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PVA Coated Glass Substrates for Acetone Detection

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ABSTRACT

Technology advancement in photonics has progressively tailor human need in healthcare industries. Inventing a new medical device or application for the mental and health sectors have make disease diagnosis easier. Without prevention, the number of sufferers may rise quickly. Studies have identified a way to diagnose diabetes illness by measuring a person's acetone level. The existing blood test have inferiority in term of invasive and dangerous if not handled properly. In this report, acetone concentration has been detected using a simple, low-cost Polyvinyl Alcohol (PVA) coated glass substrate platform as a potential diagnosis tool for diabetes patient. Based on the experiment results, the proposed sensor exhibits exceptional sensing performances for acetone detection in term of sensitivity, linearity, repeatability, stability and hysteresis.

1. Introduction

Diabetes is one of the most chronic diseases in which the body metabolic condition cannot use insulin to retain and use glucose for energy. World Health Organization (WHO) reported that diabetes patients increased from 108 million to 422 million in 2014, and the global diabetes population is expected to reach 329 million in 2045. Diabetes affects over 8.3 per cent of the world's population and can result in severe disorders affecting the heart and blood vessels, eyes, kidneys, nerves, and teeth. When diabetes is not detected early, it can result in kidney failure, stroke, blindness, heart attack, and lower limb amputation [1]. It is possible to develop diabetes at an early stage because it exhibits no symptoms or causes and can only be detected through blood glucose readings. There are several types of diabetes, including Type 1, Type 2, and gestational diabetes. Type 1 diabetes develops when the pancreas does not create enough insulin for the body and is most common in children and young adults. While Type 2 Diabetes affects persons over the age of 45, Gestational

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Diabetes can occur in pregnant women with very high blood glucose levels. Currently, diabetes is diagnosed by measuring blood glucose levels, and blood glucose levels greater than 126mg/dL are recognized to be diabetes [2].

The market-available technology for human glucose level is dominate by invasive type commercial handheld blood glucose detectors. That strategy will result in more harm than good, as the operation will require regular needle detection, will incur high costs and will demand expert supervision. Numerous studies have shown that breath analysis can be used as a reliable alternative to blood glucose levels in the diagnosis of diabetes such as of saliva as a diagnostic tool for diabetes, Since it is easily acquired and, more importantly, can be obtained using non-invasive methods [3,4]. Furthermore, the acetone recognition detector's portability and ease of use make it a more valuable tool for helping with diabetes diagnosis, monitoring, evaluation, and also acetone detection sensors could be used for non-invasive glucose monitoring. The development of nanotechnology-based sensors has facilitated the rapid emergence of these non-invasive glucose detection methods by increasing their sensitivity, selectivity, and compatibility with semiconductor technology. On a wide variety of research platforms numerous investigations on plastic optic fibre have been carried out such as paper substrates [5], PEN substrates [6], and polyimide substrates [7] has been utilized, In order to formulate a sensing device that is equally efficient and cost-effective. However, most of these platforms required a labour-intensive and intricate fabrication and manufacturing process, in addition to an expensive design. Therefore, glass substrate is a good choice for a low-cost sensing platform and high quality because it is readily available and simple to work with [8]. The uncoated glass substrate, which has no sensitive material coated on it, is less sensitive because it has a low sensing performance due to a low refractive index contrast between the surround analyte. As a consequence, a higher refractive index coating material is required to improve sensing response.

Polyvinyl alcohol (PVA) is a water-soluble synthetic polymer It is frequently used in medical applications for a variety of reasons, including a lower propensity for protein adsorption and a lower risk of hazardous side effects [9]. As a result of its biocompatibility, this material has been used in the production of contact lenses and eye drops. Number of recent experiments on this material demonstrate that the current market rate of PVA is rather promising. PVA is also applied in sensors for detecting applications such as pressure sensors and pH sensors[10]. PVA has been the subject of investigation in a variety of research fields throughout the course of the past decade, including the production of nanocomposite materials, antimicrobial sub-components, and batteries [11,12]. The modified PVA may be employed in a variety of applications, including molecular sensing in biological and biomedical sectors, fuel cell membranes, chemo sensors, hazardous metal absorption, and optoelectronic devices. PVA acts as a matrix and embedding mat for metal/inorganic nano filler used in sensing, optoelectronic devices, and a variety of other applications such as in the textile sector, paper manufacturing, coatings, adhesives, pharmaceuticals, optics, and 3D printing [10].

