Iraqi Journal of Science, 2019, Vol. 60, No.5, pp: 996-999
DOI: 10.24996/ijs.2019.60.5.8

ISSN: 0067-2904

Chloroform Vapor Sensor Based on Air-Gap of the Mach-Zehnder Interferometer

Dhuha Nihad Issa*, Hanan J. Taher
Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

Abstract

The proposal of this study is demonstrating a simple vapor sensor for chloroform ($CHCl_3$) utilitizing air gap region of the Mach-Zehnder interferometer (MZI) by using a single mode optical fiber coupler (3 dB) structure. In the last few decades, flammable liquids such as chloroform have been highly used. This chemical liquid has some degrees of carcinogenic effects in humans in addition to acute and chronic exposure results like blurred vision and nausea. The two arms of MZI contain a free space gap utilized to serve the sensing mechanism by adding chemical liquid volumes (0.2, 0.4, 0.6, 0.8, and 1) ml and to set the phase difference with air-gap distance 0.5 mm. The small variation in the effective refractive index of chloroform is due to changing the propagation of the transmitted light in the MZI's gap that will further shift the optical phase of the signal. The experimental results indicate that the output power decreased when the air gap distance is 0.5 mm, and the shifting of wavelength will increase toward blue shift when increasing the chloroform liquid volumes. A maximum wavelength shift of chloroform is 0.0251 nm when the liquid volume is 1 ml and sensitivity of chloroform is 0.0223 nm/ml at air gap distance 0.5 mm for different chloroform liquid volumes.

Keywords: Mach-Zehnder interferometer, chloroform vapor sensor, wavelength shift, sensitivity, phase shift.

متحسس بخار كلورفورم بأستخدم فجوة الهواء كمقياس التداخل ماخ-زندر

ضحى نهاد عيسى[1]*، حنان جعفر طاهر
معهد الليزر للدراسات العليا، جامعة بغداد، بغداد، العراق

الخلاصة

الغرض من الدراسة هو اظهار متحسس بخار كلوروفوم ($CHCl_3$) لمنطقة فجوة الهواء في مقياس التداخل ماخزندر MZI بأستخدام أحادي النمط للمقسم اليف البصري (3 dB). في العقود القليلة الماضية, أستخدم سائل شديدة الاشتعال مثل الكلوروفورم. هذه السائل الكيميائية له بعض درجات التأثير المسرطنة في الإنسان حيث أن نتائج التعرض الطفيفة والمزمنة تشوش الرؤية والغثيان. يحتوي ذراعي MZI على فجوة هواء بمسافة 0.5 مليميتر لتعمل كآلية استشعار بواسطة اضافة حجم البروبانول (0.2, 0.4, 0.6, 0.8, 1) مل ولضبط إشارة الطور مع مسافة الفجوة (0.5) مليميتر. يتغير ثابت الانتشار β للضوء المرسل في فجوة ماخزندر بسبب التباين الصغير الذي سيزيح اشارة الطور البصري. أشارت النتائج التجريبية إلى ان الطاقة الخارجة تنخفض عند مسافة الفجوة الهوائية 0.5 مليميتر، والتغير في الطول الموجي سيزداد نحو المنطقة الزرقاء عند زيادة أحجام السائل الكلوروفورم ، وكانت أقصى تغير في الطول الموجي للكلوروفورم هو 0.0251 نانومتر عندما يكون حجم السائل 1 مل وحساسية الكلوروفورم 0.0223 نانومتر / مل في المسافة الفجوة الهوائية 0.5 مليميتر لمختلف أحجام السائل الكلوروفورم.

*Email:duha93nihad@gmail.com

Introduction

The environmental sensor has been of interest to recent research, the optical fiber sensors are being utilized for different detecting applications, e.g. optical fiber sensors are utilized for recognizing the nearness of air poisons in the climate [1] and in addition to being utilized in the biomedical field [2, 3]. A lot of research in optical fibers has been devoted to sense, and then found applications in the chemical field [4]. Concoction detecting innovation has turned out to be vital in a wide assortment of regions, including mechanical plants, exploring labs, home and different military applications [5]. In recent years the chemical detection techniques have been developed. Chemical sensing with optical fibers is one of the most interesting emerging sensor techniques because of the geometrical flexibility and the small size to be transmitted encoding information between the spectrometer and a remote sample [6]. A chemical transducer and an optical fiber are the two components that constitute an optical fiber chemical sensor. The optical fiber is the medium which propagates the light from the source to the chemical transducer and guides the light again from the transducer to the photo detector. A chemical parameter is then measured in the form of light modified by the transducer [7, 8]. In this work, a kind of Mach-Zehnder interferometer of chloroform vapor sensor is fabricated based on the air gap using optical fiber coupler (3 dB). The system of wavelength is 1550 nm designed, this wavelength is of low cost and available components and. The transmission spectrum of the proposed sensor is obtained and then measures the sensitivity of chloroform for different volumes and adjusts 0.5 mm air distance.

Materials and Methods

Figure-1 shows the set-up utilizing light source which is a diode laser with wavelength of 1550 nm, two optical coupler (3 dB) types of single mode fiber, two chambers are Parallel Rectangle-shape sealed chambers, fabricated from Polyvinyl chloride (PVC) plastic with dimensions (length =24 cm, height = 14 cm, and width =16 cm), and finally optical spectrum analyzer (OSA). The MZI is manufactured utilizing 3 dB couplers, the first optical fiber coupler (3 dB) connected to the diode laser and the second optical fiber coupler (3 dB) joined to the OSA (YOKOKAWA, Ando AQ6370).

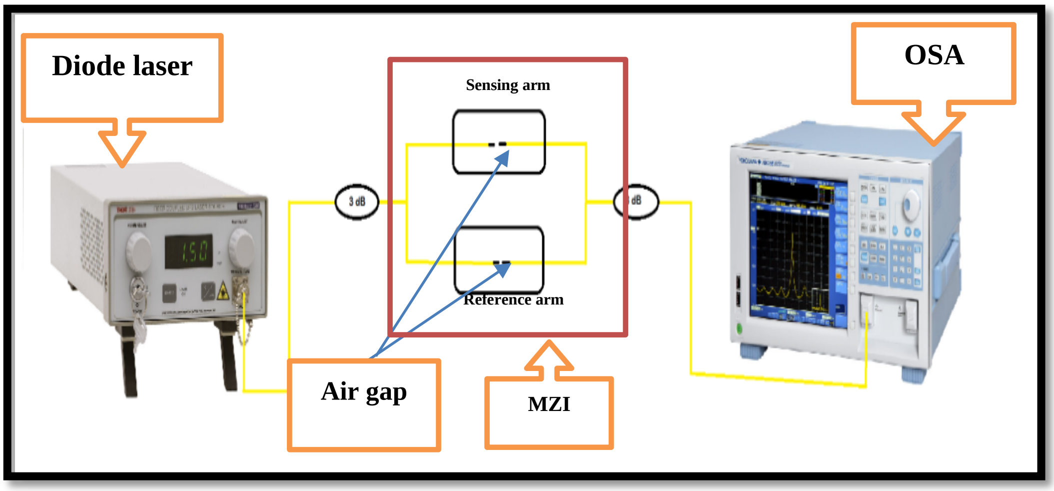

Figure 1-Experimental work for chloroform vapor sensor.

A created MZI with air gap distance is 0.5 mm under controlled conditions, the length of both arms are the same. Chloroform liquid, with volumes (0.2, 0.4, 0.6, 0.8, and 1) ml, is injected in the sensing chamber while the reference arm contains only air. The two arms of MZI cause the phase shift when the air gap is distant and adjusted, and then the chloroform liquid volumes are injected by a medical syringe through a small opening at the top of chamber in the sensing arm. Thus, the small variation in the effective refractive index inside the sensing chamber causes phase dissimilarity in the MZI, due to the disparate phase velocities [9]. Since the phase difference and the phase velocities are dependent on wavelength, the propagating wavelength along the two different arms of the MZI creates a superposition pattern. The separation between the two peaks in a two-mode interferometer is defined as [10]:-

$$\Delta\lambda=\frac{\lambda^2}{L\,\Delta n_e} \tag{1}$$

where λ represents the wavelength, L is the MZI length and Δn_e is the effective difference in the refractive index between the two MZI arms. The changes in the RI in the MZI's sensing arm can be defined as [11]:-

$$\Delta\varphi = \Delta\beta.L.\ \Delta n_e = (2\pi/\Delta\lambda).\ L.\ \Delta n_e \quad (2)$$

where $\Delta\varphi$ is the phase shift and $\Delta\beta$ is the difference between the traveling signal's initial and instant propagation constant $(2\pi/\Delta n_e\ \lambda)$.

