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Enhancement the Sensitivity of waveguide Coated ZnO thin films: Role of Plasma irradiation

Marwan Hafeedh Younus *, Muayad Abdullah Ahmed, Ghazwan Ghazi Ali
Physics Department, College of Education for Pure Science, University of Mosul, Iraq

Correspondence
*Marwan Hafeedh Younus
Physics Department, College of Education for Pure Science,
University of Mosul, Iraq
Email: marwan82hafed@gmail.com

Abstract
In this study, Dielectric Barrier Discharge plasma irradiation (DBD) is applied to treatment and improve the properties of the ZnO thin film deposited on the glass substrate as a sensor for glucose detection. The ZnO is prepared via a sol-gel method in this work. ZnO is irradiated by the DBD high voltage plasma to improve of its sensitivity. The optical properties, roughness and surface morphology of the waveguide coated ZnO thin films before and after DBD plasma irradiation are studied in this work. The results showed a significant improvement in the performance of the sensor in the detection of concentrations of glucose solution after plasma irradiation. Where the largest value in sensitivity was equal to 62.7 when the distance between electrodes was 5 cm compared to the sensitivity before irradiation, which was equal to 92. The high response showed in results demonstrating that the fabricated waveguide coated ZnO after plasma irradiation has the excellent potential application as a sensor to detect small concentration of glucose solution.

KEYWORDS: waveguide sensor, Sensitivity, ZnO thin film, plasma irradiation .

I. Introduction

The sensors have broad applications for gas and chemical liquids sensing in a variation of fields such as food, environmental sensing, and security [1] .Solid state has been achieved as by researchers a sensors to monitor different chemical and gases [2].

Due to their unique advantages of developed sensors based on metal oxide semiconductors such as inexpensive, uncomplicated fabrication and good compatibility with microsystem processes make it to use widely to measure a diverse array of chemicals and gases.

Nowadays, due to the environmental pollution concerns and the requirements of life safety, sensors development become essential to detect volatile and toxic materials. Thin films and nanoparticles have acquired a lot of attractive due to their potential applications in different fields of technology. ZnO has been considered as a promising material as a sensors because of its high electrochemical stability, non-toxicity, suitability to doping , and low cost [3-6]. In addition, ZnO has many unique properties, such as a large exciting bonding energy of 60 meV, non-toxicity, good electrical, optical and piezoelectric behavior, and low cost [7-11].

Many methods have been developed to produce ZnO [12-20]. Generally, the porous thin films can be fabricated through different ways such as screen printing [21], brush coating [22] Vapor–liquid–solid (VLS), [23] chemical vapor deposition (CVD) [24]. Overall, the facile fabrication of sensing thin films with uniform porosity and cracks is still a challenge. A low-temperature and mild approach is highly desired for the creation of crack-free homogenous films.

In recent years, non-thermal plasma dielectric barrier discharge (NTPDBD) techniques including radio frequency (RF) discharge, glow discharge and silent discharge have been used for treatment, modified and changes in the morphology of thin films surface [25–27]. Plasma treatment has various industrial applications because of their low-cost high speed and the ability to operate without vacuum. Plasma surface modification involves the interaction of the plasma generated excited species with a solid interface.

Moreover, the high energy electrons of NTPDBD low temperature lead to generate of physical on the thin film surface. Thus, plasma treatment is suitable to irradiate the thermal sensitive materials such as ZnO thin films [28]. The surface activation typically takes places with oxygen containing gas mixtures such as ambient air which is change the surface properties of the external layers of the material [29-30].

In this work, We have carried out and established our own high voltage pulse generator for atmospheric pressure plasma system by using dielectric barrier discharge. we improvement the sensitivity of waveguide coated with ZnO sensors via plasma irradiation at low temperature. The as-prepared ordered porous thin films are stable and homogenous which leads to significant enhancement in the sensing performance. This technique also appropriate for the fabrication of other metal oxide homogenous thin films sensors with suitable quality at a low temperature.

II. DBD Dielectric Barrier Discharge Plasma Setup

The schematic diagram of experimental setup for pulse high voltage power supply (PHVPS) is shown in Figure 1a. The circuit of low voltage pulse uses the TL494 integrated circuit which represents a pulse width modulation control circuit that generates variation pulse width.
The pulse width varying is performed by changing the applied voltage on the pin 4 as shown in Figure 1b. The frequency can be adjusted by the value of resistance which is connected with pin 6 and the capacitance in pin 5. In order to obtain high current to ignite the high voltage stage, MOSFET transistors are used to ensure obtaining appropriate output high voltage stage.

