Iraqi J. Laser, Issue (1), Vol.18, pp.25-29 (2019)

IRAQI JOURNAL OF LASER

Propanol Vapor Sensor Utilizing Air-Gap as Sensing Part of the Mach-Zehnder Interferometer

Dhuha N. Issa **Hanan J. Taher** and **Saif A. Mohammed**

Institute of laser for postgraduate studies, University of Baghdad, Baghdad, Iraq

(Received 24 September 2018; accepted 11 November 2018)

Abstract: The purpose of this study is to demonstrate a simple high sensitivity vapor sensor for propanol ($(CH_3)_2CHOH$). A free space gap was employed in two arms of a Mach-Zehnder interferometer to serve as the sensing mechanism by adding propanol volume (0.2, 0.4, 0.6, 0.8, and 1) ml and to set the phase reference with a physical spacing of (0.5, 1, 1.5, and 2) mm. The propagation constant of transmitted light in the Mach-Zehnder interferometer's gap changes due to the small variation in the refractive index inside sensing arm that will further shift the optical phase of the signal. Experimental results indicated that the highest sensitivity of propanol was about 0.0275 nm/ml in different liquid volume while highest phase shift was 0.182×10^3 in liquid volume 0.2 ml for spacing 1 mm.

Introduction

Environmental sensor has recent global research, the optical fiber sensors are being employed for various sensing applications, e.g. optical fiber sensors are used for detecting the presence of air pollutants in the atmosphere [1-3], as well as being employed in the biomedical field [4, 5]. Since1980, a lot of research in optical fibers has been devoted to sensing, and then found applications in chemical field [6]. Chemical sensing technology has become important in a wide variety of areas, including industrial plants, research labs, the home, and various military applications [7, 8]. 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 [9]. A chemical sensor can be defined as a portable miniaturized analytical device which can deliver real-time on-line information on the presence of specific compounds or ions in complex samples [10]. In this work, a kind of Mach-Zehnder interferometer (MZI) of propanol vapor sensor is fabricated based on air gap using optical fiber coupler (3 dB). The system is designed for 1550 nm wavelength regime, as this is a common wavelength with easily available and low cost components. The optical transmission of the proposed sensor is observed and then measured the sensitivity of propanol for different volumes and different spacing.

Experimental setup

Figure 1 displays the set-up of the proposed system utilizing light source which is a diode laser with wavelength of 1550 nm, two optical couplers (3 dB) types of single mode fiber, two chambers are a Parallel Rectangle-shape sealed chambers, fabricated from Polyvinyl chloride (PVC), and finally optical spectrum analyzer (OSA). The MZI is fabricated using 3dB couplers, with the common port of one 3 dB coupler connected to the diode laser and the common port of the other 3 dB coupler joined to the OSA (YOKOKAWA, Ando AQ6370).

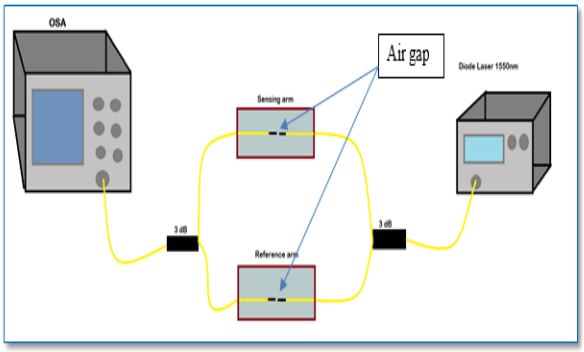


Fig.1: Experiment set-up for chemical sensor using MZI.

Theoretical concept

In this paper, a fabricated MZI with different distance of air gap (0.5, 1, 1.5, and 2) mm that under controlled conditions, the length of both arms are the same. A propanol fluid for different liquid volumes (0.2, 0.4, 0.6, 0.8, and 1) ml was injected in sensing chamber while the reference arm is consisted of only air.

