International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.9, pp 1084-1092, 2017

Fabrication and Study the Characterization of BaO/p-Si Heterojunction Photodedecter

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Abstract : Barium oxide thin films was deposited by chemical spray pyrolysis (CSP) at 450 °C substrate temperature and different thickness (50,74, 91, and 103) nm on the texturized p-Si wafer to fabricate BaO/p-Si heterojunction photodetector. Structural, electrical and photovoltaic properties are investigated for the samples. XRD analysis reveals that all the as deposited BaO films show polycrystalline structure, without any change due to increase of thickness. Average diameter calculated from AFM images shows an increase in its value with increasing thickness, ranging from 77.92-95.76 nm. The electrical properties of heterojunction were obtained by I-V (dark and illuminated) and C-V measurement. I-V characteristic of the BaO/p-Si heterojunction shows good rectifying behavior under dark condition. The ideality factor and the saturation current density was calculated. The built- in potential (V_{bi}), carrier concentration and depletion width layer are determined under different thickness from C-V measurement.
Keywords: n-BaO/p-Si; chemical spray pyrolysis; heterojunction photodetecter.

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1. Introduction

The alkaline earth metal oxides are technologically important materials because of their unique physicochemical properties [1,2]. Among them, barium oxide (BaO), has attracted special interest because of its low work function, electron emissivity and catalytic properties. Special effort has been made on the formation of BaO ultra-thin films on surfaces. Such atomic overlayers of BaO on surfaces like (depletion width layer (W)) and P_t have given notable technological applications in the fabrication of high current density cathodes,[3,4] and in the design of modern catalysts for NOx compounds storage in exhaust emission from motor vehicles [5,6]. In order to understand better the properties of the BaO/substrate, which finally determine the technological usefulness of such adsorption systems, it is required to study how the BaO overlayer develops on surfaces from the very early stages, namely at sub-monolayer to monolayer coverages. The usual way of developing BaO overlayers on surfaces is by the oxidation of preadsorbed Ba on the substrate [7 – 9] by adsorption of Ba in an activated oxygen ambient [7] and by direct deposition from a BaO evaporation source.[10 – 12] . BaO thin films with p-Si have been used in many applications such as photodetectors owing to its good optical and electrical properties, ease of fabrication, low cost [13-15]. The aim of this study was focused on the fabrication and characterization of BaO/p-Si heterojunction for solar cells with different thin film thickness utilizing chemical spray pyrolysis technique.

2. Experimental

In this study, Mirror-like single-crystal p-Si (100) with a thickness of (450 µm) and a resistivity of (1-9) Ω. cm was used as a substrate. These substrates were put in diluted 1% HF solution to remove the native oxide, washed with deionized water and dried with nitrogen gas. Square-shaped p-type silicon substrate, (1×1) cm^2 area, were prepared. The condition of deposition was summarized in the following: (0.1M) solutions were prepared by dissolving barium acetate ($Ba(Cl)_2 \cdot 2H_2O$) in deionized water .The adding of few drops of glacial acetic acid were done in order to obtain a stabilized solution. The substrate temperature was kept at 450 °C during the process of deposition. The carrier gas (compressed nitrogen (4.5 bar pressure) and solution are fed into a sprayer nozzle to obtain BaO/silicon heterojunction with different thickness. Ohmic contacts of these devices were made by evaporating a thin AL sheet mask strips on the BaO thin film and a thick Al on back surface of Si.

The thin film thickness was determined by using (LIMF-10 Optical Thin Film Measurement). X-ray diffraction (XRD) with CuKα radiation (λ = 1.5418 Å) was used in order to identify the structural of the deposited BaO films. The surface morphology was studied by atomic force microscope (AFM).The I-V characteristics of the Al-BaO/p-Si heterostructure were measured using a Keithley source meter (model 2430). The measurements were performed in dark and under light.

The capacitance–voltage (C–V) characteristic of a BaO/p-Si heterojunction was obtained using an LCZ meter at a fixed frequency of (1 MHz).

3. Results and Discussion

BaO/p-Si are prepared by (CSP) of intrinsic BaO. The structural, and electrical properties of BaO/p-Si have been studied for different thicknesses.

