proceedings

Abstract

Measurement and analysis of lateral-offset optical fiber Mach–Zehnder interferometer using near infrared light as chloride ion concentration sensor†

Jian-Neng Wang [1,*], Pei-Hsuan Wu [1]

[1] National Yunlin University of Science and Technology, Douliou, Yunlin 64002, Taiwan
* Correspondence: wangjn@yuntech.edu.tw
† Presented at the 18th International Workshop on Advanced Infrared Technology and Applications (AITA) in Kobe, Japan, 15–19 September 2025.

Abstract: This paper presents the measurement and analysis of a lateral-offset optical fiber Mach–Zehnder interferometer (MZI) as chloride ion concentration sensor using a near infrared light source (amplified spontaneous emission, wavelength = 1520-1620 nm). An 8-cm optical fiber MZI sensor was fabricated and fusion spliced using a lateral-offset process. We used this 8-cm lateral-offset op-tical fiber Mach–Zehnder interferometer (MZI) and measured chloride ions in samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% and then analyzed those interference spectra regarding normalized intensity, wavelength shift, and three ranges of the integral areas (1520-1580 nm, 1540-1600 nm, and 1520-1620 nm). The comparative spectral analysis results show that the lateral-offset optical fiber MZI sensor exhibited a linear decrease in the normalized intensity as well as wavelength shift when the concentration increased. The lateral-offset optical fiber MZI sensor displays a sine wave plot in the three ranges of integral areas when the concentration increased. Other than sensing parameters such as normalized intensity (adjusted R-squared = 0.98223) or wavelength shift (adjusted R-squared = 0.94209), the three ranges of integral areas (adjusted R-squared = 0.96425, 0.91621, and 0.9577, respectively) which possessed adjusted R-squared greater than 0.9, are also recommend as sensing parameters for this measurement and analysis of a lateral-offset optical fiber Mach–Zehnder interferometer (MZI) as chloride ion concentration sensor using a near infrared light source.

Keywords: fiber-optic sensors; Mach-Zehnder interferometer; chloride ion concentration; normalized intensity; wavelength shift; integral area

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

The Mach-Zehnder interferometers (MZIs) are suitable for sensing applications since MZI of MZI-like sensors offer many advantages such as low cost, robustness, low insertion losses, relatively simple fabrication, compact, ease of use, immunity to electro-magnetic interference, and sensitivity either to the chloride ion concentration [1-4].

2. Lateral-Offset Optical Fiber Sensing for Chloride Ion Concentration Using Mach-Zehnder Interferometer

2.1 Fabrication of lateral-offset optical fiber Mach-Zehnder interferometer

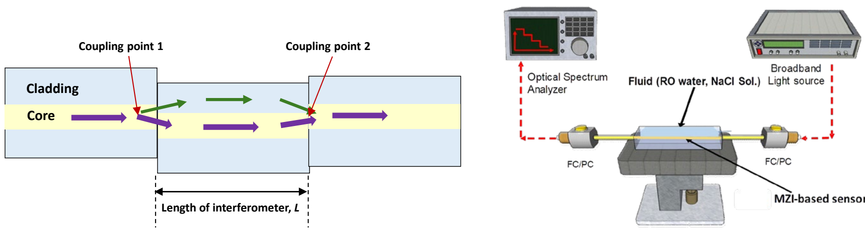
An 8-cm optical fiber Mach-Zehnder interferometer sensor was fabricated using a piece of single mode fiber (SMF, Corning SMF-28) by a lateral-offset process [5] with a fusion splicer (FITEL S178A, see Figure 1a). We used single mode fiber to make a lateral-offset Mach–Zehnder interferometer as chloride ion concentration sensor and our chloride ion concentration measurement is up to 25%.

2.2 lateral-offset optical fiber Mach-Zehnder interferometer sensing for chloride ion concentration

Figure 1b displays experimental setup of an optical fiber Mach–Zehnder interferometer platform for sensing chloride ion concentration. The schematic of experimental setup for sensing chloride ion concentration measurement with a lateral-offset optical fiber MZI sensor, which is composed of an 8-cm MZI sensor, a near infrared light source (amplified spontaneous emission, wavelength = 1520-1620 nm), an optical spectrum analyzer (HP 71450B), and a personal computer for data acquisition. Figure 2 shows the transmission spectra of the Mach–Zehnder interferometer sensor for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25%.