In this paper, the fabrication and assembly of a straightforward sensing device that employs acetone as a sensing element developed based on PVA coated glass substrate platform that has been discovered in the Arduino platform. The detection of exhaled acetone as a potential technique for monitoring diabetes, given that persons who have diabetes tend to have higher levels of acetone in their breath than healthy people by monitoring the acetone concentration level in human saliva. PVA utilised as a result of its high level of absorption, as well as its favourable biocompatibility, biodegradability, cellular binding capability, antibacterial activity [13,14]. It was realized by integrating the glass substrate with the detection circuit, which includes a simple light source, a photodetector, a conditional amplifier and a data acquisition system (DAS). Ensuring the cost and dependability of a system are within acceptable parameters is crucial when striving for an optimal integration of resources within the system [15]. Thus, The LED act as a light source propagate through the glass substrate and reach the photodetector and transform it into a voltage value. Based on a prior research [16], the green LED was selected as the light source. After photodetector convert the light into voltage signal, it needs to be condition into appropriate signal that can be accurately process by the DAS unit which is well-represent the original light signal. An accurate output data is crucial to compute data for voltage analysis output. The proposed sensor employed the distinctive property of PVA coating layer which reacts to the change of the different concentration of the acetone solution.

2. Sensing Mechanism

Diabetes is basically monitored by the blood glucose detector and not particularly adequate in their efficiency and sensitivity. By this method, it is invasive devices which it is requires a constant needle detection which are painful, less comfortable, and unsafe if not properly handle. In the sensing system, the device is proposed to reduce the possibility that these rates will continue to rise year after year by detecting early signs of diabetes in humans. Instead of using constant needle detection to examine bloods, a new method is discovered by monitoring the acetone concentration level in human saliva. The goal of this project is to create acetone sensing technology based on coated polyvinyl alcohol (PVA). The sensing mechanism is based on the change in Refractive Index (RI) of the PVA when exposed to variation of Acetone concentration level. This is due to the intensity of the light weakening by absorption and scattering when light propagated through the sensing material.

The scattering coefficient of the sensitive material and the total percentage power carried in the coating layer have a significant impact on the channel of light through the glass substrate based on the Lambert-Beer equation. The light attenuation through the sensing region is explained by Eq. (1) [17]:

$$I = I_o e^{-\alpha L} \tag{1}$$

Noted that *I* is the amount of light exiting the sensitive zone, I_o is the amount of light incoming to the sensitive zone, *L* is the length of the sensitive zone, and is the scattering coefficient. It is also affected by the concentration, absorption coefficient and total power fraction of the absorbing substance [18]. As shown in Figure 1, as light propagates through the sensor material, its intensity may be diminished by scattering and absorption. In this case, the transmission of light throughout the material signifies the coefficient of absorption exhibited by the samples [19]. Optical transmittance (T) decreases as the refractive index of the surrounding analyte rises. This results in increased light leakage, which increases sensitivity to acetone levels [20]. Upon exposure to different acetone concentrations, the output intensity surrounding the sensing zone fluctuates [21]. Depending on the concentration level, the light intensity throughout the absorbent material varies. It corresponded to fluctuations in analyte concentration in the detection area. At the output of the sensor, optical transmittance (T) is calculated using Eq. (2):

$$T = \frac{I}{I_o} = e^{-\alpha L} \tag{2}$$

It is noteworthy to mention that the proposed sensor works when the light source propagates along the glass substrate interact with the applied analyte on the substrate. When light travel through the glass substrate, the coated materials would produce a scattering effect when exposed to different acetone concentrations. This resulted in a decrease in light intensity with respect to the concentration of the surround analyte. As shown in Figure 1, the drop casting method is chosen since it requires less expensive equipment and does not require the use of inks with specific physical or chemical formulations. The output voltage of the sensor decreased when exposed to growing acetone concentrations. This is due to the greater refractive index contrast between the surrounding medium and the sensing layer. This led to a lossy waveguide which resulting in higher light leakage as concentrations rose. Consequently, as concentrations rise, less light reaches the photodetector. In addition, more light scattering occurs, resulting in increased leakage and decreased output voltage [22]. Other contributors to this phenomenon include the fluctuation in electrical conductivity caused by the analyte adsorption process on the coated layer. The pattern of voltage reduction will eventually enhance the sensing capability of the suggested sensor.

