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Fabrication Highly Sensitive Optical Sensing Devices Based on D- Shaped Fibre

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Abstract. The optical sensing devices has been fabrication based on D-Shaped Fiber coated with Graphene Oxide (GO). The single mode Step Index fiber (SMF-28) used resemble (D-Shaped Fiber) to generate an evanescent field on polishing area used as optical sensing region with (2mm2) area. This technique applying few layers (~22-layers) of Graphene Oxide (GO) with a thickness of ~ 0.09~µm used to coat D-shaped fiber. The performance D-Shaped Fiber have been test by applied different elements on polished region (without GO- coat and with GO-coat) that show increase in transmitted power by ~3.5dBm and ~21.5dBm respectively. The COMSOL Multiphasic simulation using to perform the effect of phishing on the electric field of sensing region. These features can make D-Shaped-Fiber can be used in many applications such as biomedical sensor, humidity sensor, temperature sensor and biochemical sensor.

Keywords: D-Shaped Fiber, Graphene Oxide (GO), Sensor, Single mode fiber, comsol.

INTRODUCTION

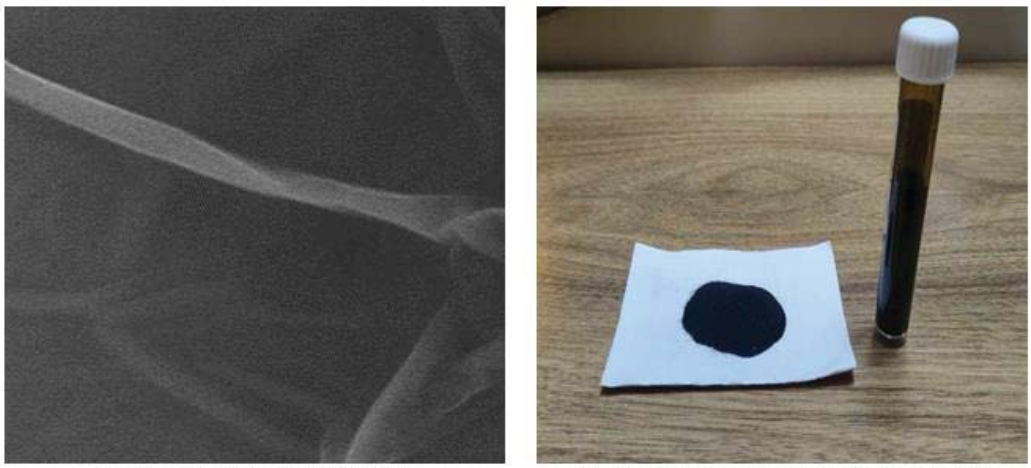
The Graphene Oxide (GO) has a large number of studies for developing the electronic properties, thus properties make researcher pay attention to Graphene. The characteristics of Graphene was describing two dimensional materials consisted single made of carbon atoms, often dubbed “miracle material”. The Carbon-based materials or Graphene Oxide (GO) with few layers has increases the interest of different application due to the Graphene properties. The graphene oxide (GO) have attracted deal due to electrical and mechanical properties and high levels

of thermal conductivity, low thermal noise where the material shows its inherent [1]. Some more the Graphene was first isolated in 2004, the thick of Graphene atomic layers stronger than 200 time than steel, most conductive materials stiffness and strength. The demonstrated that potential applications of single molecule of Graphene have excellent optical absorption, highly sensitive and selective detection properties[2]. The Graphene has been study by the researcher and company to create something unique for developing company products to be better perform [3]. The Graphene production have been synthesized with the intention for large volume due to unique properties and have attention to researcher. Graphene Oxide (GO) has distinct characteristics, Layer or multilayers of graphene oxide can be produce by drop casting technique [4]. The Graphene Oxide (GO) fabricated and prepared based on the presented work was produced using modified Hummer's method. The prepared Graphene exhibited 2.6 μL. The optical sensor have unique properties like immune to electromagnetic field, radio frequency and easy adapt to various parameter to sensing [5-11]. The aim of this paper is using D-Shaped Fiber to generate an evanescent field that can be exposed surrounding fiber to create the sensing region and coating with Graphene Oxide (GO) to create high sensitive region to sensing the different elements such as (distilled water, ethanol & human breathing).