The sensor of the two MZI arms causes the phase shift when change the length of spacing of air gap for arms and injected the propanol volumes in the sensing arm therefore the variation in the refractive index inside the chemical chamber causes a phase disparity in the MZI, due to the dissimilar phase velocities. Since the phase velocities and the phase deference are wavelength dependent, the propagating wavelength along the two different arms of the MZI creates a superposition pattern. The separation between two peaks in two-modes interferometer is defined as [11]:

$$\Delta\lambda = \frac{\lambda^2}{L\,\Delta n_e} \qquad (1)$$

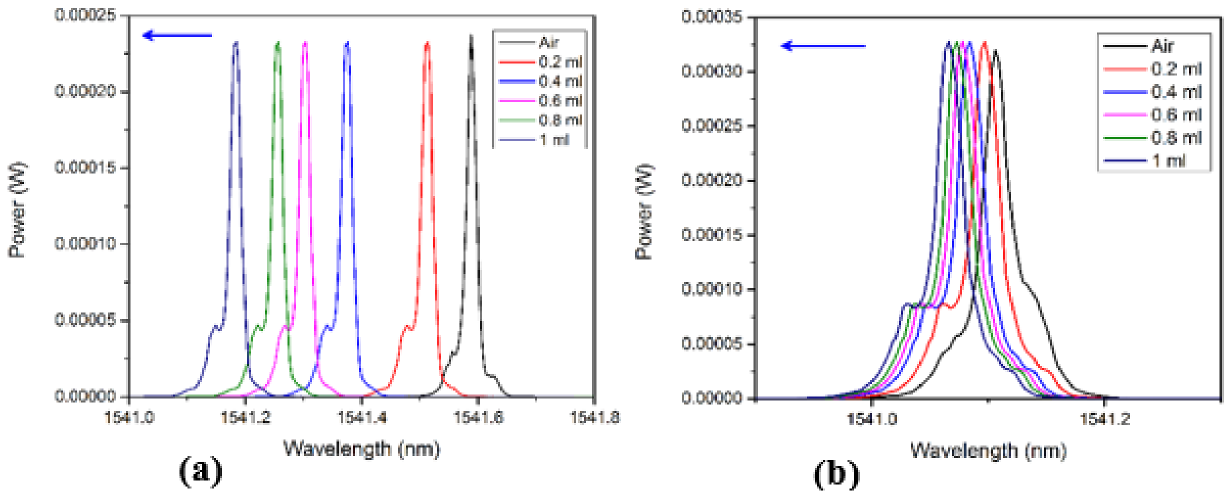
Where λ represents the wavelength, L is the MZI length and Δn_e is the effective difference in the refractive index between the two MZI arms. The changes in the RI in the MZI's sensing arm can now be defined as [12]:

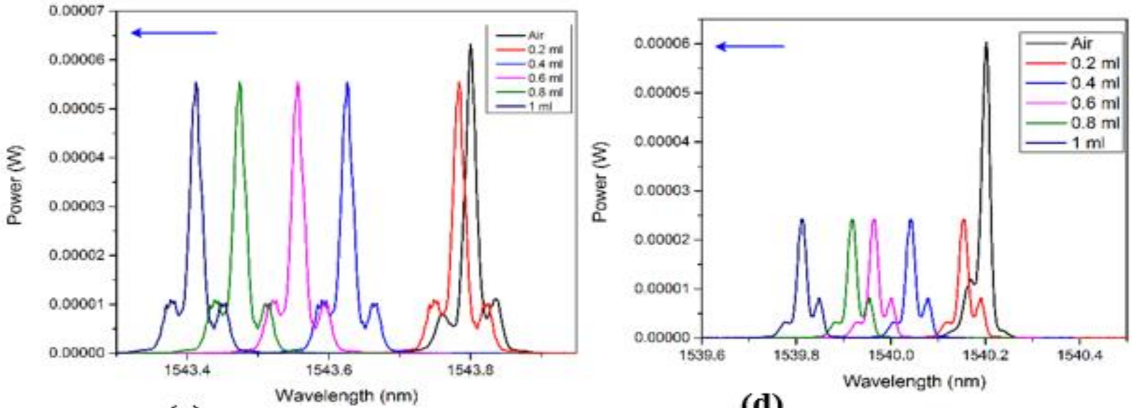
$$\Delta\varphi = \Delta\beta.L.\ \Delta n_e = (2\pi/\Delta\lambda).\ L.\ \Delta n_e \qquad (2)$$