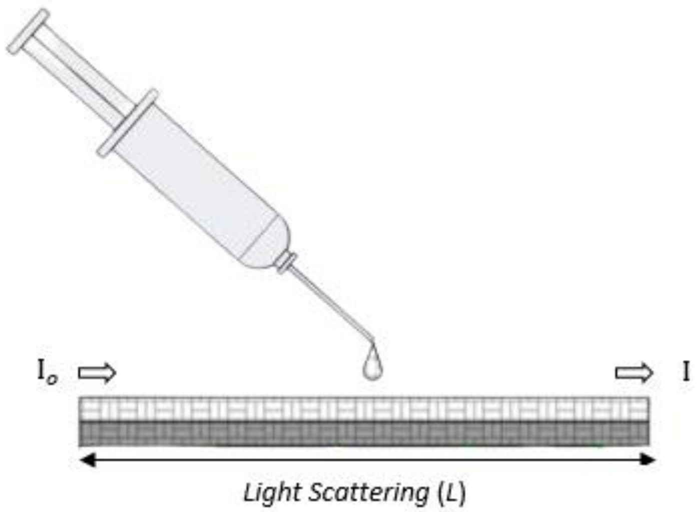

Fig. 1. Sensing mechanism of the proposed sensor

3. Experiment Details

3.1 Glass Substrate Preparation

The experiment was initially carried out using a glass substrate platform that was covered with PVA material as shown in Figure 2. The synthesis process was first conducted with 25 mm x 25 mm glass substrate platform is coated with PVA [23]. The coating material was selected due to its remarkable features, including water solubility, strong optical transmission, noncorrosive nature and thermal stability, which make it an excellent nanomaterial for optoelectronic and various other applications [10]. The glass substrates, which must be prepared for the coating operation, were ultrasonically cleaned for 15 minutes in a container containing soapy water, clear water, and acetone [CH3COCH]. After that, it spent an hour in a preheated 90°C oven to kill any remaining biological matter [24]. The Polyvinyl Alcohol (PVA) solutions of varying concentration were prepared by dissolving appropriate amount of PVA granules in deionized water at 90 °C for 1 hour with stirring. The fabricated optical fibre was cleaned with piranha solution of concentrated sulphuric acid (95–96%) and hydrogen peroxide (30%) in a 7:3 ratio respectively. The sensor was dip coated into the PVA solution with a using a dip coater. After coating, the sensor was placed in an oven to dry at 80 °C for 1 hour [25]. After that, the concentration level of the acetone is placed on top of the glass substrate, and then the concentration level of the acetone is increased progressively from 3% to 15% [26].

Fig. 2. PVA coated glass substrate

3.2 Sensor Design Module

The drop casting technique was used to apply a PVA coating with a refractive index of 1.3 to the glass substrate platform, allowing for the realisation of a low-cost sensor device that uses a detected signal from light scattered across the glass substrate as shown in Figure 3. The digital output was obtained by using the Arduino software to read the LDR sensor's readings after the refracted light from the LED has been transmitted through the glass substrate platform [27]. In this configuration, the Arduino Nano board was chosen because of its small size, which allows for the overall size of the device to be reduced. The 12c OLED Display is utilized for the user interface. It is responsible for displaying the digital output voltage, which makes it much simpler to record the reading of the output voltage that was received by the LDR sensor.