FABRICATION OF OPTICAL SENSOR

Preparation of The Graphene Oxide (GO)

The several methods that produce the Graphene Oxide solutions (GO) like hummers methods Brodie's method and Staudenmaier's method [12, 13]. The modification in hummer methods to produce Graphene Oxide (GO) solution presenting for this work and synthesis process is explain as follow:The sheet paper of Graphene Were Oxides to higher oxidation degree by mixing permanganate potassium (KMno4) and concentrated acid such as sulfuric acid with sheet paper. This mixing is stirred under room temperature for three days. The mixing colour will be change during period form dark purplish green to dark green, the process of oxidation will end by add the hydrogen peroxide (H2O2) to mixture and the colure will change to bright yellow thus indicate high level of Oxidization of Graphite. The washing process is requiring to Graphite Oxide (GO) with hydrochloric for several time and deionized (DI) water until pH of 4-5 achieved. the process of washing carries out by decantation of supernatant in centrifugation technique with force configuration 10000 g (G-force). The exfoliated process of Graphed Oxide (GO) was formed Graphene Oxide (GO) gel, finally this gel diluted with suitable DI water for suitable concentration for drop casting technique as prove in previous studies [14-16]. The Figure 1(a) show the structure and the morphology of graphene oxide (GO) synthesizes using FESEM Images the like crumpled sheet layers with diameters size of several micrometers. The crumpling could be attributed to the defective structures formed by the exfoliation process[17].



(a)-FESEM Graphene Oxide (GO) (b)-Graphene Oxide (GO) powder and liquids

FIGURE 1. (a) FESEM image of Graphene Oxide (GO)and (b) Graphene Oxide (GO) powder and liquids

FABRICATION D-SHAPED FIBER

The Single mode fiber (SMF-28) as show in Figure.2 with core diameter 8.2 µm and cladding diameter 125µm. The SMF-28 is step index fiber have uniform refractive (1.452 and 1.446) core and cladding respectively. The path of light propagation inside the optical fiber like zigzag that depend on the total internal refraction (TIR) that happen when confinement the light inside optical fiber due to the core has higher refractive index than the cladding.

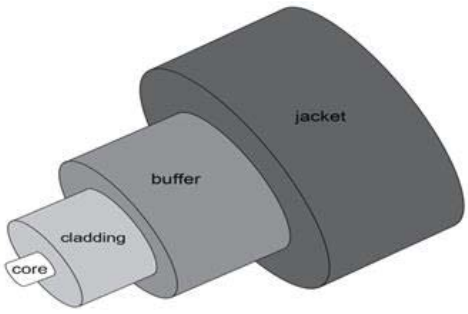


FIGURE 2. Image of optical fiber inner cable

The mechanism of optical fiber sensor consistent form core, cladding and jacket just, the electromagnetic field propagation inside the optical fiber depend on the total internal refraction and this propagation not completely configured inside the optical fiber. The fraction of electromagnetic field escape from core to cladding and penetrate outside of cladding this (polishing area) call evanescent field. This evanescent field will effect on electromagnetic field that propagate inside the optical fiber. The electromagnetic field propagate inside the core and cladding are connect by the conditions of continuity if any effect on the cladding resulting change electromagnetic field [18]. In this work, single mode fiber type (SMF-28) are polished a to create a D-Shaped Fiber as shows an illustration in Figure. 3a. The fabrication of D-Shaped Fiber start by glue optical fiber on microscope glass to hold fiber during the polishing process. The 650 nm red light used during manual polishing process with sand paper have 1200 grit size. There are two step for polishing, first start to connect laser light to pigtail then rubbing fiber by sand paper with direction from front to back unite the red light escape from core to cladding then appear in the polishing surface as show in Figure. 3b. Second, start to connect the 1550 nm laser light to pigtail and connect to the power meter to control the power transmitted loss unite reach to evanescent field. The transmitted power was measure before and after polishing in order to control polishing depth and thus polishing space roughly are 1 cm with the depth of the cladding ore are ~30%of cladding diameter that insure evanescent filed will generate in sensing region[19-22].

FIGURE 3. (a) Side view of D-Shaped Fiber (b) Propagation evanescent field

D-Shaped Fiber Coated with Graphene Oxide (GO)

One drops of Graphene Oxide (GO) with volume 2.6 µL are applied directly onto the microscope glass and D-Shaped Fiber through drop-casting technique using a micropipette[4, 23]. Start dry stage to under surrounding environment condition monitoring by optical microscope. micrograph in Figure.4 shows the coating size remain the same during drying process throughout, thus process take 15 mints to dry it. The drop casting is the process use to coating the D-Shaped Fiber with Graphene Oxides (GO). the 2.6 µL the volume of Graphene Oxide (GO) that apply to Coated D-Shaped Fiber area for 2mm the length of polishing. the thickness of Graphene Oxide (GO) coating was measure by Dektak D150 surface profile ~0.09 µm.

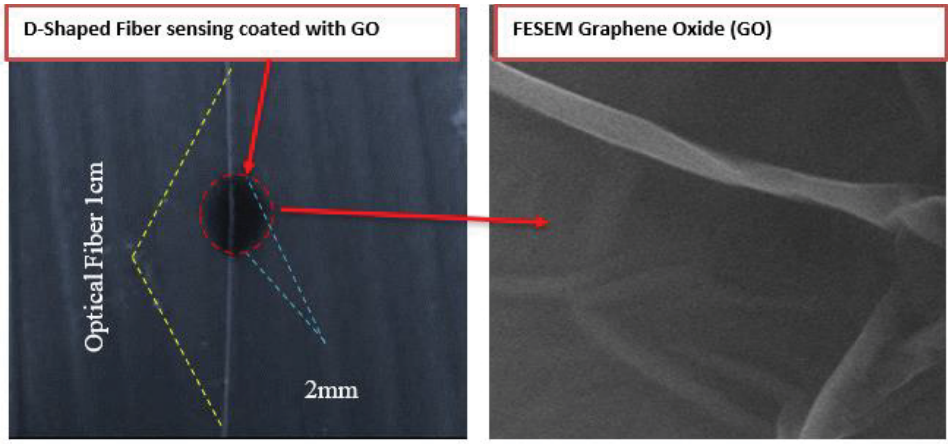


FIGURE 4. Physical view of Graphene Oxides (GO) coated on D-Shaped Fiber

EXPERIMENTAL SET-UP

The D-Shaped Fiber technique was used to setup a mechanism for a proposed sensor and D-fiber experimental setup shown in Figure.5. The (SMF-28) that polished with certain level to expose the Evanescent Field through the optical measurement. This optical fiber fusion with two pigtails with low loss 0.01 dB, these two pigtails one connect to laser light source 1550 nm and the other pigtail connect to power meter (Thorlabs Power meter model PM100 USB). The polarization controller take place to measure the expansion ratio that dependent maximum loss measurement when the polarized control is adjusted. The extension ratio has been measured when incident light passes through for D-Shaped Fiber (without and with) coated that found to be lower than -0.5 dBm and -2.5dBm respectively. The performance of D-Shaped-Fiber measured when transmission power change for different elements using power meter with 7 second interval before applied different elements on the sensing region sensing region (without-GO & with-GO coating) individually.

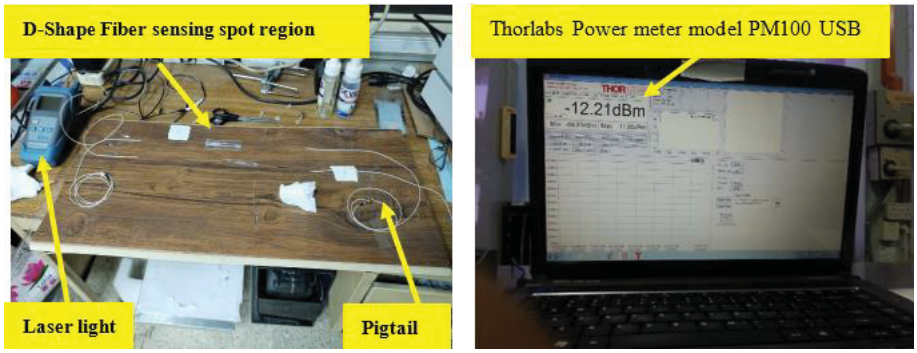


FIGURE 5. Real images of experimental set -up (D-Shaped-Fiber)

RESULTS AND DISCUSSIONS

The FESEM burnishing a standard of the fiber optics. According to our polishing process (see Figure.6), the core sizes still same around 8.2 μm and the cladding is∼ 88 μm.

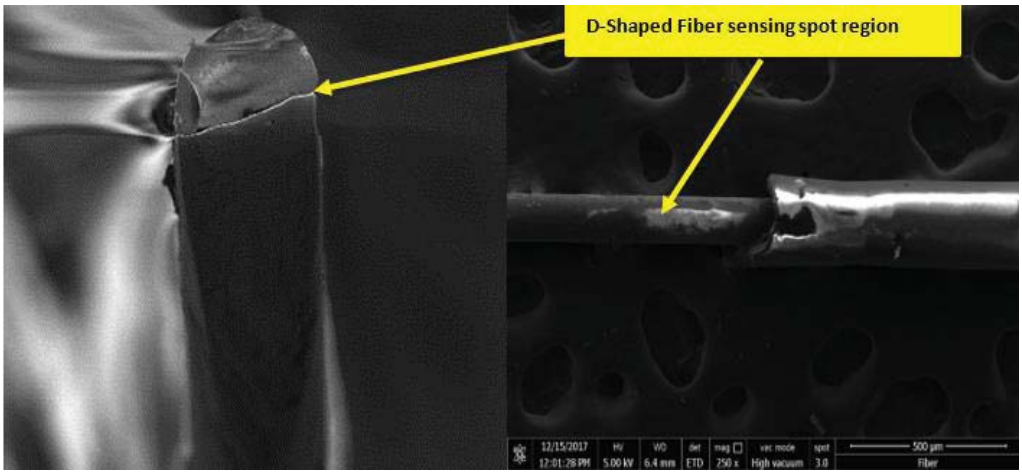


FIGURE 6. FESEM image of polishing a standard fiber

The performance D-Shaped-Fiber sensor tested by applies different elements such as (distilled water, ethanol & human breathing) on sensing region for duration 50 second with 1 second interval.

The response of D-Shaped-Fiber sensor without coated show in Figure 7, increasing in the transmittance power immediately (at7th second) for all elements by ~ (3.5, 2.2&1.3) dB respectively due to change in the refractive index from air (1) to different refractive indexes causing reduce loss power leakage when that covering the sensing region. Table .1 show the values of transmitted power distilled water, ethanol & human breathing respectively as prove in previous studies [7, 14, 17, 19, 24-27].