Where $\Delta\varphi$ is the phase shift and $\Delta\beta$ is the difference between the travelling signal's initial and instant propagation constant $(2\pi/\Delta n_e\ \lambda)$, which is taken before as well as after the change in the RI respectively.

Results and Discussion

The relationship between the wavelength and power of the transmission spectrum which was measured by OSA are shown in figure 2 when the distance of air gap are (0.5, 1, 1.5, and 2) mm for both chambers, one of the chamber's contained propanol volumes with (0.2, 0.4, 0.6, 0.8, and 1) ml. Depending on the equation (1), when the distance increased this will lead to blue shift in the transmission spectrum.





(c) (d)

Fig. (2): (a), (b), (c), and (d) Transmission spectrum of air gap at distance (0.5, 1, 1.5, and 2) mm respectively.

From the equations (1) and (2) the effective different in refractive index and the phase shift are calculated. It is presented indicated in the table (1) for propanol. The effective different in refractive index is inverse proportion with wavelength shift, the wavelength shift increasing with decreased the effective refractive index change for air-gap distances. The obtained results could be interpreted as the variation is effective refractive index between MZI arms resulting to the change in wavelength in the air-gap region while the frequency inside the optical fiber still constant with change in Δβ value.

Table (1): The values of calculated effective different in refractive index and the phase shift.

Air-gap distance	**Liquid volume (ml)**	**Δλ (nm)**	**Δn_e**	**Δβ $(nm^{-1})\times10^3$**	**$\Delta\varphi^o$ $\times10^3$**
0.5 mm	0.2	0.074	0.016	0.084	0.0026
	0.4	0.138	0.008	0.045	0.0007
	0.6	0.210	0.005	0.029	0.0002
	0.8	0.257	0.004	0.024	0.00019
	1	0.329	0.003	0.019	0.00011
1 mm	**Liquid volume (ml)**	**Δλ (nm)**	**Δn_e**	**Δβ $(nm^{-1})\times10^3$**	**$\Delta\varphi^o$ $\times10^3$**
	0.2	0.009	0.131	0.697	0.182
	0.4	0.013	0.091	0.483	0.087
	0.6	0.019	0.062	0.330	0.040
	0.8	0.024	0.049	0.261	0.025
	1	0.031	0.038	0.202	0.015
1.5 mm	**Liquid volume (ml)**	**Δλ (nm)**	**Δn_e**	**Δβ $(nm^{-1})\times10^3$**	**$\Delta\varphi^o$ $\times10^3$**
	0.2	0.096	0.012	0.065	0.0015
	0.4	0.158	0.007	0.039	0.00054
	0.6	0.228	0.005	0.027	0.00027
	0.8	0.310	0.004	0.020	0.00016
	1	0.372	0.003	0.016	0.00009
2 mm	**Liquid volume (ml)**	**Δλ (nm)**	**Δn_e**	**Δβ $(nm^{-1})\times10^3$**	**$\Delta\varphi^o$ $\times10^3$**
	0.2	0.032	0.035	0.196	0.013
	0.4	0.112	0.010	0.056	0.0011
	0.6	0.189	0.006	0.033	0.0003
	0.8	0.245	0.004	0.025	0.0002
	1	0.341	0.003	0.018	0.0001

The measured sensitivity for changing in the wavelength shift of propanol volume for each different of air gap distance is shown in the figure (3). The relationship between the wavelength shift and propanol volume is linear, and represented the sensitivity when the liquid volume increase the sensitivity will increase too, and the highest sensitivity of propanol is 0.0275 nm/ml for spacing 1 mm at different liquid volume

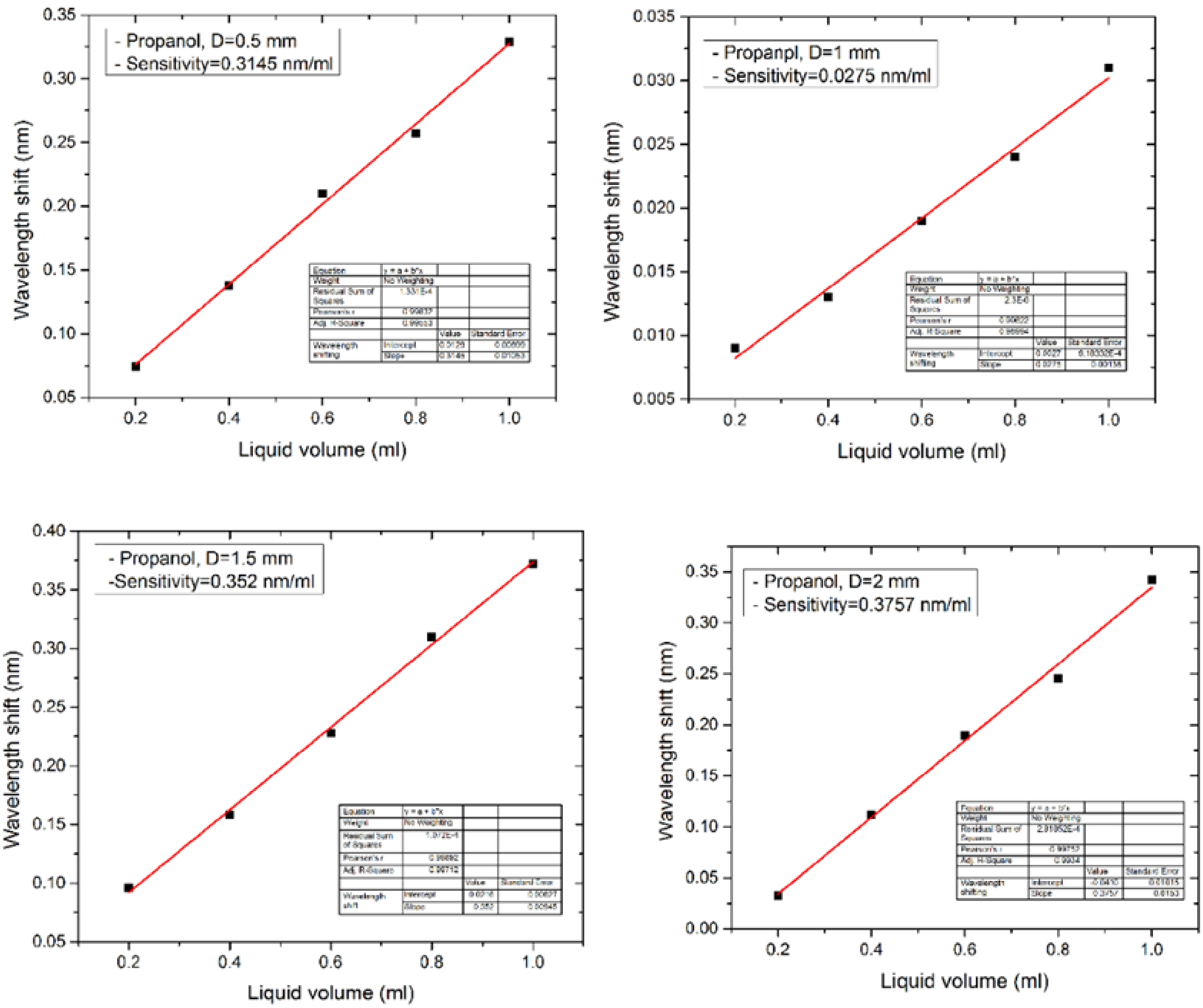


Fig. (3): Sensitivity of propanol vapor sensor.

