DI and Tehran tap water, respectively.

5. Conclusions

In summary, an intensity-based MZI fiber optic sensor was fabricated and tested for the MO concentration measurement in DI and Tehran tap water. Linear transmitted peak intensity of light was observed at low MO concentrations (< 45 ppm). The fabricated sensor shows a sensitivity of -37.2 and -37.9 dBm/ppm for MO concentration in DI and Tehran tap water, respectively. This sensor responses fast when subjected to different concentrations of MO solutions and also it is cheap, compact, and easy to fabricate showing a promising prospect of practical applications such as evaluating water quality.

References

1. F. Ahmadijokani *et. al.* **Chem. Eng. J. 399** 125346, (2020).

2. R. S. Salama *et .al.* **Int. J. Modern Chem 10**(2) 195-207, (2018).

3. V. K. Gupta *et. al.* **J. Environ. Manage 90**(8) 2313-42, (2009).

4. J. K. Sahota, *et. al.* **Opt. Eng. OPT ENG 59**(6), 060901, (2020).

5. V. Bhardwaj *et. al.* **Opt. Fiber Technol. 58** 102302, (2020).

6. A. G. Leal-Junior *et. al.* **J. Lightwave Technol. 36**(17) 3660–3665, (2018).

7. J. Villatoro *et. al.* **J. Lightwave Technol. 24**(3) 1409, (2006).

8. D. W. Duan *et. al.* **Sens. Actuators B Chem. 160**(1) 1198-1202, (2011).

9. B. Gu *et. al.* **Opt. Express 17**(25) 22296-22302, (2009).

10. N. Agrawal *et. al.* **IEEE. Trans. Biomed 67**(6) 1542-7, (2019).

11. M. Olivero *et. al*. **IEEE Trans. Instrum. Meas. 67**(5) 1223-9, (2017).

12. F. C. Tsai *et. al.* **J. Water Process. Eng. 1** 2-7, (2014).