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Manufacturing Zener diode using ZnO-CuO-ZnO/PSi structures deposited laser-induced plasma technique

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Abstract

In this paper, Zener diode was manufactured using ZnO-CuO-ZnO/PSi heterostructure that used laser-induced plasma technique to prepare the nanostructure films. Five samples were prepared with a different number of laser pulses, started with 200 to 600 pulses on ZnO tablet with fixed the number of laser pulses on CuO tablet at 300 pulses. The pulse energy of laser deposited was 900mJ using ZnO tablet and 600mJ using CuO tablet. All prepared films shown good behavior as a Zener diode when using porous silicon as substrate.

Key words
Zener diode, heterojunctions device, semiconductors.

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تصنيع الصمام الثنائي زينر باستخدام التركيبة أوكسيد الخارصين-أوكسيد النحاس-أوكسيد الخارصين/سليكون المسامي

صفا كمال مصطفى و رائد كامل جمال

قسم الفيزياء، كلية العلوم، جامعة بغداد

الخلاصة

في هذا البحث، تم تصنيع الصمام زينر الثنائي باستخدام بنية متجانسة (أوكسيد الخارصين-أوكسيدالنحاس-أوكسيد الخارصين)/سليكون المسامي التي تستخدم تقنية البلازما المحتثة بالليزر لإعداد الأغشية ذات التركيب النانوي. تم تحضير خمس عينات مع عدد نبضات مختلفة بالليزر تبدأ من 200 الى 600 لأوكسيد الخارصين مع عدد نبضات ثابت على قرص اوكسيد النحاس 300 نبضة. طاقة الليزر النبضية 900 ملي جول لترسيب أوكسيد الخارصين و600 ملي جول لترسيب أوكسيد النحاس. أظهرت جميع الأفلام المعدة سلوكا جيدا مثل ثنائي زينر عند استخدام السيليكون المسامي كركيزة.

Introduction

The Zener diode is a p-n junction device that allows the current to pass from positive semiconductor to negative semiconductor and vice versa if the voltages reach the Zener voltages, a breakdown large current passes through the diode when the voltage difference is n to p type. Zener diodes have very high doped p–n junction. It is one of the normal diodes that get the break down at a reverse voltage. It is operated in the breakdown region. It is widely used in the electronic circuit. It is an essential element of the electronic circuits. It is also used to protect high-voltage electronic circuits, and is used to protect high-voltage circuits [1].

When we connect the collector and the emitter together we consider them as the negative region and the base to be as the positive region, in which case we can use the NPN transistor as a surface the Zener diode surface. Surface Zener diode is closed to the base doping leads to create the electrical filed at breakdown voltage. The hot carriers made by acceleration in the field that leads to damage agree with the change in the Zener voltage of the junction [2, 3]. Because of this damage Zener diode can be used as 'Zener zap'. Zener zap diode are made as a p-n junction with an intensely n-type diffusion and moderately doped p-type diffusion. The breakdown voltage for the junction can determine by the doping in p-type diffusion. The emitter-base of a standard NPN transistor like the Zener zap [2, 4]. Zener diode is used as regulator to regulate the voltage across small circuits and also uses as a Waveform clipper [5-7]. In this paper, Zener diode was manufactured using ZnO-CuO-ZnO/PSi heterojunction structure. A Zener diode exhibits almost the same properties of conventional diode, except the device is specially designed so as to have a reduced breakdown voltage, the so-called Zener voltage. The Zener diode is therefore ideal for applications such as the generation of a reference voltage, or as a voltage stabilizer for low-current applications.

Experimental details

ZnO-CuO-ZnO/PSi heterostructure films were prepared experimentally in this work as shown in Fig.1. ZnO and CuO nanopowder where measured about (35-45 nm for ZnO and 40nm for CuO) with purity 99.99% has been used in this studying. It was pressed as a tablet using piston. The ZnO and CuO tablets have 2 cm diameter and 1 cm thickness.

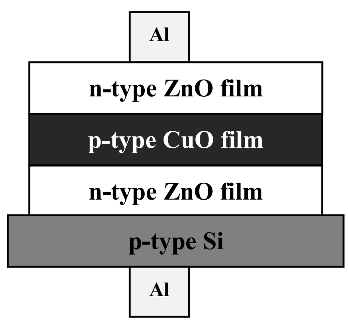

Fig.1: Schematic diagram of the ZnO-CuO-ZnO/Si heterojunction structure.