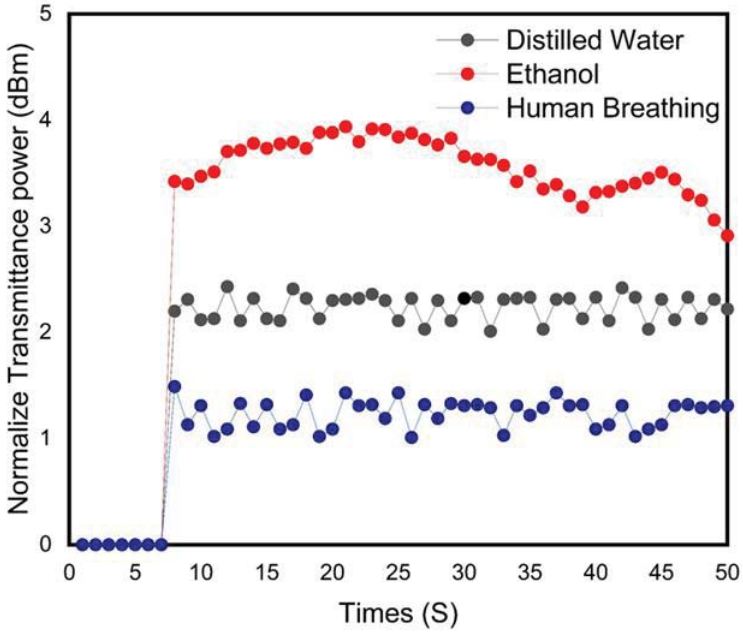


FIGURE 7. The response of D-Shaped Fiber without GO coated for different elements

TABLE 1. Displays D-Shaped Fiber without GO coated response for different elements

Elements	Transmitted Power (dB)
Distilled water	3.5
Ethanol	2.3
Human Breathing at 26c°	1.3

The response of D-Shaped-Fiber sensor with Go coated show in Figure 8, increasing in the transmittance power immediately (at7th second) for all elements by ~ (21.5, 15&9) dB respectively due to due to penetrations of distilled water into Graphene Oxide(GO), the distilled water will effect on dielectrics properties Graphene Oxide (GO) by widening the band gap which reduce the conductivity of Graphene Oxide (GO) and resulting reduce the loss power leakage with no fluctuation as prove in previous studies[7, 14, 17, 19, 24-27].

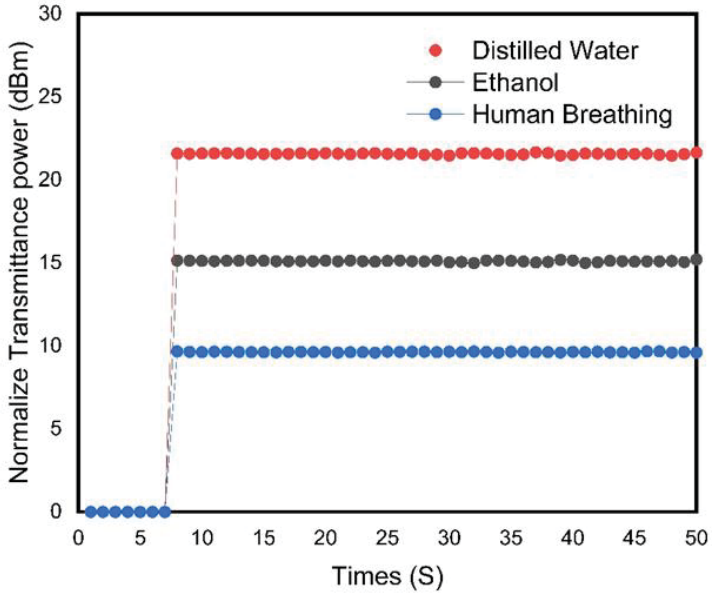


FIGURE 8. The response of D-Shaped Fiber with GO coated for different elements

TABLE 2. Displays D-Shaped Fiber with GO coated response for different elements

Elements	Transmitted Power (dB)
Distilled water	21.5
Ethanol	15
Human Breathing at 26c°	9

D-SHAPED-FIBER MODELING

To investigate the D-shaped fiber optic sensor's performance, we modelled a simulation using the COMSOL Multiphysics Finite Element Method (FEM) tools. Here, we display Maxwell's equations for the situation in which optical fibres have an electromagnetic field and neither a current nor an external electrical charge.

$$\nabla \times E(r,t) + \frac{\partial B(r,t)}{\partial t} = 0 \quad (1)$$
$$\nabla \times H(r,t) + \frac{\partial D(r,t)}{\partial t} = J \quad (2)$$
$$\nabla . D(r,t) = \rho B(r,t) \quad (3)$$
$$\nabla . B(r,t) = 0 \quad (4)$$

