Nexo Revista Científica

Vol. 36, No. 6, pp. 1132-1140/Diciembre 2023

ISSN-E 1995-9516
Universidad Nacional de Ingeniería
http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v36i06.17469

Graphene Oxide-Coated Mach-Zehnder Interferometer Based Ammonia Gas Sensor

Interferómetro Mach-Zehnder recubierto de óxido de grafeno basado en Sensor de gas de amoníaco

Dhiya A. Fenjan[1*] , Bushra R. Mahdi[2] and Hashim A. Yusr[3]
[1,3] Department of Physics, College of Science, University of Wasit, Kut, Wasit, Iraq
[2] Ministry of Since and Technology Iraq

[*]dhiyaf401@uowasit.edu.iq

(recibido/received: 07-agosto-2023; aceptado/accepted: 23-noviembre-2023)

ABSTRACT

The presence of high levels of ammonia in the bloodstream can lead to unconsciousness and convulsions, making it a prime example of dangerous air pollution. The presence of certain gases in our environment can be quite discomforting. In light of these concerns, we present a contemporary approach to designing and developing an exceptionally sensitive ammonia gas sensor. This sensor utilizes a substrate composed of single-mode fiber (SMF), photonic crystal fiber (PCF), and SMF to create a Mach-Zehnder interferometer (MZI). The sensing mechanism involves the immobilization of an Au and GO nanocomposite. In this setup, the region of interference between the waves of the SMF and the solid crystal fiber creates a collapse zone that is utilized to excite the core and cladding modes of the PCF. This innovative technique ensures remarkably rapid response and recovery times.The reusable probe showcased in this study displays significant potential for achieving rapid, highly accurate, and reproducible ultratrace ammonia detection. This introduces a novel avenue for conducting online measurements and environmental monitoring. The intersection point of the SMF and the solid crystal specialty fiber generates a collapse zone that effectively excites the core and cladding modes of the PCF, resulting in the promised rapid response and recovery times.The reusable probe exhibits the capability to swiftly detect ultratrace amounts of ammonia, boasting good selectivity, consistent characteristics, and sensitivities of up to 18.65 nm/ppm. This development opens up new possibilities for environmental monitoring and real-time measurements, offering improved insights into our surroundings.

Keywords: Graphene Oxide, Interferometer, Ammonia, Gas Sensor

RESUMEN

La presencia de altos niveles de amoníaco en el torrente sanguíneo puede provocar inconsciencia y convulsiones, convirtiéndolo en un ejemplo destacado de contaminación del aire peligrosa. La presencia de ciertos gases en nuestro entorno puede resultar bastante incómoda. A la luz de estas preocupaciones, presentamos un enfoque contemporáneo para diseñar y desarrollar un sensor de gas de amoníaco excepcionalmente sensible. Este sensor utiliza un sustrato compuesto por fibra monomodo (SMF), fibra de cristal fotónico (PCF) y SMF para crear un interferómetro Mach-Zehnder (MZI). El mecanismo de detección implica la inmovilización de un nanocompuesto de Au y GO. En esta configuración, la región de interferencia entre las ondas de la SMF y la fibra de cristal sólido crea una zona de colapso que se utiliza para excitar los modos del núcleo y el revestimiento de la PCF. Esta técnica innovadora garantiza tiempos de respuesta y recuperación notablemente rápidos. La sonda reutilizable presentada en este estudio muestra un potencial significativo para lograr una detección rápida, altamente precisa y reproducible de trazas ultrabajas de amoníaco. Esto introduce una nueva vía para realizar mediciones en línea y monitoreo ambiental. El punto de intersección de la SMF y la fibra de cristal sólido genera una zona de colapso que excita de manera efectiva los modos del núcleo y el revestimiento de la PCF, lo que resulta en los prometidos tiempos de respuesta y recuperación rápidos. La sonda reutilizable exhibe la capacidad de detectar rápidamente cantidades ultrabajas de amoníaco, con una buena selectividad, características consistentes y sensibilidades de hasta 18.65 nm/ppm. Este desarrollo abre nuevas posibilidades para el monitoreo ambiental y las mediciones en tiempo real, ofreciendo una mejor comprensión de nuestro entorno.