Conclusion

In this work, a simple, and high sensitivity single mode MZI propanol vapor sensor was performed. The experimental results of propanol vapor show the blue shift of transmission spectrum with increasing for each air gap distance. The value of shift was increasing with increased of propanol volumes. At air-gap distance 1 mm, highest phase shift was 0.182×10^{3} and also highest sensitivity was 0.0275 nm/ml.

References

[1] Wolfbeis, O.S. "Fiber-Optic Chemical Sensors"; CRC Press: Boca Raton, FL, USA, 1991; Volume 1–2.

[2] Wolfbeis, O.S.; Posch, H.E. "Fiber optic fluorescing sensor for ammonia". Anal. Chim. Acta 11 (1986) 185–321.

[3] Rowe-Taitt CA, Ligler FS. "Optical fiber Biosensors. Handbook of optical fiber sensing technology" Edited by J. M. Lopez-Higuera, John Wley & Sons Ltd 2001:687-700

[4] Tubb, A.J.C.; Payne, F.P.; Millington, R.B.; Lowe, C.R. "Single-ModeOptical Fiber Surface Plasma Wave Chemical Sensor". Sens. Actuators B Chem. 41 (1997) 71–79.

[5] Rhines, T.D.; Arnold, M.A. "Fiber-Optic Biosensor for Urea Based on Sensing of Ammonia Gas". Anal. Chim. Acta 1989, 227, 387–396.

[6] Wolfbeis. "Optical fiber chemical sensors and biosensors". CRC Press, Boca Raton, Florida: 1991, 1992:Vol1 &2.

[7] D. Kohl, "Function and applications of gas sensors", J. Phys. D. Appl. Phys. 34 (2001) 125–149.

[8] X. Liu, S. Cheng, H. Liu, S. Hu, D. Zhang, H. Ning, "A survey on gas sensing technology", Sensors (Switzerland). 12 (2012) 9635–9665.

[9] B.H. Timmer, K.M.v. Delft, R.P. Otjes, W. Olthuis, A.v.d. Berg, " A miniaturized measurement system for Ammonia in air", Anal. Chim. Acta 507 (1), 2004, 139–145.

[10] D. Marcuse, "Theory of Dielectric Optical Waveguides", Academic Press, New York, 1974.

[11] M. R. K. Soltanian et al, "A simple humidity sensor utilizing air-gap as sensing part of the Mach–Zehnder interferometer", Opt Quant Electron. 49 (2017) 308.

[12] N. A. Salman and H. J. Taher, "Refractive index sensor based on a solid-core photonic crystal fiber interferometer", Iraqi Journal of Physics. 15 (2017) 99-105.

مستشعر بخار بروبانول يستخدم فجوة الهواء كجزء متحسس من مقياس التداخل ماخ-زندر

ضحى نهاد عيسى   حنان جعفر ظاهر   سيف عقيل محمد

معهد الليزر للدراسات العليا، جامعة بغداد، بغداد، العراق

الخلاصة: الغرض من الدراسة هو اظهار اعلى حساسية من مستشعر بخار بروبانول $((CH_3)_2CHOH)$. يتم استخدام فجوة هواء في ذراعي مقياس تداخل ماخزندر 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 ، 1 ، 1.5 ، 2) مليميتر. يتغير ثابت الانتشار β للضوء المرسل في فجوة ماخزندر بسبب التباين الصغير الذي سيزيح اشارة الطور البصري. النتائج التجريبية تشير إلى أن اعلى حساسية بوربانول تبلغ حوالي 0.0275 نانومتر / مل في مختلف حجم السائل بينما اعلى تغير الطور يكون 0.182×10^3 عند حجم سائل 0.2 مل للمسافة 1 مليميتر.