Article

JOURNAL OF UNIVERSITY OF BABYLON
For Pure and Applied Sciences (JUBPAS)

Vol.32; No.4.| 2024

Design Study of an Optical Sensor Based on Optical Fiber with Graphene Oxide

Shahad H. Kadhum[1*] **M.H.Mezher[2]**

[1]Department of Physics, College of Education for Pure Science, University of Babylon, Babylon, Iraq
[2] Department of Electronics and Communication, College of Engineering, University of Al-Qadisiyah, Iraq

Corresponding author. E-mail: pure.shahad.ali@uobabylon.edu.iq

Accepted:	**27/10/2024**		**Published:**	**31/12/2024**

ABSTRACT

Background

The Fabrication an optical sensing devices base on different polishing losses (0.37, 0.68& 1.28dBm) and integrated by Graphene Oxide (GO). The sides polished of single mode Fiber used to resemble D- shape Fiber with area ($2mm^2$) by removing outer jacket and cladding to generate an evanescent field on polishing area that used as optical sensing region. The optical sensing devices integrated by coat D- shape fiber with few layers (~22-layers) of Graphene Oxide (GO) with a thickness of ~ 0.09µm. The Performance D-Shaped Fiber has been done experiment by two test. First test of D-Shaped Fiber without coat done by applied acetone on polished region that show increase in transmitted power. Second test of D-Shape Fiber coated thin layer of graphene oxide (GO) that show increase in transmitted power, thus open promising way to be applied in many applications such as biomedical sensor, humidity sensor, temperature sensor.

Materials and Methods: D- shape Fiber with different polishing losses and integrated Graphene Oxide (GO)

Results: testing of Acetone by applied on polishing area that shows an increase in transmitting power Thus, transmitting power increased immediately due to a change in the refractive index from dry air to Acetone, which caused decreasing in power leakage that covered the sensing region.

Conclusion: The testing D-Shape Fiber that coated with GO shows enhancement, fast response, highly sensitivity and stable measurement (without fluctuation) to acetone camper to D-Shape Fiber only.

Key words: D-Shaped Fiber; Graphene Oxide (GO); Sensor; Single mode fiber; different polishing losses.

مجلة جامعة بابل للعلوم الصرفة والتطبيقية

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

INTRODUCTION

The single mode fiber (SMF-28) consist from core and cladding, the dimension are measures as core 8 µm and cladding 125 µm. The core has higher refractive index than cladding, these different in refractive index lead confinement light inside the core. The optical fiber sensor have unique properties like immune to electromagnetic field, radio frequency and easy adapt to various parameter to sensing [1]. The advantage of using an optical sensor represent by D-shape fiber to generate an evanescent field that can be exposed surrounding fiber to create the sensing region [2-5]. 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 Graphene Oxide (GO) with few layers has increases the interest of different application due to the Graphene properties and attracted deal due to electrical and mechanical properties and high levels of thermal conductivity, low thermal noise where the material shows its inherent[6, 7]. 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[8]. The demonstrated that potential applications of single molecule of Graphene have excellent optical absorption, highly sensitive and selective detection properties [9-15]. 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 [9, 16-18]. The optical sensor have unique properties such as immune to electromagnetic field, radio frequency and easy adapt to various parameter to sensing [1-5, 19-22]. The aim of study, use to polishing single mode fiber with different polishing losses (0.37, 0.68& 1.28 dBm) to create D-Shape Fiber that generate an evanescent field on sensing region. This optical sensor integrates by Graphene Oxide (GO) coating on sensing region and performance of this study by drop acetone on sensing region

MATERIALS AND METHODS:

Fabrication an Optical Sensor: Preparation of Graphene Oxide (GO)

The several methods that produce the Graphene Oxide solutions (GO) such as hummers methods Brodie’s method and Staudenmaier’s method [23-26]. The modification in hummer methods to produce Graphene Oxide (GO) solution presenting for this work and synthesis process is explain as follow: [7, 27-29]. 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 color 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 show in Figure (1)

ISSN: 2312-8135 | Print ISSN: 1992-0652

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

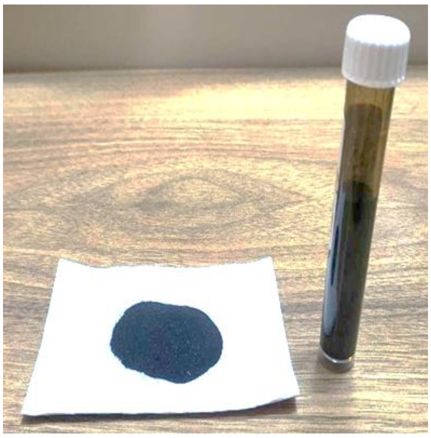

FIGURE1. Graphene Oxide (GO) powder and liquids.