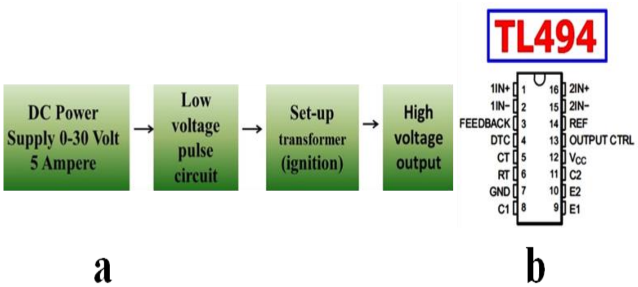

Fig. 1: (a) Schematic presentation of dielectric barrier discharge used for surface, (b) Diagram of TL494 integrated circuit.

PHVPS was launched as shown in Figure 2. The low voltage pulse was generated, which represents a pulse width modulation control circuit. This circuit can be operated safely from power supply as high as (+12 volt). It generates a successive sequence pulses with a peak varying from 0 to 2 volt when the input DC power supply ranging between 0 to 30 volts, and 5Ampere. The UNT-I 60 MHz digital storage oscilloscope (Model UT2062CE, China) and the GOULD-15 MHz oscilloscope (Model OS255, England) were used to measure the voltage value of pulse and the current passed through a resistance of 1.2 Ώ respectively.
On the other hand, the high voltage pulse was measured using a probe pulse high tension type Tesla (Model BS375A, England). Figure 3 shows the atmospheric pressure plasma (APP) using the dielectric barrier discharge (DBD) method floating discharge [1, 2]. The high voltage obtained from PHVPS was used in the dielectric barrier discharge system for surface treatment. After that, the samples of ZnO coated glasses substrate were placed between the two electrodes of the DBD plasma discharge to irradiate the ZnO film. The exposure time of 20 second was fixed for the samples during the plasma irradiation process, while the distance between the two electrodes of plasma was chosen to be 0.5 cm, 1 cm, 1.5 cm.

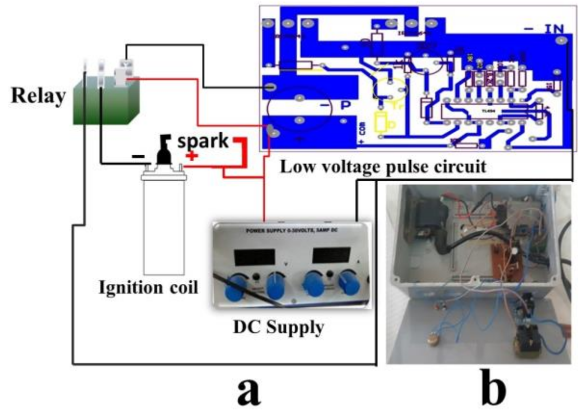

Fig. 2: (a) The circuit of high voltage pulse power supply, (b)the high voltage power supply components.

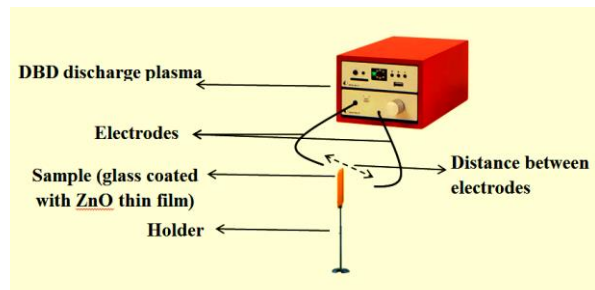

Fig. 3: Schematic presentation of dielectric barrier discharge used for treatment surface.

III. Waveguide Sensor Coated ZnO Setup

The fabrication of the waveguide sensor coated with ZnO thin film is carried out according to our previous work [14]. Figure 4 illustrates the setup of waveguide sensor coated with ZnO thin film for glucose detection. Its tested in the transmission system where optical source (Broad Band Source supplied by JDS Uniphase) placed near the one end of the waveguide sensor, and the Optical Spectrum Analyzer (ANDO AD6317B) was placed near the other end. The ZnO was cleaned by distilled water and ethanol respectively before the detection process. The experiment was conducted with the sensor being immersed in a container to be in contact with the glucose solution. The container was covered with a glass slide to prevent the impurity during the experiment. All the experiments were achieved at room temperature and were carried out for different concentrations of glucose ranging from 1% to 5%. In addition, the light from the source was effectively passed into the surface of the waveguide coated ZnO and the light exiting from the other end was detected directly by Optical Spectrum Analyzer to record the spectrum.

