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A Study On the Structure and Electrical Properties of $Pb_{0.9}Sn_{0.1}Se/Si$ Heterojunction

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Abstract

In this work, as Study on the structural and electrical properties of $Pb_{0.9}Sn_{0.1}Se/Si$ hetrojunction was made by depositing compound of Lead, Tin and Selenide film on Si by thermal evaporation.

XRD diffraction analysis of the film, shows the dominant crystal orientation is (200) as well as ($Pb_{0.9}Sn_{0.1}Se$) film deposited is polycrystalline structure.

Electrical properties of $Pb_{0.9}Sn_{0.1}Se/Si$ heterojunction detector have been investigated. The electrical properties under dark condition show a rectifying behavior with low rectification factor, and exhibit 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 (0.4V).

دراسة الخصائص التركيبية والكهربائية للمفرق ألهجيني $Pb_{0.9}Sn_{0.1}Se/Si$

الخلاصة

في هذا البحث تم دراسة الخصائص التركيبية الكهربائية لكاشف المفرق الهجين $Pb_{0.9}Sn_{0.1}Se/Si$ المصنع من خلال ترسيب غشاء المركب رصاص قصدير سلينيوم على قاعدة سليكونية بطريقة التبخير الحراري.

في الخصائص التركيبية للغشاء تم اعتماد تقنية حيود الأشعة السينية (XRD) وأوضحت الاتجاه البلوري السائد (200) وان الغشاء المترسب كان متعدد التبلور.

حيث تم دراسة خصائص تيار - جهد عند الظلام وتبين إن له خصائص تقويمية وذات معامل تقويم منخفض وكذلك أظهرت فولتية انهيار متدرجة في الانحياز العكسي.

ومن قياس سعة – جهد أوضحت أن المفرق من النوع الحاد وتم حساب جهد البناء الداخلي من خلال اخذ امتداد $1/C^2$-V إلى النقطة (V=0) حيث بلغ (0.4V).

1- Introduction

IV-VI semiconductors are commonly considered to be promising materials for optoelectronic, thermoelectric,[1] and other IV-VI layers (lead chalcogenides) on Si-substrates applications in the mid-infrared as optoelectronic emitters, sensors, and detectors.[2,3] The lead-chalcogenide layers are such as $Pb_{1-x}Sn_xSe$ and PbTe with band gaps of 0.1- 0.2 eV.[4]

Recently, high-quality epitaxial growth of PbSe and related materials on (111) oriented Si substrates has been accomplished by incorporating thin intermediate BaF2/CaF2 buffer

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layers. 1, 2 Heteroepitaxial growth of PbSe on silicon takes advantage of silicon integration technology to obtain inexpensive photonic devices. Infrared sensor arrays with 3-12 µm cutoff wavelengths in PbSe and PbSnSe layers grown heteroepitaxially on Si(111) have been fabricated.[5]

The as prepared film shows *n*-type electrical conductivity [6]. This paper contains a first report on $Pb_{o.9}Sn_{0.1}Se$ thin film fabricated by the thermal evaporation technique. The preliminary results of structural and electrical properties of this alloy film have been presented

2- Expermental Work

Substrates of *p*-type single-crystal Si wafers 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. [7]. The films of $Pb_{o.9}Sn_{0.1}Se$ 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 thicknesses 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 ($Pb_{o.9}Sn_{0.1}Se/Si$ films of thickness 350 nm). Ohmic contacts of aluminum [8] were evaporated on the silicon side and $Pb_{o.9}Sn_{0.1}Se/Si$ side.

3-Result And Discussion

3-1 X-ray Diffraction Studies

X- ray diffraction (XRD) studies have been carried out to identify the $Pb_{o.9}Sn_{0.1}Se$ phase present in the film. Fig.1 shows the XRD pattern recorded on $Pb_{o.9}Sn_{0.1}Se$ film, coated on slide glass substrate. The film is polycrystalline and has an cubic crystal structure.

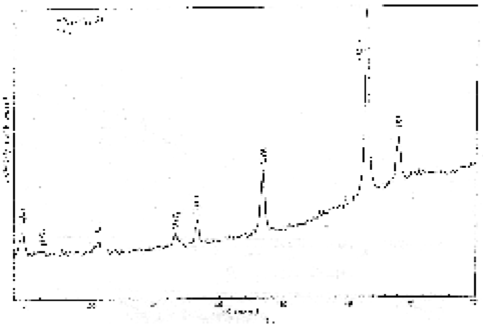

Fig. (1): XRD spectrum of lead tin selenide coated glass substrate

3-2 I-V characteristics

A typical current-voltage (I-V) characteristic, in dark, for forward and reverse bias of $Pb_{o.9}Sn_{0.1}Se/p$-Si heterojunction is shown in Fig. 2. 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.