Results and Discussion

Figure-2 shows the transmission spectrum of MZI for air- gap distance with injected chloroform liquid volumes. The black color line refers to only air in air-gap region and the red, blue, pink, green, and indigo color lines refer to liquid volume (0.2, 0.4, 0.6, 0.8, and 1) ml in air-gap region respectively. The transmission spectrum displacement shows that the chloroform liquid volumes increased. The wavelength shift increased toward the blue region because the refractive index of chloroform was 1.43 while the refractive index of air was 1. The refractive index is of an inverse proportion with the wavelength as shown in equation (1), therefore the chloroform liquid with the higher refractive index will show the wavelength shift in the blue region.

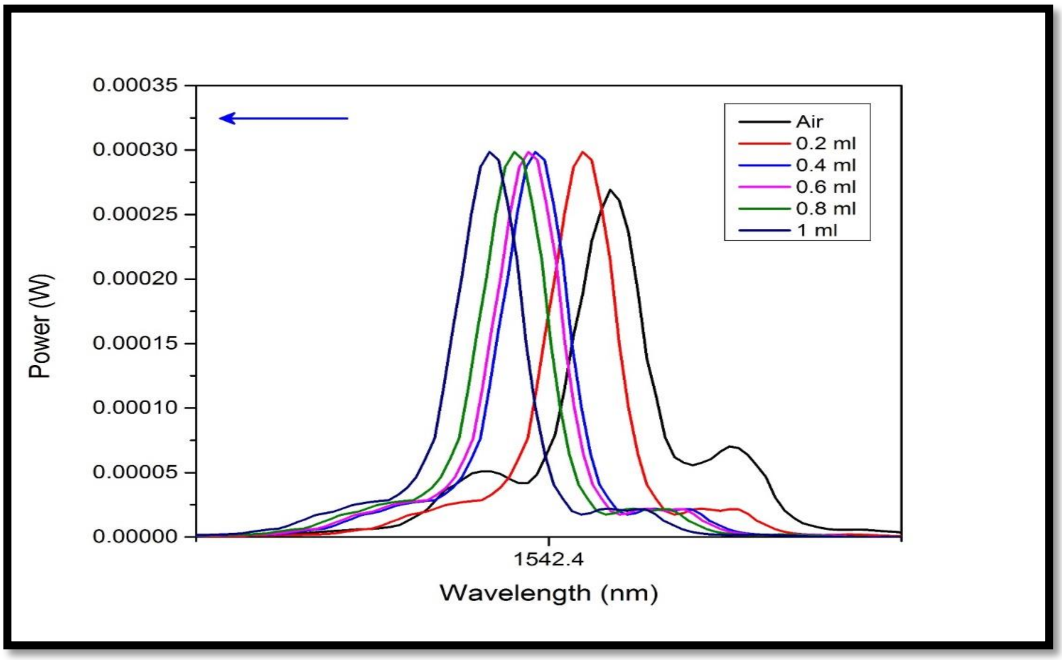

Figure 2-Transmission spectrum of chloroform at air-gap 0.5 mm.

To calculate the changes in effective refractive index, propagation constant, and the phase shift can be done by using equations (1) and (2). This is shown in Table-1 below:

Table 1-The numerical calculation of chloroform

Air gap distance	Liquid volume (ml)	$\Delta\lambda$ (nm)	Δn_e	$\Delta\beta$ $(nm^{-1})\times10^3$	$\Delta\varphi^o$ $\times10^3$
0.5 mm	0.2	0.0074	0.152	0.848	0.257
	0.4	0.0110	0.108	0.570	0.123
	0.6	0.0164	0.072	0.382	0.055
	0.8	0.0210	0.056	0.299	0.033
	1	0.0251	0.047	0.250	0.023

The sensitivity of chloroform was calculated by using the program Origin 9, the experimental measurement of the wavelength shift responds to the chloroform liquid volumes. From Fig. 3, it can be observed that air-gap distance at 0.5 mm shows the sensitivity (0.0223 nm/ml). The relationship between the wavelength shift and chloroform volume was linear when the liquid volume increased the sensitivity increased too.