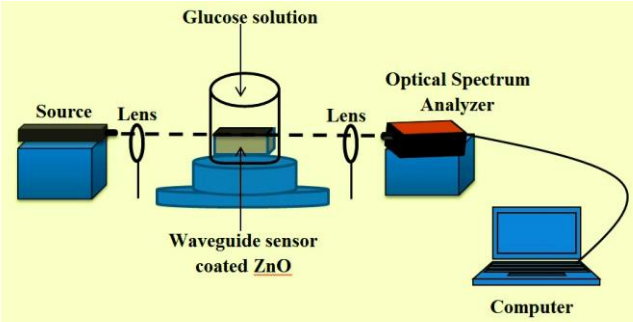

Fig. 4: waveguide Sensor Coated ZnO Setup for glucose detection.

IV. Results and Discussion

A. Absorption Analysis

ZnO thin film was exposed to plasma irradiation in order to improve its sensitivity to detect the glucose solution. The distance between the electrodes of the plasma was chosen to be 0.5 cm, 0.8 cm and 1 cm respectively. Figure 5 shows the absorption spectra of ZnO thin film before and after plasma irradiation in UV-visible range from 300 to 800 nm. It can be seen that the ZnO thin film has strong absorption in the visible range with the absorption edge from 380 to 450 nm, which can be attributed to the fundamental absorption of ZnO. In addition, the absorption of ZnO has been increased after plasma irradiation as the distance between the electrodes is decreased, which can be ascribed to increase the roughness of the ZnO surface after irradiation.

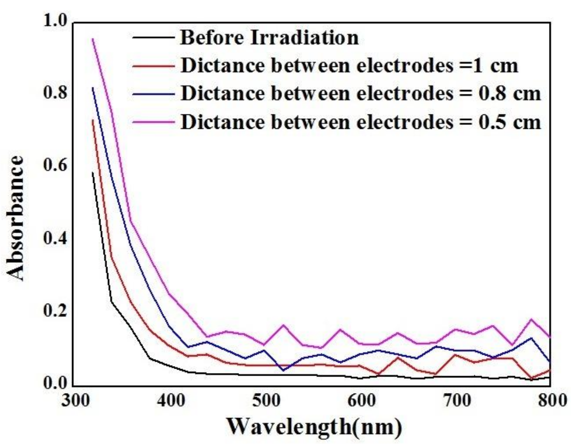

Fig. 5: Optical absorbance spectrum of ZnO thin films at different plasma irradiation.

B. Roughness Surface Morphology

Atomic force microscope (AFM) was used to study the surface topography of ZnO thin films before and after plasma irradiation as shown in Figure 6. The ZnO thin film before irradiation is packed and continuous without the presence of porosity or voids due to the homogeneous distribution of ZnO grains on the surface as shown in Figure 6a. However, the porosity and voids started to appear on the ZnO surface after plasma irradiation. Moreover, the porosity and the voids were increased as the distance between the electrodes of plasma is decreased as shown in Figure 6 b,c and d. The increase in porosity and voids on the surface of irradiated ZnO thin films were due to the occurrence of cracks on the surface of irradiated ZnO thin films. The appearance of the cracks is also significant to improve in the sensitivity of the waveguide sensors to detect the glucose solution.

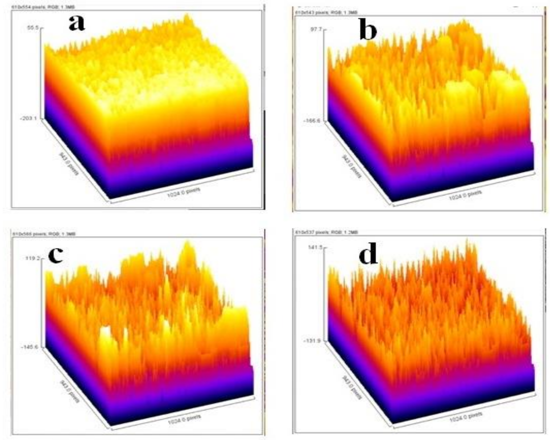

Fig. 6: AFM morphology of waveguide coated ZnO thin films (a) before exposed to DBD irradiation (b) after DBD irradiation (distance at 1 cm) (c) after DBD irradiation (distance at 0.8 cm) (d) after DBD irradiation (distance at 0.5 cm).

