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# High level illumination effect on MS′S solar cell characteristics with a new material $Ga_2Se_3$, as an intermediate layer

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Compound semiconductor heterostructure (Al–$Ga_2Se_3$–nSi) uses a new material for photovoltaic applications. This Metal-Semiconductor-Semiconductor (MS′S) structure with $Ga_2Se_3$ as an intermediate layer has been proposed as a better alternative to conventional Metal-Insulator-Semiconductor (MIS) solar cells for normal illumination. It is shown here that in the whole range – starting from lower intensity, i.e. at a concentration ratio, $C_r \sim 1$, to very high illumination level, $C_r \sim 2000$, the proposed new structure gives better results than corresponding MIS solar cells. © *1998 Chapman & Hall*

## 1. Introduction

It has been shown [1, 2] that a wide band gap semiconductor layer with a thickness less than the Debye screening length behaves like an insulator and such a layer could be used in place of oxide on silicon. $Ga_2Se_3$ (band gap $\approx 1.9$ eV) has a very good lattice match with silicon and has been shown experimentally to be equivalent to a metal–oxide semiconductor (MOS) in structure with reduced interface states ($D_s = 10^{13}$ m$^2$). Recently [3], current–voltage ($I$–$V$) characteristics, power fill factor and other parameters have been calculated for a metal–$Ga_2Se_3$–$n$Si system under normal illumination and have been found to be better than the typical MOS solar cell [4] because of the improved interface having a thickness of $\sim 3.5$ nm. Further, such a layer has been fabricated and reported [5, 6] for some other application. The effect of high temperature on these cells has already been considered elsewhere [7]. In the present work we show the effect of high intensity on these MS′S solar cells.

The solar-cell structure (metal–$Ga_2Se_3$–$n$Si) considered here is shown in Fig. 1. With increasing intensity of light, the open circuit voltage, $V_{oc}$, of the cell increases, initially in accordance with the Shockley equation and then it starts to saturate. At a high level of illumination the concentration of the minority carrier becomes comparable with that of the majority carrier and as such a new expression for the majority carrier current, $J_n$, may be given as [8]

$$J_n = J_{no}\left\{1 + \frac{\delta p}{n_{no}}[\exp - q(V_s - \Delta V_s)/kT]\right\} \times \exp(-b_n \chi_n^{1/2}\delta)\,[\exp(q\Delta V_s/kT) - 1] \quad (1)$$

and

$$(J_{no})_{\text{effective}} = J_{no}\left\{1 + \frac{\delta p}{n_{no}}\exp[-q(V_s - \Delta V_s)/kT]\right\} \quad (2)$$

where $\delta p$ is the number of excess carriers generated at high illumination; and $\Delta V_s$ is the change in $V_s$, where $V_s$ is the drop across the base Si.

The majority current is increased by a factor

$$\left\{1 + \frac{\delta p}{n_{no}}\exp[-q(V_s - \Delta V_s)/kT]\right\}$$

This brings about a saturation in the voltage developed across the semiconductor which in turn saturates the change in the open circuit voltage.

The expression for the open circuit voltage is given by

$$V_{oc} = \left(1 + \frac{\delta}{W}\frac{\varepsilon_s}{\varepsilon_{s'}}\right)\frac{kT}{q}\ln\left\{\frac{J_{sc}}{J_{no}}[\exp(b_n\chi_n^{1/2}\delta) + 1]\right\} + \frac{\delta}{\varepsilon_{s'}}qD_s(f_s - f_{so}) \quad (3)$$

where $\varepsilon_{s'}$ is the permittivity of compound semiconductor, $Ga_2Se_3$; $W$ is the depletion width; $b_n$ the tunnelling transmission coefficient; $\chi_n$ the barrier height for electrons (in electron volts); $\delta$ the thickness of the compound semiconductor layer (in nanometres); and $D_s$ is the density of the surface states.

## 2. Results and discussion

The $I$–$V$ characteristics of MS′S (with $n$Si, 1 $\Omega$ cm$^{-1}$ resistivity) solar cells at higher levels of illumination $C_r = 1, 2, \ldots, 6$) have been calculated for $D_s = 10^{13}$ m$^{-2}$ and $\delta = 3.4$ nm. The results are plotted in Fig. 2. Although the trend is the same as for the MOS solar cell [8], the open circuit voltage is greater for MS′S. From the $I$–$V$ characteristics with a new value of $J_{no}$, $V_{oc}$ has been plotted against log $C_r$, where $C_r$ is the concentration ratio and varies from $C_r = 1, 10, 20, \ldots, 100, 200, \ldots, 1000$ (Fig. 3). On comparing the two types of solar cells (MOS and MS′S) at

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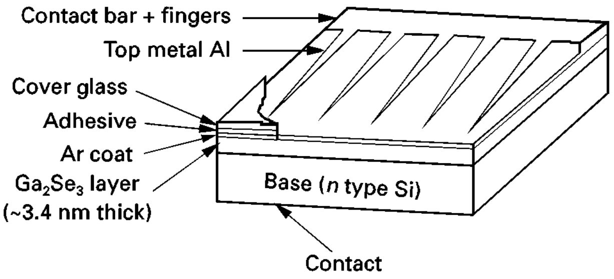

*Figure 1* Structure of the solar cell (Al–$Ga_2Se_3$–*n*Si).

