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Detection of alcohol concentration level in sanitizer using PMMA/PVA coated glass substrate

***Abstract**. A proposed sensor detecting alcohol concentrations level in sanitizer is fabricated by employing Polymethyl Methacrylate (PMMA) and Polyvinyl alcohol (PVA) coated glass substrate as a sensing platform. The platform is integrated with Arduino Nano as a data acquisation in order to realise the biosensor. The sensor module was aligned with a green light-emitting diode and photodetector via 3D printing based setup. Light leakage through the glass substrate affects forward and backward scattering when exposed to variation of alcohol content in sanitizer. The proposed biosensor is capable to detect alcohol in sanitizers with 60%–80% concentrations. It produced exceptional sensing performances results in term of sensitivity, linearity and stability. In terms of sensitivity and linearity, PMMA-coated glass substrate outperforms PVA by 6% and 2% improvement respectively. Henceworth, the proposed sensor features low production costs, ease of use, and stability which show a good potential as alcohol sensor.*

***Streszczenie.** Proponowany poziom stężenia alkoholu wykrywający alkohol jest wytwarzany przez zastosowanie metakrylanu polimetylowego (PMMA) i alkoholu poliwinylowego (PVA), jako platforma wykrywająca. Platforma jest zintegrowana z Arduino Nano jako pozyskiwanie danych w celu zrealizowania bioczujnika. Moduł czujnika został wyrównany z diodą zieloną i fotodetektorem emitującym światło za pomocą konfiguracji opartej na druku 3D. Wyciek światła przez szklany podłoże wpływa na rozpraszanie do przodu i do tyłu po wystawieniu na zmienność zawartości alkoholu w środku dezynfekującego. Proponowany bioczujnik jest w stanie wykrywać alkohol w środkach dezynfekujących ze stężeniami 60–80%. Wytworzył wyjątkowe wyniki wykrywania, powodując termin czułości, liniowości i stabilności. Pod względem czułości i liniowości, szklany podłoże pokryte PMMA przewyższa PVA odpowiednio o 6% i 2% poprawy. Stąd proponowany czujnik ma niskie koszty produkcji, łatwość użycia i stabilność, które wykazują dobry potencjał jako czujnik alkoholu. (**Wykrywanie poziomu stężenia alkoholu w środku odkażającym przy użyciu podłoża szklanego pokrytego PMMA/PVA**)*

Keywords: PMMA, PVA, glass substrate, alcohol
Słowa kluczowe: PMMA, PVA, podłoże szklane, alkohol

Introduction

Hand hygiene is the most efficient method to eliminate germs and bacteria for maintaining personal cleanliness and good health. Furthermore, with recent COVID-19 diseases, personal hygiene become more important and effective infection control measures to prevent the spread of COVID-19 is crucial [1]. To overcome these hurdles, waterless alcohol-based hand sanitizers have been invented to be more effective than soap-and-water handwashing. There are generally 60% to 75% ethanol or isopropanol contain in sanitizer since they are one of the most efficient antimicrobial agents for lowering the number of viable germs on the hands, especially under artificial fingernails. Commonly hand sanitizers contain 60% of alcohol concentrations or higher. However, the used of alcohol-based sanitizer could be quite harmful to several people who experienced eczema or sensitive skin if the alcohol content is too high. They could experience inflammation on their skins if the sanitizer has approximately 75% of alcohol content [2].

