Qatar Univ. Sci. J (2005), 25: 40-45

Experimental Investigation of the N-Pbs/P-Si Heterojunction Band Lineup with I-V and C-V Measurements

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بناء المخطط الطاقي للمفرق الهجيني n-PbS/p-Si من الفحوصات التجريبية لقياسات C-V و I-V

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في هذا البحث تم بناء المخطط الطاقي للمفرق الهجيني نوع PbS/Si من خلال قياسات تيار - جهد وسعة - جهد. أوضحت قياسات سعة - جهد أن الديودات المصنعة من النوع الحاد وتم تحديد مقدار جهد البناء الداخلي من خلال المنحني$(1/C^2)$-V. كان مقدار ΔEc بحدود 0.15eV ومقدار ΔEv =0.55eV حيث تم حسابهما عند درجة حرارة الغرفة. تمت دراسة خصائص تيار - جهد عند درجات حرارة قريبة من درجة حرارة الغرفة لإيجاد حاجز الجهد لعملية انتقال الالكترونات خلال منطقة الاتصال.

Keywords: *PbS/Si, lineup, thermal evaporation.*

ABSTRACT

In this paper we present experimental investigation of band lineup of near ideal PbS/Si heterojunction diode using I-V and C-V measurements. The C-V measurements show that the fabricated diodes were abrupt type, and the built–in potential V_{bi} was determined from C^{-2}–V plot. The band offsets of $\Delta Ec = 0.15$ eV and $\Delta Ev = 0.55$ eV were calculated at 300 K for conduction and valence bands, respectively. The energy band diagram of n-PbS/p-Si heterojunction was constructed. I-V measurements of different temperatures near 300K were employed to find the potential barrier to electron transport process across the junction.

Introduction

Despite of the large mismatch lattice constant (9%) between the PbS and Si ,PbS-Si HJ.s have been reported to be successful for IR detection [3,4], IR charge couple devise (IRCCD) images and gas detection [5,6].The fabrication and structural and compositional properties of the PbS-Si HJ have been previously reported [7]. We have recently reported near-ideal electrical characteristics of n-PbS/p-Si HJ diodes [8].

In this paper, we report and analyze the I-V and C-V measurements on n-PbS/p-Si heterojunctions (anisotype HJ's) so as to determine the n-PbS/p-Si lineup configuration.

Experimental

Mirror like single crystal p-type silicone wafers of (111) orientation having electrical resistivity of 4 Ω.cm was Prior to deposition of PbS films, the substrates were thoroughly cleaned to remove organic and inorganic contaminants from their surface using (HF 1:10) chemical etchant. The substrates were then washed in ultrapure running deionized water and immediately transferred to vacuum chamber. PbS thin films were deposited on Si using thermal resistive technique. Ohmic contacts were made on both PbS and Si sides. The I-V and C-V measurements of HJ diodes were carried out at 300K and some were also measured with temperature as a parameter in the range (273-317). LCZ meter type (hp/4192 ALF) was used for C-V measurements at frequency of 10kHz.

Results and Discussion

The I-V characteristics (forward and reverse) of n-PbS/Si HJ diode at 300K exhibited good characteristics and uniformity as shown in Figure 1.

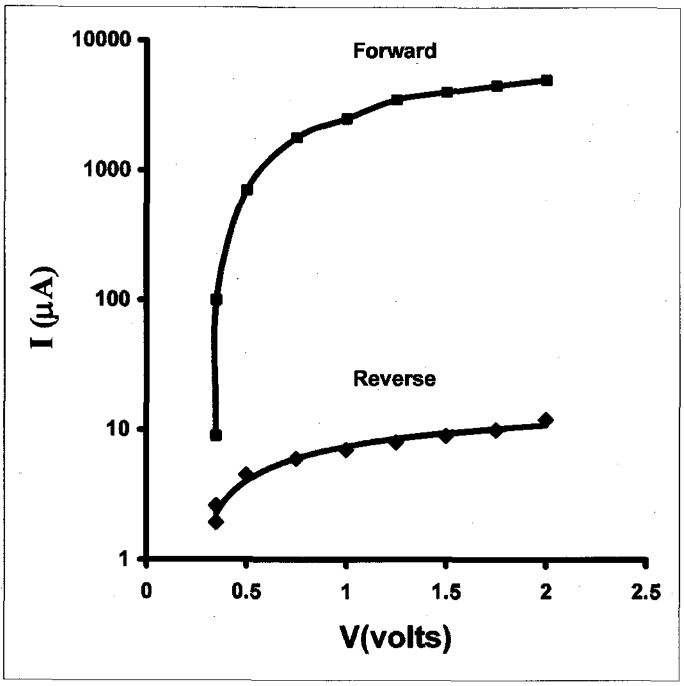

Figure 1: I-V characteristics of n-PbS/p-Si heterojunction diode at 300 K.

The ideality factor (n) of HJ diode determined from I-V characteristics the equation:

$$n = \frac{q}{K_B T} \frac{\Delta V / \Delta I_f}{Is} \qquad (1)$$

where I_f: forward current (A), q: the electron charge (C), K_B: Boltzmann's constant (J/K), and T: the operating temperature (K).

The HJ diodes gave n-values near 1.2 at 300K.The value of the ideality factor give an indication that the recombination currents are not limiting the diode characteristics at 300K, hence misfit dislocations may not be electrically active defects limiting device characteristics.

The forward-bias characteristics exhibits no turn-on voltage at 300K, and this has good agreement with results published by Steckl *et al* [9].

In an n-PbS/p-Si HJ, the junction capacitance (C) related to the reverse bias voltage according to the following equation:

$$C^{-2} = \frac{2(\varepsilon_1 N_{D1} + \varepsilon_2 N_{A2})}{qN_{D1}N_{A2}\varepsilon_1\varepsilon_2} \cdot \frac{(V_D - V - 2kT)}{q} \qquad (2)$$

where indices 1 and 2 refer to PbS and Si respectively, ε the dielectric constant, N_D the concentration of donor, N_A the concentration of acceptor and V_D is built-in-potential.

The extrapolation of the straight-line of ($1/C^2$-V) plot to the point $1/C^2 = 0$ gives

$$V_{\text{int}} = V_D - \frac{2kT}{q} \qquad (3)$$

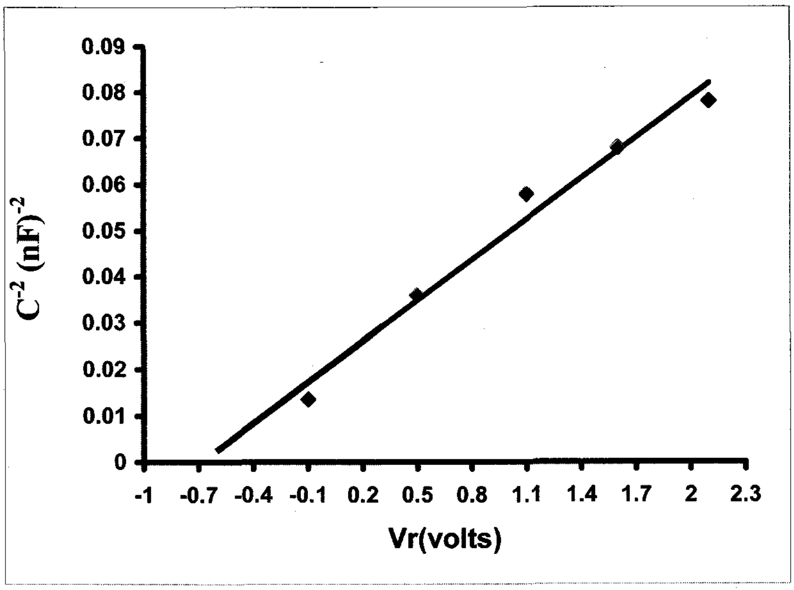

Figure 2: Reciprocal of square capacitance with reverse bias of n-PbS/ p-Si heterojunction diode.

