Investigation of michelson interferometer for volatile organic compound sensor

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Abstract. The sensor device is required to monitor harmful gases in the environments and industries. Many volatile organic compounds adsorbed on the sensor material will result in changes of the optical properties including the refractive index and the film thickness. This study designed and realized a vapor detection device using the principle of Michelson Interferometer. The laser light beamed with a wavelength of 620 nm was divided by using a beam splitter. Interference occurred when the two separated lights were recombined. The phase difference between the two beams determined whether the interference would destruct or construct each other to produce the curved fringes. The vapor samples used in these experiments were ethanol and benzene. The results showed that the ethanol concentration of 1611-32210 ppm produced a fringe shift of 197 pixels, while the concentration of benzene of 964-19290 ppm produced a fringe shift of 273 pixels.

1. Introduction

Volatile organic compounds are widely used in the industrial manufacture of paints, cosmetics, fragrances and others. However, in short term, the exposure to the vapors can be harmful at high concentrations due to its effect on causing health problems such as shortness of breath, dizziness, and eye irritation. While in the long term, it can even cause cancer.

Currently, sensors have been developed to detect volatile organic compounds, including crystal resonator, surface acoustic wave (SAW), fiber optic sensors, and the likes. This study uses the Michelson interferometer because it has a sharper and clearer interference pattern and narrower distance between the interferometer fringes [1]. In addition, this type of interferometer has several advantages including high sensitivity, fast response, low power consumption, stable in hot temperatures, and resistant to electrical or magnetic field interference [2][3][5].

The experiment was conducted by observing the fringe shift when exposed to various concentrations. Differences in travel time of two beams of light when one of the light passed through a vapor sample would result in a fringe shifts [3][4]. In addition, the Michelson interferometer was also expected to provide high sensitivity by using image processing as data acquisition method for measuring the concentration of gas. The type of sensor can be developed into a gas sensor that is effective, efficient, high accuracy in a long term usage.
2. Method
The measurement of concentrations of the volatile organic compound with Michelson interferometer was conducted by observing the interference pattern shift. The vapor concentration changed the value of the refractive index. When light passes through a medium, in which its refractive index value is greater than the air’s one, that will decrease its speed; there is the phase change between the two beams of light [2]. The observance of magnitude of the fringe shift is shown in Equation 1.

\[ \Delta m = \Delta m + 1 - \Delta m = \frac{sv}{a} \] (1)

Where \( \Delta m \) is the shift of the fringe, \( s \) is the distance the beams splitter to the screen, \( a \) is the different optical path [2]. The number of fringe shift is affected by changes in the refractive index of vapor, with the initial condition of the shift is expressed by Equation 2.

\[ m = \frac{2d}{\gamma} \] (2)

where \( m \) is the initial fringe, \( d \) is the thickness of the sample chamber (4 cm), and \( \lambda \) is the wavelength of the laser light (620 nm). Equation 3 expresses the change of \( m \):

\[ m = \frac{2d}{\gamma/n} \] (3)

where \( n \) is the refractive index of vapor. The fringe shift is expressed in Equation 4.

\[ \Delta m = m_2 - m_1 = (n - 1) \frac{2d}{\gamma} \] (4)

![Figure 1. Experimental set-up. AP: Air Pump, SG: Silica Gel, V: Valve, SC: Sample Chamber, IH: Injection Hole, DL: Diode Laser, BS: Beam Splitter, M1: Mirror 1, M2: Mirror 2, S: Screen, C: Camera, PC: Personal Computer](image)

The refractive index can be calculated by Equation 5.

\[ n = 1 + \frac{\Delta my}{2d} \] (5)
In this study, the light source was a laser diode with a wavelength of 620 nm and the vapor samples were ethanol and benzene. The block diagram of the equipment is shown in Figure 1. The light source of DL was divided by the BS towards the M1 and SC. Reflected light from the M1 and M2 was recombined to form a pattern displayed on the S and captured by the camera.

3. Result and discussion
The vapor concentration was given by injecting sample fluid into the chamber. The fluid volume ranged between 0.05 to 1 mL. The number of fringe shifts was observed in the pattern and intensity is shown in Figure 2 and Figure 3 respectively. The results of the measurement of ethanol and benzene solvents are shown in Figure 4 and Figure 5 respectively.

The vapor concentration can be estimated by using Equation 6 [6].

\[
C(\text{ppm}) = \frac{\rho V_m V_c}{M} \times 10^6
\]

where C is the vapor concentration in ppm, \(\rho\) is the liquid density (g / mL), V is the volume of fluid (mL), M is the molar mass of fluid (g / mol), Vm is the molar volume of ideal gas (22.4 L / mol) and Vc is the volume of the chamber (0.013 L).

![Figure 2. Fringe pattern before the phase shifts and intensity pattern](image1)

![Figure 3. Fringe pattern after the phase shifts and intensity pattern](image2)

![Figure 4. The fringe shift of the benzene vapor](image3)
The results showed that the number of the fringe shift was proportional to the concentration. The ethanol concentration of 1611-32210 ppm produced a fringe shift of 197 pixels, while the concentration of benzene of 964-19290 ppm produced a fringe shift of 273 pixels.

4. Conclusion
This study has been made of the gas sensor based on Michelson interferometer. This type of sensor is used to measure the concentration of volatile organic compound vapor observed from the change in the number of fringe shifts. The results show that the number of the fringe shift is proportional to the concentration. The ethanol concentration of 1611-32210 ppm produces a fringe shift of 197 pixels, while the concentration of benzene of 964-19290 ppm produces a fringe shift of 273 pixels. The use of polymer materials is needed to increase the sensitivity and selectivity of this optical sensor. An array of polymers with different its polarities will result in a shift of the fringe pattern that is unique to each sample of vapor.

References
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