3.1 X-Ray Diffraction Analysis of BaO Deposition on p-Si

Figure (1) shows the XRD spectrum of BaO thin films grown on silicon substrate with different thickness (50,74,91, and 103) nm. Each sample shows reflection peaks from BaO thin film and Si substrate. The single crystallinity of Si substrate from (100) plane is more prominent than those of BaO thin films peaks. Two prominent diffraction peaks viz. (111), and (200) which corresponding to different angle (27^o) and (32^o), respectively. In the sample deposited at (5 no. of spray) interval, because the low thickness leads to a very thin film, (111) diffraction peak was detected. Better crystallinity is apparent at higher thickness and one-peak (100) corresponding to different angle (69^o) of Si are observed. Table (1) show the crystallites size estimated by Debye Scherrer's equation ($D_S = \frac{0.94\ \lambda}{\beta\ COS(\theta)}$) where (D_s crystallite size, λ: is the X-ray wavelength (1.5406Å) , θ full width at half maximum and θ: is Bragg's angle which represents the incident angle (10^o -70^o).

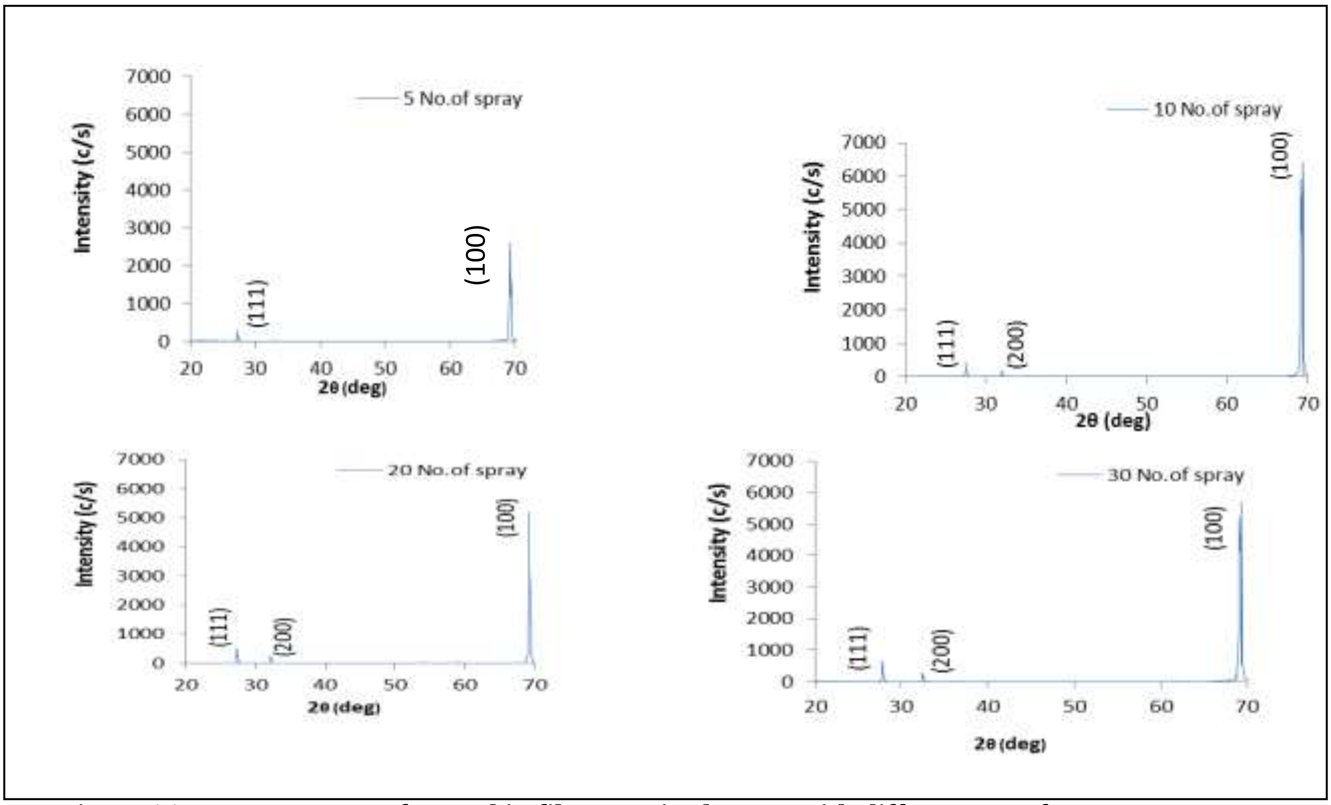

Figure (1): XRD patterns of BaO thin films on Si substrate with different no. of spray (5,10, 20, and 30) at 450 °C.

