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TEMPERATURE ACTIVATED TUNNELING PROCESSES IN aSe/pSi HETEROJUNCTION

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ABSTRACT
Heterojunction is fabricated by depositing amorphous selenium (aSe) on p-type crystalline silicon (pSi) subtract of 3-7Ωcm resistivity by vacuum evaporation method. DC electrical conduction record from 82k up to room temperature (RT). Results of current – voltage (I-V) and capacitance – voltage (C-V) measurements are compared with the two tunneling processes purposed by Riben – Feucht and Matsuura et al. At high temperature (>140k), the forward bias is T dependent, while the reverse bias gives an exponential $\left(-\frac{1}{T}\right)$ *dependence. However at low temperatures (<140k), the conductivity is constant. It is deducted that tunnel hopping of electrons is prevalent in the aSe side while barrier tunneling of holes occur in the pSi of the interface. Recombination of electron and hole becomes predominant at high negative bias due to whole injection into the interface coming from the pSi.*

Keywords: Temperature, Tunneling, Resistivity, Vacuum, Evaporation.

INTRODUCTION

Heterojunctions formed by depositing thin films of silicon or germanium on their crystalline counterparts have been investigated (Grigorovic, et al. 1964), (Yohida and Arizumi, 1975), (Brodsky, Dohler, and Steinherdt, 1975), (Koshy, 1955), (Sinha, and Misra 1983). The conduction in the amorphous layer of amorphous semiconductor/crystalline semiconductor heterojunction be by phonon-assisted hopping between localized states the Fermi level band conductivity dominates in the crystal (Dohler and Brodsky 1974).

Experiments on crystalline (n) Ge/GaAs (p) heterjunctions (Riben and Feucht, 1966) indicate the I-V and C- results to deduce the basic Anderson model (Anderson, R.L 1962) for abrupt heterojunctions is still valid. From the I- characteristics, the slope of the exponential curve changes slowly as a function of temperature. Matsuura et al. (1984) applied the Riben-Feuchtmultitunneling model to the case of an aSi/pSiheterojunctions. According to them, the relation between J and V, J gives describing the tunneling phenomenon, = Jo exp (A), where A is a temperature independent constant and J_o is temperature dependent. Experimental Riben and Feucht have shown that J_o changes exponentially with T, but on the contrary, J_o obtained experimentally by Matsuura et al varies experimentally with negative T^{-1}. Consequently, Matsuura et al proposes the multitunneling capture-emission model to correct this anomaly.

Sample Fabrication and Measurements

Amorphous selenium film (aSe) is deposited by vacuum evaporation technique onto p-type silicon (pSi) subtract of 3-8Ωcm resistivity and carrier concentrations of 2.8 x $10^{15}cm^{-3}$. The pressure during deposition is 1.33mPa and the mean substrate temperature is kept at room temperature (RT). The thickness of the aSe film is 0.1µm as measured by Edward Film Thickness Monitor, Model FTM3. The junction is circular in shape with approximate area of $0.13cm^2$, Gold evaporated on the aSe side forms the reference electrode in which the direction of voltage bias is applied. Indium-Mercury forms the back contact on the pSi, after first cleaning the silicon surface with diamond paste and acetone.

Current-voltage measurements are made at RT and at 82k, and conductance various with temperature of the hetrojunction from 82k up to RT is also measured. For low temperature measurements, sample is mounted in a torr Cryogenics Liquid Nitrogen Cryostate Model 761 within which a vacuum about 10^{-4}torr is maintained by means of a rotary pump while the dc current is registered by a Model 410C Hewlett-Packard Multimeter.

RESULT

In Fig.1 see from caption at the end of paper, an energy band diagram of the aSe/pSi heterojunction at equilibrium is proposed. Ec^{cr} and EV^{cr} are respectively the conduction and valence band edges in the pSi. Ec^{cr} and EV^{cr} in aSe are called the "mobility edges" of the conduction and valence bands respectively. The edges separate the localized gap states from the extended states. If the density of localized states at the Fermi level, E_F is high, conduction process will be by phonon assisted hopping between localized states near the Fermi level. A typical path of an electron through the amorphous selenium (aSe) is shown schematically in Fig. 1. The diffusion potential VD (barrier due to band bending in pSi) is calculated from the relationship

$$V_D = \phi_B - \delta p \qquad (1)$$

Where ϕ_B is the barrier height and is the distance in energy from Fermi level to valence band. The barrier height is determined from the relationship,

$$\phi_B = \frac{K_B T}{q} \text{in}\left[\frac{A^{**}T^2}{Js}\right] \qquad (2)$$

Where KB is the Botzman's constant, q is the electronic charge, T is the absolute temperature and A** is the modified Richardson constant (Crowell, C.R. and Sze, S.M 1965). The constant Js is the saturation current density obtained by the extrapolation of the linear region of In J_F versus V_F curve to zero bias (for V_F>3K_B T/q).

The separation between the Fermi level and valence band, δp is determined from the relationship,

$$\delta p = \frac{K_B T}{q} \text{ In } \left[\frac{N_V}{N_A}\right] \qquad (3)$$

Where N_V is the effective density of states in the valence band of the pSi (=1.04 x 10^{19} localized states/cm^3eV) and N_A is the doping concentration in pSi (=2.8x10 cm3). A value of ϕ_B=0.7eV is calculated from equation (2) while δp = 0.21 as computed from equation (3). Using above values, VD, calculated from equation (1) is 0.51eV.

In fig. 2, see figure caption at the end of paper, the current –voltage characteristics of the sample at RT and at 82K plotted on a log-log scale for both biases is shown. The transition voltage, V_T is the voltage level at which there is a difference of the rate of increase of current with applied bias from one voltage region to the other. Fig. 3 (see figure caption at the end of paper)'shows the energy band diagram of the aSe/pSi heterojunction, (a) Forward bias indicated by ohmic (I), multitunneling via tail stage (II) and recombination (III), (b) Reverse

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bias, where the mechanism is ohmic (I), Barrier surmounting (II), tunneling into tail-stages (III) and electron hole generation (IV). Fig. 4(a) (see figure caption at the end of paper) shows the forward current versus $(V\text{-}Vo)^{1/2}$ of the sample replotted from fig. 2, to show the tunneling phenomenon. In (b), reverse current versus $(V+Vo)^{1/2}$ of the sample replotted from fig. 2 to show tunneling phenomenon. Fig. 5 (see figure caption at the end of paper) shows the logarithm of conductance versus T and 1/T for testing simultaneously the pre-exponential dependence on T in the tunneling mechanism of the sample. A test of the proportionality between the current and temperature for the sample at forward and reverse bias as derived from fig. 5 is presented in Table 1.

Table 1: A test of proportionality between current and temperature for the aSe/pSi heterjunction at forward and reverse bias as derived from Fig. 5.

BIAS	T>140K	T<140K
FORWARD	Exp(T)	constant
REVERSE	$\exp\left(-1/T\right)$	constant

Discussion

The I-V characteristics of the sample (see Fig. 2) at reverse bias show that at RT there is a linear regime up to Vj_2 followed by some power-law. This trend is similar to Riben and Feucht's I-V curve for reverse bias. In forward bias and at high temperature, there are sufficient supplies of electrons to assist in the diffusion-emission process. It is therefore possible for the electrons to surmount the barrier into pSi as shown by process I in Fig. 3(a), thus explaining the RT ohmic-like behaviour and the saturated current at 82k in Fig. 2. At 82k, between V_T3 and V_T4 (Fig. 2) there is a trap-filling process, possibly in the tail-states of aSe. Therefore, electrons from -aSe would tunnel into localized states (Process II in Fig. 3 a) followed by multitunneling, until they reach the interface, where they recombine with holes (Process III in Fig. 3a) whereby the latter process occurs beyond Vt4 (Fig. 2).

In reverse bias, due to ohmic conduction up to Vn in Fig. 2, thermionic emission of electrons from pSi into aSe is insignificant at RT, hence the process I in Fig. 3(b) dominates. At 82k, electrons surmounting the barrier (as shown in the process of Fig. 3b) become more significant. Between VTS and VTG, (see Fig. 2) electrons tunnel into the tail states of aSe to perform localized states conduction (process III in Fig. 3b). Beyond V_{r6} (see Fig. 2) there is emission of holes into the pSi and electrons into the aSe, due to earner generation at the interface (process IV of Fig. 3b).

The existence of the tunneling mechanism is further established by the linearity of the current versus $(V\text{-}Vo)^{1/2}$ plot in forward bias [Fig. 4(a)J and the current versus $(V+Vo)^{1/2}$ plot in reverse bias [Fig. 4(b)j. A similar linearity characteristic has also been confirmed by Matsuura *et al*. (1984)

In Fig. 5, we tested the logarithm of conductance plotted against both T and 1/T for the heterojunctions. We find that the relationship of forward and reverse bias takes on two different forms beyond 140k. In forward bias, it is T dependent while in reverse bias, it is -1/T dependent (see Table 1). At lower temperatures, i.e. at T<140k, the logarithm of current in both biases is almost a constant.

CONCLUSION

In our study, current-voltage and capacitance-voltage measurements of aSe/pSi heteroj unction are performed at 82k and up to room temperature (RT). Comparing our results with Riben-Feucht model and Matsuura's multitunneling capture-emission model, we find that tunneling is the dominant feature of conduction in our heterojunction. depending on the voltage bias and region of temperature.

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