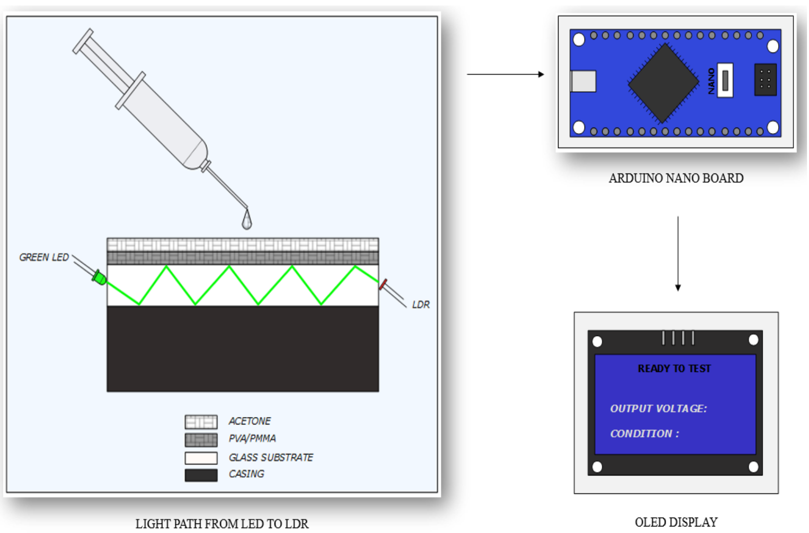

Fig. 3. Experimental setup

3. Results and Discussion

The repeatability tests were undertaken to observe the reproducibility of the sensor at least three times for the purpose of determining the output voltage's standard deviation. As shown in Figure 4, the distribution of repeatability readings for PVA glass is quite uniform especially at concentrations of 15%. The rest of the readings exhibit quite similar trend value in each trial, showing exceptional constancy.

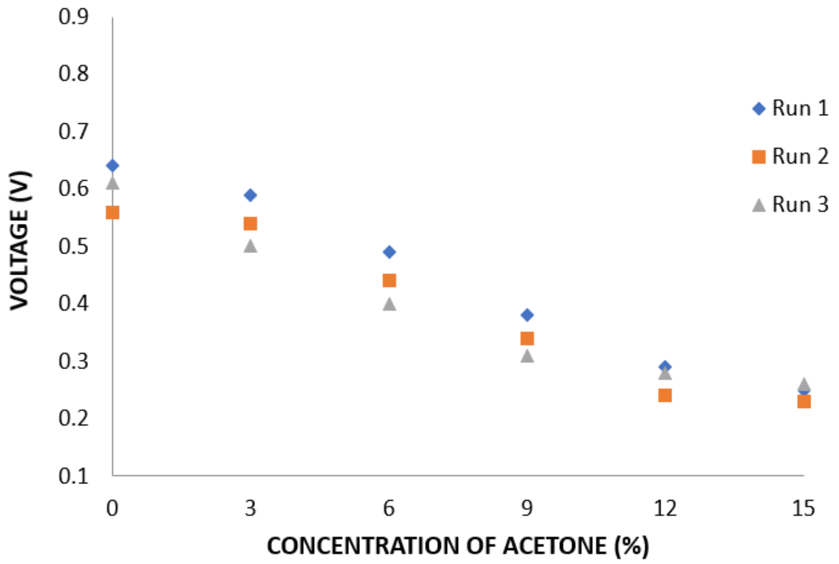

Fig. 4. The repeatability of PVA coated glass

Figure 5 depicted the hysteresis behaviour of the proposed sensor. It was conducted by alternately applied the sensor with acetone solution from low percentage value to a high percentage value and subsequently from high percentage value to low value. The proposed sensor shows narrow discrepancies between forward and reverse values, especially at concentration levels of 6, 9 and 12 percent. The minor deviancy normally occurred during the hysteresis test due to the variation of absorption rates during the reverse and forward measurement.