2.3 Comparative spectral analysis

For the comparative spectral analysis of the lateral-offset optical fiber Mach–Zehnder interferometer (MZI) as a chloride ion concentration sensor, we analyzed traditional sensing parameters such as normalized intensity as well as wavelength shift, and proposed three sensing parameters including three ranges of integral areas (1520-1580 nm, 1540-1600 nm, and 1520-1620 nm). The proposed integral area for each optical spectrum (curve) was integrated and calculated the area above the lowest point. We analyzed three ranges of integral areas (1520-1580 nm, 1540-1600 nm, and 1520-1620 nm) for each optical spectrum.



(a) (b)

Figure 1. (a) Schematic of lateral-offset process for the fabrication of Mach–Zehnder interferometer; (b) Experimental setup for an optical fiber Mach–Zehnder interferometer platform for sensing chloride ion concentration.

3. Results and Discussion

Figure 3a shows the plot of the chloride ion concentration versus normalized intensity for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% and Figure 3b displays a linear plot of the sodium chloride solution concentration versus normalized intensity (1526 nm). Results show that the optical fiber MZI sensor exhibited a linear decrease in the normalized intensity when the concentration increased (adjusted R-squared = 0.98223). Figure 4a shows the plot of the chloride ion concentration versus wavelength shift for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% and Figure 4b displays a linear plot of the sodium chloride solution concentration versus wavelength shift (1590-1592 nm). Results show that the optical fiber MZI sensor exhibited a linear decrease in the wavelength shift when the concentration increased (adjusted R-squared = 0.94209). Figure 5a shows a sine wave plot of the chloride ion concentration versus integral area (1520-1580 nm) for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% (adjusted R-squared = 0.96425), Figure 5b displays a sine wave plot of the sodium chloride solution concentration versus integral area (1540-1600 nm) for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% (adjusted R-squared = 0.91621), and Figure 5c exhibited a sine wave plot of the sodium chloride solution concentration versus integral area (1520-1620 nm) for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% (adjusted R-squared = 0.9577). Thus, those which possessed adjusted R-squared greater than 0.9 are recommend as sensing parameters such as normalized intensity (adjusted R-squared = 0.98223), wavelength shift (adjusted R-squared = 0.94209) as well as the three ranges of integral areas (adjusted R-squared = 0.96425, 0.91621, and 0.9577, respectively).

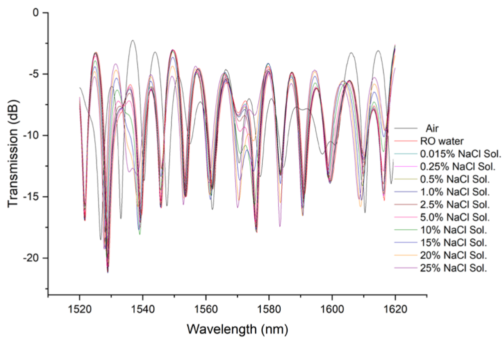
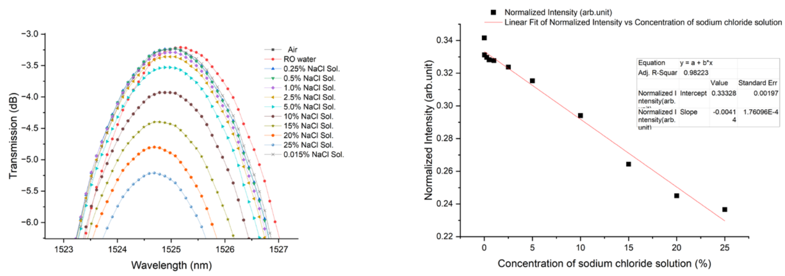
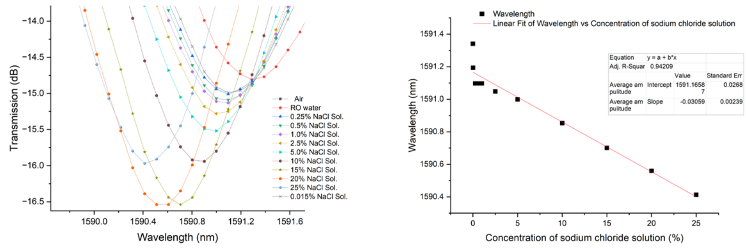


Figure 2. Spectra of the Mach–Zehnder interferometer sensor for sensing samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25%.