Optical waveguides sensor

The single mode fiber as show in Figure 2, 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. The sensing mechanism of the proposed sensor has been achieving when electromagnetic field propagation inside the optical fiber that 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. The electromagnetic field propagate inside the core and cladding are connect by the conditions of continuity if any effect on the cladding resulting change electro-magnic field and the sensitive to environment surround it [30, 31].

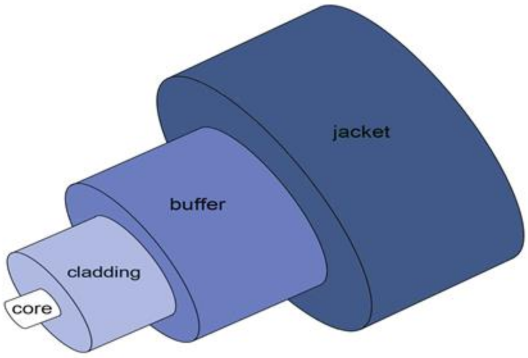

FIGURE 2. Single mode fiber in the current study.

Article

JOURNAL OF UNIVERSITY OF BABYLON
For Pure and Applied Sciences (JUBPAS)

Vol.32; No.4.| 2024

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

The Side POLISH of D-Shape Fiber

The Non-circular symmetry characterizes D-shaped fiber, its cross-sectional shape is similar to D-shape fiber may be produced by polishing the side of a single mode fiber to expose the fiber core and remove cladding as show in Figure 3.

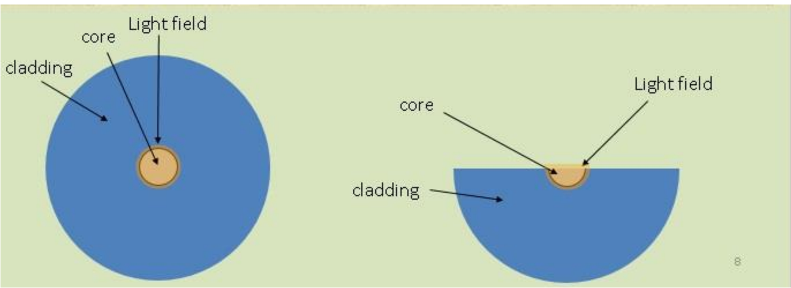

FIGURE3. Side view of D-Shape Fiber in the current study.

The depth of standard single mode fibers is with different polishing losses (0.37, 0.68& 1.28 dBm). The initial step in polishing is splicing two terminals of a single mode fiber to the fiber pigtails. One is linked to an optical power meter, and other to a red laser source with a wavelength of 650 nm. The fiber was adhered to the glass slide during the polishing process using a microscope's glass slide as a fiber holder. To take off the cladding, 1200 grit sandpaper was employed. The first step in this hand polishing procedure is to rub the fiber with sand paper back and forth until red light that is propagating through the fiber core shows on the polishing surface as shown in the below Figure4.

FIGURE4. Evanescent field Propagation in the current study.

D-Shape Fiber Coating with Graphene Oxide (GO)

The drop-casting technique has been used to coat Graphene Oxide (GO) onto D-Shape Fiber by micropipette as show in Figure 5. The 1μL the volume of Graphene Oxide (GO) that apply to D-Shape Fiber with area for 2mm^2 of polishing length and drying process takes 15 mints to dry. The thickness of Graphene Oxide (GO) was measure by Dektak D150 surface profile as result ~0.09 μm

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

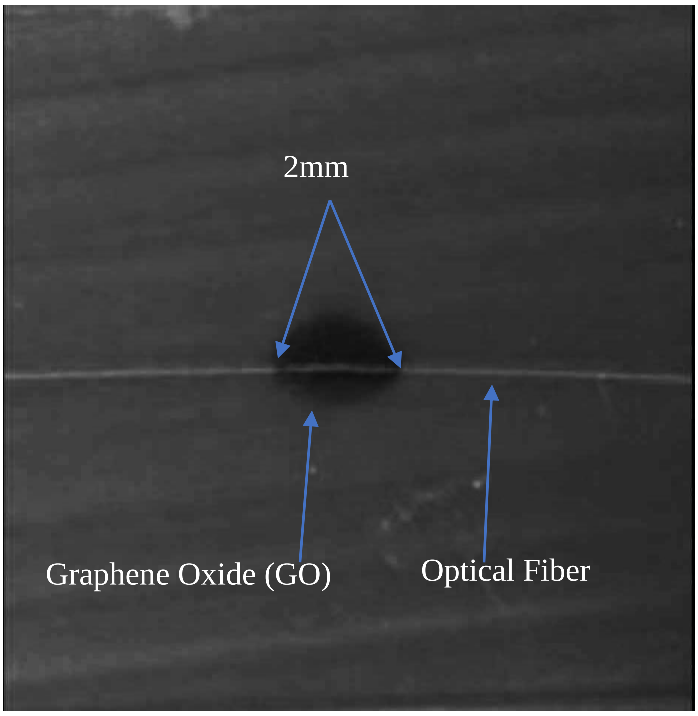

FIGURE 5. Physical view of Graphene Oxides (GO) coated on D-Shape fiber [32].

Optical Sensing Device

Optical sensors experimental setup shown in Figure 6. This optical fiber fusion with two pigtails has low loss 0.01 dB, these two pigtails one connects to laser light source 1550 nm and the other pigtail connect to power meter (Thorlabs Power meter model PM100 USB). The sensor performance done by applied acetone on the sensing region (without-GO coating) individually.

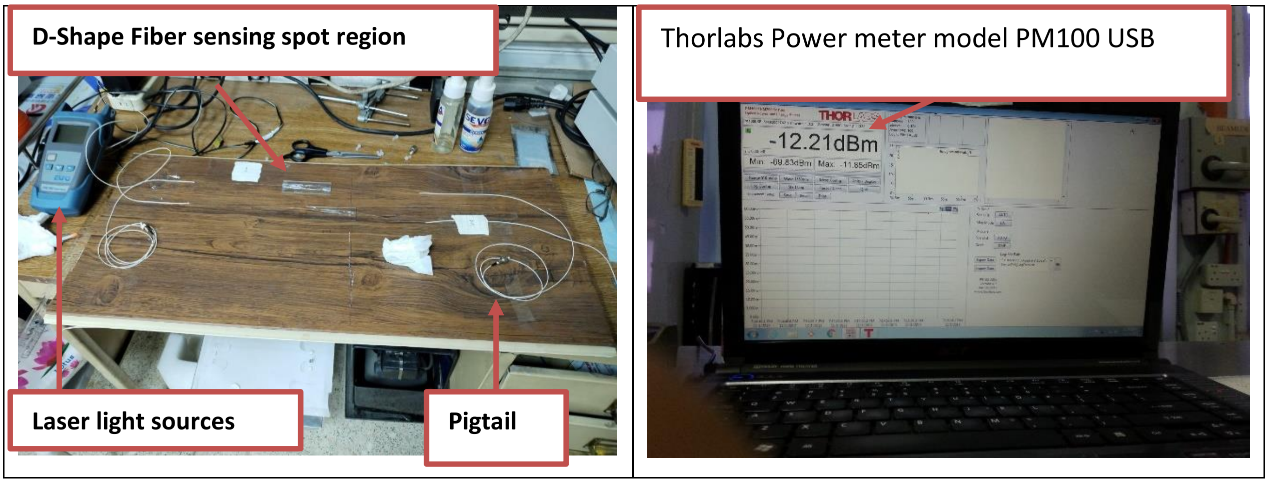

FIGURE.6 Physical view of experimental setup of D-Shape Fiber in the current study.

JOURNAL OF UNIVERSITY OF BABYLON
For Pure and Applied Sciences (JUBPAS)
Vol.32; No.4.| 2024
ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com
مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

RESULTS AND DISCUSSION

Field Emission Scanning Electron Microscopy (FESEM)

The microscope type Hitachi SU8000 (Tokyo, japan) performed by field emission scanning microscopy (FESEM) to insure the polishing area represent D-Shape Fiber as show in Figure 7.

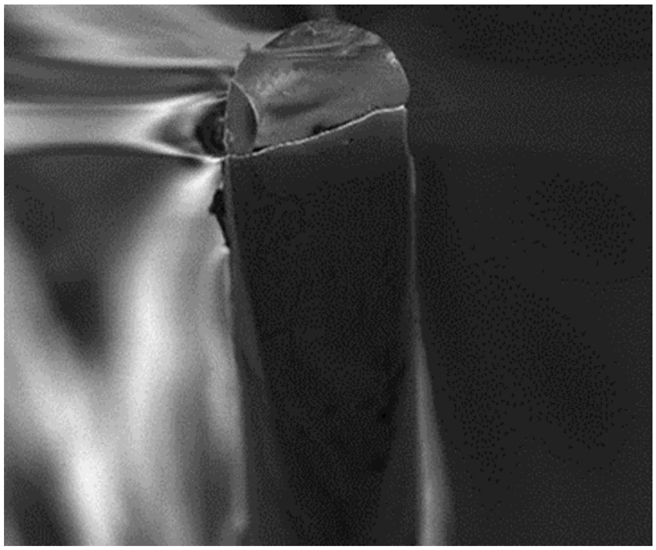

FIGURE.7 FESEM image of D-shape fiber [32].

The performance D-Shaped Fiber without coat test by applied acetone on sensing region for 35 second duration with 5 second interval. The power polishing leakage (0.37, 0.68 & 1.28dBm) represent First, second and third in D-shape fiber respectively. The three samples (S1, S2 and S3) represents the response to power polishing leakage in D-shape Fiber as shown in Table 1.

Table1: Show the response of the D-shape fiber without coat to Acetone

Polishing power loss (leakages) of D-shape fiber	Acetone samples	Transmittance Power
0.37dBm	S1	0.02dBm
0.68dBm	S2	0.11dBm
1.28dBm	S3	0.29dBm

The performance test of D-Shape Fiber without coating shown in Figure 8. First, (S1) is the sample response to acetone when applied on sensing region that shows an increase in transmitting power by (~0.02 dBm) immediately at 5 s. Second, (S2) is the sample response to acetone when applied on sensing region that shows an increase in transmitting power by (~0.11 dBm) immediately at 5 s. Third, (S3) is the sample response to acetone when applied on sensing region that shows an increase in transmitting power by (~0.92 dBm) immediately at 5

s. Thus, the transmitting power increased immediately (at 5 seconds) due to a change in the refractive index from dry air to acetone, which caused decreasing in power leakage that covered the sensing region.

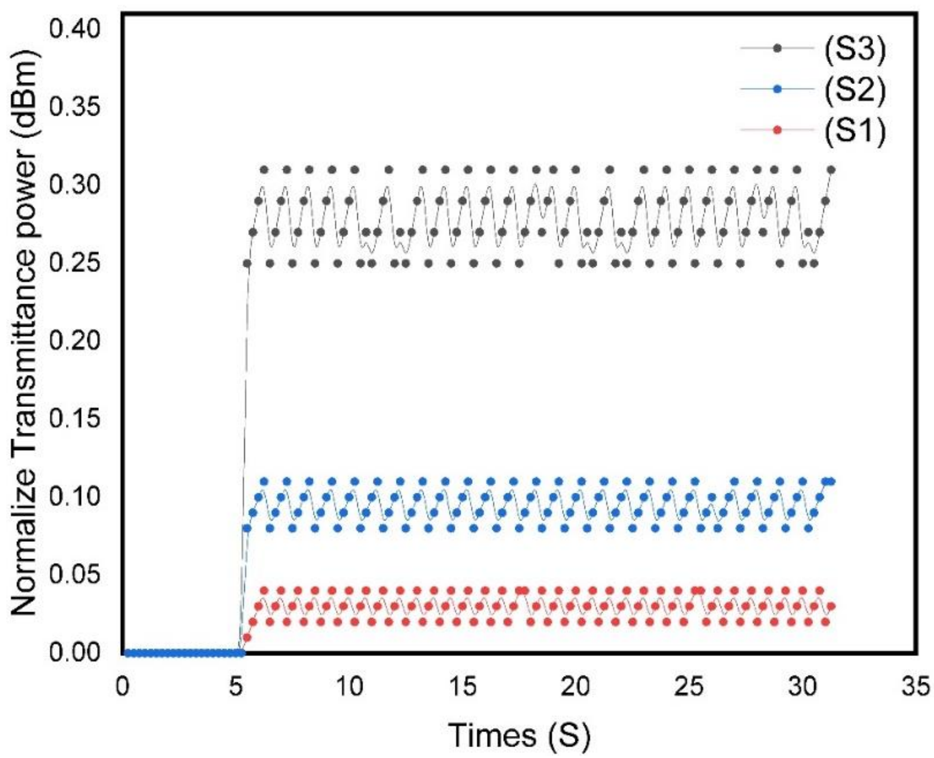

FIGURE 8: The response of transmittance power to acetone using D-shape fiber without coating.

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com | ISSN: 2312-8135 | Print ISSN: 1992-0652

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

The Figure 9 show linear relationship between change in the transmittance power and different power polishing loss (leakage). The sensitivity of purpose sensor for different polishing loss is calculated 0.3112 dBm/dBm of sensing acetone.

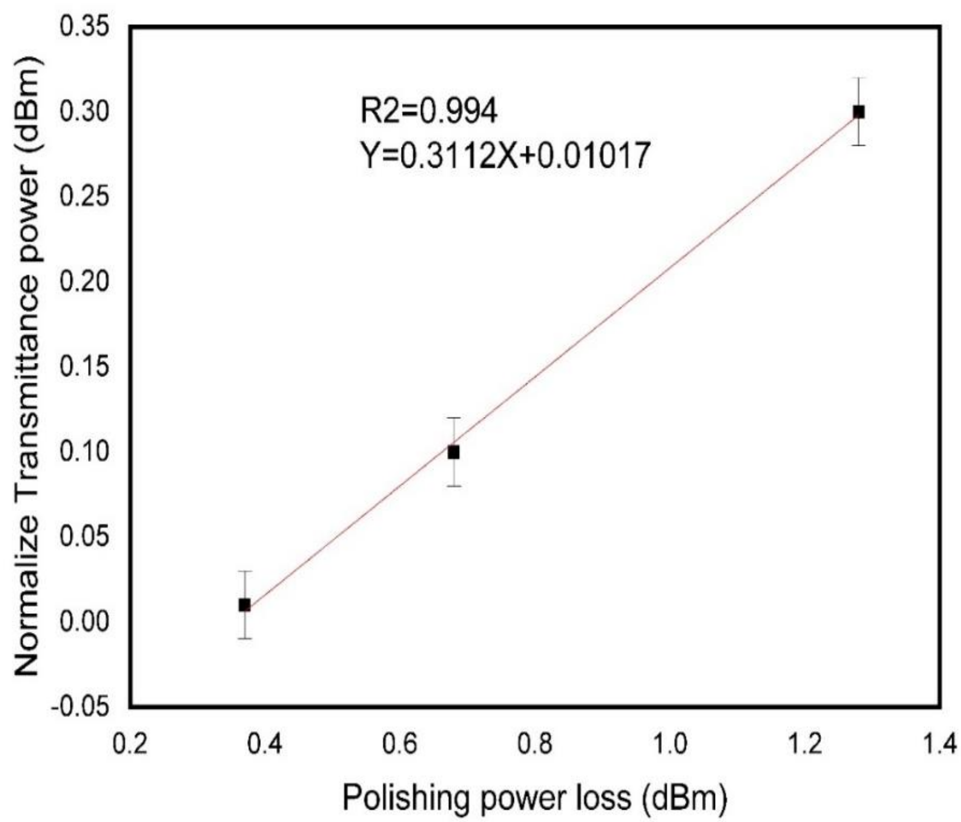

FIGURE 9: The sensitivity of linear relationship between transmittance power and different polishing leakage.

The performance D-Shaped Fiber with Graphene Oxide (GO) coat test by applied acetone on sensing region for 35 second duration with 5 second interval. The power polishing leakage (0.37, 0.68 & 1.28dBm) represent fourth, fifth and six in D-shape fiber respectively. The three samples (S4, S5 and S6) represents the response to power polishing leakage in D-shape Fiber as shown in Table2.

Table2: Show the response of the D-shape fiber with Graphene Oxide (GO) coat to Acetone.

Polishing power loss(leakages)D-fiber	Acetone samples	Transmittance Power
0.37dBm	S4	0.501dBm
0.68dBm	S5	0.612dBm

The performance test of D-Shape Fiber with Graphene Oxide (GO) coat shown in Figure 10. Fourth, (S4) is the sample response to acetone when applied on sensing region that shows an increase in transmitting power by (~0.501 dBm) immediately at 5 s. Fifth, (S5) is the sample response to acetone when applied on sensing region that shows an increase in transmitting power by (~0.612 dBm) immediately at 5 s. Sixth (S6) is the sample response to acetone when applied on sensing region that shows an increase in transmitting power by (~0.901 dBm) immediately at 5 s. Thus, the transmitting power increases immediately (at 5 seconds) due to reduced power leakage. penetrate the Water content in acetone inside the Graphene Oxide (GO), resulting in a decrease in conductivity by further widening the band gap, which results in a decreased transmission loss of the GO-coated D-shaped fiber.

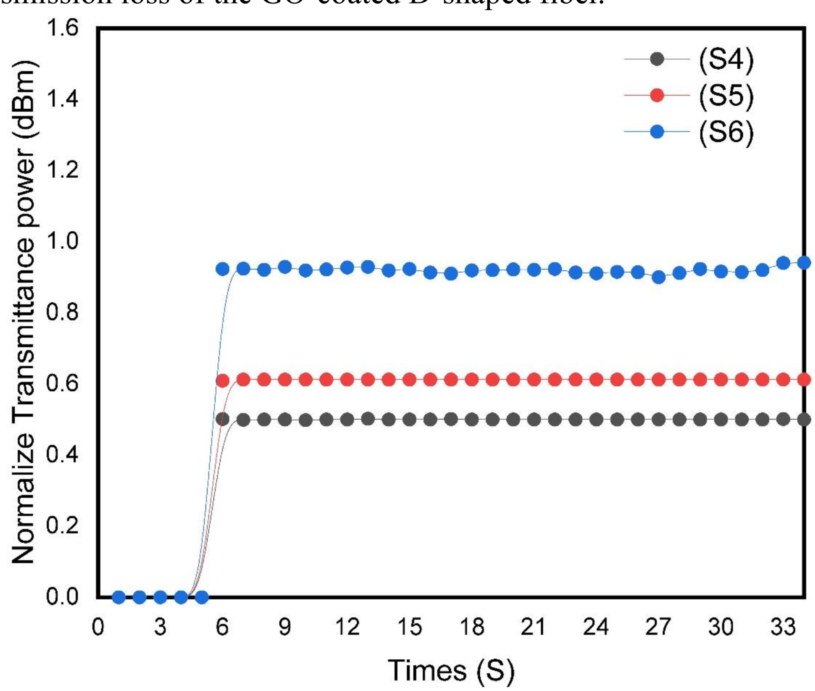

FIGURE 10: The response of transmittance power to acetone using D-shape fiber with coating.

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

The Figure 11 show linear relationship between change in the transmittance power and different power polishing loss (leakage). The sensitivity of purpose sensor for different polishing loss is calculated 0.445 dBm/dBm of sensing acetone.