From Figure 2 the V_{int} was determined to be 0.6V at 300K. On the other hand the straight line of $1/C^2$-V_r plot exhibited that the junction is abrupt type. By using Eq. (3) the $V_D \approx V_{int}$ the conduction band offset ΔE_C of PbS/Si is calculated from:

$$\Delta E_c = qV_D\left(E_{g2} - \Delta E_{F1} - \Delta E_{F2}\right) \qquad (4)$$

where E_{g2} is the energy gap of PbS, ΔE_{F1} and ΔE_{F2} are the energy separation between the Fermi level and conduction bands and valence bands of PbS and Si respectively.

Using Eq. (4), values of $\Delta E_C = +0.15$ eV and by using $\Delta E_C + \Delta E_V = \Delta E_g$ relation $\Delta E_V = +0.55$ eV for PbS/Si HJ are obtained. Steckl *et al* [9] have shown that the valence band barrier between PbS and Si of $\Delta E_v = 0.67$ eV at 300K.

Figure 3 shows the energy band diagram of n-PbS/p-Si HJ from C-V results.

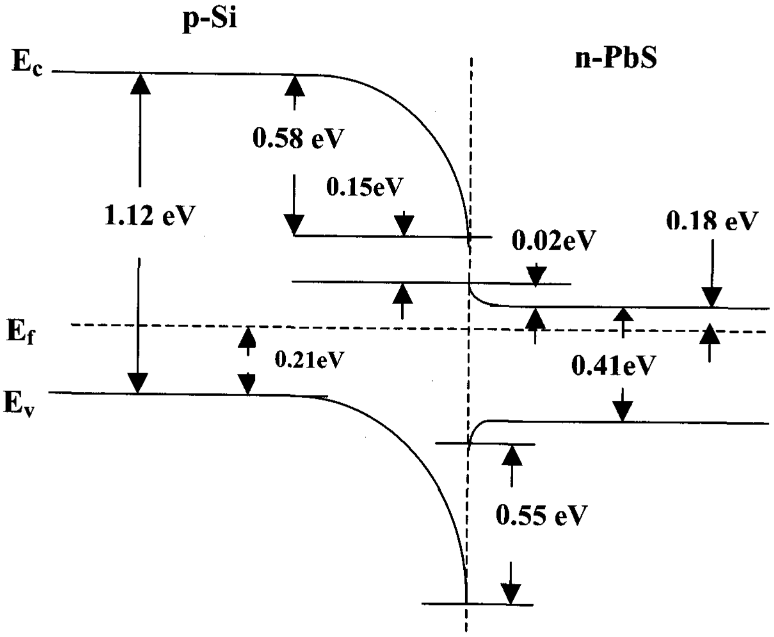

Figure 3: Energy band diagram for the n-PbS/p-Si.

From Eq. (1) the saturation current (Io) can be given by [9]:

$$I_o = A\exp\left(-\frac{qV_D - \Delta E_C}{k_B T}\right) \qquad (5)$$

where A is constant.

I_o: determined from I-V characteristics around 300K as shown in Figure 4. Figure 5 shows I_o vs. 1000/T plot, the slope of this plot will give ($qV_D - \Delta E_C$) of 0.3 eV. To make a comparison with C-V measurement, a value of $qV_D - \Delta E_C = 0.4$ was obtained. These results give an indication that both methods agree well.