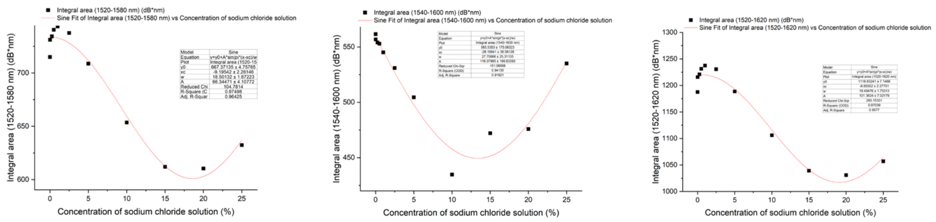
(a) (b)

Figure 3. (a) Plot of the chloride ion concentration versus normalized intensity using the optical fiber Mach–Zehnder interferometer sensor; (b) Linear plot of the sodium chloride solution concentration versus normalized intensity (1526 nm).



(a) (b)

Figure 4. (a) Plot of the chloride ion concentration versus wavelength shift using the optical fiber Mach–Zehnder interferometer sensor; (b) Linear plot of the sodium chloride solution concentration versus wavelength shift (1590-1592 nm).



(a) (b) (c)

Figure 5. The optical fiber Mach–Zehnder interferometer sensing results: (a) Sine fitting of the chloride ion concentration versus integral areas (1520-1580 nm); (b) Sine fitting of the sodium chloride solution concentration versus integral areas (1540-1600 nm); (c) Sine fitting of the sodium chloride solution concentration versus integral areas (1520-1620 nm).

4. Conclusions

We have conducted the comparative spectral analysis of a lateral-offset optical fiber Mach–Zehnder interferometer as a chloride ion concentration sensor by analyzing normalized intensity, wavelength shift, and three ranges of integral areas. The 8-cm lateral-offset optical fiber MZI sensor was fabricated and fusion spliced using a lateral-offset process. We measured chloride ions in samples of sodium chloride solutions with different weight concentrations ranging from 0.015% to 25% and analyzed those interference spectra regarding normalized intensity, wavelength shift and three ranges of the integral areas (1520-1580 nm, 1540-1600 nm, and 1520-1620 nm). Results show that the lateral-offset optical fiber MZI sensor exhibited a linear decrease in the normalized intensity and wavelength shift when the concentration increased. The lateral-offset optical fiber MZI sensor exhibits a sine wave plot in the three ranges of integral areas when the concentration increased. Other than sensing parameters such as normalized intensity (adjusted R-squared = 0.98223) or wavelength shift (adjusted R-squared = 0.94209), the three ranges of integral areas (adjusted R-squared = 0.96425, 0.91621, and 0.9577, respectively) which possessed adjusted R-squared greater than 0.9, are also recommend as sensing parameters for this measurement and analysis of a lateral-offset optical fiber Mach–Zehnder interferometer (MZI) as chloride ion concentration sensor using a near infrared light source.

References

1. Tang, J.L. and Wang, J.N., "Measurement of chloride-ion concentration with long-period grating technology," *Smart Mater. Struct.* 2007, 16(3), 665-672.
2. Wang, J.N., "A microfluidic long-period fiber grating sensor platform for chloride ion concentration measurement," *Sensors* 2011, 11(9), 8550-8568.
3. Wang, J.N. and Tang, J.L., "Photonic crystal fiber Mach-Zehnder interferometer for refractive index sensing," *Sensors* 2012, 12(3), 2983-2995.
4. Villatoro, J., Minkovich, V.P., Pruneri, V., and Badenes, G., "Simple all-microstructured-optical-fiber interferometer built via fusion splicing," *Opt. Express* 2007, 15, 1491-1496.
5. Bianchetti, M. et al., "Symmetric and Asymmetric Core-Offset Mach–Zehnder Interferometer Torsion Sensors," *IEEE Photonics Technol. Lett.* 2017, 29(18), 1521-1524.