The vectors of the electric and magnetic fields, respectively, are denoted by E and H in these equations. An electromagnetic (EM) field is described by these two field vectors. and J are the electric charge and current densities, and they can be thought of as the origins of the fields E and H. D and B are the field's effects on matter and are known as magnetic induction and electric displacement. In terms of electric field waveforms, the Fourier transform is expressed as:

$$\nabla \times (\nabla \times E(r,\omega) - K_0^2[\varepsilon_r'(r,\omega)E(r,\omega)] = 0 \quad (5)$$

Similarity is the magnetic field

$$\nabla \times [\varepsilon_r'(r,\omega)]^{-1} \nabla \times H(r,\omega) - K_0^2 H(r,\omega) = 0 \quad (6)$$

Where $c = \sqrt{\varepsilon_0 \mu_0}$ is the speed of light and $k = \omega c^{-1}$ is defend as mode wave number. A material's refractive index and its angular frequency (Eqs. (5) and (6) determine the electric and magnetic fields, respectively. To conduct an analysis of propagation in optical waveguides, it is crucial to take into account the transmission and reflection of electromagnetic radiation of dielectric surfaces. We can be derived boundary conditions directly from maxwell's equation. In fields of optics, it is a common occurrence for both the surface charge and current density to become negligible. As a result, the magnetic field, the tangential component of the electric field's continuity, the normal component of the electric displacement, and the magnetic induction across the interface dividing the two media all influence the boundary conditions. By reducing the simulation domain into smaller and smaller subdomains to produce a mesh, as shown in Figure. 9, Comsel Multiphysics employs the FEM (Finite Element Method).

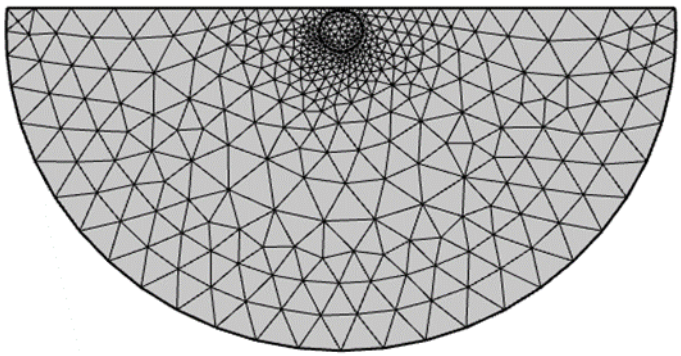


FIGURE 9. Finite element for D-shaped optical fiber using COMSOL Multiphysics.

The "mode Analyses" tool allowed us to see the intensity of the electric field in an optical fibre with a D-Shaped-Fiber. Figure 10 shows the propagation mode of an incident energy incident as a function of wavelength and the electrical field of a d-shaped fiber. The light spectrum that was used ranged from 1350 to 1550 nm[6, 14, 25]. No source conditions are required for mode analysis because it is an eigenvalue investigation. The geometry of the modes as well as their damping and leaking can be affected by the boundary conditions, thus it is important to specify them correctly.