The films were deposited on two different materials: glass and porous silicon substrate using laser-induced plasma technique LIP at fixed pulse energy and different number of laser pulses and at RT, as shown in Table 1 and Fig.2. Nd:YAG laser source with wavelength 1064nm and chamber vacuum pressure 2.5×10^{-2} mbar has been used to prepare the ZnO-CuO-ZnO films. The distance between target and substrate was 1.5cm. Glass substrates that have 2.5×7.5 cm^2 areas are cleaned by the ultrasonic device using water for 10min and then use acetone for 10min. Finally, it dried in an oven in 1 h.

Table 1: The information of six films was deposited with thickness.

Sample No.	Parameters	$t(\mu m)$	Eg(eV)
S1	First and last layers were deposit ZnO at 900mJ and 600 shoots. Middle layer is deposit CuO at 600mJ and 300 shoots.	0.429	3.85
S2	First and last layers were deposit ZnO at 900mJ and 500 shoots. Middle layer were deposit CuO at 600mJ and 300 shoots.	0.370	3.8
S3	First and last layers were deposit ZnO at 900mJ and 400 shoots. Middle layer were deposit CuO at 600mJ and 300 shoots.	0.343	3.75
S4	First and last layers were deposit ZnO at 900mJ and 300 shoots. Middle layer were deposit CuO at 600mJ and 300 shoots.	0.257	3.62
S5	First and last layers were deposit ZnO at 900mJ and 200 shoots. Middle layer were deposit CuO at 600mJ and 300 shoots.	0.200	1.3

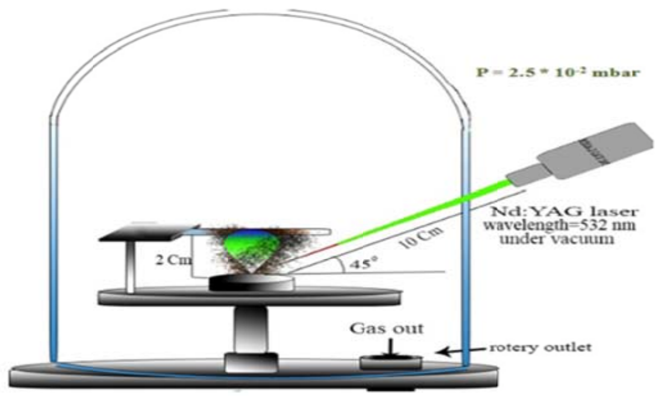

Fig. 2: Schematic diagram of LIP with (λ =1064nm) [8].

The films that prepared on glass substrate were used to measure the optical properties using UV/ Visible SP-8001 spectrophotometer at different conditions. P-type (111) silicon wafers were used to manufacture heterostructure device. Five films were prepared, as shown in the Table 1. The films from sample 1 to sample 5 were deposited on porous silicon with change in the number of laser pulses for ZnO with fixed the number of laser pulse of CuO. The first column represents the sample number and the second column represents the energy and number of laser pulses that used to prepare the films. The third column represents the film thickness. Finally, the forth column represents the energy gap of prepared film.

The electrical measurements for heterostructure (Zener diode) included current-voltage characteristic measurements were measured, as shown in Fig.3 at two state forward and reversed bias.

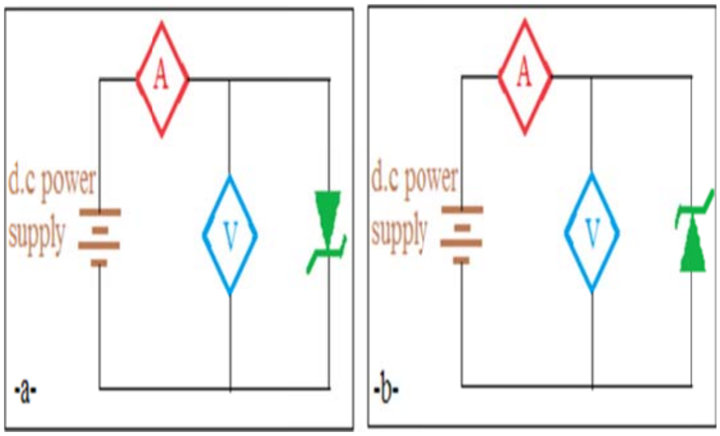

Fig. 3: The circuit for I-V measurements for heterojunction, (a) Forward (b) Reverse bias.

Results and discussion

The SEM images of the first layer (ZnO) of heterostructure device that deposited on pores silicon using LIP technique at RT were shown in Fig.4, where, this image showed the nanoparticle structures of ZnO, where their value ranges from 1nm to 20 nm. Fig.5 represents the SEM of pores silicon configuration which are up 10 nm.

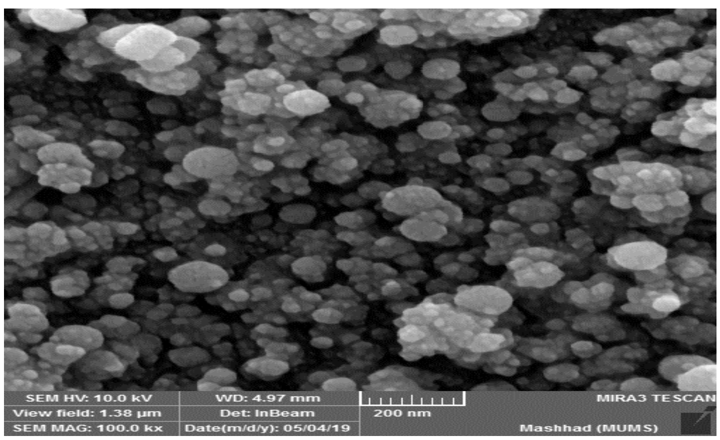

Fig. 4: SEM of ZnO nanostructure (cluster structure) deposit on porous silicon at RT.

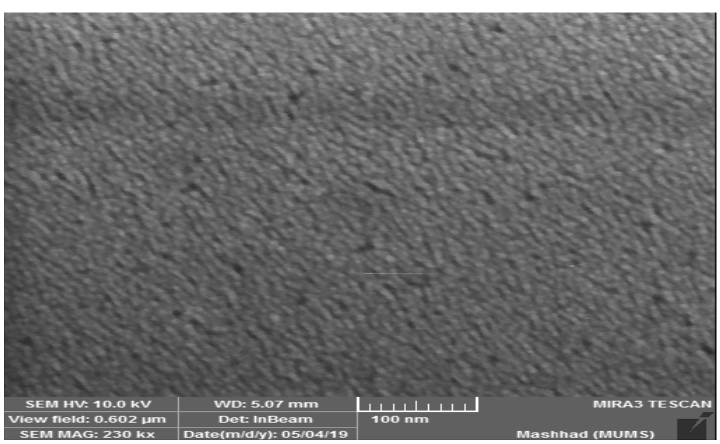

Fig.5: SEM of pores silicon configuration.

The absorbance spectrum as function of wavelength in the range (300-1100) nm for ZnO-CuO-ZnO films deposited on glass substrate using LIP at RT, was shown in Fig.6. It can be seen from this figure that the absorption spectra of the films prepared in general have high values in the visible and infrared regions and low values in the range of ultraviolet region, which depends mainly on the energy gap values of those materials. The absorbance spectra of all ZnO-CuO-ZnO films increase with increasing the number of laser pulses for ZnO films, where the increasing is due to increase concentration of the particles of the deposited substances when the eradication time increases this shows that the relationship between the concentration and the number of pulses is not linear [6]. The optical absorption coefficient constant (α) has been calculated using the following equation [1]:

$$\alpha = 2.303 A/t \quad (1)$$

where A is the absorbance and t is the thickness of prepared films that appear in the Table 1.

The variation of αhυ as a function of photon energy for ZnO-CuO-ZnO films was shown in Fig.7. The variation of (αhυ) is estimated by Tauc's Equation [3]:

$$(\alpha h\upsilon) = A(h\upsilon - E_g)^n \quad (2)$$

where A is a constant, α is an absorption coefficient, hυ the incident photon energy and (Eg) is the optical energy band gap. This equation used n=1/2 for direct transition [1, 3]. In Fig.7, the variation of (α hυ) spectra for ZnO-CuO-ZnO films increase with an increasing number of laser pulses for ZnO in the first and third layers. The reason for this behavior is that an increase in the thickness of the ZNO film and thus the value of the energy gap of structure increases and the value of the energy gap of structure is shifted to ZnO. Table 1 shows the effect of the films thickness on the energy gap.

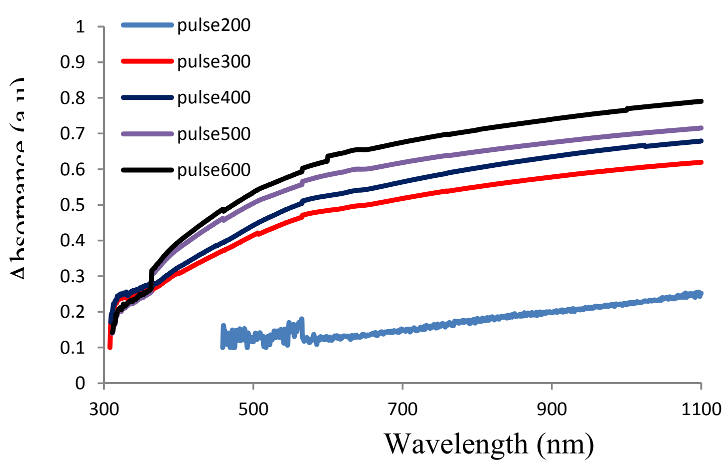

***Fig.6:** The absorption spectra of ZnO-CuO-ZnO films deposited on glass substrate at a different number of laser pulses.*

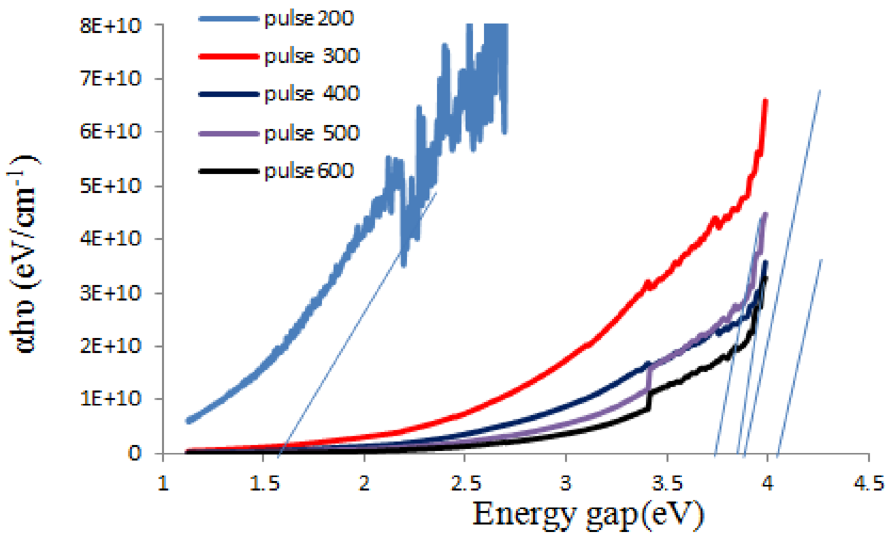

Fig.7: (αhυ) vs energy gap (eV) of ZnO-CuO-ZnO films at different number of laser pulses.

The variation of refractive index spectrum various wavelengths of ZnO-CuO-ZnO films at different number of laser pulses were shown in Fig.8. Fig.8 shows decreasing in refractive index spectrum with increasing the number of laser pulses on ZnO tablet. The n values are between (2-2.6) for all samples except for the S5 where n are ranging (1-2.5). The reason for the behavior of this sample is that the thickness of the CuO in film is thicker than ZnO, That's why the sample 5 behaves like a CuO film.

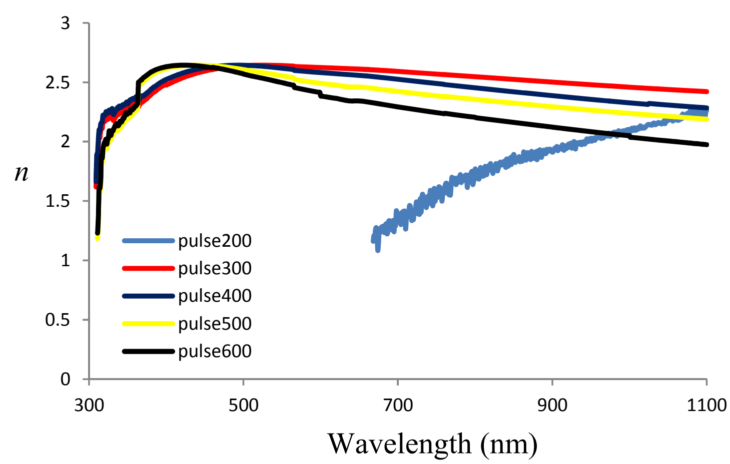

Fig.8: The n spectra of ZnO-CuO-ZnO films at different number of laser pulses.

The variation of the extinction coefficient various wavelengths of ZnO-CuO-ZnO films were shown in Fig.9. The extinction coefficient spectra are decreasing with increasing of number of laser pulses of ZnO tablet. *K* values range from 0.5-1.5 for all samples except S5 ranging from 0.6-0.3. The reason for this behavior is that an increase in the thickness of the ZNO film and thus the value of the *K* of structure decrease and the value of the *K* of structure is shifted to ZnO. The reason for this behavior is due to the same reason that the CuO is the thickest of the ZNO.

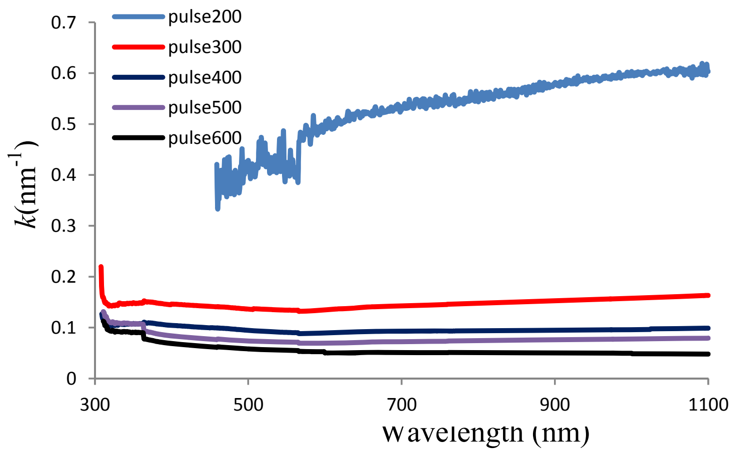

Fig.9: The k spectra of ZnO-CuO-ZnO films at different number of laser pulses.

The real part of the dielectric constant value depends on the refractive index (n) and the extinction coefficient K, but the imaginary part depends on the refractive index (n) only. The spectrum of the excited electron can be explained by dielectric constant (real and imaginary parts), where the imaginary part represents the absorption of energy from the electric field because of the molecules that possess the bipolar moment in the material, but the imaginary part represents the low speed of light in the material. The real and imaginary parts evaluated by the following equations [5]:

$$\varepsilon r = n^2 - k^2 \quad (3)$$

$$\varepsilon i = 2nk \quad (4)$$

where (εr) is a real part and (εi) is imaginary part of the dielectric constant. Fig.10 shows the spectra of imaginary part dielectric constant (εi), where (εi) decreasing with increasing the number of laser pulses on ZnO tablet. Fig.11 represents the imaginary part of dielectric constant (εi) versus wavelength of ZnO-CuO-ZnO films at different number of laser pulses on ZnO tablet, where the (εi) spectrum is increasing with increasing the number of laser pulses on ZnO tablets.

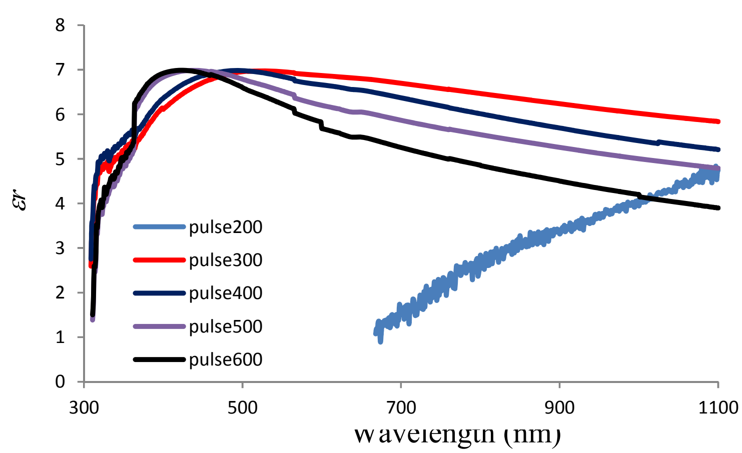

Fig.10: The εr spectra of ZnO-CuO-ZnO films at different number of laser pulses.

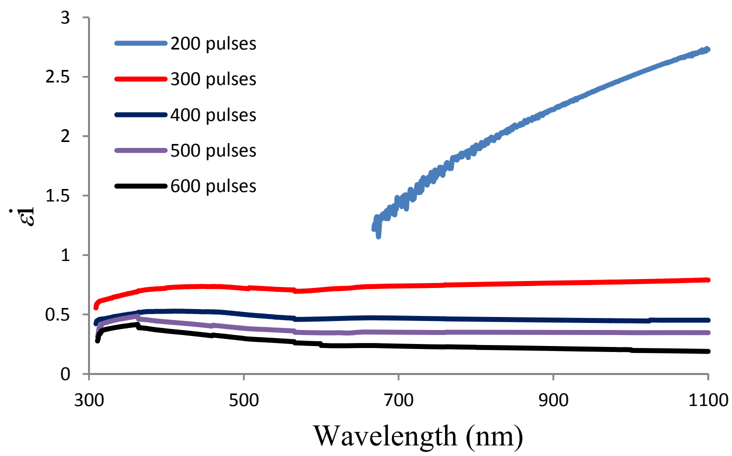

Fig.11: The εi spectra of ZnO-CuO-ZnO films at different number of laser pulses.

The diode shows resistance as any load in the circuit. The resistance of the diode is different from the resistance being nonlinear relationship. Diode resistance does not change in a linear sense but in a parabolic sense. The diode resistance can be written as follows:

$$R=V_t/I_d \quad (5)$$

where V_t represents the thermal voltage and I_d represent the current passing through the diode. The thermal voltage formula is $V_t = kT / q$ where k is the Boltzmann constant, T is the absolute temperature of the pn junction (300 K), and q is the magnitude of electron charge.

When looking at the figures from 12 to 16, Current-voltage characteristic of a Zener diode with a breakdown voltage were fixed in Table 2. We observe from Table 2, that there is a change in the voltage scale in the positive direction (forward bias) and negative direction (reverse bias). Through the figures, we observe that if the reverse bias is connected, at a certain voltage value called (Zener Voltage) the value of the flow current becomes very high. This area is called breakdown region and this voltage is called breakdown voltage. But in the case of forward bias, we observe that diode act as a normal diode and also note that the diode will not work until it reaches a certain voltage value beyond the threshold voltage value. Normal diodes are not designed to operate in the breakdown region, whereas Zener diodes operate reliably in this region. Zener diodes are widely used in electronic equipment of all kinds and are one of the basic building blocks of electronic circuits. They are also used to protect circuits from overvoltage. Another mechanism that produces a similar effect is the avalanche effect as in the avalanche diode. The two types of diode are in fact constructed the same way and both effects are present in diodes of this type. In silicon diodes up to about 5.6 volts as shown in Fig.13, the Zener effect is the predominant effect and shows a marked negative temperature coefficient. Above 5.6 volts, the avalanche effect becomes predominant and exhibits a positive temperature coefficient, where we did not get this situation in our work. Modern manufacturing techniques have produced devices with voltages lower than 5.6 V with negligible temperature coefficients, but as higher-voltage devices are encountered, the temperature coefficient rises dramatically as shown in Figs.14 and

15. Zener and avalanche diodes, regardless of breakdown voltage, are usually marketed under the umbrella term of "Zener diode". Under 5.6 V, where the Zener effect dominates, the IV curve near breakdown is much more rounded, which calls for more care in targeting its biasing conditions. The IV curve for Zener's above 5.6 V (being dominated by Avalanche), is much sharper at breakdown.

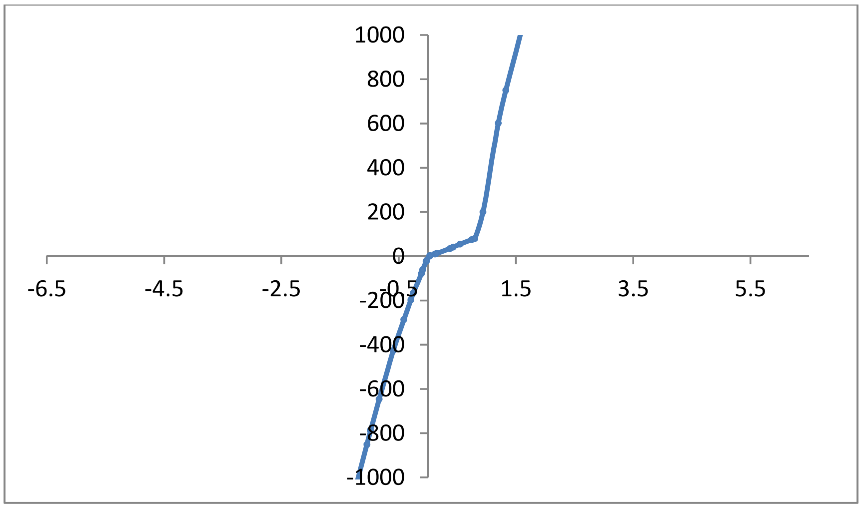

Fig. 12: I-V characteristic of Zener diode for sample 1.

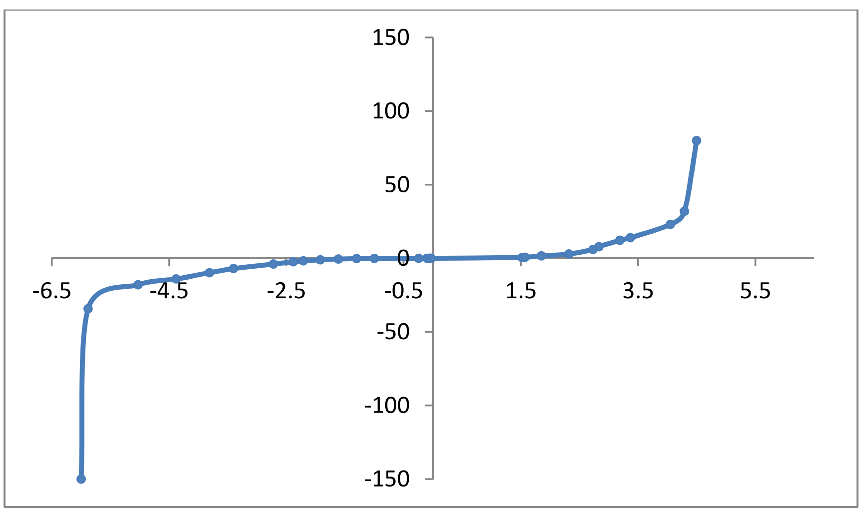

Fig.13: I-V characteristic of Zener diode for sample 2.

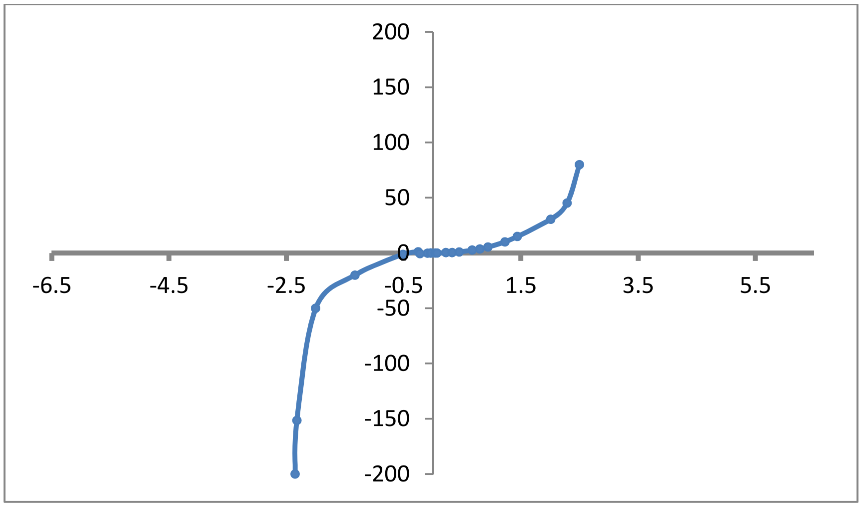

Fig.14: I-V characteristic of Zener diode for sample 3.