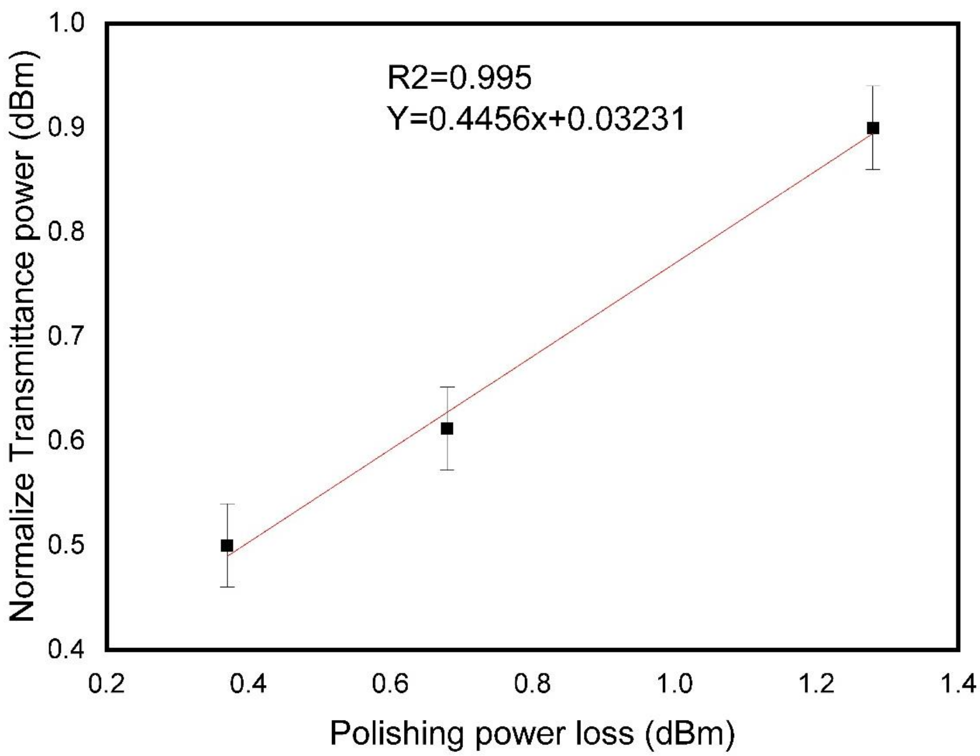

FIGURE 11: The sensitivity of linear relationship between transmitted power and different polishing leakage.

CONCLUSIONS

These results have been done under a room-temperature with two performance tested. The first tested of D-Shape Fiber without coating shows fast response, excellent sensitivity with fluctuation to acetone. The second tested D-Shape Fiber coated with thin layers of GO shows enhancement, fast response, highly sensitivity and stable measurement (without fluctuation). In concluded, thin layer of Graphene Oxide (GO) make D-Shaped-Fiber using in many applications such as biomedical sensor, humidity sensor, temperature sensor and biochemical sensor.

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

Conflict of interests.

There are non-conflicts of interest.

References

[1] T. Bosworth, S. Setford, R. Heywood, and S. Saini, "Pulsed amperometric detection of furan compounds in transformer oil," *Analytica chimica acta,* vol. 450, no. 1, pp. 253-261, 2001.
[2] 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.
[3] Q. Bao *et al.*, "Broadband graphene polarizer," *Nature Photonics,* vol. 5, no. 7, pp. 411-415, 2011.
[4] M. Liu *et al.*, "A graphene-based broadband optical modulator," *Nature,* vol. 474, no. 7349, pp. 64-67, 2011.
[5] A. Gorbach, A. Marini, and D. Skryabin, "Graphene-clad tapered fiber: effective nonlinearity and propagation losses," *Optics letters,* vol. 38, no. 24, pp. 5244-5247, 2013.
[6] F. Schedin *et al.*, "Detection of individual gas molecules adsorbed on graphene," *Nature materials,* vol. 6, no. 9, pp. 652-655, 2007.
[7] R. Zakaria, "GRAPHENE MALAYSIA 2017."
[8] H. M. Mezher, "Fabrication and characterization of metal nanostructures and graphene nanolayers and their application in optical sensing/Mezher H Mezher," University of Malaya, 2018.
[9] R. Nair, H. Wu, P. Jayaram, I. Grigorieva, and A. Geim, "Unimpeded permeation of water through helium-leak–tight graphene-based membranes," *Science,* vol. 335, no. 6067, pp. 442-444, 2012.
[10] K. S. Novoselov *et al.*, "Electric field effect in atomically thin carbon films," *science,* vol. 306, no. 5696, pp. 666-669, 2004.
[11] A. K. Geim and K. S. Novoselov, "The rise of graphene," *Nature materials,* vol. 6, no. 3, pp. 183-191, 2007.
[12] H. Bi *et al.*, "Ultrahigh humidity sensitivity of graphene oxide," *Scientific reports,* vol. 3, 2013.
[13] 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.
[14] Y. Yao, X. Chen, J. Zhu, B. Zeng, Z. Wu, and X. Li, "The effect of ambient humidity on the electrical properties of graphene oxide films," *Nanoscale research letters,* vol. 7, no. 1, p. 1, 2012.
[15] D.-W. Wang, A. Du, E. Taran, G. Q. M. Lu, and I. R. Gentle, "A water-dielectric capacitor using hydrated graphene oxide film," *Journal of Materials Chemistry,* vol. 22, no. 39, pp. 21085-21091, 2012.
[16] W. Lim *et al.*, "Graphene oxide-based waveguide polariser: From thin film to quasi-bulk," *Optics express,* vol. 22, no. 9, pp. 11090-11098, 2014.
[17] 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.
[18] M. A. A. Chabuk and M. M. Al Ibraheemi, "Performance improvement of OFDM system based on reed-solomon encoder and block interleaver in fading channel," in *AIP Conference Proceedings*, 2023, vol. 2787, no. 1: AIP Publishing.

