Chapter 4

Some analytical studies on the conversion efficiency of metal-insulator-semiconductor solar cells
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4.1 Introduction:

Metal insulator semiconductor (MIS) solar cells have been studied extensively during the last few decades by different researchers. Card and Yang [1] have theoretically shown that the open circuit voltage of the MIS solar cells increases due to the increase in the thickness of the interfacial layer. Ponpon and Siffert [2] have experimentally shown that the open circuit voltage of the MIS solar cells may be increased with the increase in the barrier height at the metal insulator semiconductor interface or by increasing the diode quality factor n. Lue and Hong [3] have theoretically calculated the optimum thickness of the barrier metal which gives the maximum short circuit current of the MIS solar cells and shown that it depends on the intensity of the incident light. They also satisfied the theoretically obtained results with experiment. A detailed theoretical calculation on metal-oxide-semiconductor solar cells have been presented by Srivastava et al. [4]. The short circuit current of MIS solar cell changes with the increase in the insulator layer thickness. It is mainly due to the increase in the interface state recombination current, as shown by Sen and Srivastava [5]. Krawczyk et al. [6] has reported theoretically and experimentally that the short circuit current of the MIS solar cells, decreases with increasing temperature. Shousha [7] has studied the effect of the various parameters like interfacial layer thickness, back surface field, diffusion length etc to improve the performance of the MIS solar cells.

The objective of our present work is to investigate theoretically the effect of doping concentration of the semiconductor base region, back surface field and interfacial layer thickness to improve the performance of the MIS solar cells.
4.2 Analysis:

Though Schottky barrier solar cells (SBSC) are easy to fabricate and inexpensive, but due to their higher dark current, the open circuit voltage and the conversion efficiency of such cells are lower than the conventional p-n junction solar cells. An efficient way to improve the performance of the SBSC is to introduce an insulating interfacial layer between the metal and the semiconductor interface.

The schematic diagram of a metal insulator semiconductor (MIS) solar cell has been shown in Figure 1.

![Schematic diagram of MIS solar cells](image)

**Figure 1. Schematic diagram of MIS solar cells**
4.2.1 The Dark Current:

The dark current of MIS solar cells generally have three components, (i) the tunneling current density, (ii) the diffusion current density at the depletion region and (iii) the recombination current density at the depletion region.

The reverse saturation current densities are given by

\[ J_{T0} = A^{**}T^2 \exp(-X_n^{0.5}\delta)\exp\left(-\frac{q\Phi_B}{kT}\right) \]  

(1)

\[ J_{D0} = \left(\frac{qn_i^2}{N_d}\right) \frac{S\cosh\left(\frac{H'}{L_p}\right) + \left(\frac{D_p}{L_p}\right)\sinh\left(\frac{H'}{L_p}\right)}{\left(\frac{S\tau_p}{D_p}\right)\sinh\left(\frac{H'}{L_p}\right) + \cosh\left(\frac{H'}{L_p}\right)} \]  

(2)

\[ J_{R0} = \frac{qn_iW}{2\tau_p} \]  

(3)

where, \(J_{T0}, J_{D0}\) and \(J_{R0}\) are the reverse saturation current densities due to electron tunneling [8], hole diffusion [7] and the carrier recombination [7]. \(A^{**}\) is the effective Richardson constant, \(X_n\) is the barrier height provided for tunneling by the interfacial layer, \(\Phi_B\) is the barrier height at the interface. S is the back surface recombination velocity for the holes, \(D_p, L_p\) and \(\tau_p\) are the diffusion coefficient, diffusion length and the diffusion lifetime for the minority carriers. \(\delta\) is the thickness of the interfacial layer. \(W\) is the width of the depletion layer [7]. \(H' = H - W - \delta\), where, H is the width of the solar cell.

The total saturation current density is

\[ J_0 = J_{T0} + J_{D0} + J_{R0} \]  

(4)

Thus the equation for the dark current density will be

\[ J_{dark} = J_0 \left[ \exp\left(\frac{qV_j}{nkT}\right) - 1 \right] \]  

(5)

where, \(V_j\) is the voltage introduced across the junction either by incident photons or by some other means. \(n\) is the diode ideality factor [2].
4.2.2 The Short Circuit Current:

