Effect of Thermal Radiations on Performance of Solar Cells

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Abstract. The effect of grain boundaries on the photovoltaic effect across the grain boundary of two different materials constituting a p-n junction has been studied theoretically. It is found theoretically that the presence of the grain boundary affect the open circuit voltage of the solar cell. It is observed that as the grain boundary potential increases the open circuit voltage decreases.

1. Introduction
As made clear by numerous electron microscope studies, an important structural characteristic of a polycrystalline film is the presence of ‘grain boundaries’ which separate small single crystal regions with in the film. [1-3] In other words, the film consists of a conglomeration of tiny single crystals with sizes which lie typically within the range 10 nano-meter to 10 micro-meter. Generally the individual crystallizes are slightly misaligned with respect to each other so that the boundaries contain high densities of dislocations and so-called 'dangling bonds (atoms not properly chemically bonded).[4-6]
These interface regions contain a high density of electron states which trap electron charge and result in band-bending within the crystal grains.
At normal temperatures where the shallow donor atoms are thermally ionized, free electrons exist in the conduction band of the grain material and are able to move freely within the grains. [7] Some of these will reach the grain boundaries where they may be captured by interface states, becoming spatially localized in the process. [8] This fixed negative charge has the property of repelling free electrons from the region of the grain close to the interface and give rise to a depletion region similar to that associated with a Schottky barrier contact to a semiconductor. In terms of the conduction band energy, the depleted region is characterized by the band-bending. [8, 9] The separation between the conduction band $E_c$ and the Fermi level $E_f$ increases consistent with the reduction in free carrier density in this region-remember that

\[ n = N_c \{ \exp \left( \frac{E_c - E_f}{kT} \right) \} \]  \hspace{1cm} (1)

If N is the density of donors and $N_0$ is the interface trap states then band bending $\Phi_b$ is given by

\[ \Phi_b = e^2 NW^2/2 \varepsilon \varepsilon_0 \]  \hspace{1cm} (2)

where $W$ is the extend of the depletion region because of the grain boundary potential. [10, 11]

2. Modelling
We consider a p type and n type semiconductor material fused to form a p-n junction. Along the junction we can assume a spatial homogeneity in the formation of the dead layer. The grains of the p-type and n-type material can be assumed to have potentials of their own. We can assume that the transport across the barrier set up by the grain boundary in this hetero-structure potential is composed of 3 sequential steps: 1) Drift diffusion in the depletion region of the grain boundary potential 2) Thermionic emission at the boundary plain and 3) followed by drift diffusion into the depletion layer of the junction.

The relation for band bending at an interface is given by equation (1). First when there is a drift diffusion transport in the grain the steady state current under these condition depend on the quasi fermi
level on the either side of the depletion region namely $E_{nn}$ & $E_{pn}$. This is followed by thermionic transfer across the boundary plane which depends on the quasi-fermi level on either side of the plane namely $E_{nn}$ and $E_{pn}$. Finally there is a drift diffusion transport depending on the quasi fermi levels and $E_{pn}$. These 3 solutions coupled by the unknown quasi fermi level on either sides of the boundary are limited by the same current density in all 3 regions. Transport in the n type material can be expressed in terms of the gradient

$$J_d = en \mu_n (d E_{nn} / db)$$

(3)

where $J_d$ is the conventional current density following from right to left. The concentration of electrons $n$ can be expressed in terms of quasi fermi level and the effective density of states in the C.B. by the results

$$n = N_c \exp(-e[E_{pn}(x) - E_f(x)] / kT)$$

(4)

Using equation (4) in equation (3) and integrating between the limit 0 to $b$, we can write

$$J_d' = (\mu N_c kT / I') \left[ \exp(e \Phi_b / kT) - \exp(eE_f' / kT) \right]$$

(5)

Where $J_d'$ is the diffusion current density in the n type material and is $I'$ is defined by,

$$I' = \int_0^b \exp(e E_{nn}(x) / kT) dx$$

(6)

Similarly for the p type material we can write that,

$$J_d'' = (\mu N_c kT / I'') \left[ \exp(eE_{pn}(x) / kT) - 1 \right]$$

(7)

Where $J_d''$ is the diffusion current density on the p type material and

$$I'' = \int_0^b \exp(e E_{pn}(x) / kT) dx$$

(8)

3. Results and Discussion

Elementary kinetic theory tells that flux incident on a boundary plane is $(n\bar{U}/4)$, where $\bar{U}$ is the electron mean thermal velocity. The next thermionic current density is directed from the n type material to the p type material and can be given by $(\bar{U}(n_n - n_p)e/4)$, where $n_n$ and $n_p$ are concentration of electrons on the right and left side of the grain boundary potential. The next thermionic current density can be approximated to

$$J_t = (1-c/2) e N_c \bar{u} / 4 \exp(-e \Phi_b / kT) \left[ \exp(eE_f' / kT) - \exp(eE_f'' / kT) \right]$$