Hence, a device that capable to detect the alcohol concentration level in sanitizer is crucial to those who have an allergy reaction to excessive alcohol level. The device was developed by utilising commercial light-emitting diode (LED), Polymethyl Methacrylate (PMMA), and Polyvinyl alcohol (PVA) coated glass substrates that serve as sensing elements and LDRs to detect dispersed light from the LEDs [3-5]. Both coating material is made from polymer and it can increase the sensing response for the alcohol detection [6]. A glass substrate measuring 25mm x 22mm was used for this biosensor device in order to achieve a higher output voltage. Based on previous studies, green LEDs were chosen as the light source for the biosensor system [3]. An Arduino platform is used for calibration and analyzing the voltage at the output of a circuit [7]. The proposed sensor would react with PMMA and PVA as the coated material, and their ability to absorb and release moisture from the environment would affect their refractive index and the amount of light that would travel through the material. The variance in voltage output measured was correlated to the measured alcohol concentration. The signal that is sent out by the sensors varies as a result of the interaction between the electromagnetic waves and the biological or chemical substances

In the process of determining the best sensitive material, a comparison was intended to be made between the PVA and PMMA-coated materials. The output voltage of PMMA and PVA coated glass substrate was measured while varying the amount of sanitizer. The synthesis process of the sensor platform is conducted using drop casting technique. The concentrations of alcohol content in hand sanitizer was varies in the range of around 66%, 70% and 75%. The proposed methods achieves exceptional sensing performance results such as high sensitivity, linearity, compactness and stability. This proposed sensor which detected concentrations level of sanitizer has been demonstrated for the first time to our knowledge.

Experimental setup

The platform of the proposed sensor was fabricated by coating the glass substrate with Polymethyl methacrylate (PMMA) and Polyvinyl alcohol (PVA). Firstly, glass substrates of 22 millimetres lengths was prepared, with a thickness of 1 millimetre and a refractive index of 1. Before the coating process, glass substrate needs to be cleaned to remove impurities. In order to remove the dirt on surface of the glass substrates, the following chemically process has been done [8]. The glass substrates platform is placed for in an ultrasonic bath using hydrochloric acid (HCl), sodium hydroxide (NaOH), soap, water, acetone, ethanol and deionized water. This process is essential to make sure that the glass substrates are free from dirt, dust and stains on their surfaces. After 15 minutes, the glass substrates were then placed for 1 hour in an atmospheric oven before it was coated with PMMA and PVA [3]. For the coating process, the drop casting method is chosen as shown in Fig. 1, since it requires less expensive equipment and does not require the use of inks with specific physical or chemical formulations [8]. The Poly(methyl methacrylate) (PMMA) and Polyvinyl alcohol (PVA) was chosen because it is a simple and low-cost deposition method for the fabrication of small-area films.

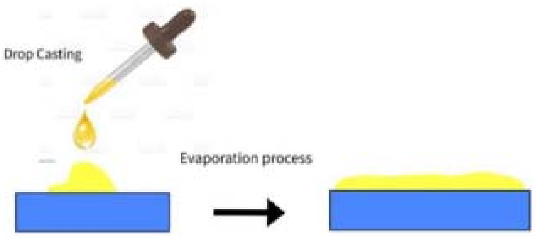

Fig. 1. Drop casting technique

The circuit for the data acquisation need to be positioned in a appropriate base to ensure it produce an accurate results. The base is designed using AutoCAD software. During this phase, a 3D printer is used to fabricate a three-dimensional object using the layering approach. Fig. 2 shows the orthographic view of the fabricated alcohol sensor device. The length of this casing was designed to be 85 millimetres, while the width was calculated to be 65 millimetres. This particular case had a height of around 40 millimetres. Besides, a green LED with a wavelength range of 492-577 nm (with semiconductor, GaN) was used as the light source and a LDRs was employed as the light detector to create a low-cost sensor device [9]. The LDRs were placed at the edge against the LEDs with a 4mm (diameter) small aperture window, while the LEDs were pointed as closely as possible at the corner of the glass substrate. The distance of 25 millimetres was chosen to be maintained between the LED and the LDR. This sensor produces an output voltage of LDRs that is proportionate to the amount of light that is reflected from LEDs, and it does so by measuring the reflected light intensity [10].