The photo current developed in the MIS solar cells, consist of two components, (i) the photocurrent due to the excess photo-generated minority carriers i.e. holes in the n-type base region [9] and (ii) the high field in the depletion region sweeps the photo-generated carrier out before they can recombine, resulting in the drift current density [9]. The hole current density in the n-type base region can be written as [10]

\[ J_p = \frac{qG_{ph} \alpha I_p}{(\alpha^2 I_p^2 - 1)} (1 - R_c) \exp(-\alpha W) [\alpha I_p \right. \]

\[ \left. - \frac{\left(Sl_p \right)}{D_p} \left[ \cosh \left( \frac{H'}{L_p} \right) - \exp(-\alpha H') \right] + \sinh \left( \frac{H'}{L_p} \right) + \alpha I_p \exp(-\alpha H') \right] \]

\[ \frac{\left(Sl_p \right)}{D_p} \sinh \left( \frac{H'}{L_p} \right) + \cosh \left( \frac{H'}{L_p} \right) \]  

(6)

The drift current density [10] in the depletion region will be

\[ J_{dr} = q(1 - R_c) G_{ph} (1 - \exp(-\alpha W)) \]

(7)

where, \( \alpha \) is the absorption coefficient [10] and depends on the wavelength of the incident photon flux and \( R_c \) is the reflection coefficient of the solar cell.

Thus the total current density is

\[ J_{TOT} = J_p + J_{dr} \]

(8)

When sun light or light from any other light source, with certain spectral distribution is incident on the MIS solar cell, the short circuit current density of the cell can be obtained by integration [7].

\[ J_{SC} = \int_{\lambda_{min}}^{\lambda_{g}} \left( J_p(\lambda) + J_{dr}(\lambda) \right) d\lambda \]

(9)

The equation for the open circuit voltage [2] is
\[ V_{oc} = n \left[ \Phi_{BN} + \left( \frac{kT}{q} \right) x_n^0 \delta + \left( \frac{kT}{q} \right) \ln \left( \frac{J_{sc}}{A^* T^2} \right) \right] \]  \hspace{1cm} (10)

Assuming unit cross sectional area of the MIS solar cell, the current density corresponding to the maximum output power is

\[ J_m = (J_{sc} + J_o) \left[ \frac{\beta V_m}{1 + \beta V_m} \right] \]  \hspace{1cm} (11)

where, \( \beta = \frac{q}{nkT} \) and \( V_m \) is the output voltage corresponding to the maximum output power. \( V_m \) can be found by solving numerically the equation

\[ V_m = V_{oc} - \frac{1}{\beta} \ln(1 + \beta V_m) \]  \hspace{1cm} (12)

The fill factor of the MIS solar cell can be obtained as

\[ F_F = \frac{V_m J_m}{V_{oc} J_{sc}} \]  \hspace{1cm} (13)

And the conversion efficiency of the MIS solar cell is

\[ \eta = \frac{P_m}{P_{in}} \times 100\% = \frac{V_m J_m}{P_{in}} \times 100\% \]  \hspace{1cm} (14)

where, \( P_{in} \) is the incident optical power and \( P_m \) is the maximum output power.

\textbf{4.3 Results and discussion:}

In the above analysis the diffusion coefficient [8], diffusion length [8], diffusion lifetime [11], carrier mobility [12] and the depletion region width, all are dependent on doping concentration. As a result the conversion efficiency is also dependent on doping concentration.
Figure 2. The variation of the conversion efficiency $\eta$ with interfacial layer width $\delta$ for different back surface recombination velocity.

From Figure 2, it can be seen that with the increase in the interfacial layer width the conversion efficiency increases, which is quite evident. But another aspect can also be found out from this graph. With the decrease in the back surface recombination velocity the conversion efficiency increases. With the decrease in the back surface recombination velocity more carriers can be available to cross the barrier and increase in the photo-current, as well as the conversion efficiency.
Considering $S=0$ cm/s i.e. using back surface field, the variation of the conversion efficiency $\eta$ with doping concentration $N_d$ has been shown in Figure 3.

![Diagram showing the variation of conversion efficiency $\eta$ with doping concentration $N_d$.](image)

**Figure 3. The variation of the conversion efficiency $\eta$ with doping concentration $N_d$**

From Figure 3, it can be observed that with the increase in doping concentration the conversion efficiency increases. This is mainly due to the fact that with the increase in doping concentration the diffusion length of the carriers decreases resulting in an decrease in the short circuit current density. Consequently the open circuit voltage increases. Thus the conversion efficiency increases.
4.4 Conclusion:

Based on the theoretical analysis carried out in this chapter, for an MIS solar cell, the variation of the conversion efficiency with interfacial layer width has been studied for different back surface recombination velocity. And observed that the conversion efficiency increases with the increase in the interfacial layer width and also increases with the decrease in the back surface recombination velocity. We also studied the variation of the conversion efficiency with the doping concentration of the n-type base region. And observed that with the increase in the doping concentration the conversion efficiency increases.

References: