Chapter 3

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3.1 Introduction:

Lot of research work has already been done on Schottky-barrier solar cells [1-6]. A comparison between Schottky diodes and p-n junction diodes was done by Rhoderick [7] in the detailed review of metal-semiconductor contacts. Detailed discussion on these solar cells is available in standard texts [8,9]. Mandelkorn and Lamneck Jr. [10] have determined the method of for fabrication of 10-Ω cm back surface field solar cell by alloying and diffusing aluminium at the back surface of the conventional solar cell and have shown that it can give higher open circuit voltage and better efficiency. Sinha and Chattopadhyaya [11] have theoretically investigated the effect of the back surface field on n⁺p solar cells. They concluded that if the base layer have lower impurity concentration the back surface recombination velocity decreases, resulting in increased photocurrent. In another work the same authors [12] have studied the minority carrier reflecting properties of the high-low junction, taking into account of the heavy doping effect. Dhariwal and Kulshreshtha [13] have developed a theory, based on the transport of both the minority and majority carriers under charge neutrality condition, that explains the behavior of the back surface field solar cells.

On the basis of analytical work carried out on the Schottky-barrier solar cells, a new design of Schottky-barrier solar cell has been suggested by us [15] in which an additional heavily doped n⁺ layer has been incorporated at the back of the normal Schottky-barrier solar cell, which already has been discussed in Chapter 2. In the present work, the proposed new design of
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Schottky-barrier solar cell has been studied further, assuming two limiting values of the back-surface-recombination-velocity, to get a clear picture of the advantages of using a back-surface-field Schottky-barrier solar cell.

3.2 Analysis:

An analytical study of the n-type silicon Schottky-barrier solar cell (SBSC) having a back ohmic contact has been previously undertaken by us [16] and the minority carrier distribution and photocurrent of this cell have been studied in detail. A modification of this conventional solar cell has been investigated by us and a new Schottky-barrier solar cell structure with a back-surface-field (BSF) has been suggested [15], which is shown in Figure 1.

![Figure 1: Schottky-barrier Si solar cell with a BSF](image)

In this chapter it has been assumed that an n⁺ layer is incorporated at the back of the normal SBSC. The low-high junction at the back of the cell should reflect the minority carriers towards the depletion region of the cell. This, in effect, reduces the effective back-surface-recombination velocity (S).

For the ideal case, the value of S should be negligible. Assuming S=0, the expression for photocurrent due to the n-type base layer becomes
\[ J_p = \left[ \frac{qFT\alpha L_p}{(\alpha^2 L_p^2 - 1)} \right] \left[ \exp(-\alpha W) \right] \left[ aL_p - \frac{\sinh \left( \frac{H'}{L_p} \right) + \alpha L_p \exp(-\alpha H')}{\cosh \left( \frac{H'}{L_p} \right)} \right] \]  

(1)

where \( F \) is the incident photon-flux, \( T \) is the transmission coefficient of light through the metal, \( \alpha \) is the absorption coefficient, \( q \) is the charge of electron and \( L_p \) is the diffusion length of the holes. \( H' = H - W \), where \( W \) is the depletion layer width. The expressions for \( \alpha, L_p \) and \( W \) have already been shown in Chapter 1.

The spectral response corresponding to a wavelength \( \lambda \) is given by

\[ SR(\lambda) = (1 - \exp(-\alpha W)) \]

\[ + \left[ \frac{\alpha L_p}{(\alpha^2 L_p^2 - 1)} \right] \left[ \exp(-\alpha W) \right] \left[ aL_p - \frac{\sinh \left( \frac{H'}{L_p} \right) + \alpha L_p \exp(-\alpha H')}{\cosh \left( \frac{H'}{L_p} \right)} \right] \]  

(2)

For comparing the results obtained for this new structure, the photocurrent may be computed for the case where an ohmic contact exists at the back surface. For this case, \( S = \infty \) and the spectral response becomes

\[ SR(\lambda) = (1 - \exp(-\alpha W)) \]

\[ + \left[ \frac{\alpha L_p}{(\alpha^2 L_p^2 - 1)} \right] \left[ \exp(-\alpha W) \right] \left[ aL_p - \frac{\cosh \left( \frac{H'}{L_p} \right) - \exp(-\alpha H')}{\sinh \left( \frac{H'}{L_p} \right)} \right] \]  

(3)

It may be mentioned here that detailed studies on the minority carrier reflecting properties of the low-high junctions were carried out earlier by researchers on n'-p-p' back-surface-field (BSF) solar cell [10-14] and it was found that the efficiency of the cell increased significantly. The same approach has been suggested by the authors for the Schottky-barrier solar cells [15]. The analysis presented in this paper would therefore enable a comparative study for the cases of back ohmic contact and perfect low high junction assumed for a SBSC.
3.3 Results and discussions:

Based on the theoretical expressions derived in the previous section, some calculations have been performed. The analytical expressions for the doping dependent minority carrier (hole) life time and the carrier mobility have been obtained from published literatures [17,18]. The corresponding values of doping dependent diffusion coefficients were found from the Einstein’s relationship [19]. For Silicon the value of static dielectric constant $\varepsilon_s$ is taken as $1.053 \times 10^{12}$ F cm$^{-1}$ and the total width of the solar cell is taken as 300 $\mu$m.

