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Study of Electrical Properties of *p*-PbSe/*p*-Si Heterojunction

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Abstract

Electrical properties of *p*-PbSe/*p*-Si heterojunction detector have been investigated. The electrical properties under dark condition show a rectifying behaviour with low rectification factor, and exhibits soft breakdown reverse current.

C-V characteristics suggest that the fabricated diode was abrupt type, built in potential determined by extrapolation from $1/C^2$-V curve to the point (V=0) and it was equal to (0.49V).

Results of I-V characteristics under illumination conditions with reverse bias voltage exhibit linear behavior with no saturation limit.

دراسة الخصـــائص الكـــهربائية للمفرق ألهجيني *p*-PbSe/*p*-Si

الخلاصة

في هذا البحث تم دراســـــة الخصـــائص الكـــــهربائية لكاشــف المفــرق الهجـــــين *p*-PbSe/*p*-Si حيث تم دراسة خصائص تيار - جهد عند الظلام وتبــين إن لـــه خصـــائص تقويمية وذات معامل تقويم منخفض وكذلك أظهرت فولتية انهيار متدرجة في الانحياز العكسي.

ومن قياس سعة – جهد أوضحت أن المفرق من النوع الحاد وتم حســاب جهــد البنــاء الداخلي من خلال اخذ امتداد $1/C^2$-V إلى النقطة (V=0) حيث بلغ (0.49 V).

تم قياس تيار – جهد في حالة الإضاءة مع الانحياز العكسي، أبدى الكاشف المصنع سلوك خطي مع عدم ملاحظة وجود منطقة تشبع.

1-Introduction

IV-VI semiconductors are commonly considered to be promising materials for optoelectronic, thermoelectric,[1] and other applications in the mid-infrared as optoelectronic emitters, sensors, and detectors.[2,3] PbSe is a polar semiconductor, which crystallizes in a face center cubic (f.c.c.) lattice of NaCl type. It is characterized by high dielectric susceptibility, high carrier mobility [4], and a narrow band gap (T=293K, PbSe)~0.27eV [5,6]. Optical properties in the visible and infrared regions of spectra are related to the electron transitions. The as-grown films show *p*-type conduction [7,8].

There has been a considerable interest during the past few years in PbSe films, several investigators have attempted, Y. Yoshizumi et al. [9] we have shown the effect of oxygen on the properties of evaporated films of photosensitive PbSe, F. Brionis et al. [10] are investigated the role of structure in the oxygen sensitization processby comparing the conducting properties of PbSe with a diversity of structures, S.P. Varfolomeev et al. [11] the influence study of ultraviolet illumination at room temperature on photoelectric properties of activated (by annealing in air) polycrystalline

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PbSe films. Preparation of these devices can be achieved by different methods of depositing the PbSe films onto single crystal Si substrates, Bala Waclaw et al. [12] an investigation of the electrical transport in PLD grown n-PbSe/n-Si heterojunction by DC and AC current measurement techniques. The aim of the present investigation reports the optoelectronic properties of heterojunctions of *p*-type PbSe deposited on *p*-Silicon.

2- Expermental

Substrates of p-type single-crystal Si wafers[13] of resistivity 3-5 ohm-cm and orientation (111) were used in the present study. After scribing these wafers into small pieces (typically 1cm x 0.6cm in size), with one surface polished with 2HF : $3HNO_3$: $3CH_3COOH$ mixture (3:5:3) were cleaned ultrasonically by dipping in distilled water, acetone and isopropyl alcohol alternately. After cleaning, the samples were oxidized in dry oxygen. [14]. The films of PbSe were prepared by thermal evaporation in vacuum of the order of 10^{-5} torr, the rate of evaporation was ≈1.6 nm/min, onto clean silicon mirror-like side substrates at room temperature (~300K). The average thickness of the deposits were determined by microbalance method. The maximum error in the determination of thickness was of the order of 10% estimated for the thinnest films (PbSe films of thickness 250 nm). Ohmic contacts of aluminum [15] were evaporated on the silicon side and PbSe side.

Electrical measurements included current-voltage, capacitance-voltage and reverse I-V characteristics under different illuminations were characterized.

3-Result And Discussion

3-1 (I-V) characteristics

A typical current-voltage (I-V) characteristic, in dark, for forward and reverse bias of *p*-PbSe/*p*-Si heterojunction is shown in Fig. (1). In the forward bias the current increases exponentially with voltage as expected. But in reverse bias, the current was found to increase slowly with voltage (soft breakdown) and did not show any trend of saturation or sharp breakdown. This could be due to the domination of edge leakage current which is caused by the sharp edge at the periphery of the contact and also due to the generation of excess carriers in the depletion region at higher fields.