Table (1): The crystailline size , dislocation density, micro strain, and number of plans for BaO/p-Si at different thickness at 450 °C.

No. of Spray	Thickness (nm)	2θ (Degree)	D_S (nm)	$\delta_D X10^{14}$ (lin m^{-2})	$SX10^{-4}$ (lin^{-2} m^{-4})	N_ℓ
5	50	27.24	85.38	0.34	2.12	8.03335E-05
10	74	27.48	114.64	0.34	2.11	0.00011871
		31.96		0.48	2.51	
20	91	27.32	128.57	0.34	2.11	1.82666E-05
		32.20		0.46	2.47	
30	103	27.80	132.96	0.34	2.11	2.06117E-05
		32.44		0.46	2.47	

3.2 AFM of BaO Deposition on p-Si

The 3-D AFM images and granularity accumulation distribution charts for BaO thin films deposited on silicon substrate with different thickness shown in Figure (2). The calculated values of the grain sizes and surface roughness are calculated and listed in Table (2). It has been observed that a surface roughness has been equal to (0.42, 2.12, 3.66, and 2.76) nm for the different thickness (50,74,91,and 103) nm respectively. The grain size has been observed (77.92, 108.90, 91.60, and 95.76) nm for (50,74,91,and 103) nm respectively.

Table (2): The grain size, average roughness, and root mean square for BaO thin films deposited on Si substrate with different thickness at 450°C.

No. Of spray	*Thickness(nm)*	*Grain size (nm)*	*Roughness average (nm)*	*Root mean square(nm)*
5	50	77.92	0.42	0.50
10	74	108.90	2.12	2.65
20	91	91.60	3.66	4.54
30	103	95.76	2.76	3.31