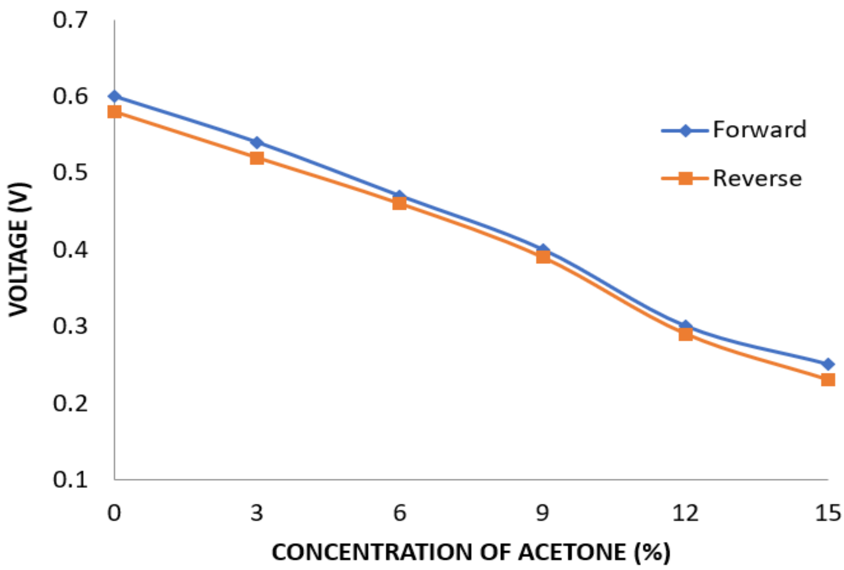

Fig. 5. The hysteresis graph of PVA coated glass

Figure 6 illustrates the stability of the proposed sensors. Continuous measurements of output voltages were taken for 5 minutes (300 seconds) per second. The result show that the proposed sensor produces quite steady output voltage throughout the duration of the test. This is owing to the high refractive index difference between the PVA coated glass and the surrounding medium which resulting in greater stability when the proposed sensor applied with several percentage acetone level.

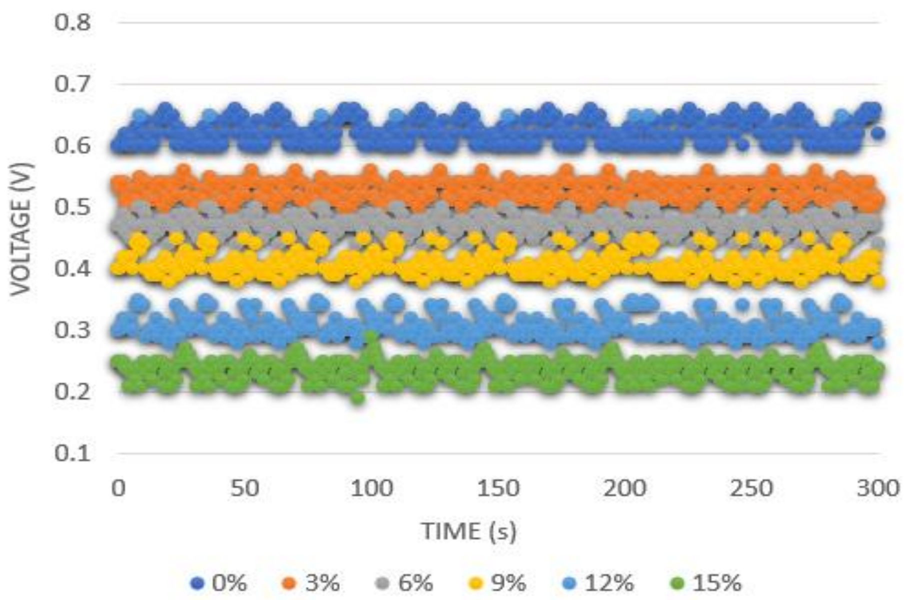

Fig. 6. The stability of the proposed sensor

Throughout the duration of the experiment, both the reaction time and the recovery time of each coating material will be timed, quantified, and analysed. The time allotted for the test is 240 seconds, which is equal to 4 minutes. Every sixty seconds, or one minute, the concentration of acetone will decrease, and the concentration will progress from the lowest concentration to the greatest concentration and vice versa until both rounds have completed. Figure 7 shows the overview of response time for PVA coated glass substrate.