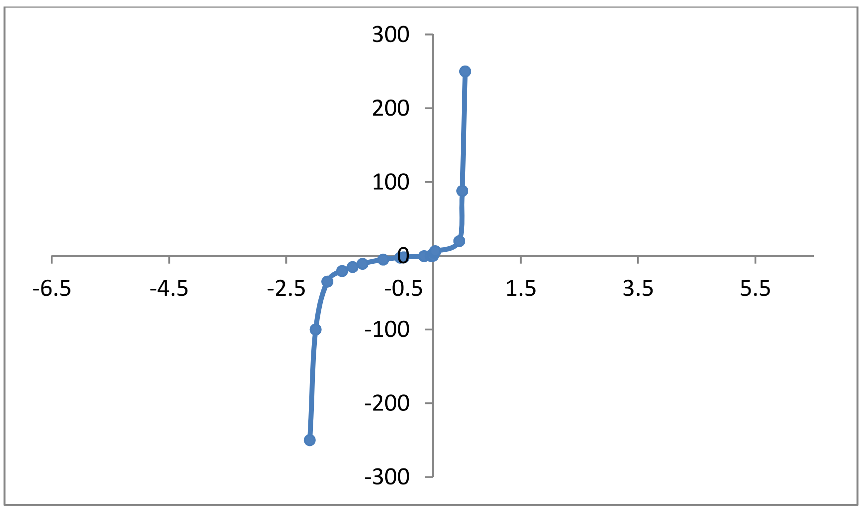

Fig.15: I-V characteristic of Zener diode for sample 4.

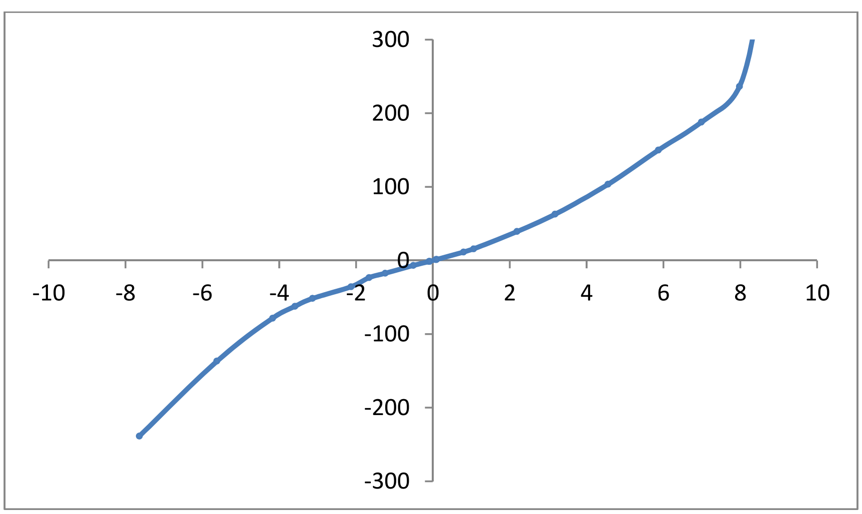

Fig.16: I-V characteristic of Zener diode for sample 5.

Table 2: Represents forward and revers voltage values for Zener diode.

Sample number	Forward voltage (V)	Reverse voltage(V)
S1	0.75	1.5
S2	4.29	5.88
S3	2.29	2
S4	0.45	1.8
S5	7.98	4.17

Conclusion

Through the above, we conclude that the laser-induced plasma technique is very important in the generation of films. The SEM images appear nanostructures were deposited over porous silicon. Also, we concluded that the less the thickness of the films have less of the energy gap. With regard to the Zener diode to argue that the fewer the number of laser pulses will have less forward and reverse voltage. Modern manufacturing techniques have produced devices with voltages lower than 5.6V with negligible temperature coefficients, but as higher-voltage devices are encountered, the temperature coefficient rises dramatically as shown in Figs.14 and 15.

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