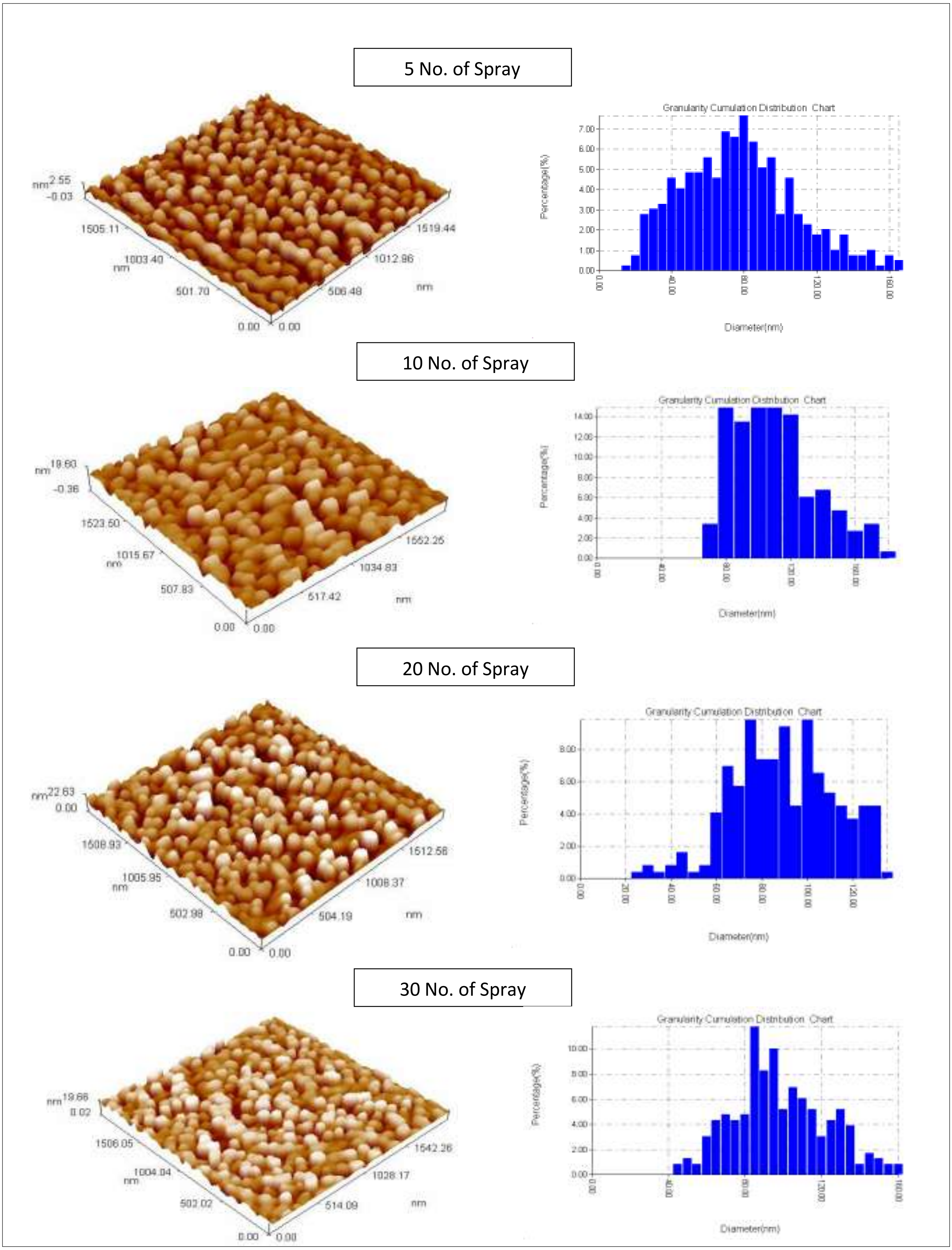

Figure (2): 3-D AFM image and granularity accumulation for BaO/Si with different no. of spray (5,10, 20, and 30) at 450°C .

Figure (3) shows the I-V dark characteristics in forward and reverse direction of Al/BaO/p-Si/Al photoconductive detectors deposited at bias thickness. The forward current of all photodetectors is very small at voltage less than 0.5V. This current is known as "recombination current" which occurs at low voltages only. It is generated when each electron excited from valence band to conduction band which will recombine with a hole in the valence band to get the balance back.

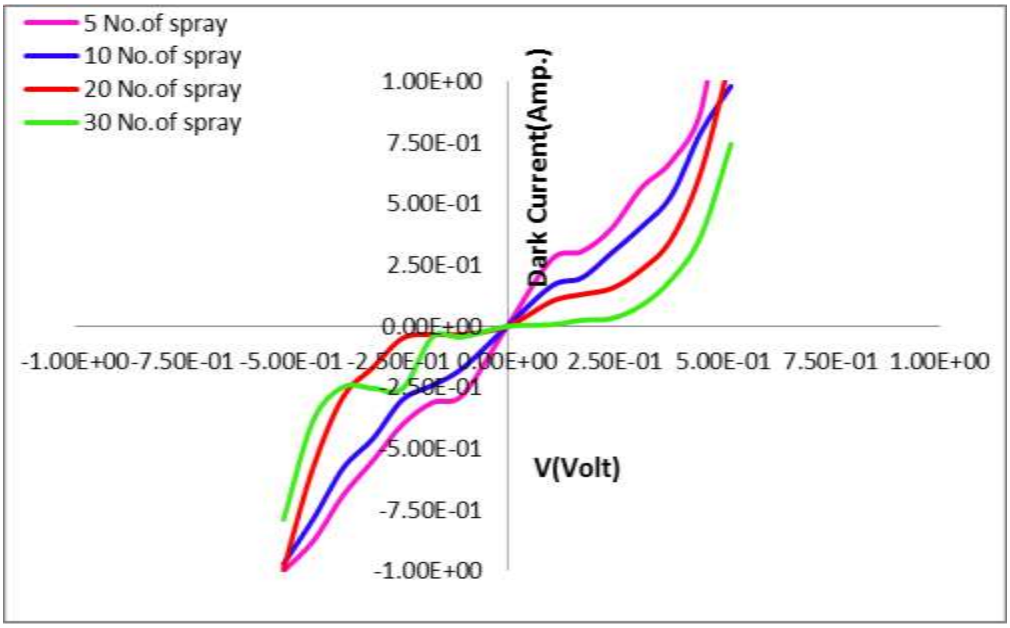

Figure (3): I-V Characteristics curves for Al/BaO/p-Si photocondective detectors under dark at different no. of spray (5,10, 20, and 30) at 450°C.

