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REGULAR ARTICLE

Fabrication of p-Bi_2O_3/n-CdSe Nanoparticles Heterojunction at Different Substrate Temperatures

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Cadmium selenide and bismuth oxide nanoparticles were synthesized by chemical bath deposition technique. CdSe nanoparticles have a negative conductivity (n-type) and Bi_2O_3 have a positive conductivity (p-type), both are formed p-n heterojunction. Bi_2O_3 semiconductors were deposited by spray pyrolysis at various substrate temperatures (100, 200 and 300 °C) for every 10 sprays on CdSe semiconductors have been prepared on the glass substrates by CBD. The electrical characteristics for Bi_2O_3/CdSe diode at (100, 200 and 300 °C) under dark and illumination have been studied. The substrate temperature was affected by the diode parameters such as the forward and the saturation current. Threshold voltage has been decreased as increasing the substrate temperature at 300 °C. Ideality factor of Bi_2O_3/CdSe nanoparticles was changed with substrate temperatures, it was increased and have maximum value at 300 °C. Bandgap energy has minimum value at 100 °C and it increases by approximately 0.15 % when compared to the substrate temperature 300 °C. Cross-sectional area of Bi_2O_3/CdSe nanoparticles were investigated by cross-sectional SEM at (100, 200 and 300 °C). The surface has become roughness at 300 °C and it led greatly stimulated grain growth.

Keywords: Bi_2O_3 Nanoparticles, CdSe films, Spray, CBD, Heterojunction.

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1. INTRODUCTION

Bismuth trioxide nanoparticles have a wide interest of many researches due to some important characteristics' factors of their values such as mechanical strength, photoconductivity, energy gap, transparency and refractive index [1-2]. Many applications are suitable for Bi_2O_3 example optoelectronic, solar cell, photo detectors, sensors and antireflecting coating [3] because it has distinctive characteristics such as high photosensitivity to ultraviolet radiation [4], high refractive index larger than 2.4 and high oxygen conductivity 1-1.5 $(\text{ohm·cm})^{-1}$ [5]. These thin films were fabricated using different techniques such as anodic oxidation [6], CVD [7-8], sputtering [9], Laser ablation [10] and chemical bath method [11-14].

CdSe-based nanostructures have many applications in different fields such as solar cells [15-17] and thin-film transistors [18]. They have been electrical conductivity n-type. In this paper, CdSe was prepared by CBD method on glass substrates, then Bi_2O_3 (p-type) semiconductor nanoparticles were deposited on CdSe films by spray pyrolysis at various substrate temperatures (100, 200 and 300 °C) and the electrical properties were discussed.

2. EXPERIMENT DETAILS

CdSe Nanoparticles were synthesized by adding 0.5M sodium sulphite on the 0.5 M Se powder, which has been put in a reflux system with distilled water and heated for 3 hours to be form sodium selenosulphite. Moreover, we prepared 0.5 M $CdCl_2$ and 1 ml ammonia in the (10 ml) distilled water after that they were mixed with the Sodium selenosulphite and they were placed in the bath about 20-24 hours at room temperature.

Bismuth oxide nanoparticles were synthesized from mixing 4.08 gm of bismuth nitrate Bi $(NO_3)_3$ which it dissolved in 70 ml of deionized water by adding 4 gm of potassium hydroxide KOH and 2.5 ml ammonium nitrate NH_4NO_3. The solution was heated for about 2 hours by CBD technique where it is formed Bi_2O_3 nanoparticles. After that the precipitate is separated from the solution using filter paper and the solution is used by spray pyrolysis at (100, 200 and 300 °C) substrate temperatures on the CdSe layer for every 10 sprays and the distance was 20 cm nozzle to substrate.

3. RESULTS AND DISCUSSIONS

Figures (1-3) show (I-V) curve for Bi_2O_3/CdSe diode at various substrate temperatures (100, 200 and 300 °C) under dark and illumination states respectively.