[19] 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.
[20] 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.
[21] 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.
[22] 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.
[23] H. N. Ming, "Simple room-temperature preparation of high-yield large-area graphene oxide," *International journal of nanomedicine,* vol. 6, 2010.
[24] W. S. Hummers Jr and R. E. Offeman, "Preparation of graphitic oxide," *Journal of the American Chemical Society,* vol. 80, no. 6, pp. 1339-1339, 1958.
[25] L. Staudenmaier, "Verfahren zur darstellung der graphitsäure," *European Journal of Inorganic Chemistry,* vol. 31, no. 2, pp. 1481-1487, 1898.
[26] B. C. Brodie, "On the atomic weight of graphite," *Philosophical Transactions of the Royal Society of London,* vol. 149, pp. 249-259, 1859.
[27] D. C. Marcano *et al.*, "Improved synthesis of graphene oxide," 2010.
[28] 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.
[29] 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.
[30] D. K. Mahanta and S. Laskar, "Transformer Condition Monitoring using Fiber Optic Sensors: A Review," *ADBU Journal of Engineering Technology,* vol. 4, 2016.
[31] C. Langhammer, Z. Yuan, I. Zorić, and B. Kasemo, "Plasmonic properties of supported Pt and Pd nanostructures," *Nano letters,* vol. 6, no. 4, pp. 833-838, 2006.
[32] 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.

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com | ISSN: 2312-8135 | Print ISSN: 1992-0652

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

ISSN: 2312-8135 | Print ISSN: 1992-0652

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

الخلاصة

المقدمة: تعتمد صناعة أجهزة الاستشعار الضوئية على خسائر تلميع مختلفة (0.37 و0.68 و1.28 دي سيبل) ومتكاملة بأكسيد الجرافين (GO). يتم تلميع جوانب الألياف أحادية الوضع المستخدمة لتشبه الألياف على شكل D بمساحة (2 مم 2) عن طريق إزالة الغلاف الخارجي والكسوة لتوليد مجال متلاشي على منطقة التلميع المستخدمة كمنطقة استشعار ضوئية. يتم دمج أجهزة الاستشعار الضوئية عن طريق طلاء الألياف على شكل D بطبقات قليلة (~ 22 طبقة) من أكسيد الجرافين (GO بسمك ~ 0.09 مايكرومتر . تم إجراء تجربة أداء الألياف على شكل D من خلال اختبارين. الاختبار الأول للألياف على شكل D بدون طلاء تم إجراؤه عن طريق وضع الأسيتون على المنطقة المصقولة التي تظهر زيادة في الطاقة المنقولة. الاختبار الثاني للألياف على شكل D المغطاة بطبقة رقيقة من أكسيد الجرافين (GO والتي تظهر زيادة في الطاقة المنقولة، وبالتالي فتح طريق واعد للتطبيق في العديد من التطبيقات مثل المستشعرات الطبية الحيوية ومستشعر الرطوبة ومستشعر درجة الحرارة.

طرق العمل: ألياف على شكل حرف D مع خسائر تلميع مختلفة وأكسيد الجرافين المتكامل.

الاستنتاجات: أظهرت الألياف على شكل D التي تم اختبارها والمغطاة بـ GO تحسنًا واستجابة سريعة وحساسية عالية وقياسًا مستقرًا (بدون تقلب) لمعسكر الأسيتون لألياف على شكل D فقط