C. SEM Morphology

The SEM morphology of the deposited ZnO thin films before and after plasma irradiation is depicted in Figure 7. Figure 7a illustrates that the surface of the ZnO thin film before irradiation is smooth, packed and continues as well no cracking is observed. However, the ZnO thin film after plasma irradiation ()shows considerable morphological differences as shown in Figure 7 b, c, d for the electrodes distance of 1 cm, 0.8 cm and 0.5 cm respectively. As can be seen, the surface of the resulting ZnO films were directly influenced by the irradiation which leads to display the porosity, voids and cracks, suggesting that the irradiation plasma improve the sensitivity of the waveguide sensor coated with ZnO for glucose solution detection.

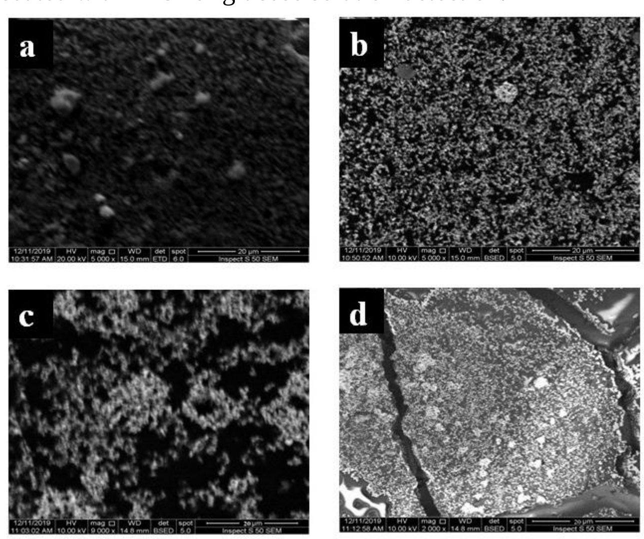

Fig. 7: SEM micrographs of waveguide coated ZnO thin films (a) before plasma irradiation (b) after plasma

irradiation (distance at 1 cm) (c) plasma irradiation (distance at 0.8 cm) (d) after plasma irradiation. (distance at 0.5 cm) irradiation (distance at 0.5 cm) .

D. Response of Waveguide Coated with ZnO Thin Films for Glucose Detection

As a proof of the waveguide coated with ZnO sensor principle, our sensor before and after plasma irradiation was immersed in different concentrations (1% to 5%) of glucose solution. Figure 8 shows the spectrum of output intensity of the ZnO coated waveguide sensor before and after plasma irradiation for different glucose concentrations. From Figure 6, it can be observed that the transmittance intensity of waveguide sensor after plasma irradiation decreases at all the glucose concentrations, indicating that the sensor presents a good response to glucose. Further, the response of the waveguide sensor after plasma irradiation is more when the distance between the electrodes of 0.5 cm, this due to the increasing in the porosity and cracks via plasma irradiation which leads to increase the absorbance of the ZnO surface during the glucose detection. While the response of the sensor was less when the distance between the electrodes of 0.8 cm and 1 cm.

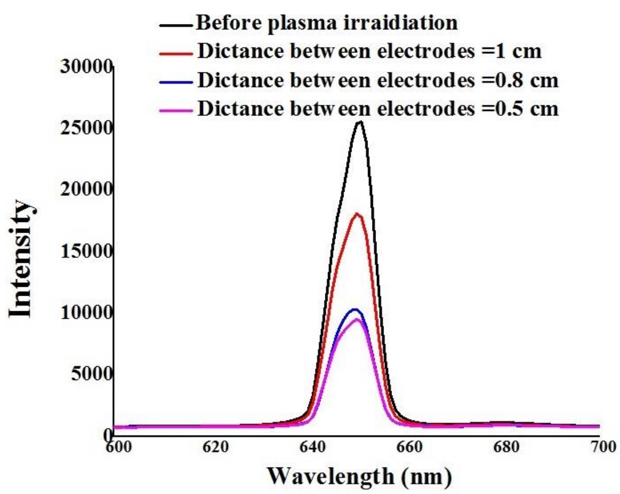

Fig. 8: spectrum of output intensity of the sensor coated ZnO before and after plasma irradiation at different glucose concentrations.