The temperature has been affected by the diode electrical properties. The real reason is the increase in minority charge carriers due to electron-hole pairs which lead to decrease in the junction voltage V_B because the relative decrease in the concentration of majority and minority charge carriers, Moreover the width of the depletion region also

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decreases. One of the negative results of the increase in temperature at 300 °C is the increase in the leakage current or saturation resulting from the minority carriers which due to the loss of an important property of the crystalline diode, which is preventing the passage of current in reverse bias as shown in Fig. (1, 2 and 3).

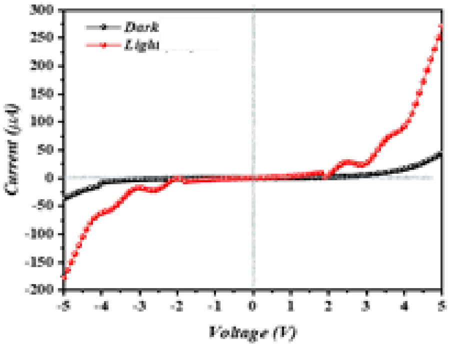


Fig. 1 – *I-V* Plot of Bi_2O_3/CdSe diode at 100 °C

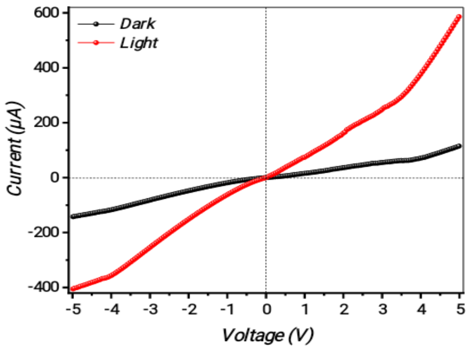


Fig. 2 – *I-V* characteristics of 200 °C sample under dark and illuminated states

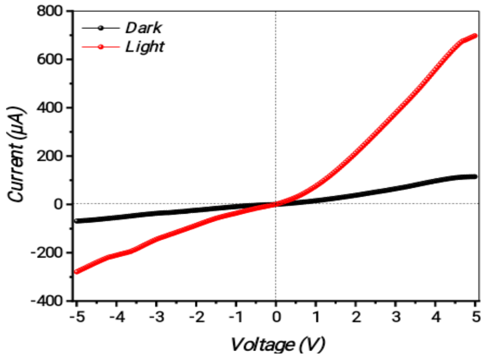


Fig. 3 – *I-V* curve of sample under dark and illuminated at 300 °C

The forward current does not grow with the same strength as the reverse current when the temperature is increased, as can be seen from Figure 4. It depends mainly on the concentration of impurities (donors and acceptors). It can be seen that the decrease in the barrier voltage with the increase in temperature at 300 °C is the direct reason behind the increase in the forward current.

The voltage-current equation for a crystalline diode is given by [19]

$$I = Is\left(e^{\frac{V}{\frac{KT}{e}}} - 1\right) \quad (1)$$

q electron charge (Columb) and K Boltzmann's constant (J/K).

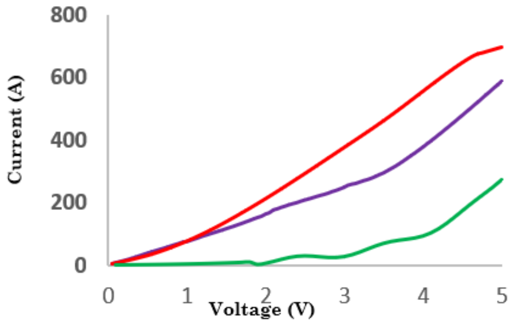


Fig. 4 – The forward current vs. voltage at (100, 200 and 300 °C)

But increasing the temperature led to increase the saturation current I_S and therefore the barrier voltage must decrease as show in Fig. 5.

We are noting that the forward current does not start to flow except at a certain voltage called the threshold voltage or the cut-off voltage and it is inversely proportional to the reverse saturation current which is given in eq. (2) [18] and tabled in Table 1. Threshold voltage has maximum value 0.831 V at substrate temperature 100 °C and this value decreased to 0.381 V at 300 °C for Bi_2O_3/CdSe nanoparticles heterojunction.

$$V_B = \frac{KT}{e} ln\ \frac{I}{Is} \quad (2)$$

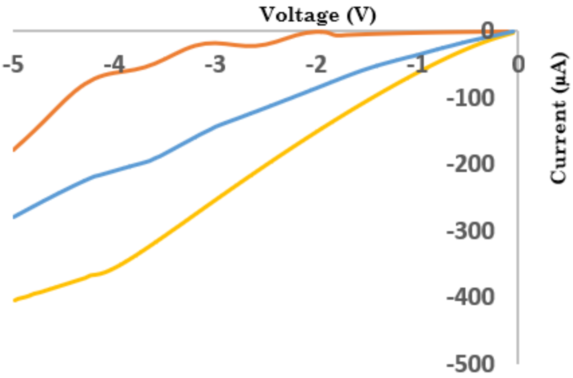


Fig. 5 – The saturation current vs. voltage at substrate temp. (100, 200 and 300 °C)

Ideality factor n can be determined from eq. (3) as [17-19].

$$n = \frac{q}{kT}\left(\frac{d(V)}{dln(I)}\right) \quad (3)$$

Ideality factor in term voltage was affected by changed substrate temperatures and it was depended to the Bi_2O_3/CdSe structured diode. We noticed that the n was increased and has maximum value 2.6 with increasing substrate temperature at 300 °C in the heterojunction, but it has minimum values 1.5 and 1.8 at 100 and 200 °C respectively, these values are close to the ideal behavior of the diode as shown in Table 1.

Energy bandgap E_g was calculated by eq. (4) [17].

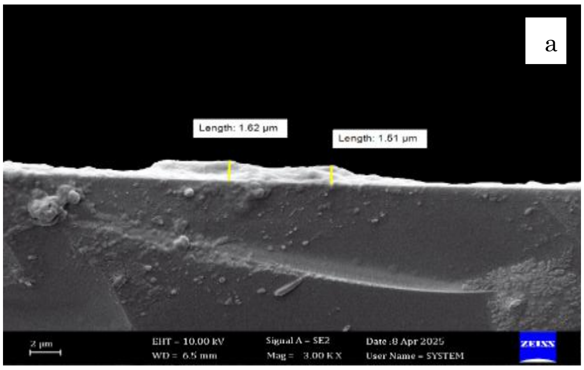
$$\log I_s = constant - 5.036\frac{10^3}{T} \times E_g \quad (4)$$

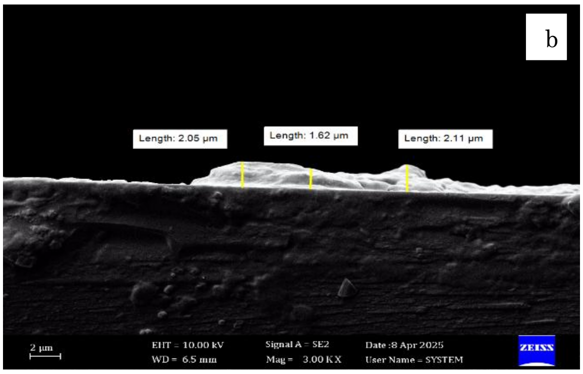
The bandgap energy has minimum value 0.291 eV at 100 °C and this value increased to 0.443 eV with increasing substrate temperature at 300 °C for Bi_2O_3/CdSe heterojunction as shown in Table 1. This means it was proportional directly to both reverse saturation current and temperature.

Table 1 – The Results of Electrical Parameters for Bi_2O_3/CdSe Heterojunction Semiconductors

Substrate temp. /°C	Threshold voltage V_B / *Volt*	Ideality factor n	Energy bandgap E_g (eV)
100	0.831	1.5	0.291
200	0.468	1.8	0.347
300	0.381	2.6	0.443

Surface of the Bi_2O_3/CdSe diode with substrate temperatures (100, 200 and 300 °C) were studied by cross sectional SEM as shown in Fig. 6 (a, b and c) respectively. In Figure 6. (a) we observed that the slower layer growth by lengths (1.4 – 1.5 μm) and the result in a thin, flat layer, but less dense. Fig. 6 (b) an increasing substrate temperature at 200 °C led to increase the thickness to approximately 2.1 μm. The reason may be that the heat gives the deposited atoms kinetic energy, causing them to move across the surface and settle into their correct positions. In the two figures (a and b) the layer appears compact and adheres more regularly to the substrate. In Figure 6 (c), the surface has become clumped. This indicates that the temperature (300 °C) greatly stimulated grain growth, resulting in high surface roughness. The spaces between the clumps become more pronounced, which may indicate that crystal growth has become random.





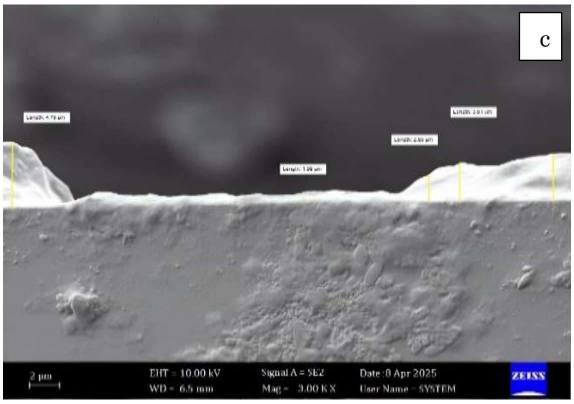


Fig. 6 – Cross sectional SEM for Bi_2O_3/CdSe at (a) 100 °C (b)200 °C (c)300 °C

CONCLUSION

Bi_2O_3/CdSe heterojunction parameters were affected by changes in the substrate temperatures at 100, 200 and 300 °C. The forward current and the saturation current were increased when the substrate temperature was increasing at 300 °C. The cut-off voltage of Bi_2O_3/CdSe diode decreased from 0.831 to 0.381V at substrate temperatures 100 and 300 °C respectively. The ideality factor values were 1.5 and 1.8 at 100 and 200 °C and it increases to 2.6 at 300 °C. Energy bandgap for Bi_2O_3/CdSe was changed from 0.291 to 0.443 eV by increasing the substrate temperature at 300 °C. From cross sectional SEM, we observed that the layer growth by lengths (1.4-1.5 μm) and it was increased the thickness to approximately 2.1 μm at 200 °C. At the temperature 300 °C, the surface has become clumped and the crystal growth has become random.

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Виготовлення гетеропереходу наночастинок *p*-Bi_2O_3/*n*-CdSe за різних температур підкладки

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Наночастинки селеніду кадмію та оксиду вісмуту були синтезовані методом хімічного осадження у ванні. Наночастинки CdSe мають негативну провідність (*n*-тип), а Bi_2O_3 мають позитивну провідність (*p*-тип), обидві утворюють *p-n* гетероперехід. Напівпровідники Bi_2O_3 були осаджені методом розпилювального піролізу за різних температур підкладки (100, 200 та 300 °C) для кожних 10 розпилень на напівпровідники CdSe, отримані на скляних підкладках методом CBD. Були досліджені електричні характеристики діода Bi_2O_3/CdSe за температур (100, 200 та 300 °C) в темряві та на освітленні. Температура підкладки впливала на такі параметри діода, як прямий струм та струм насичення. Порогова напруга знижувалася зі збільшенням температури підкладки на 300 °C. Коефіцієнт ідеальності наночастинок Bi_2O_3/CdSe змінювався з температурою підкладки, він збільшувався та досягав максимального. значення при 300 °C. Енергія забороненої зони має мінімальне значення при 100 °C та збільшується приблизно на 0,15 % порівняно з температурою підкладки 300 °C. Площа поперечного перерізу наночастинок Bi_2O_3/CdSe досліджувалася за допомогою поперечного скануючого електронного мікроскопа (SEM) при (100, 200 та 300 °C). Поверхня ставала шорсткою при 300 °C, що призвело до значного стимулювання росту зерен.

Ключові слова: Наночастинки Bi_2O_3, Плівки CdSe, Спрей, CBD, Гетероперехід.