Palabras clave: Óxido de grafeno, Interferómetro, Amoníaco, Sensor de gas

1. INTRODUCTION

The chemical formula for gaseous ammonia is NH_3 (Jorgenson and Yee, 1993). It is simple to create an ammonium cation because of its electro-positivity, which exhibits alkaline behavior in an aqueous environment.

Gases that are toxic, flammable, and explosive are frequently encountered in daily life and industrial processes that result in severe safety incidents. An essential part of industrial manufacturing is poisonous and volatile ammonia gas (Jorgenson and Yee, 1993). Ammonia gas leaks can harm the environment and constitute a major health danger. For example, concentrations exceeding 100 ppm can cause functional issues by quickly irritating the eyes and respiratory system.

As a result, ammonia gas detection and early warning are essential. Sensing using electrochemistry are often used for their high-precision measurements (Siddik et al., 2020), and they have disadvantages, including their weak reproducibility, simple contamination, and limited life, as the applications for detecting ammonia gas leaks are in important places subject to corrosion damage. A sensor that can overcome such defects and provide fast, accurate and stable sensing for the detection of ammonia gas is an important point of research. Optical fiber sensors have gained popularity since their introduction. Optical fiber sensing techniques differ from traditional sensing techniques in that they are small and light in weight and are not affected by electromagnetic fields and can be monitored remotely via an Internet network.

The metal surface is covered in free electrons resonate when a Ppolarized light wave hits the metal-dielectric contact, absorbing energy and causing surface plasmon resonance (SPR) (Siddik et al., 2020). The ambient temperature and refractive index (RI) of the metal surface, in other words, affect the SPR characteristic absorption spectrum. The drift of the SPR spectrum may consequently be used to reverse refractive index and temperature fluctuations, which can subsequently be used for parametric detection.

The advantages of both fiber optic and SPR sensor technologies are combined in the more recent type of sensor known as a fiber optic SPR sensor (Siddik et al., 2020). Over and beyond the fiber-optic sensors it comes with by default, the SPR sensor has the advantages of high detection sensitivity and label-free detection. This method has been extensively applied in physical quantometry (Chen et al., 2019, Wang et al., 2022, Barnes et al., 2003).

The SPR resonance wavelength calculation equation (Teng et al., 2022) states that temperature changes have an impact on the refractive index of metals and dielectric materials.

It is unavoidable for the SPR's resonance peak wavelength to move due to temperature change (where λ_0 is the incident wavelength ε_m is the dielectric constant of the metal film, and ε_d is the dielectric constant of the ambient medium, respectively, $\lambda_{Sp}=\lambda_0(1/\varepsilon_m+ 1/ \varepsilon_d)^{1/2}$

The rapid advancement of correlation technology has substantially aided research on the structural layout, experimental set-up, and temperature self-compensating fiber-optic SPR sensors in real-world applicationsTo excite SPR channels by the effect of temperature and concentration, respectively, Wang et al. (Wang et al., 2022) A single-mode optical fiber mediated by a multi-mode fiber sensor was made to be the MM-SM-MM sensorVaporized Au film on PDMS was used to cover the surface of the normal fiber , a temperature-sensitive material., to carry out temperature-compensable assessments of glucose concentration. Furthermore, Teng et al. (Teng et al., 2022) Both sides of the sensor made of U-shaped plastic fiber polished were coated with an Au film with a evaporation system, then one surface a film by Au was coated with PDMS has a sensitivity of up to 1258 nm / RIU, to achieve temperature-compensated refractive index measurements.

In this study, a MZI (Mach-Zehnder interferometer) covered with graphene oxide was introduced to monitor the concentration of ammonia gas. Conduct a region-wide evanescent field augmentation, which is used to increase the sensor's sensitivity to changes in the external environment, based on MZI interferometer installation, which primarily creates a stable and unambiguous interferometer. A section of tapered core fiber (TCF) is cut and welded between multimode fibers (MMF) to create the MZI structure. When the mode fields are out of phase, the multimode fiber acts as a light beam splitter and recombiner. The TCF region has an active role in the process of sensing changes in the surrounding conditions.