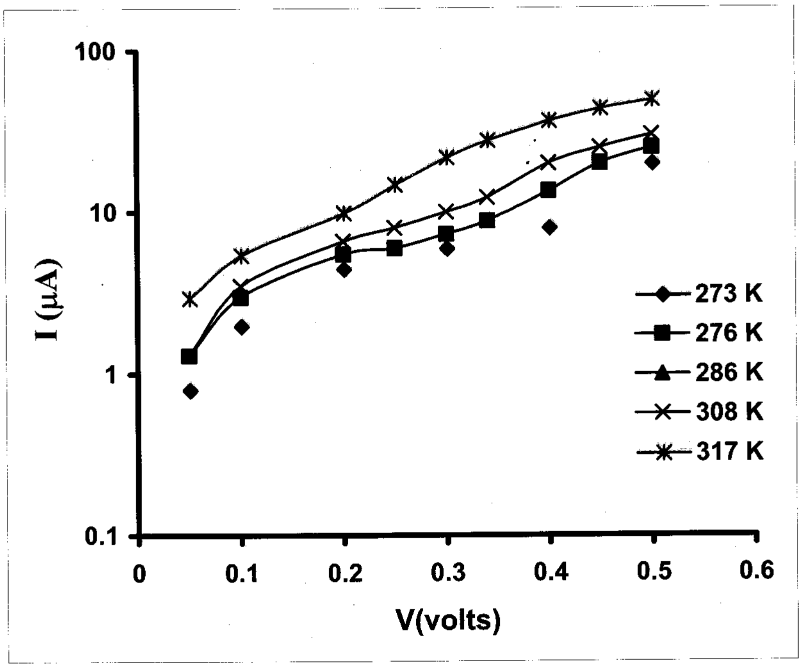

Figure 4: I-V characteristics of n-PbS/p-Si heterojunction under different operating temperatures.

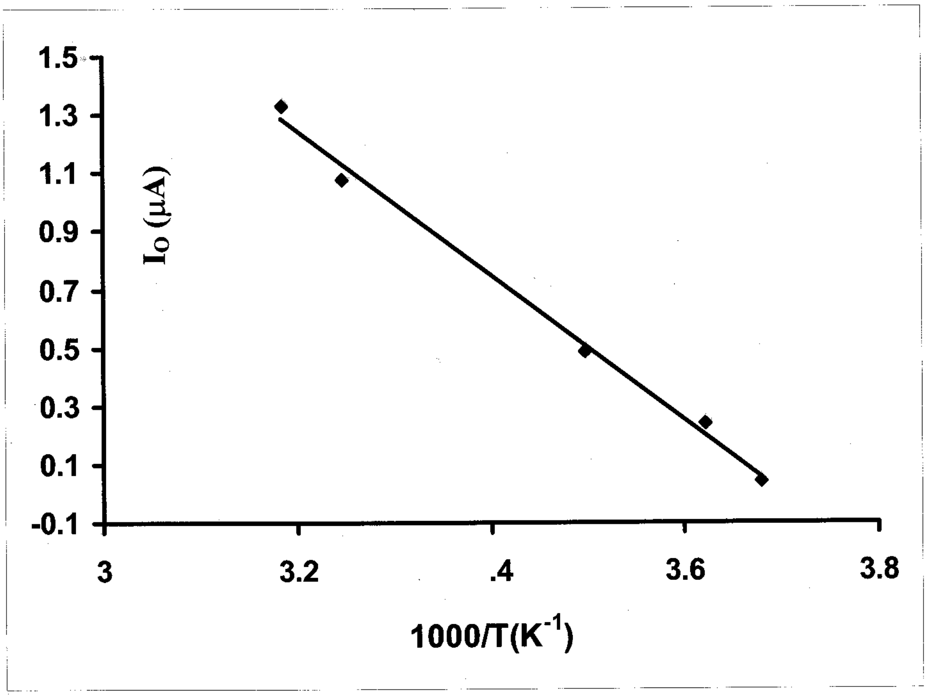

Figure 5: I_o vs. 1000/T for determination of the potential barrier $(qV_D - \Delta E_C)$ to electron motion.

Conclusions

The edge of lineup of n-PbS/p-Si heterojunction diodes having near-ideal electrical characteristics was determined with the aid of I-V and C-V measurements. Both methods are exhibiting good agreement. Furthermore, the obtained results are very close to theoretical models predicting that most of the energy gap difference in the n-PbS/p-Si is accommodated as valence band discontinuity ΔE_v, when ΔE_C is relatively small.

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