In Fig. (2), Typical semi logarithmic plot of the forward current characteristics of PbSe/Si junction. The low forward-bias region could be explained by an equation of the form [$J \approx exp(eV/\eta kT)$] and the high-bias region by the equation, [$J \approx exp(Av)$] where η is a constant of the order of (2-6), and A is another constant, of the order of (13-14.5) and is practically independent of temperature. Further analysis of these current characteristics with temperature shows that ln J varies approximately as $-1/T$ in the low-bias region: in the high-bias region, ln J varies as T. [16]

3-2 C-V characteristics

Junction capacitance measured as a function of bias voltage for the PbSe/Si diodes shows $C \propto V^{-1/2}$ dependence (Fig.3) which indicates an abrupt junction in that case. Abrupt (when relation between $1/C^2$ and V straight line) or graded (when relation between $1/C^3$ and V straight line) according to the distances during which the transition from one region to the other is completed near the interfaces. Under these conditions, The C-V characteristics of the heterojunction can be explained on the basis of Anderson's model [12], according to which

$$\frac{C}{a}=\left[\frac{qN_{A1}N_{D2}e_1e_2}{2(e_1N_{A1}+e_2N_{D2})}\cdot\frac{1}{V_D-V}\right]^{\frac{1}{2}} \quad (1)$$

Where q: is the electronic charge, ε_1: and N_{A1}: are dielectric constant and concentration of acceptors in p-type semiconductor, ε_2: and N_{D2}: are dielectric constant and concentration of acceptors in p-type semiconductor (i.e. Si) and V and V_D are the applied bias and built-in Voltage, respectively. Value of V_D estimated from $1/C^2$ versus V plot obtained for heterojunction, the built- in potential ($V_{bit.}$) for the PbSe/Si System was found to be (0.49 V).

To calculate concentration of acceptors in p-type semiconductor (i.e. Si) according to relation (2) is found to be ($N_{D2}=3.472\times10^{15}$) cm^{-3}.

$$N_{A1}=(\rho\, q\, \mu_p)^{-1} \quad (2)$$

Where μ_p : is mobility carriers (450 $cm^2/V.s$) and ρ: is resistivity.

Fig.(4)gives the I-V characteristics for the PbSe/Si heterojunction at different illuminations. It is shown that photocurrent increases with reverse bias voltage and no saturation region was observed. This can be attributed as follows; since photocurrent (I_{ph}) is a function of diffusion length and junction width [17]:

$$I_{ph} = q\,A\,G\,(W + L) \quad (3)$$

Where A: is area, G: is generation rate, W: is the depletion width and L: is the diffusion length, therefore when L becomes so short (<<W) due to the effect of mismatch defects, I_{ph} will depend essentially on W which in turn depends on bias voltage. Thus, I_{ph} will increase with increasing bias voltage.

Conclusion

From what has been mentioned above, we can conclude that these type *p*-PbSe/*p*-Si heterojunction behaves as a poor rectifier due to the noise that comes from the narrow gap PbSe film. The junction is abrupt type.

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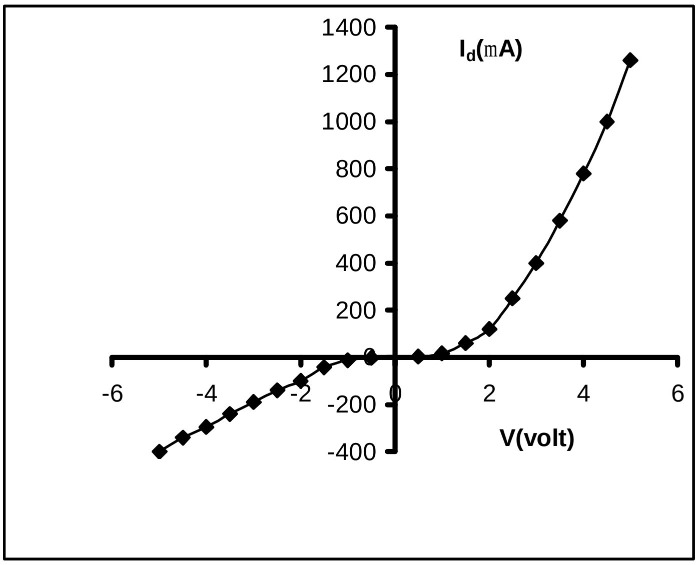