Fig. 2. Orthographic view of the fabricated alcohol sensor device

Sensing Mechanism

The green LEDs with wavelength of 492-577 nm has been choosen as a light source for this proposed sensor base on report in [11]. The LDRs is positioned at other end of the glass substrate. The intensity of LDRs varies as the light travel through the sensing region [12]. To improve the sensing response on the glass substrate, a higher refractive index coating material which are PMMA and PVA was applied to the glass substrate using the drop casting method. As light travels through the coated glass substrate, it interacts with the alcohol in sanitizer before reaching the LDR sensor. Since the PMMA and PVA have a higher refractive index with 1.49 and 1.48 respectively as compared to glass substrate with refractive index of 1, the leakage of light would occur. Therefore, refractive loss occurs when the light refracted from low reflective index to high refractive index which results in light attenuation at LDR. A portion of the incident light will be reflected at the top surface of the glass substrate, while the remainder will be refracted back into glass [13]. As for data acquisation, Arduino Nano is used to convert the analog signal input to digital output and it will be display through the i2c OLED. To compare the sensitivity of PMMA and PVA, the sensing performance was validated on the fabricated sensor as shown in Fig. 3. The sanitizer % will then be displayed on an i2C-OLED. The sensing experiment will be repeated five times to evaluate sensitivity, stability, and linearity.

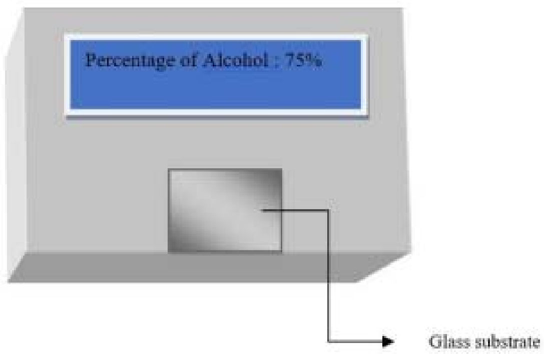

Fig. 3. Position of glass substrate

Result and discussion

To increase the sensing capability of the proposed sensor, PMMA and PVA were deployed as coating materials. Three runs were performed to evaluate the reproducibility of the samples. Fig. 4 represents the repeatability in form of output voltage of the PVA coated glass substrate when it is exposed to various percentages of alcohol in sanitizer ranging from 66% to 75%. Based on the result, it is observed that the repeatability of the PVA coated glass during the three trials is a bit lacking especially at concentrations level of 70% and 75%. The disparity in output values is unable to produce identical results for all trials. According to the graph, the repeatability of PVA coated glass substrate is rather unsteady but still dependable. Fig. 5 shows the repeatability of the PMMA coated glass substrate. The reproducibility is more consistent in all 66, 70, and 75 percent alcohol in sanitizer. Hence, PMMA coated glass produce better reliability than PVA coated glass because it able to produce homogeneous result when tested multiple times.

Other important factor in sensing applications is stability. The stability of the sensor was conducted by continuously records the output voltages for one minute (60 seconds) during exposure to variation sanitizer concentrations level. Fig. 6 depicted the stability of an PVA coated glass substrate. As time passed, the graph became highly noisy. This show the instability characteristics of the sample. Fig. 7 demonstrates the stability of a PMMA coated glass substrate when tested within 60 seconds with different ranging of alcohol in sanitizer. The graph shows less noisy output with time. This exhibits the stability of PMMA-coated glass substrates as compared to PVA coated glass. Even though the PMMA coated glass still contain noise, the improvement is quite significant. Hence, PMMA coated glass substrate is more stable as compared to PVA coated glass substrate because it exhibit lesser noise level when compared to PVA coated glass. The lesser noise level would translate to the greater sensing response for yhe proposed sensor.