![Graph showing spectral response vs absorption coefficient]

**Figure 2: Variation of spectral response with absorption coefficient for the proposed new SBSC with back surface field, and for the conventional SBSC with back ohmic contact.**

Figure 2. shows the variation of spectral response (SR) versus absorption coefficient $\alpha$ for the two values of $S=0$ and $S= \infty$. Here the doping concentration is taken as $1 \times 10^{15}$ cm$^{-3}$. It is observed that much higher values of photocurrent are obtained for the case of $S=0$ cm/s, which corresponds to the new back surface field Schottky-barrier solar cell, considered in this chapter. The difference is more pronounced for smaller values of $\alpha$, which corresponds to photons.
absorbed deep inside the solar cell, near the back contact. In a normal SBSC these photo-generated carriers recombine at the back ohmic contact and are lost. In the new SBSC these photo-generated minority carriers are reflected back towards the depletion region of the solar cell and swept away by the field present there. As result of which the photocurrent contribution increases significantly. Higher values of $\alpha$ corresponds to photons that are absorbed very near the front surface of the solar cell. The effect of back surface field on these photo-generated carriers is negligible, as they are far away from the back surface. As a result of which, the spectral response is nearly the same for both $S=0$ and $S=\infty$ when higher values of $\alpha$ are considered.

![Graph](image.png)

**Figure 3:** Variation of spectral response with doping concentration of the semiconductor layer of the SBSC, for the two limiting cases of back surface recombination velocity $S$.

The spectral response (SR) has been plotted in Figure 3. for different values of doping concentration $N_d$ in the semiconductor, considering the two limiting cases of $S=0$ and $S=\infty$. It is observed that the photocurrent increases drastically for the case where back surface field is present ($S=0$) as compared to the case where back ohmic contact ($S=\infty$) exists. This supports our argument that the incorporation of a BSF at the back should improve the performance of the Schottky-barrier solar cell. For higher values of doping concentration however, the magnitude of SR falls and the two curves eventually coincide. This may be due to the fact that at higher doping...
concentrations, degradation of life-time of minority carriers takes place and the overall SR falls. Also, the effect of back surface recombination velocity $S$ then become less pronounced since most of the carriers are lost before reaching the depletion layer, as they recombine owing to their lower values of lifetime.

![Graph of Spectral Response vs Wavelength](image)

**Figure 4:** Variation of Spectral Response with wavelength of the incident photon flux for two limiting cases of back surface recombination velocity.

Figure 4 shows the variation of the spectral response with wavelength of the incident photon flux for two limiting cases of $S=0$ and $S=\infty$. Here the doping concentration is taken as $1 \times 10^{15}$ cm$^{-3}$. From this graph it is observed that for smaller values of wavelength of the incident light the spectral response is high for both BSF SBSC and normal SBSC and approaches unity. For higher values of wavelength, there is significant difference in the magnitude of spectral response for the two cases. This is mainly due to the fact that for higher values of wavelength the values of absorption coefficient are lower. As a result the photons with higher wavelength are absorbed deep inside the solar cell, near the back contact. In normal SBSC these photo-generated carriers
near the back ohmic contact are readily lost by the recombination process in the back ohmic contact. In the new BSF SBSC these photo-generated carriers are reflected back to the depletion region and are swept away by the field in the depletion region, producing higher values of the photo-current and the spectral response. On the other hand, for lower values of wavelength the absorption coefficient is very high. So most of the incident photons are absorbed near the depletion region and there is almost no effect of the back surface field. Thus the spectral response is almost same for both BSF SBSC and normal SBSC. It may be mentioned here that the photocurrent contribution from a diffused p-n junction has been obtained for a region with nonuniform doping [20]. The same approach may be used for obtaining the photocurrent of a Schottky barrier solar cell also.

3.4 Conclusion:

In this chapter, an analytical study has been carried out on a Schottky barrier solar cell in which a heavily doped n’ layer is incorporated at the back of a normal cell, to give rise to a back-surface-field SBSC. Results of the study show that much improved spectral response is obtained in this case as compared to the case of a normal SBSC, having ohmic contact at its back. Suitable interpretation of the results obtained has been discussed at appropriate places.

References:


