THE MINORITY CARRIER PROFILE IN THE FRONT REGION OF A p⁺n JUNCTION SILICON SOLAR CELL AND ITS CONTRIBUTION TO THE SPECTRAL RESPONSE.

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ABSTRACT

Silicon solar cells have been previously studied both theoretically and experimentally by many researchers. In this paper, the light generated excess minority carrier distribution in the front p^+ region of a p^+ n junction silicon solar cell has been studied, taking into account different parameters such as front surface recombination velocity, doping concentration and absorption coefficient. The minority carrier profile thus obtained helps in understanding the physics of the solar cells, particularly the photocurrent contribution from the front region of the cell.

Keywords: Doping concentration, minority carrier distribution, solar cell, surface recombination velocity.

I. INTRODUCTION

Silicon solar cells have been studied extensively by variously researchers during the last few decades [1-8]. Most of the research work has been done on n^+ p silicon solar cells. In this paper, a p^+ n solar cell structure has been selected and an analytical research work has been carried out on the minority carrier distribution and photocurrent contribution from the front region of this cell. It may be mentioned here that an analytical study of minority carrier distribution and photocurrent of a Schottky-barrier silicon solar cell has been recently undertaken by the authors [9] and the results obtained have been interpreted from physical considerations.

II. ANALYSIS

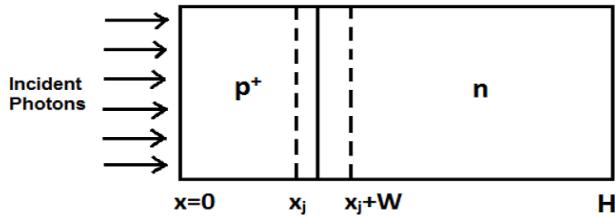The schematic diagram of a p^+-n solar cell is shown in figure (1).

$$x=0 \qquad x_j \qquad x_j+W \qquad\qquad H$$

Figure 1: A p^+ n junction silicon solar cell

In order to obtain the expression of excess minority carrier distribution and photocurrent of this cell, the method described by Hovel [10] and Sze [11] for an n-p junction solar cell, is followed here for a p^+ n junction solar cell. The generation rate of electron-hole pairs as a function of distance x from the surface is given by [10]

$$G(\lambda) = \alpha(\lambda) F(\lambda) [1 - R(\lambda)] \exp[-\alpha(\lambda)x] \qquad (1)$$

where λ is the wavelength of the incident light, α is the absorption coefficient, $F(\lambda)$ is the number of incident photons per cm^2 per second and $R(\lambda)$ is the fraction of this photons reflected from the surface.

The continuity equation for electrons in the p^+ front layer is given by

$$G_n - \frac{n_p - n_{po}}{\tau_n} + \frac{1}{q}\left(\frac{dJ_n}{dx}\right) = 0 \qquad (2)$$

where n_{po} is the thermal equilibrium value of electrons, τ_n is the life time of electrons and q is the electronic charge.

Considering abrupt p^+ n junction having uniform doping in the two regions, the electron current is given by

$$J_n = qD_n\left(\frac{dn_p}{dx}\right) \qquad (3).$$

Combining equations (1), (2) and (3) we obtain

$$D_n\frac{d^2 n_p}{dx^2} + \alpha F(1-R)\exp(-\alpha x) - \frac{n_p - n_{po}}{\tau_n} = 0 \qquad (4)$$

The general solution of this equation is

$$n_p - n_{p0} =$$

$$A\cosh\left(\frac{x}{L_n}\right) +$$

$$B\sinh\left(\frac{x}{L_n}\right) - \frac{\alpha F(1-R)}{\alpha^2 L_n^2 - 1}\tau_n \exp(-\alpha x) \qquad (5)$$

where $L_n = (D_n\tau_n)^{1/2}$ is the diffusion length of electrons, A and B are the constants, which may be evaluated using boundary conditions described here [10, 11].

At the surface (x = 0), there will be recombination with a surface recombination velocity S_n.

$$D_n\frac{d(n_p - n_{po})}{dx} = S_n(n_p - n_{po}) \qquad (6)$$

At the depletion region edge (x = x_j), due to presence of electric field, the excess minority carrier density falls to zero.

$$n_p - n_{po} = 0 \qquad (7)$$

Using the boundary conditions, the values of the constants A and B have been determined, which when substituted in equation (5) gives

$$n_p - n_{p0} = \left[\frac{\alpha F(1-R)\tau_n}{\alpha^2 L_n^2 - 1}\right] \times$$

$$\left[\frac{\left(\frac{S_n L_n}{D_n} + \alpha L_n\right)\sinh\left(\frac{x_j - x}{L_n}\right) + \exp(-\alpha x_j)\left\{\frac{S_n L_n}{D_n}\sinh\left(\frac{x}{L_n}\right) + \cosh\left(\frac{x}{L_n}\right)\right\}}{\frac{S_n L_n}{D_n}\sinh\left(\frac{x_j}{L_n}\right) + \cosh\left(\frac{x_j}{L_n}\right)} - \exp(-\alpha x)\right] \qquad (8)$$

The expression for the resulting electron photocurrent density from the front (p^+) region of the cell is given by

$$J_n = -\left[\frac{qF(1-R)\alpha L_n}{\alpha^2 L_n^2 - 1}\right] \times$$

$$\left[\frac{\left(\frac{S_n L_n}{D_n} + \alpha L_n\right) - exp(-\alpha x_j)\left(\frac{S_n L_n}{D_n}cosh\left(\frac{x_j}{L_n}\right) + sinh\left(\frac{x_j}{L_n}\right)\right)}{\frac{S_n L_n}{D_n}sinh\left(\frac{x_j}{L_n}\right) + cosh\left(\frac{x_j}{L_n}\right)} - \alpha L_n \, exp(-\alpha x_j)\right] \quad (9)$$

The contribution of the spectral response from the front region is thus given by

$$SR = \left|\frac{J_n}{qF(1-R)}\right| = \left[\frac{\alpha L_n}{\alpha^2 L_n^2 - 1}\right] \times$$

$$\left[\frac{\left(\frac{S_n L_n}{D_n} + \alpha L_n\right) - exp(-\alpha x_j)\left(\frac{S_n L_n}{D_n}cosh\left(\frac{x_j}{L_n}\right) + sinh\left(\frac{x_j}{L_n}\right)\right)}{\frac{S_n L_n}{D_n}sinh\left(\frac{x_j}{L_n}\right) + cosh\left(\frac{x_j}{L_n}\right)} - \alpha L_n \, exp(-\alpha x_j)\right] \quad (10)$$

Since the front (p^+) region is heavily doped, the lifetime of the minority carrier electrons and also their mobility is dependent on the impurity concentration. The doping dependent lifetime of the electrons have been taken from the formula given by Fossum [12] and the values of doping dependent mobility of electrons have been taken from published literature [13].

velocity starting from 10 cm/sec to 10^8 cm/s. The value of absorption coefficient α is taken as 10^4 cm^{-1}. It is observed from this figure that the value of minority carrier electron concentration is large at the surface for smaller values of surface recombination velocity S_n. The sharp fall in the minority carrier concentration near the surface for larger values of S_n is due to the carrier lost because of the high recombination at the surface for these values of S_n.
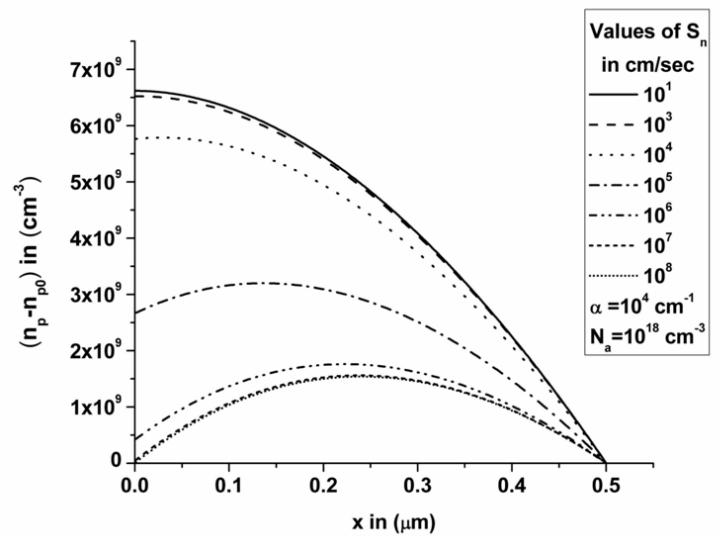

Figure 2: Variation of excess minority carrier concentration with distance from the front surface for different values of surface recombination velocity.

III. RESULTS AND DISCUSSION

The nature of the photocurrent contribution from the front region can be interpreted considering the minority carrier distribution in this region. For this reason, using equation (8), the excess minority carrier distribution in the front p^+ layer has been computed under different conditions.

Figure (2) shows the variation of excess minority carrier electron distribution as a function of distance x from the front surface in the p^+ region, for different values of front surface recombination

Figure (3) shows the distribution of excess electrons concentration in the p^+ region, for different values of absorption coefficient α. Here the chosen value of $S_n = 10^5$ cm/sec. It is observed that the value of excess electron concentration is small for $\alpha = 10$ cm^{-1}, whereas it increases significantly for larger values of α. This may be interpreted as follows. Since the wavelengths corresponding to larger values of α are absorbed mostly in the front region, they give rise to more electron-hole pairs, whereas the wavelengths

corresponding to smaller values of α are not all absorbed in the front region, but are absorbed in the next n-type base region. This is the reason why the excess minority carrier concentration increases with increasing values of α in the front region.
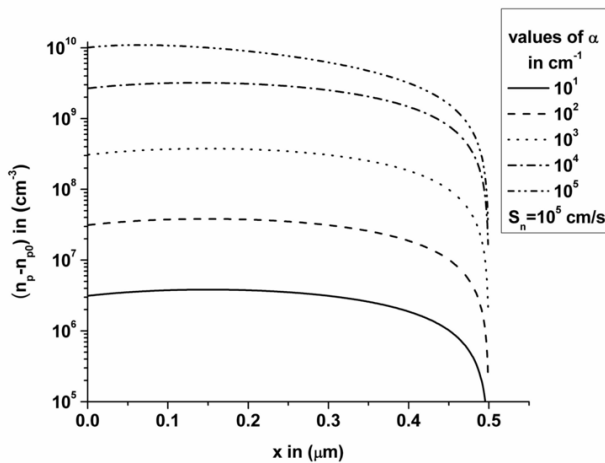

Figure 3: Variation of excess minority carrier concentration with distance from the front surface for different values of absorption coefficient α.

Figure (4) Shows the variation of electron distribution as a function of distance x in the p^+ region, for different values of acceptor doping concentration N_a in the p^+ region. It is observed that the value of excess electron concentration increases as the magnitude of N_a is increased. This is easily understood from the fact that the electron concentration in the region increases with increase in the doping concentration.
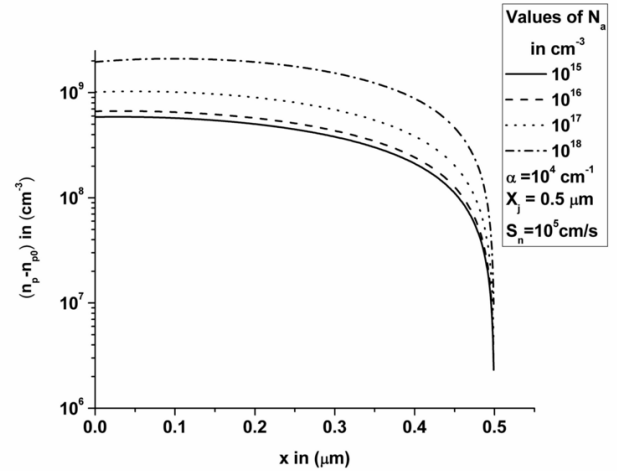

Figure 4: Variation of excess minority carrier concentration with distance from the front surface for different values of acceptor concentration N_a.

The plot of spectral response due to the front region, as a function of absorption coefficient, corresponding to different values of front surface recombination velocity is shown in figure (5). Its magnitude is higher for lower values of S_n and smaller for larger values of S_n. This may be explained from the fact that for large values of S_n, the recombination at the surface increases, which in turn reduces the contribution of photocurrent.
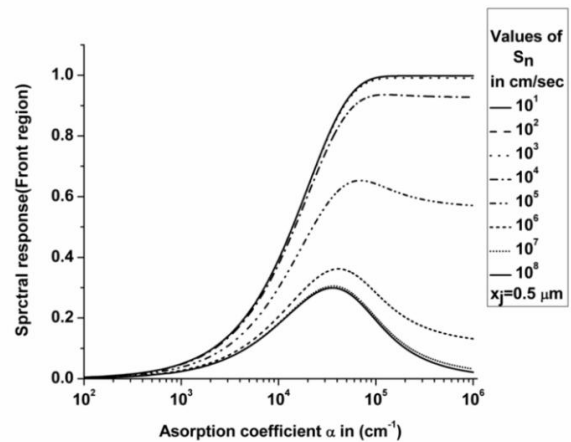

Figure 5: Variation of spectral response with absorption coefficient for different values of recombination velocity.

The corresponding plot of spectral response due to the front region as a function of wavelength is

shown in figure (6). Since the absorption coefficient of a material depends inversely on the wavelength of light incident on it, it is observed that figure (6) is somewhat complementary to figure (5). This clearly explains the behavior of the spectral response component due to the front layer.
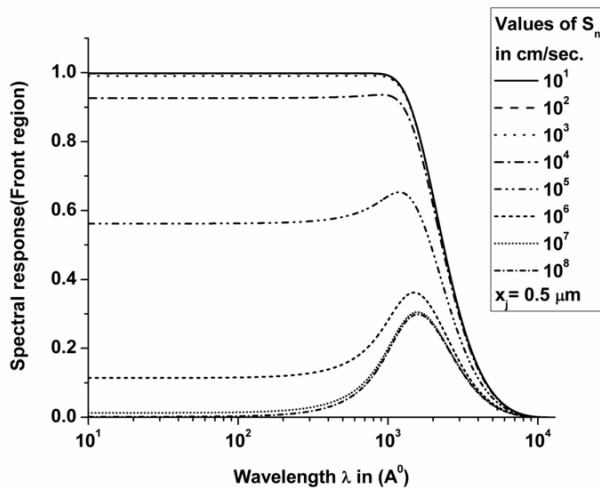

Figure 6: Variation of spectral response with wavelength of the incident light for different values of recombination velocity.

IV. CONCLUSION

In this paper, the light generated excess minority carrier distribution and photocurrent contribution from the front region of a p^+ n silicon solar cell has been studied analytically. It is observed that the minority carrier concentration increases with increase in the doping concentration and the absorption coefficient and decreases with increase in the front surface recombination velocity. An explanation has been given for this behavior, and subsequently the spectral response contribution from the front region has been evaluated.

Acknowledgement

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