To understand the spectral response of the sensors more clearly, we have plotted the variation of normalized intensity (it is the ratio between the initial intensity to the intensity falling on the detector) with glucose concentration before and after plasma irradiation as shown Figure 9. It can be seen that the normalize intensity of sensor increases with increase in the value of glucose concentrations after plasma irradiation. The normalized intensity is found to be the maximum for sensor when the distance between the electrodes of 0.5 cm than the other sensors.

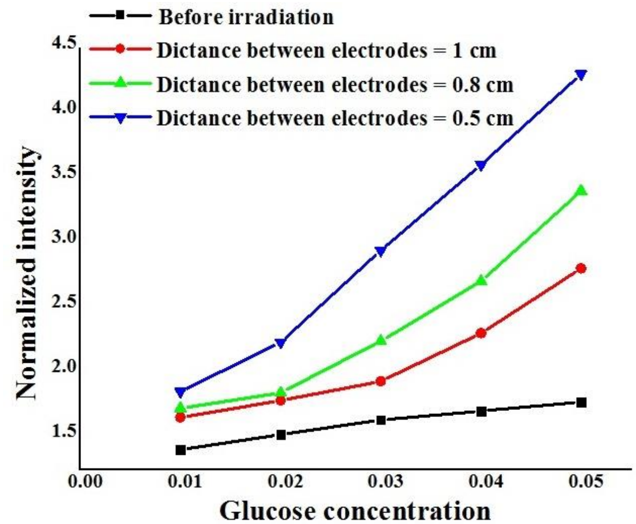

Fig. 9: Normalized intensity of the waveguide sensor versus different glucose concentrations.

To compare the performance of waveguide sensor before and after plasma irradiation, we have plotted the variation of sensitivity (the ratio between the normalized intensity and the glucose concentration) with the distance between the electrodes in Figure 10. It is found that the sensitivity increases with decreasing in the distance between the electrodes, because the possibility of produced the porosity and cracks increases when the distance between the electrodes is decreased, which leads to increase the impact of plasma irradiation on the surface of ZnO thin film. A maximum sensitivity of 62.7 is achieved when the distance between the electrodes was 0.5 cm which is at least six times larger than the sensitivity of the waveguide sensor before irradiation (9.2). Additionally, the sensitivity of sensors at distance between the electrodes of 1 cm and 0.8 cm found to be 28 and 42.2 respectively. The large value of the sensitivity obtained in the sensor can be used to detect a small changes in the surrounding medium which may be used to detect the presence of chemical or biological agents.

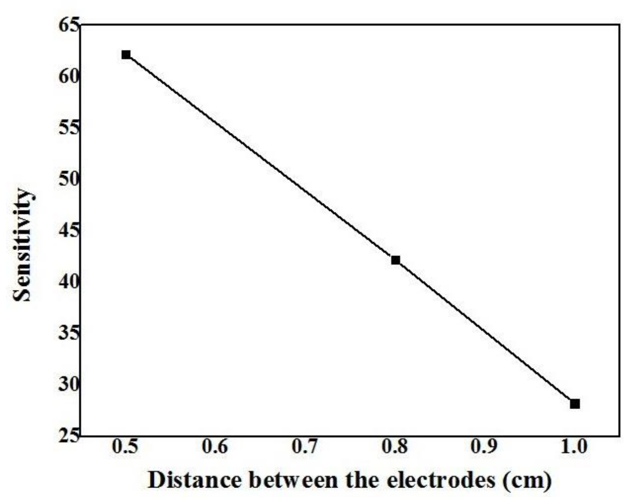

Fig. 10: Sensitivity of the waveguide sensor versus distance between the electrodes of DBD plasma.

IV. Conclusion

The waveguide coated ZnO thin films as sensor for glucose detection is fabricated and characterized in this study. The Physical properties of the sensor before and after (DBD) plasma irradiation are analyzed by uv-visible-IR, AFM and SEM analysis. The observation from AFM and SEM revealed that the morphology of the ZnO thin films are completely changed and the porosity and cracks produced on the ZnO surface after irradiation which enhancement the sensitivity of the sensor during the detection process. The results show that the waveguide sensor has a high sensitivity of 62.7 when the distance between the electrodes is 0.5 cm which is higher at least six time than the sensitivity of the sensor before irradiation (9.2). The high sensitivity obtained exhibits that the fabricated waveguide coated with ZnO thin film can be used as sensor to detect small concentration of glucose after plasma irradiation.

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CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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