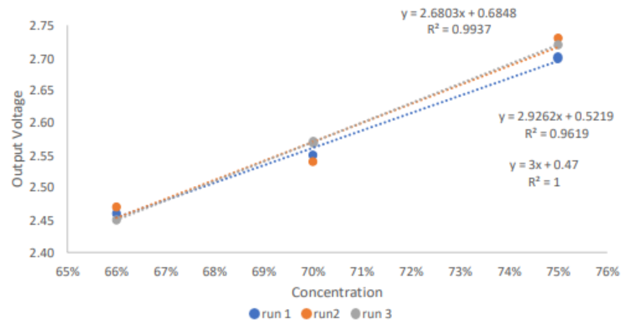

Fig. 4. Repeatability of PVA coated glass substrate

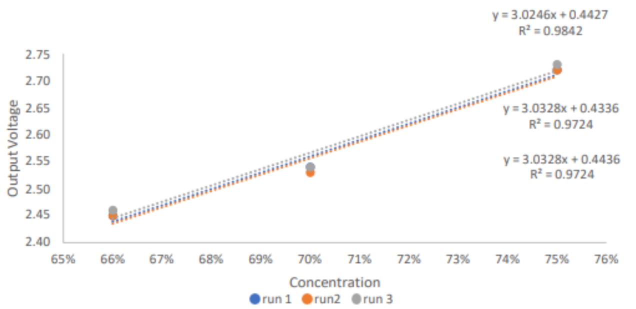

Fig. 5. Repeatability of PMMA coated glass substrate

Then the response time of the proposed sensor need to be analysed to determine the reaction time of the sensor towards the sensing speciment. It was carried out by rapidly exposed the sensing device from the least concentration value to the maximum concentration value. The amount of time required for the sensor output to achieve the saturation level at the highest concenrations level is referred as the time response. Fig. 8 represents the time response of the fabricated sensor for a PVA coated glass substrate. The result shows that it takes up to 0.5s for the fabricate sensor to respond from the least concentration to the maximum concentration level. While, Fig. 9 shows the time response of the fabricated sensor for PMMA coated glass substrate. The graph shows that it takes up to 0.25s for the fabricate sensor to respond from the least concentration to the maximum concentration for alcohol. This unequivocally demonstrates that the performance of a PMMA-coated glass substrate is significantly superior than PVA coated glass substrate. PMMA coated glass has faster respond time with 0.25 seconds margin as compared to PVA coated glass.

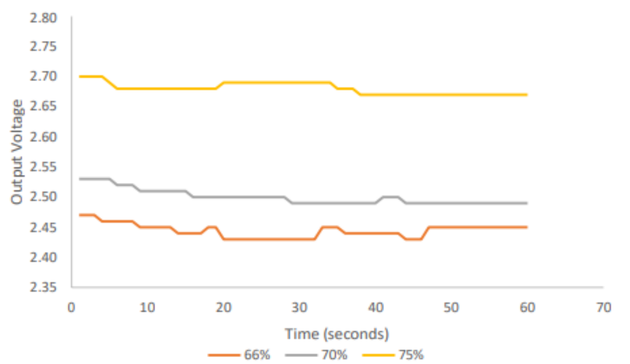

Fig. 6. Stability PVA coated glass substrate

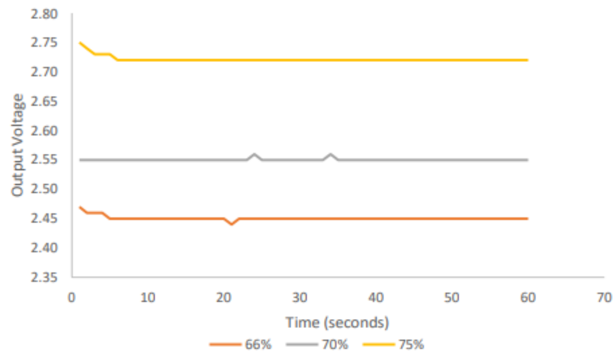

Fig. 7. Stability PMMA coated glass substrate

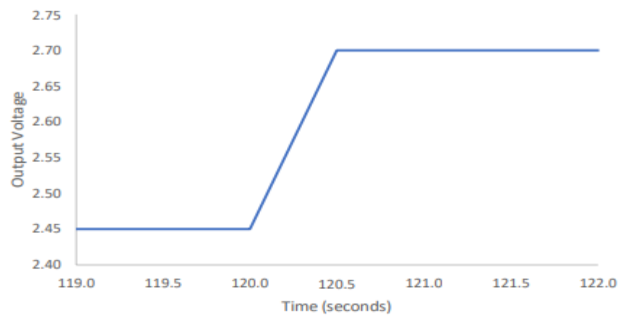

Fig. 8. Time Response PVA coated glass substrate

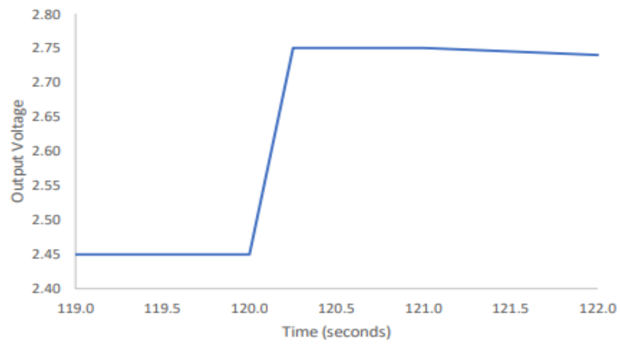

Fig. 9. Time Response PMMA coated glass substrate

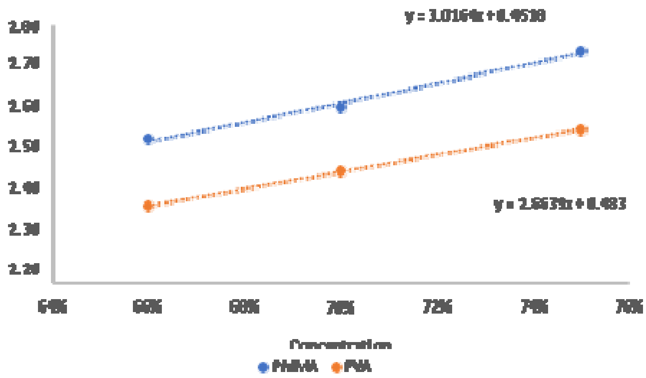

Fig. 10. Sensitivity graph for both samples

Table 1: Summary of sensing Performances

	PMMA	PVA
Sensitivity (V/%)	3.0164	2.6639
Linearity (%)	99.21	98.108
Response time (s)	0.25	0.5

Figure 10 shows the sensing response of the proposed sensor when exposed to increasing sanitizer concentrations level. It shows that the output voltage increased proportionally with the increment of alcohol concentrations level. This is due to the coated material on the glass substrate become changeable refractive index layer which interact according to the variations of alcohol level. PVA coated glass produce sensitivity of 2.6639 while PMMA coated glass with 3.0164. Thus, the PMMA coated glass improved the sensitivity by a factor of 1.13 as compared to PVA coated glass substrates. Henceforth, the overall results are summarized in Table 1. PMMA coated glass performed better than PVA coated glass in term of sensitivity, linearity, response time, repeatability and stability.

Conclusion

The detection of the alcohol percentage in hand sanitizer as the primary aim of this work was successfully demonstrated. The low cost sensing device is capable to detect levels of alcohol effectively using commercially available components. In short, the PMMA coated glass substrate has demonstrated superior sensing performance outcomes in comparison to PVA coated glass in terms of sensitivity and linearity. Furthermore, PMMA coated glass substrate has exhibited faster response times as compared to PVA coated glass by 0.25 seconds margin. Besides that, PMMA coated glass substrate also produce better repeatability and stability results. This work contributes to development of a low cost and simple device for optical sensor application. In order to refine future analysis, the effect of coatting surface area towards the sensing response could be considered. The used of another coating material such as zin oxide could also been investigate to improve the sensing response [14].

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REFERENCES

[1] M. Whitby, C. Pessoa-Silva, M.-L. McLaws, B. Allegranzi, H. Sax, E. Larson, *et al.*, "Behavioural considerations for hand hygiene practices: the basic building blocks," *Journal of Hospital Infection,* vol. 65, pp. 1-8, 2007.

[2] J. Hilburn, B. S. Hammond, E. J. Fendler, and P. A. Groziak, "Use of alcohol hand sanitizer as an infection control strategy in an acute care facility," *American journal of infection control,* vol. 31, pp. 109-116, 2003.

[3] H. H. M. Yusof, M. H. Jali, M. A. M. Johari, K. Dimyati, S. W. Harun, M. Khasanah, *et al.*, "Detection of formaldehyde vapor using glass substrate coated with zinc oxide nanorods," *IEEE Photonics Journal,* vol. 11, pp. 1-9, 2019.

[4] B. Schyrr, S. p. Pasche, G. Voirin, C. Weder, Y. C. Simon, and E. J. Foster, "Biosensors based on porous cellulose nanocrystal–poly (vinyl alcohol) scaffolds," *ACS Applied Materials & Interfaces,* vol. 6, pp. 12674-12683, 2014.

[5] W. Huang, J. Yu, X. Yu, and W. Shi, "Polymer dielectric layer functionality in organic field-effect transistor based ammonia gas sensor," *Organic Electronics,* vol. 14, pp. 3453-3459, 2013.

[6] Z. Harith, H. A. A. Zain, M. Batumalay, and S. W. Harun, "A study on relative humidity sensors using PVA and PMMA coating," in *Journal of Physics: Conference Series*, 2019, p. 012027.

[7] M. Jali, "Effect of HEC/PVDF coating on glass substrate for formaldehyde concentration sensing," *PrzeglĄd Elektrotechniczny,* vol. 1, pp. 42-45, 2022.

[8] M. Eslamian and F. Soltani-Kordshuli, "Development of multiple-droplet drop-casting method for the fabrication of coatings and thin solid films," *Journal of Coatings Technology and Research,* vol. 15, pp. 271-280, 2018.

[9] H. H. M. Yusof, S. W. Harun, K. Dimyati, T. Bora, K. Sterckx, W. S. Mohammed, *et al.*, "Low-cost integrated zinc oxide nanorod-based humidity sensors for arduino platform," *IEEE Sensors Journal,* vol. 19, pp. 2442-2449, 2018.

[10] K. Bult and G. J. Geelen, "A fast-settling CMOS op amp for SC circuits with 90-dB DC gain," *IEEE Journal of Solid-State Circuits,* vol. 25, pp. 1379-1384, 1990.

[11] Y. Suzuki, N. Nakano, and K. Suzuki, "Portable sick house syndrome gas monitoring system based on novel colorimetric reagents for the highly selective and sensitive detection of formaldehyde," *Environmental science & technology,* vol. 37, pp. 5695-5700, 2003.

[12] H. A. Sohag, M. Hasan, M. Khatun, and M. Ahmad, "An accurate and efficient solar tracking system using image processing and LDR sensor," in *2015 2nd International Conference on Electrical Information and Communication Technologies (EICT)*, 2015, pp. 522-527.

[13] M. Chang, B.-C. Chen, J. L. Gabayno, and M.-F. Chen, "Development of an optical inspection platform for surface defect detection in touch panel glass," *International Journal of Optomechatronics,* vol. 10, pp. 63-72, 2016.

[14] A. Rashid, N. Shamsuri, A. Surani, A. Hakim, and K. Ismail, "Zinc oxide coated polymer optical fiber for measuring uric acid concentrations," *Optoelectronics and Advanced Materials-Rapid Communications,* 2019.