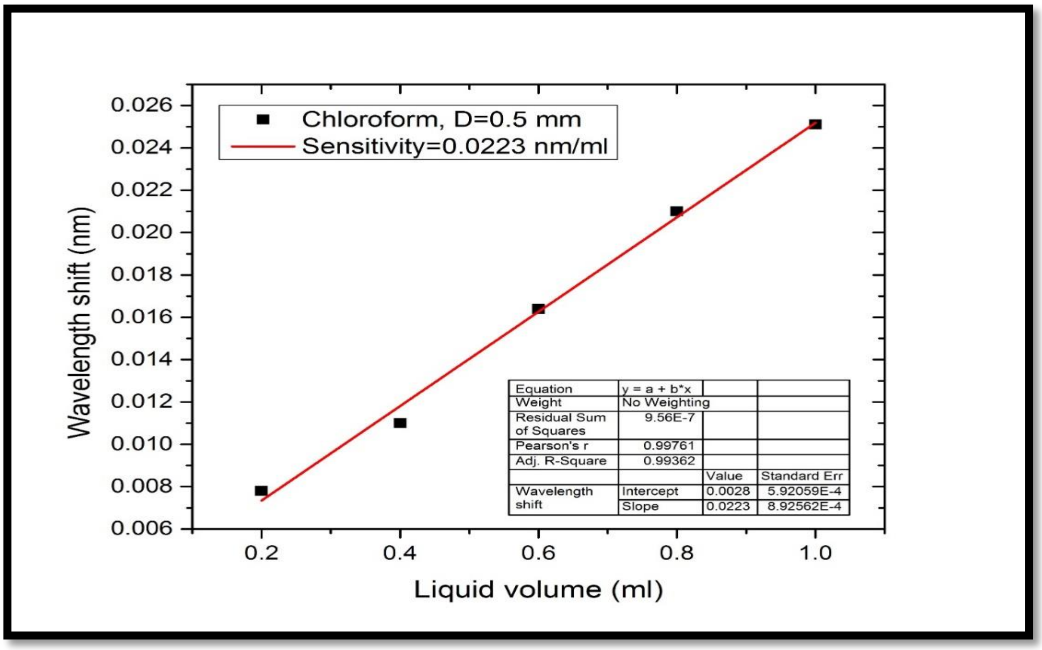

Figure 3-Sensitivity of chloroform vapor sensor at air-gap distance 0.5 mm.

Conclusion

In this paper, a novel and simple single mode MZI chloroform vapor sensor are proposed. Experimental results of chloroform vapor sensor show the increase in the chloroform liquid volume causes the shift in wavelength (blue shift). The sensitivity of this sensor is 0.0223 nm/ml.

Reference

1. Hisham. H.K. **2018.** Optical Fiber Sensing Technology: Basics, Classifications and Applications, *American Journal of Remote Sensing*, **6**(1): 1-5.
2. Tubb, A.J.C., Payne, F.P., Millington, R.B. and Lowe, C.R. **1997**. Single-Mode Optical Fiber Surface Plasma Wave Chemical Sensor, Sens. *Actuators B Chem*., **41**: 71–79.
3. Rhines, T.D., Arnold. **1989.** Fiber-Optic Biosensor for Urea Based on Sensing of Ammonia Gas, *Anal. Chim. Acta*., **227**: 387–396.
4. Rodriguez-Rodriguez, E., Barrales, R. and Torres, R.Q. **2016**. Fiber Optics Evanescent Wave Sensor, *Merida-DL Tentative, International Society for Optics and Photonics*, **5**: 17130–17134.
5. Liu, X., Cheng, S., Liu, H., Hu, S., Zhang, D. and Ning. H. **2012**. A survey on gas sensing technology, *Sensors (Switzerland)*, **12**: 9635–9665.
6. Wang, X.D. and Wolfbeis, O.S. **2008.** Fiber-optic chemical sensors and biosensors (2008–2012). *Anal. Chem.* 2013, **85**: 487–508.
7. Timmer, B.H., Delft, K.M.Y. Otjes, R.P., Olthuis, W. and Berg, A.y.d. **2004**. A miniaturized measurement system for Ammonia in air, *Anal. Chim. Acta*., **507**(1): 139–145.
8. Pospíšilová, M., Kuncová, G. and Trögl. J. **2015**. Fiber-Optic Chemical Sensors and Fiber-Optic Bio-Sensors, *Sensors*, **15**: 25208-25259.
9. Patel, P.B. and Hamde, S.T. **2017**. Analysis of the Mach-Zehnder interferometer waveguide structure for refractive index measurement, *J Opt*. **46**(4): 398-402.
10. Soltanian, M.R.K., Amiri, I.S., Ariannejad, M.M., Ahmad, H. and Yupapin. P. **2017**. A simple humidity sensor utilizing air-gap as sensing part of the Mach–Zehnder interferometer, *Opt Quant Electron*, **49**: 308.
11. Salman, N.A. and Taher, H. **2017**. Refractive index sensor based on a solid-core photonic crystal fiber interferometer, *Iraqi Journal of Physics*, **15**: 99-105.