(9)

where $c$ is the fraction of thermionic flux from the either side of the boundary which is trapped at the grain boundary. Continuity equation requires that,

$$J_t = J = [eN_c \bar{V}' / (1+ \bar{V}' / \bar{V}_d)] \exp(-e \Phi_b / kT)$$

(10)

where $\bar{V}' = (1-c/2) \bar{u} / 4$ is termed the recombination velocity and $\bar{V}_d$ is defined as

$$\bar{V}_d = [(e/ \mu kT) (I''+I') \exp(-e \Phi_b / kT)]^{-1}$$

(11)
Equation (10) represents the current density through a grain boundary because of a voltage drop across it. This includes both drift diffusion and thermionic emission. It also shows that the current density is reduced because of the presence of a grain boundary potential. This shows that the total current density is the sum of the conventional current density $J_\text{d}$ and thermionic current density $J_\text{t}$. The maximum current density is achieved when the band bending is equal to $\Phi_b^{\text{max}}$. Under this condition the photovoltaic effect is increased. We have shown that the current through the junction is reduced considerably compared to that of the current produced due to the thermo photo voltaic effect of the grain boundary. For sufficiently large grain boundary potential the drift velocity can be approximated as

$$V_d = \mu e N_d / \varepsilon (ab/a+b)$$  \hspace{1cm} (12)

This equation can be expressed in terms of the barrier height $\Phi_b$ and the open circuit voltage for solar cell as

$$V_d = \mu (2e N_d / \Delta) \times (\Phi_b + V_{oc})^{1/2} \times (\Phi_b^{1/2} + (\Phi_b + V_{oc})^{1/2})$$  \hspace{1cm} (13)

The open circuit voltage,

$$V_{oc} = (kT/q) \ln \{ \Delta n(0) \times N_d + \Delta p(0) / n_i^2 \}$$  \hspace{1cm} (14)

where $n_i$ is the intrinsic carrier concentration and $\Delta n$ & $\Delta p$ represent the change in carrier concentration because of illumination by a flux. We know that,

$$\Phi_b = Q_b^2 / 8\varepsilon q N_d$$  \hspace{1cm} (15)

So that (14) can be rewritten as

$$V_{oc} = (kT/q) \ln \{ \Delta n(0) \times Q_b^2 / 8\varepsilon q \Phi_b + \Delta p(0) / n_i^2 \}$$  \hspace{1cm} (16)

The above equation shows that as the grain boundary potential increases $V_{oc}$ is reduced.

4. Conclusions

The effect of grain boundary potential on the electrical parameters of the solar cells was studied in this work. In this work it has been theoretically proved that the total current density was reduced because of the presence of grain boundary potential. We have shown that the current through the junction is reduced considerably compared to that of the current produced due to the thermo photo voltaic effect of the grain boundary. Therefore we conclude that to increase the efficiency of the solar cell, the thermal radiation must be reflected from the solar cell.

References

1. A.J. Diefenderfer, Principles of Electronic Instrumentation, Saunders, 1979 (Chapter 5).
2. H.V. Malmstadt et al., Electronic Measurements for Scientists, Benjamin, Menlo Park, 1974 (Section 2-1).
3. J. Millman and C.C. Halkias, Integrated Electronics: Analog and Digital Circuits and Systems, McGraw-Hill, N.Y., 1972 (Chapters 1 and 2).
4. R.J. Smith, Electronics: Circuits and Devices, Wiley, N.Y., 1973 (Chapter 5).
5. Y. Zohta, Solid-State Electron.16, 1029-1034 (1973).
6. R. J. Tocci and M.E. Oliver, Fundamentals of Electronic Devices, Fourth Edition, Merrill, N.Y., 1991, (Chapter 5) p. 143
7. FJ Humphreys, M Hatherly (2004). Recrystallisation and related annealing phenomena. Elsevier. AP Sutton, RW Balluffi (1987). "Overview no. 61: On geometric criteria for low interfacial energy". Acta Metallurgica 35 (9): 2177–2201.
8. RD Doherty; DA Hughes; FJ Humphreys; JJ Jonas; D Juul Jensen; ME Kassner; WE King; TR McNelley; HJ McQueen; AD Rollett, "Current Issues In Recrystallisation: A Review". Materials Science and Engineering A238: 219–274 (1997).
9. G Gottstein, LS Shvindlerman, Grain Boundary Migration in Metals: Thermodynamics, Kinetics, Applications, 2nd Edition. CRC Press(2009) p. 245
10. S. S. Simeonov, Phy. Rev.B 36, 9171-79 (1987)
11. P. de Mierry, O.Ambacher, H.Kratzer and M.Stutzmann, Phys. Status Solidi A158, 597-603 (1996).