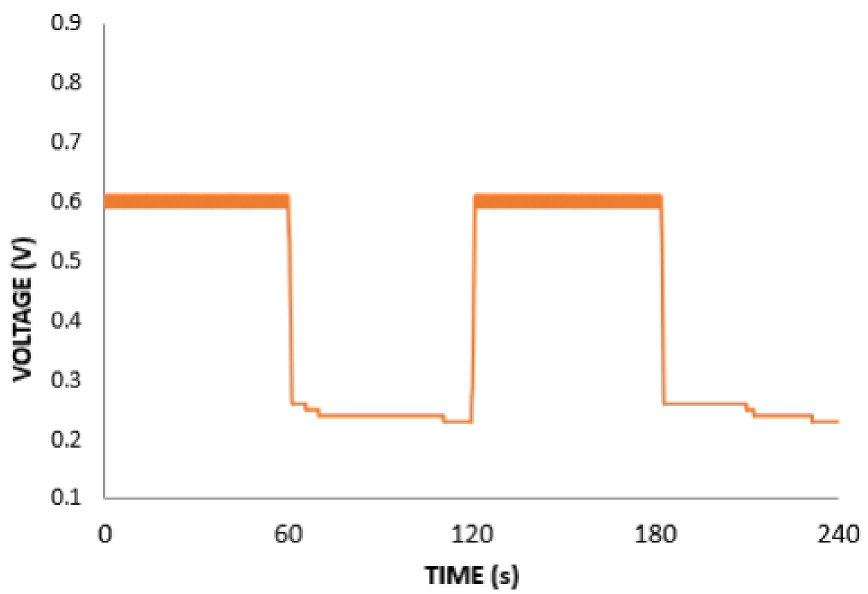

Fig. 7. Overview of Time Response of Coated Glass Substrate with PVA

Which is the peak response time for a glass substrate coated with PVA to react from the lowest concentration to the highest concentration is approximately 1.32 seconds as shown in Figure 8.

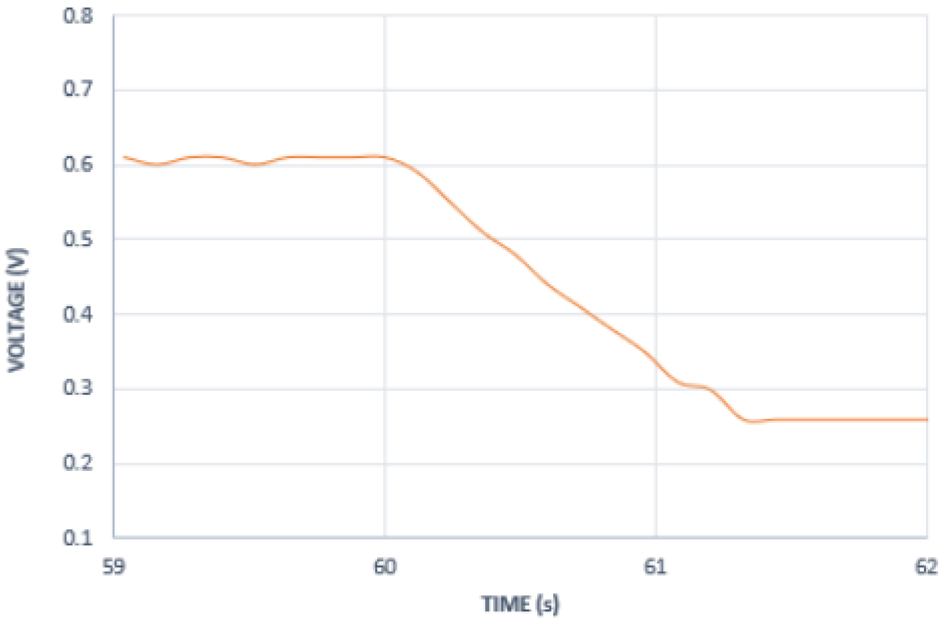

Fig. 8. Response time of coated glass substrate with PVA

Moreover, Figure 9 demonstrates that the recovery time for a glass substrate coated 46 with PVA is also 1.32 seconds. The temporal response of a glass substrate coated with PVA is suitable for sensing performance.