From Figure (3) we can see that the forward dark current decreased in dark current for other current densities that can be ascribed to increasing of layer resistance which in turns decreases the thermally generated carriers ($v < 3K_BT/q$) , this result agrees with [16].

Figure (4) shows the semi–log relation between dark forward current density and bias voltage ((-1) - 1)) Volt for BaO/Si photoconductive detectors at different thickness. We can recognize two regions in this figure; the first one represents the recombination current, while the second region represents the tunneling current.

We can see from this figure that the saturation current increases with the increasing of thickness. From the first region, the ideality factor (η) of BaO/Si photoconductive detectors has been calculated using($\eta = \frac{q}{KT}\left(\frac{dV}{dlnI}\right)$) (V) is the applied voltage, (K) Boltizeman constant, (I) dark current ,and (T) is the temperature in Kelvin. It may be observed that the ideality factor increases with the increasing of thickness as shown in Table (3).

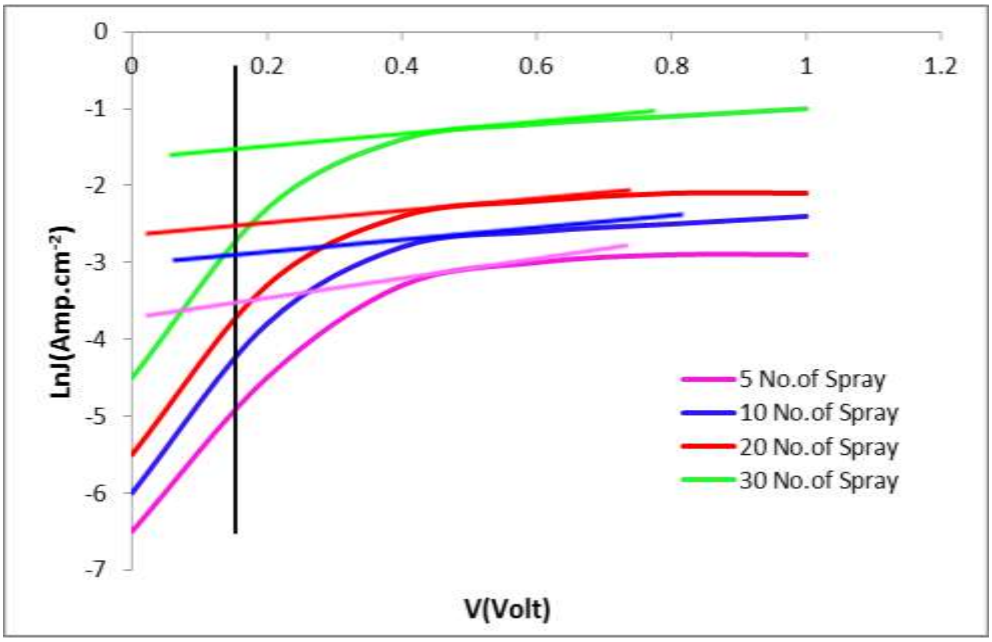

Figure (4): Ln (J) versus (V) for fowared bais of dark for Al/BaO/p-Si photocondective detectors at different no. of spray (5,10, 20, and 30) at 450°C.

Table (3): Ideality factor, Barrier height, and Saturation current density values for Al/BaO/p-Si photocondective detectors with different thickness.

Thickness (nm)	Ideality factor(η)	Barrier height(Φ_b) (eV)	Saturation current density(J_S) (μAmp/cm^2)	Tunneling factor (ɣ) (V^{-1})
50	1.808	0.553	0.0016	0.19
74	1.851	0.540	0.0027	0.18
91	1.896	0.527	0.0044	0.22
103	2.162	0.462	0.054	0.25

Figure (5) shows the current–voltage (I–V) characteristics of the Al/BaO/p-Si/Al heterojunctions prepared at different thickness under light illumination condition. It is evaluated that the series resistance and interface state density properties have an important effect on the I–V curve of the heterojunction under illumination. The light illumination increases the reverse current of the heterojunction. This indicates that the resistance of the diode decreases with the illumination .