Fig. (1): I-V characteristics of PbSe/Si heterojunction in dark

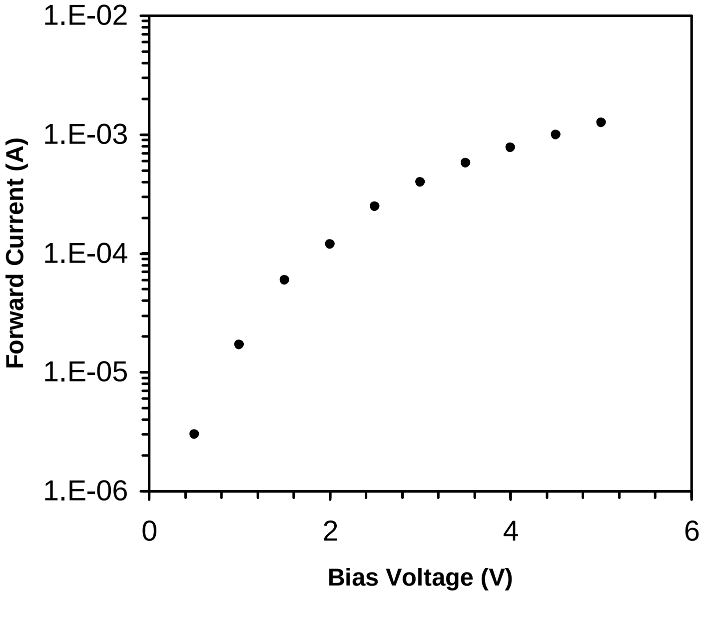

Fig. (2): Typical Semi logarithmic plot of forward current as a function of bias voltage for *p*-PbSe/*p*-Si junction.

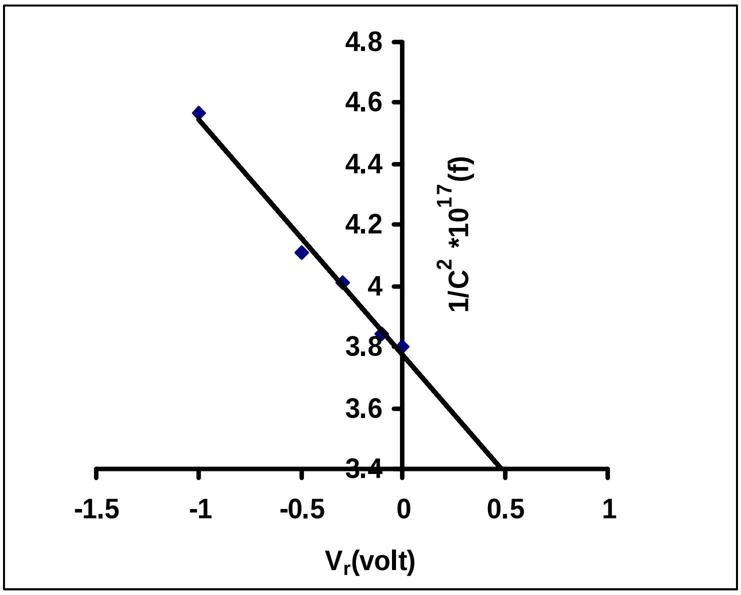

Fig. (3): $1/C^2$ (C = Capacitance per unit area) as a function reverse bias voltage

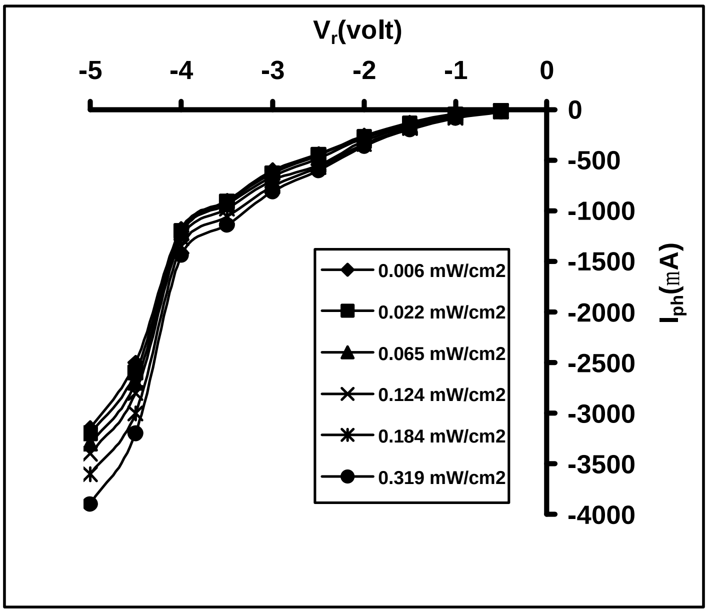

Fig. (4): Reverse photocurrent as a function of bias voltage