To increase sensitivity, a GO film is deposited onto the surface. When the GO film absorbs NH_3 gas, charge exchanges will take place, changing the GO's refractive index as a result. As a result, the cladding mode's(RI_{eff})will alter. The Δ phase between the core mode and the cladding mode will change, which will cause the MZI's resonant wavelength to alter.

Therefore, by measuring the shift, the concentration of ammonia gas can be determined. This essay is organized as follows: The topology and workings of the sensor are discussed in portion(2). The sensing head's construction is described in portion(3)in detail. Portion(4) contains the experiment's analysis and findings,and portion(5) summary

Sensor Principle and Structure

The three layers that generally comprise an optical SPR sensor are the sensing medium, the metal, and the core, as seen in Figure 1 (Wang et al., 2022). ε_0 represents the dielectric constant of metal , ε_m represents the sensing medium, and ε_d represents the core. The light wave is entirely reflected at the interface between the core and the metal layer if incident light is transmitted in the fiber core at a particular angle. However, a portion of the energy will go through the metal layer as an evanescent wave, causing the surface plasma resonance wave to occur. Typically, (Teng et al., 2022, Zhao et al., 2023) may be used to demonstrate the plasma wave's transmission constant on a metal surface.

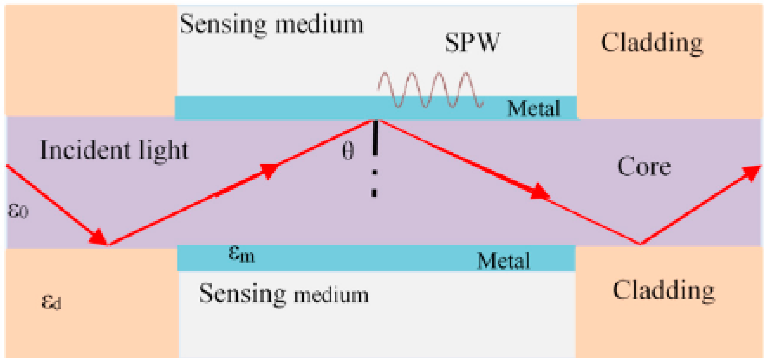


Figure (1) shows a schematic of an SPR optical fiber sensor(Wang et al., 2022)

In a vacuum, light travels at a speed of c, and the incident light wave's angular frequency is given by the formula

$$K_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

According to Figure 1, In between metallic and base medium, composite parallel propagation constant for evanescent waves is given by (Zhang et al., 2022)

$$K = \frac{\omega}{c}\sqrt{\varepsilon_\circ}\ \sin\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where q is the angle of incidence. when the incidence angle or incident wavelength is a respectable value, Phase matching is achieved via the propagation constants of plasma and evanescent waves criteria, leading to $K_{sp} = K$. The evanescent wave and the surface plasma wave are now interacting resonantly. In order to attenuate the reflected light and finally form a resonance absorption peak in the transmission spectrum, a portion of the incoming light wave energy that meets the resonance criteria is converted into the oscillation energy of plasma wave.

2. EXPERIMENTAL WORK

The coated sensor required two phases to fabricate, as indicated in Figure (2) is scheme