The current in the reverse bais is increased with the illumination. This suggests that the carrier charges are effectively generated in the junction by illumination. This effect is due to electron hole pair generation. When the diode illuminated with light, a current is created in the device. The photo current at a given voltage for the Al/BaO/p-Si/Al heterojunction under illumination is higher than that under dark condition. This indicates that the light illumination increases the production of electron–hole pairs. The increase in charge production depends on the difference in the electron affinities between BaO semiconductors and Si. No saturation in photocurrent with the increasing of light intensity is noticed (good linearity characteristics).

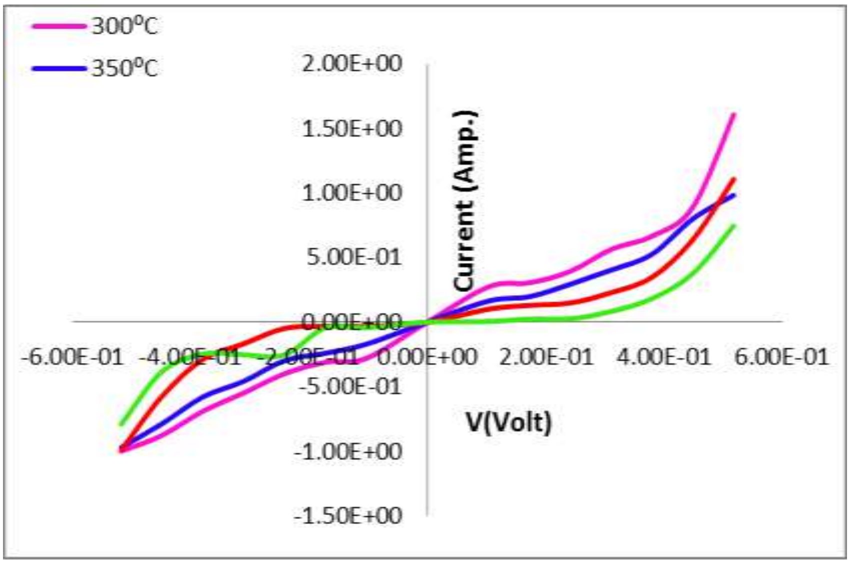

Figure (5): I-V Characteristics curves for Al/BaO/Si photoconductive detectors under illumination at different no. of spray (5,10, 20, and 30) at 450 ℃.

Figure (6) demonstrate the variation of the junction capacitance with the reverse bias voltage for Al/BaO/p-Si/Al heterojunctions prepared at different thicknesses and different temperature respectively. It is observed that the junction capacitance decreases with the increase the reverse bias voltage. This behavior is due to an increase in the width of depletion layer with the increase reverse biased voltage, and this behavior confirms junction formation.

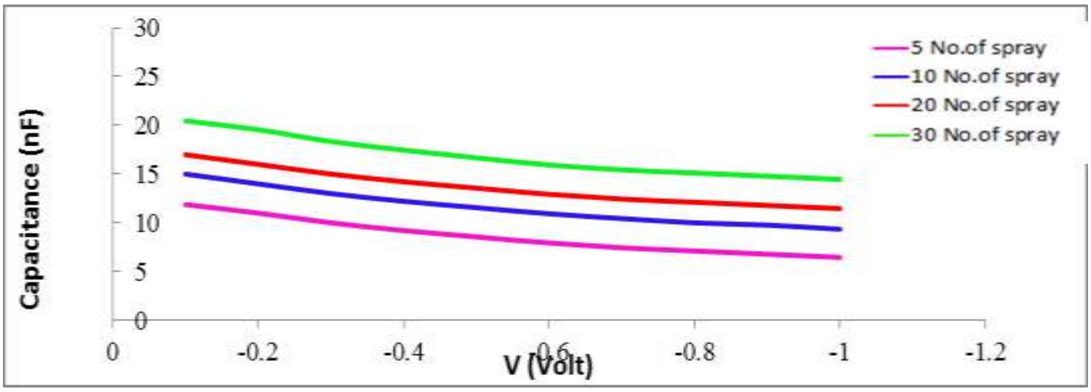

Figure (6): The variation of capacitance as a function of voltage for Al /BaO /p-Si heterojunction at different no. of spray (5,10, 20, and 30) at 450°C .