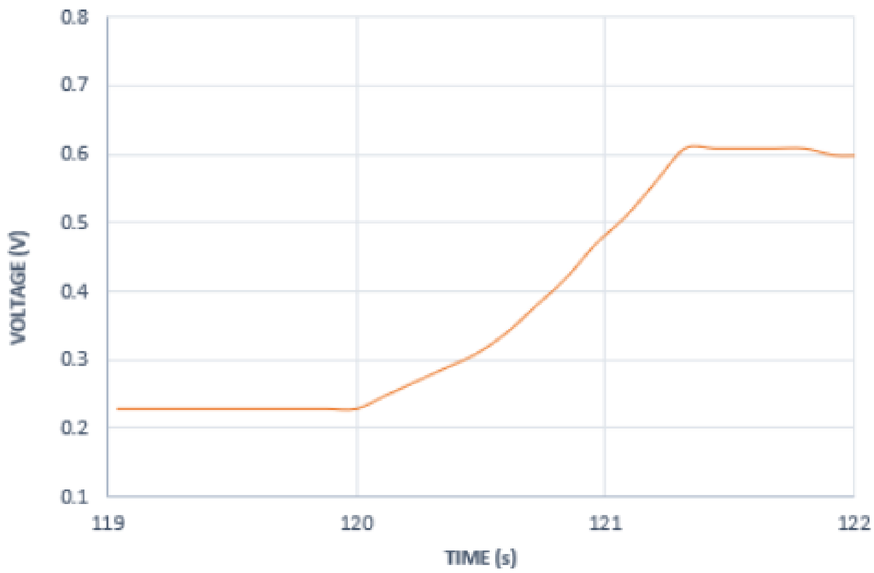

Fig. 9. Recovery time of coated glass substrate with PVA

Figure 10 shows a trend line graph represent the sensing response when applied with acetone solution from 0% to 15%. The sensitivity of the proposed sensor is 0.0257 V/%, and the linearity is 98.79%. This is because acetone detection is dependent on a change in the refractive index of the coating substance. The RI of the coating materials will influence the intensity of the emitted light. As a result, the coating layer has a greater RI value than the glass substrate, resulting in a lossy waveguide and a decrease in output voltage.

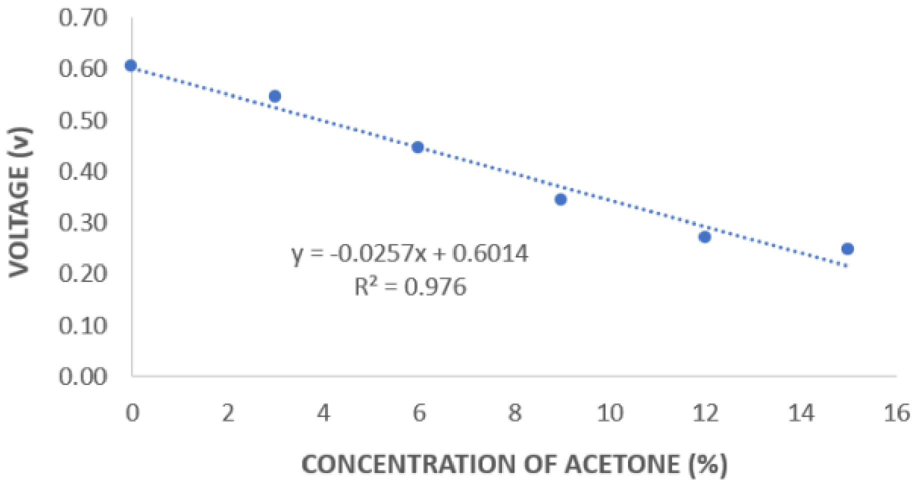

Fig. 10. Trendline of the proposed sensor

Table 1 summarize the sensing performances of the proposed sensor. The major results which are linearity and sensitivity are compared with the uncoated glass based on our previous work [24]. In short, PVA coated glass produce better results as compared to uncoated glass. The sensitivity of the proposed sensor is 0.0257 V/% which is better than uncoated glass with 0.025 V/%. The linearity of the proposed sensor also improved by a 3% as compared to the uncoated glass.

Table 1
Summary of the sensing performances

Parameters	PVA coated glass	Uncoated glass [17]
Sensitivity (V/%)	0.0257	0.025
Linearity (%)	98.79	95.41

4. Conclusions

This paper has successfully developed an acetone sensor as a potential diabetes patient diagnosis tool. The detection is based on PVA coated glass substrates, which have the advantage of avoiding the usage of costly laser source-based equipment that is impractical for mass manufacturing. By including components that are readily available on the market, the proposed sensor becomes more practicable for widespread use. In short, the proposed sensor demonstrated exceptional sensing performance in terms of linearity, sensitivity, stability, repeatability and hysteresis. This is due to the PVA coating material acts as a variable RI layer when different acetone percentages are applied. It enhanced both the light interaction with the surrounding analyte and the sensor response. Therefore, our low-cost and straightforward acetone detection system has the potential to serve as a reliable early indicator for diabetes diagnosis.

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