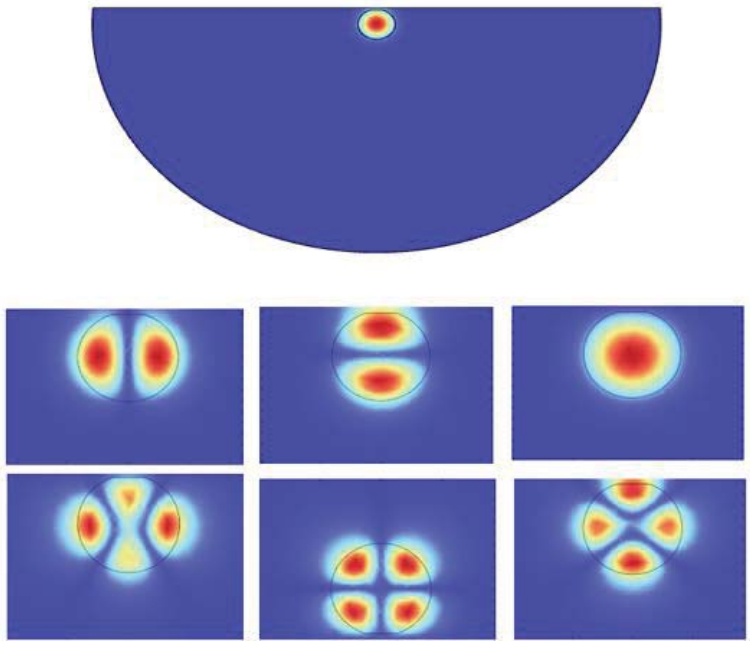


FIGURE 10. Electric field mode distribution near the core of SMF fiber

CONCLUSION

These results have been done under a 26co room-temperature with two tested. The first testing of D-Shaped Fiber sensor shows fast response and excellent sensitivity to different elements due to mechanism of change refractive index with fluctuation. The second testing of D-Shaped Fiber coated with thin layer of Graphene Oxide (GO) shows fast response, stable measurements (without fluctuation) and excellent sensitivity to water contents in the elements only. In concluded that thin layer of Graphene Oxide (GO) enhance the sensitivity and stable the measurement and made D-Shaped- Fiber sensitive to water content only.

REFERENCES

1. W. H. Lim, Y. K. Yap, W. Y. Chong, and H. Ahmad, "All-optical graphene oxide humidity sensors," *Sensors,* vol. 14, no. 12, pp. 24329-24337, 2014.
2. Y. Du *et al.*, "Influence of hybrid graphene oxide/carbon nanotubes on the mechanical properties and microstructure of magnesium potassium phosphate cement paste," *Construction and Building Materials,* vol. 260, p. 120449, 2020.
3. U. Mogera, A. A. Sagade, S. J. George, and G. U. Kulkarni, "Ultrafast response humidity sensor using supramolecular nanofibre and its application in monitoring breath humidity and flow," *Scientific reports,* vol. 4, p. 4103, 2014.
4. A. A. Chan, A. A. A. Raman, W. L. Chong, and A. Buthiyappan, "Graphene oxide impregnated activated carbon derived from coconut shell through hydrothermal carbonization for cationic dye removal: Adsorptive performance, kinetics, and chemistry of interaction," *Journal of Cleaner Production,* p. 140655, 2024.
5. T. Chen, C. Liao, D. Wang, and Y. Wang, "Passively mode-locked fiber laser by using monolayer chemical vapor deposition of graphene on D-shaped fiber," *Applied optics,* vol. 53, no. 13, pp. 2828-2832, 2014.
6. N. Shanmuga Vadivu *et al.*, "Graphene oxide coated side polished surface plasmon resonance optical fibre sensor with varying polishing losses," *Optical and Quantum Electronics,* vol. 51, pp. 1-12, 2019.

7. A.-A. W. Al-Isawi *et al.*, "Investigation the nonlinear optical properties of silver nanoparticles using femtosecond laser," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 871, no. 1, p. 012065: IOP Publishing.
8. O. M. Makki, H. M. Al-Mutairee, and M. H. Mezher, "Survey the Behaviour of Impacted Shallow and Deep Beams," *Journal of Engineering Science & Technology Review,* vol. 16, no. 1, 2023.
9. E. Oner *et al.*, "Investigation of berberine and its derivatives in Sars Cov-2 main protease structure by molecular docking, PROTOX-II and ADMET methods: in machine learning and in silico study," *Journal of Biomolecular Structure and Dynamics,* pp. 1-16, 2022.
10. X. Liu *et al.*, "Graphene-clad microfibre saturable absorber for ultrafast fibre lasers," *Scientific reports,* vol. 6, no. 1, p. 26024, 2016.
11. M. K. Salman, M. M. Karhib, K. A. Mohammed, M. Mezher, S. A. Jasim, and A. J. AlRubaie, "Preparing and studying some physical properties of TiO2-PVA hybrid nanocomposite material for possible environmental applications," in *AIP Conference Proceedings*, 2023, vol. 2839, no. 1: AIP Publishing.
12. L. Staudenmaier, "Verfahren zur darstellung der graphitsäure," *European Journal of Inorganic Chemistry,* vol. 31, no. 2, pp. 1481-1487, 1898.
13. B. C. Brodie, "On the atomic weight of graphite," *Philosophical Transactions of the Royal Society of London,* vol. 149, pp. 249-259, 1859.
14. S. Karthikeyan, M. H. Mezher, F. Ibrahim, D. Vigneswaran, I. S. Amiri, and R. Zakaria, "Graphene oxide-based optical waveguide for moisture sensing in transformer oil," *Photonics and Nanostructures-Fundamentals and Applications,* vol. 36, p. 100727, 2019.
15. N. S. Vadivu *et al.*, "Graphene oxide coated side polished surface plasmon resonance optical fibre sensor with varying polishing losses," *Optical and Quantum Electronics,* vol. 51, no. 11, pp. 1-12, 2019.
16. Y. Zheng, B. Cheng, W. You, J. Yu, and W. Ho, "3D hierarchical graphene oxide-NiFe LDH composite with enhanced adsorption affinity to Congo red, methyl orange and Cr (VI) ions," *Journal of hazardous materials,* vol. 369, pp. 214-225, 2019.
17. M. H. Mezher, "Fabrication and Characterization of Metal Nanostructures and Graphene Nanolayers and their Application in Optical Sensing," University of Malaya (Malaysia), 2018.
18. D. K. Mahanta and S. Laskar, "Transformer Condition Monitoring using Fiber Optic Sensors: A Review," *ADBU Journal of Engineering Technology,* vol. 4, 2016.
19. R. Zakaria, M. H. Mezher, A. Z. G. Zahid, N. S. Rohizat, S. K. Patel, and I. S. Amiri, "Nonlinear studies of graphene oxide and its application to moisture detection in transformer oil using D-shaped optical fibre," *Journal of Modern Optics,* vol. 67, no. 7, pp. 619-627, 2020.
20. A. Patnaik, K. Senthilnathan, and R. Jha, "Graphene-based conducting metal oxide coated D-shaped optical fiber SPR sensor," *IEEE Photonics Technology Letters,* vol. 27, no. 23, pp. 2437-2440, 2015.
21. Y.-T. Luo, H.-B. Wang, G.-M. Ma, H.-T. Song, C. Li, and J. Jiang, "Research on high sensitive D-shaped FBG hydrogen sensors in power transformer oil," *Sensors,* vol. 16, no. 10, p. 1641, 2016.
22. Y. Dong *et al.*, "Magnetic field and temperature sensor based on D-shaped fiber modal interferometer and magnetic fluid," *Optics & Laser Technology,* vol. 107, pp. 169-173, 2018.
23. N. A. a. M. Zainuddin, A. A. S. Falah, M. H. Mokti, R. Zakaria, Z. Jusoh, and W. R. Wong, "Investigation on the Effect of Fluorescence Material based on D-Shaped Hollow Core Photonic Crystal Fiber," in *Journal of Physics: Conference Series*, 2023, vol. 2627, no. 1, p. 012012: IOP Publishing.
24. N. Shanmuga Vadivu *et al.*, "Graphene oxide coated side polished surface plasmon resonance optical fibre sensor with varying polishing losses," *Optical and Quantum Electronics,* vol. 51, no. 11, pp. 1-12, 2019.
25. S. F. A. Z. Yusoff *et al.*, "Detection of moisture content in transformer oil using platinum coated on D-shaped optical fiber," *Optical Fiber Technology,* vol. 45, pp. 115-121, 2018.
26. M. Mezher, W. Chong, and R. Zakaria, "Third-order optical nonlinearity studies of bilayer Au/Ag metallic films," *Laser Physics,* vol. 26, no. 5, p. 055401, 2016.
27. M. Mezher, W. Chong, and R. Zakaria, "Nonlinear optical response of platinum nanostructures and application for water detection in transformer oil," *RSC Advances,* vol. 6, no. 106, pp. 104624-104631, 2016.