Figure (6) give the variation of capacitance with bias voltage at different thicknesses and different temperature respectively. It is observed that the capacitance increase as thickness decreased, this can be explained by the rise in the value of capacitance due to the small area of depletion layer width at these conditions and is further supported by the large values of V_{bi} and thus increase in the value of capacitance accordingly. Increasing the reverse bias voltage leads to a decrease in the junction capacitance. This can be ascribed to the increasing the depletion width with the bias voltage. There is an increase in capacitance when thickness and temperature increase , this is due to reduce defects and increase in the concentration of carriers on both sides of heterojunction, that leads to increase in the value of V_{bi} and therefore low width of the depletion layer, which in turn leads to increase the capacitance value. Increasing of junction capacitance can be attributed to the uniformity of ablated particles which in turns reduce the structural defects such as clustering and recombination. Built-in-potential (V_{bi}) can be estimated by extrapolating the linear part of the curve to $1/C^2 = 0$ points as shown in Figure (7).

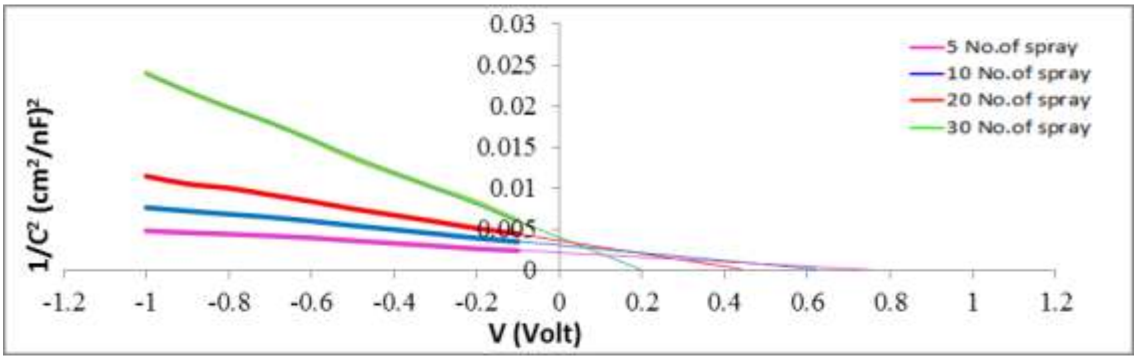

Figure (7): The variation of ($1/C^2$) as a function of reverse bias voltage for BaO/p-Si heterojunction at different no. of spray (5,10, 20, and 30) at 450°C .

The linear relationship of $1/C^2$ –V plot confirms that the all heterojunctions are abrutpt type.

From $1/C^2$ –V plots, the built-in potential V_{bi} was calculated and listed in Table (4). The obtained results revealed that the built-in potential is dependent on preperation condition of Al/BaO/p-Si .

From $1/C^2$ V plot, the doping concentration of Si substrate was calculated from equation ($W = \frac{\varepsilon_s A_j}{C_0}$) where ($W$) the depletion width layer , (C_0) is the capacitance at zero biasing voltage ,(ε_s) is semiconductor permittivity and (A_j) is the effective area of the junction.

Table (4): Values of V_{bi} as a function of different thickness for BaO/Si heterojunction.

No. of spray	Thickness (nm)	V_{bi} (V)
5	50	0.61
10	74	0.60
20	91	0.41
30	103	0.20

Conclusions

High quality BaO thin films were successfully deposited on silicon substrates by chemical spray pyrolysis. The XRD analysis shows that all the deposited films were polycrystalline and the crystallite size was in (111) direction. Good rectifying and great photovoltaic behaviors are examined and analyzed by *I-V* measurements minutely. The ideality factor and the saturation current density of BaO/Si heterojunction photodetecter are obtained with different thickness. The ideality factor is less than 2, indicating that the diode exhibits an ideal behavior. The heterojunction shows a great photovoltaic effect under power (160 mW) White lamp illuminate. The quantum efficiency initially increases with the increasing of thickness, while the C-V measurement revealed that those prepared devices are of abrupt type.

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