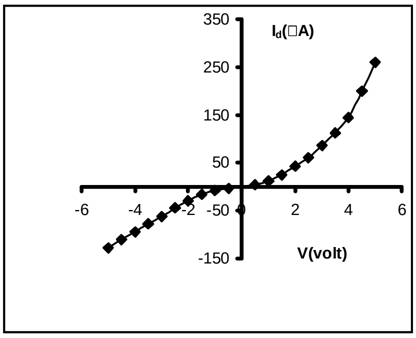

Fig. (2): I-V characteristics of Pbo.9Sn0.1Se/p-Si heterojunction in dark

Fig. 3 shows the dark and under illuminated I-V plots measured at 300° K for a typical n-Pbo.9Sn0.1Se/p-Si diode. Notice that the magnitude of the photocurrent under reverse bias exhibits a flat dependence when the voltage value is higher than 2.5 V. At this voltage the structure is suitable to be used as an efficient photo-detector.

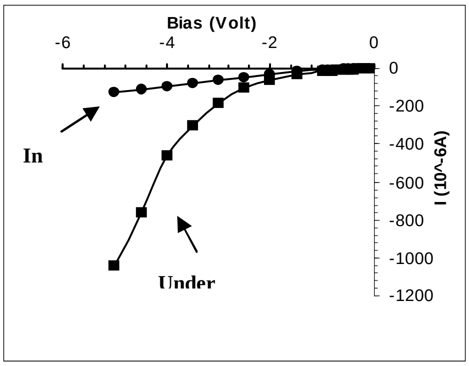

Fig. (3): Dark and illuminated I-V curves for a typical $Pb_{o.9}Sn_{0.1}Se/p$-Si

Fig. 4, shows typical semi logarithmic plot of the forward current characteristics of n-$Pb_{o.9}Sn_{0.1}Se/p$-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

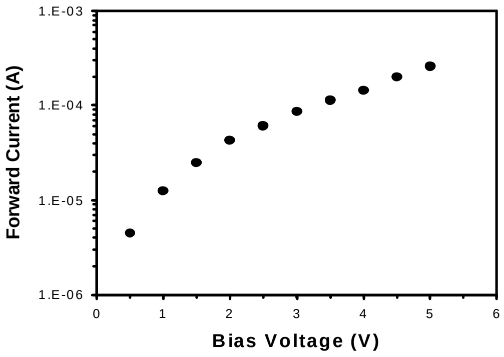

Fig.(4): Typical Semi logarithmic plot of forward current as a function of bias voltage for n-$Pb_{0.9}Sn_{0.1}Se/p$-Si junction.

3-3 C-V characteristics

Junction capacitance measured as a function of bias voltage for the n-$Pb_{0.9}Sn_{0.1}Se/p$-Si diodes shows $C \propto V^{-1/2}$ dependence Fig. 5 which indicates an abrupt junction in that case. Abrupt (when relation between $1/C^2$ and V is 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 [10], according to which

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

where q: is the electronic charge, ε_1: and N_{A1}: are dielectric constant and concentration of donors in *n*-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 is 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 *n*-Pb$_{o.9}$Sn$_{0.1}$Se/*p*-Si System was found to be (0.4V).

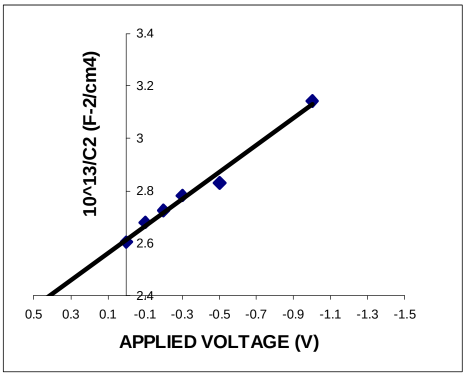

Fig.(5): $1/C^2$ (C = Capacitance per unit area) as a function reverse bias voltage

4-Conclusion

From what has been mentioned above, we can conclude that this type of n-Pb$_{o.9}$Sn$_{0.1}$Se/*p*-Si heterojunction behaves as a poor rectifier due to the noise that comes from the narrow gap Pb$_{o.9}$Sn$_{0.1}$Se film. The junction is abrupt type.

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