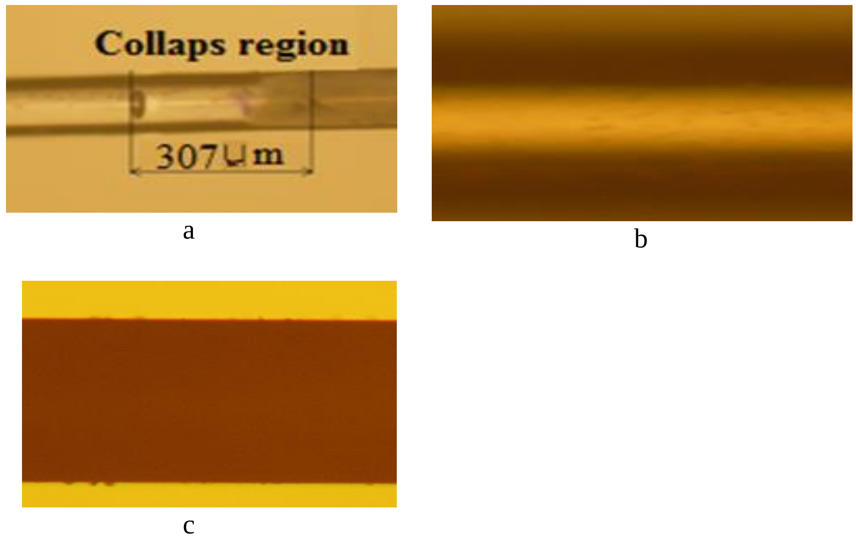


Figure (2) Microscopic images (a) Welding and collapse of the crystal fiber with the regular fiber, which is 307 µm long. (b) The gold coating film (c) graphene oxide film and the phenomenon ..

The first stage is utilizing the manual mode software of a fiber optic splicer to splice a brief (2 cm) segment of Thorlabs USA-prepared crystalline silica fiber (PCF) to a single-mode fiber (SMF 28e, Thorlabs USA) Tokyo, Japan; Fujikura 40S. Figure (2a), which is 307 m long and depicts the collapse of the air gaps of the crystal fiber at the weld area, and Figures 2b and c, which show microscopic images of the gold and graphene oxide coating films, respectively.

sensitivity zone is activated in the second stage Using the DC plasma sputtering equipment, coating it with a thin layer of nano-gold that is 20 nanometers thick and covering it with a layer of graphene oxide that is 20 nanometers thick.

The schematic diagram of the manufactured sensor is shown in the figure (3)

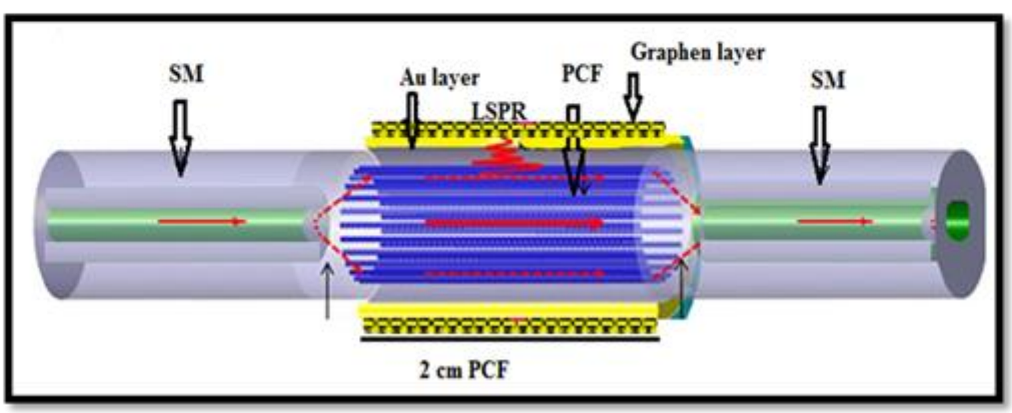


Figure (3) The schematic of a crystal fiber sensor with a regular fiber and coatings of graphene oxide and gold paint.

The constructed sensor was put to the test by being moved through a chamber containing a gas entry and exit aperture. The far end of the sensor was placed into a spectral analyzer by Ocean Company, model HR -2000, which has a range of 200-1100 nm, and fed with a semiconductor laser at a wavelength of 650 nm. The explanation diagram for how the experiment was set up is shown in Figure (4).