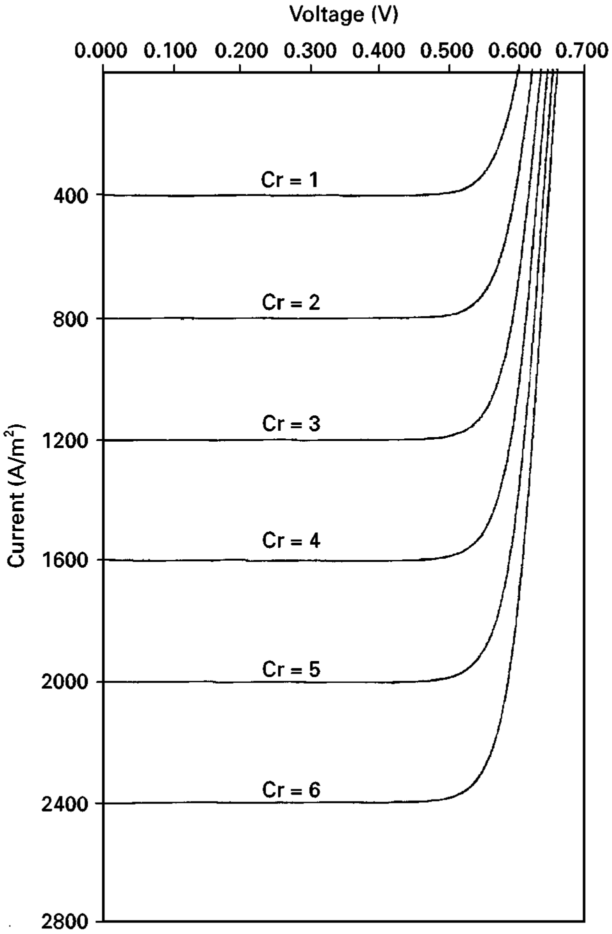

*Figure 2* Theoretical *I–V* characteristics at higher levels of illumination for MS'S (Al–$Ga_2Se_3$–*n*Si) with an intermediate layer thickness, $\delta = 3.4$ nm.

very high levels of illumination up to $C_r = 10^3$, it is seen that $V_{oc(sat)}$ for MS'S (0.793 V) is much higher than for MOS (0.643 V). Thus one gets higher open circuit voltage even at lower concentration ratios, $C_r$, with these MS'S solar cells.

## 3. Conclusions

Thus MS'S has proved to be a better alternative for photovoltaic applications because:

1. It has a thicker intermediate layer of $Ga_2Se_3 \approx 3.4$ nm, compared with only a 1.0 nm thick non-uniform layer in MOS solar cells that is only two–three lattice distances thick.
2. It has higher open circuit voltage, thereby improving the efficiency of the cell.

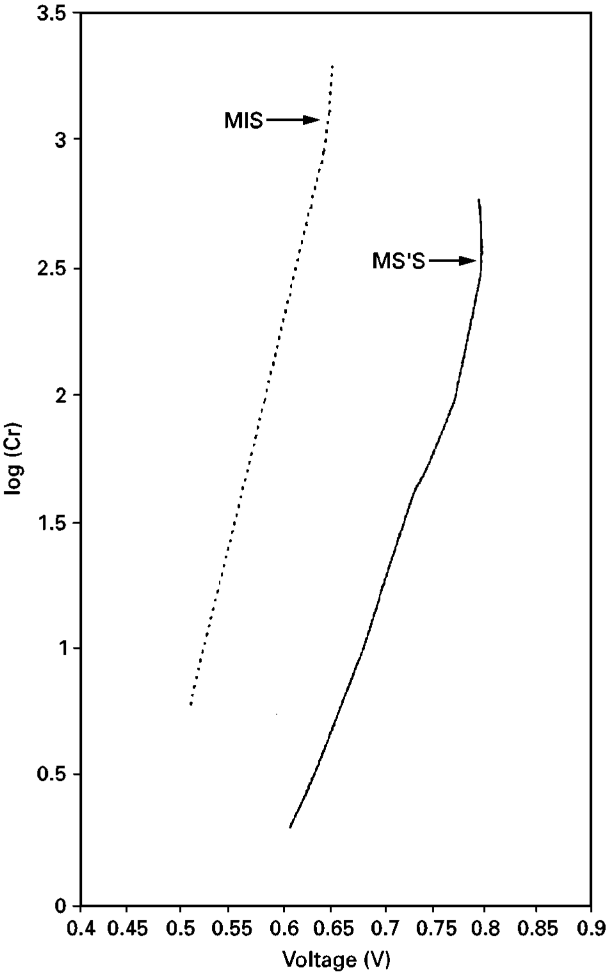

*Figure 3* Variation of open circuit voltage, $V_{oc}$, with concentration ratio $C_r$, for MIS and MS'S structures.

3. It has a reduced number of interface states, i.e. $D_s = 10^{13}\ m^{-2}$ for normal illumination, thus providing a better interface.

It is also seen that in the case of higher level illumination, the open circuit voltage is higher when compared with that of MIS.

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