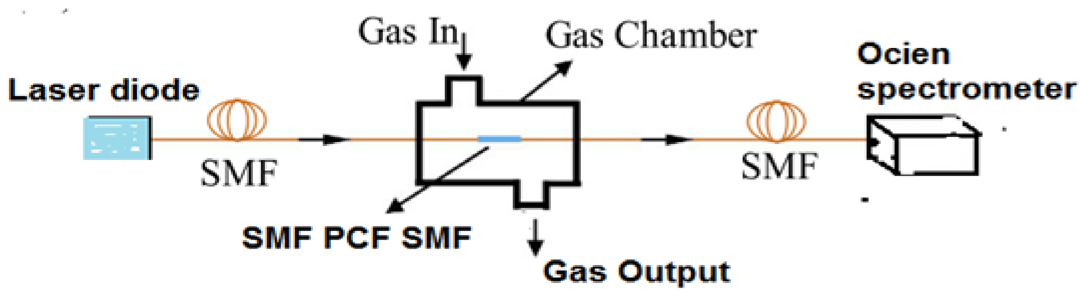


Figure (4) The schematic diagram of the parts of the ammonia gas sensor

3. RESULT AND DISCUSION

. Thin layer deposition of GO has opened up new avenues for sensor applications. Surface GO film resonance (SPR) demonstrated that the platform is more sensitive than the conventional configuration. The GO layer is reinforced surface polariton (SPP) so that the hybrid structure is more sensitive to changes in the surrounding environment.

GO shows a strong adsorption of surrounding material particles compared with the conventional surface activation in environmental sensitizers, monolayer GO deposition is a simplified approach on the other side. Fiber-optic sensors are well demonstrated by their small size, flexibility, ability to monitor in critical and hazardous locations, and unaffected by electromagnetic magazines. By utilizing both GO-modified SPR and optical fibers, GO-on-gold coatings combined with chemically treated optical fibers to achieve improved sensor sensitivity.

Enhance the performance of the MZPCFIS, the sensor was coated with a layer of graphene on top of the gold layer, using the same coating technique. The coated sensor was tested on the same contaminated materials that were tested with the gold-coated fiber sensor.

Figure (5) displays the intensity spectrum of gold and GO-coated MZPCFI. From the results of the spectrum's intensity, it can be seen that when NH3 concentrations rise, the sensor's usual spectrum intensity gradually declines. At the spectrometer's output, less light is detected as NH3 concentration rises.

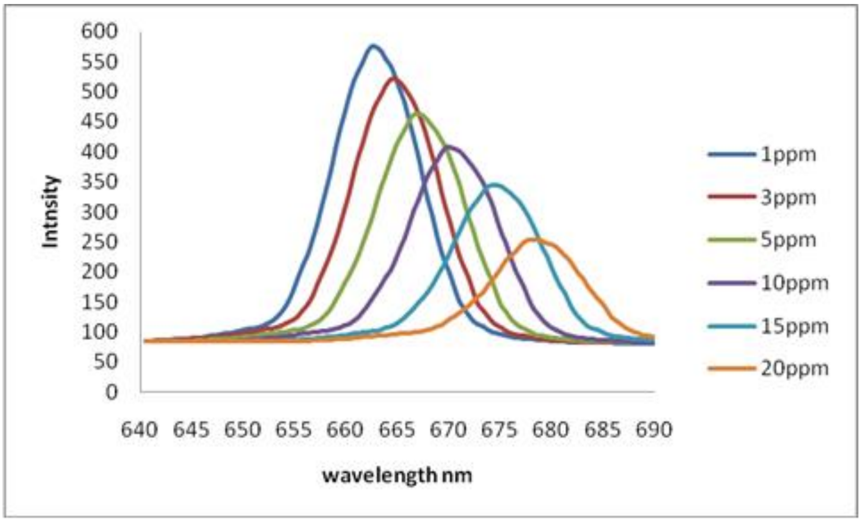


Figure (5) The composition of the GO sensor on the proposed Au for ammonia gas.

The coated MZPCFI sensor's modular transmitter normlized spectrum, shown in Figure (6), demonstrates a commensurate decline in the fiber's output light signal's levels of transmission . The rise in NH3 concentrations and the decline in permeability are closely connected. Absorption modifications are to blame for this

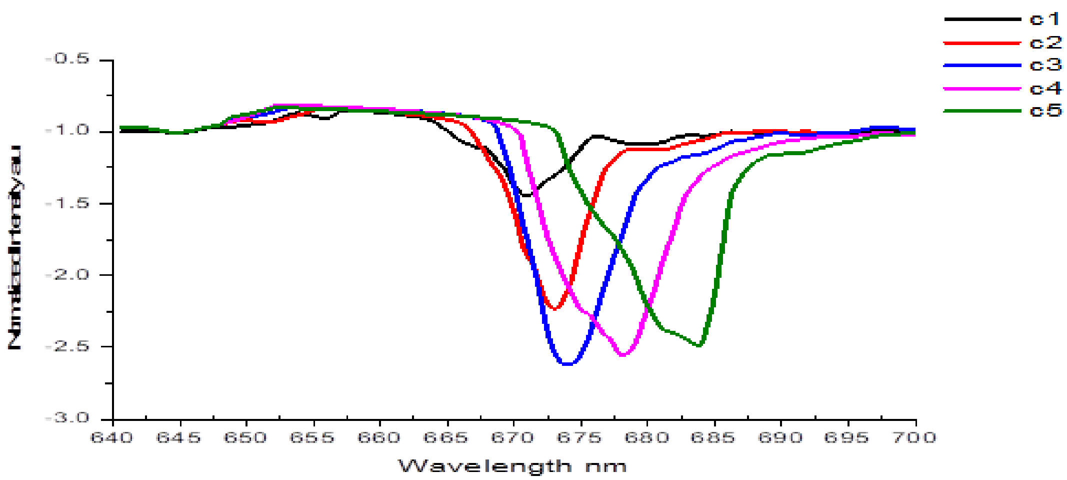
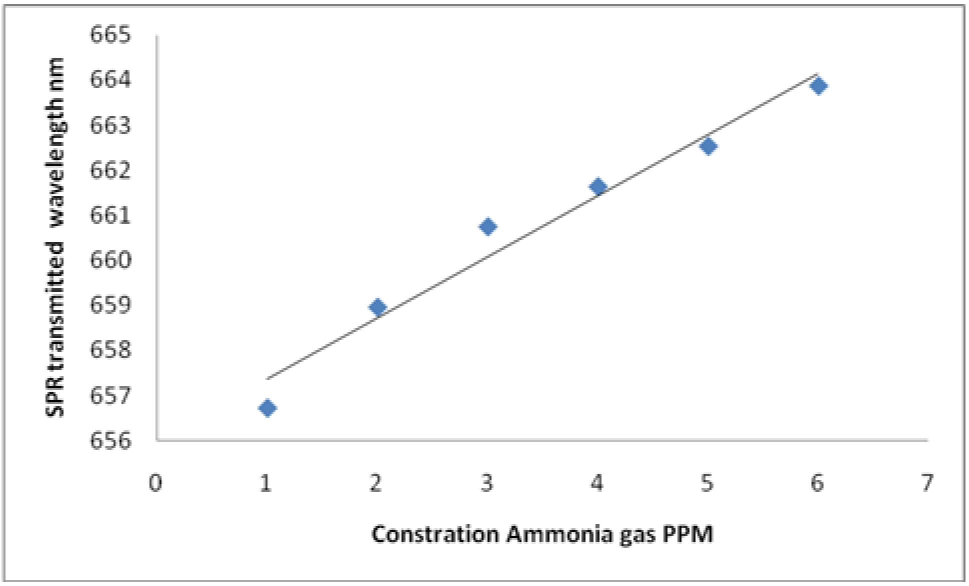


Figure (6) transmission spectra of the GO sensor on gold for determining various NH_3 gas concentration.

As NH3 concentration rises between 0 and 20 ppm, the wavelength of low resonance moves to the longer wavelengths. The adsorption of NH3 on GO can be improved by the numerous polar functional groups that are present in GO. GO absorbs and reacts with NH3, and since GO is highly conductible and forms surface hydrogen bonds, the charge transfer from NH3 to GO is essential. Because it is inversely related to conductivity and dielectric constant, the refractive index of GO will increase as a result, which will then have an impact on the cladding mode's effective refractive index. Due to the difference in (n_{eff}) between the fundamental mode and the cladding mode, the resonance gradient wavelength will subsequently shift to the long wavelength. As the concentration of ammonia gas rises, the adsorption effect will as well. With increasing concentration, the phase difference between the main and cladding mode gets larger, which causes the lower resonance's wavelength to keep moving toward the long wavelength. On the other hand, when NH3 is absorbed from GO, the low resonance's wavelength will move back to close to its original location.

In Figure (7), the association between the SPR wavelength shift and the NH_3 gas concentration is depicted. According to the results of linear matching, the range of 0–20 ppm for NH_3 gas concentration yields a sensitivity of 18.625 nm/ppm.(Peng and Li, 2013)



Figure(7) resonant wavelength against Ammonia gas concentration.

4. CONCLUSION

A MZFI with GO coating is recommended in this study for sensing the concentration of NH3 gas. Both the effective refractive index (neff) of the cladding mode and the phase of light in the fiber are impacted by the change in the GO film's refractive index brought on by the absorption of ammonia gas. The neff of the GO optical fiber sensor is significantly affected by NH3 adsorption on graphene, and the interferometric phase signal of an all-optical microfiber-based MZI experiences spectrum changes as a result. The NH3 content can be detected extremely sensitively with a resolution of 1 ppm. The wavelength of the interferometer response's dip is shifted as a result. Based on the findings, it is possible to attain a sensitivity of 18.625 nm/ppm with a linear fit coefficient (R2) of 98.988% in the NH3 gas concentration range of 0–20 ppm. Simple manufacture, a compact volume, and a passive design are benefits of the proposed sensor. In a temperature-controlled setting, it may be utilized for real-time ammonia gas monitoring.

REFERENCES

BARNES, W. L., DEREUX, A. & EBBESEN, T. W. 2003. Surface plasmon subwavelength optics. *nature*, 424**,** 824-830.

CHEN, Y., SUN, W., ZHANG, Y., LIU, G., LUO, Y., DONG, J., ZHONG, Y., ZHU, W., YU, J. & CHEN, Z. 2019. Magnetic nanoparticles functionalized few-mode-fiber-based plasmonic vector magnetometer. *Nanomaterials*, 9**,** 785.

JORGENSON, R. C. & YEE, S. S. 1993. A fiber-optic chemical sensor based on surface plasmon resonance. *Sensors and Actuators B: Chemical*, 12**,** 213-220.

PENG, Y. & LI, J. 2013. Ammonia adsorption on graphene and graphene oxide: a first-principles study. *Frontiers of Environmental Science & Engineering,* 7**,** 403-411.
SIDDIK, A. B., HOSSAIN, S., PAUL, A. K., RAHMAN, M. & MOLLAH, A. 2020. High sensitivity property of dual-core photonic crystal fiber temperature sensor based on surface plasmon resonance. *Sensing and Bio-Sensing Research,* 29**,** 100350.
TENG, C., SHAO, P., LI, S., LI, S., LIU, H., DENG, H., CHEN, M., YUAN, L. & DENG, S. 2022. Double-side polished U-shape plastic optical fiber based SPR sensor for the simultaneous measurement of refractive index and temperature. *Optics Communications,* 525**,** 128844.
WANG, H., CHEN, S., DAI, W., XIE, T., PAN, P., LUO, J. & FU, H. 2022. Dual-Channel SPR Sensor Based on MSM Fiber for Detection of Glucose Concentration and Temperature. *IEEE Photonics Technology Letters,* 34**,** 919-922.
ZHANG, S., HAN, B., ZHANG, Y. N., LIU, Y., ZHENG, W. & ZHAO, Y. 2022. Multichannel fiber optic SPR sensors: Realization methods, application status, and future prospects. *Laser & Photonics Reviews,* 16**,** 2200009.
ZHAO, H., WANG, F., HAN, Z., CHENG, P. & DING, Z. 2023. Research advances on fiber-optic SPR sensors with temperature self-compensation. *Sensors,* 23**,** 644.