Minority Carrier Distribution in the Base Region of a p^+ n Junction Silicon Solar Cell and its Contribution to the Spectral Response

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Abstract-Analytical and experimental research work has been done previously by various researchers on silicon solar cells. In this paper, an analytical study has been carried out on the light generated excess minority carrier distribution and photocurrent in the base region of a p^+ n junction solar cell. The effect of back surface recombination velocity, doping and absorption coefficient on the minority carrier distribution in the n type base layer have been observed and the spectral response component due to this region has been obtained. The minority carrier profile helps in understanding the physics of the solar cells.

Keywords - minority carrier distribution; solar cell; spectral response.

1. Introduction

Lot of research work has been done on silicon solar cells by researchers during last few decades [1-8]. Most of the research work has been carried out on n^+ p junction solar cells. In this paper analytical work has been done on the minority carrier concentration and photocurrent in the n-type base region of a p^+ n junction solar cell. The minority carrier profile obtained from theoretical considerations helps us in understanding the physics of the solar cell, particularly with reference to the doping concentration, surface recombination velocity, absorption coefficient and so on. It may be mentioned that an analytical study of the minority carrier distribution and photocurrent of a Schottky – barrier silicon solar cell has been carried out and the results obtained have been explained from physical considerations [9].

2. Analysis

The diagram of the solar cell considered in this paper and its assumed dimensions are shown in Fig. 1.

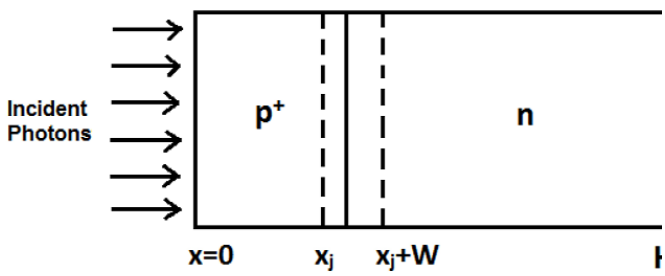

Fig.1. A p^+ n junction solar cell.

Analytical expressions for the minority carrier distribution and the photocurrent in the base region (n-region) of the p^+ n solar cell have been obtained here following the method described by Hovel [10] and Sze [11], in which they have studied an n p junction solar cell.

The continuity equation for holes in the n-type base region is

$$G_p - \frac{p_n - p_{n0}}{\tau_p} - \frac{1}{q}\left(\frac{dJ_p}{dx}\right) = 0 \quad (1)$$

Where p_{no} is the thermal equilibrium concentration of holes in the n region and τ_p is the lifetime of holes.

Assuming an abrupt p^+ n junction having uniform doping in the two regions, the hole current is given by

$$J_p = -qD_p\left(\frac{dp_n}{dx}\right) \quad (2)$$

The generation rate of electron - hole pairs is given by [10]

$$G(\lambda) = \alpha(\lambda)F(\lambda)[1 - R(\lambda)]\exp[-\alpha(\lambda)x] \quad (3)$$

where the symbols have their usual significance .

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

$$D_p \frac{d^2 p_n}{dx^2} + \alpha F(1 - R)\exp(-\alpha x) - \frac{p_n - p_{n0}}{\tau_p} = 0 \quad (4)$$

The general solution of this differential equation is

$$p_n - p_{n0} = C\cosh\left(\frac{x}{L_p}\right) + D\sinh\left(\frac{x}{L_p}\right) - \frac{\alpha F(1-R)\tau_p}{(\alpha^2 L_p^2 - 1)}\exp(-\alpha x) \quad (5)$$

Where $Lp = (D_p\tau_p)^{1/2}$ is the diffusion length of holes, C and D are constants, which may be evaluated using the following boundary conditions [10, 11].

1. At the depletion layer edge in the base region (x = xj+W), the excess minority carrier concentration falls to zero, because of the presence of electric field

$$p_n - p_{n0} = 0 \quad (6)$$

Where S_p is the recombination velocity at the back of the cell. Using these boundary conditions, the values of the constants C and D have been evaluated. The values of these constants have been substituted in Eq. (5), which gives an expression for the excess light generated minority carriers.

2. At the back of the solar cell (x = H),

$$D_p \frac{d(p_n - p_{n0})}{dx} = -S_p(p_n - p_{n0}) \quad (7)$$

$$p_n - p_{n0} = \left[\frac{\alpha F(1-R)\tau_p}{(\alpha^2 L_p^2 - 1)}\right]\left[\exp\{-\alpha(x_j + W)\}\right]\times \left[\cosh\left(\frac{x - x_j - W}{L_p}\right) - \exp\{-\alpha(x - x_j - W)\} - \frac{\frac{S_pL_p}{D_p}\left\{\cosh\left(\frac{H'}{L_p}\right) - \exp(-\alpha H')\right\} + \sinh\left(\frac{H'}{L_p}\right) + \alpha L_p\exp(-\alpha H')}{\frac{S_pL_p}{D_p}\sinh\left(\frac{H'}{L_p}\right) + \cosh\left(\frac{H'}{L_p}\right)} \times \sinh\left(\frac{x - x_j - W}{L_p}\right)\right] \quad (8)$$

Where H′= H – (xj+W)

The value of depletion layer width W is obtained from published literature [11].

The expression for the hole photocurrent current density of the cell is given by

$$J_p = -\left[\frac{\alpha qF(1-R)L_p}{(\alpha^2 L_p^2 - 1)}\right]\left[\exp\{-\alpha(x_j + W)\}\right]\times \left[\alpha L_p - \frac{\frac{S_pL_p}{D_p}\left\{\cosh\left(\frac{H'}{L_p}\right) - \exp(-\alpha H')\right\} + \sinh\left(\frac{H'}{L_p}\right) + \alpha L_p\exp(-\alpha H')}{\frac{S_pL_p}{D_p}\sinh\left(\frac{H'}{L_p}\right) + \cosh\left(\frac{H'}{L_p}\right)}\right] \quad (9)$$

The spectral response contribution due to this region of the solar cell is thus given by

$$SR = \left|\frac{J_p}{qF(1-R)}\right| = \left[\frac{\alpha L_p}{(\alpha^2 L_p^2 - 1)}\right]\left[\exp\{-\alpha(x_j + W)\}\right]\times \left[\alpha L_p - \frac{\frac{S_pL_p}{D_p}\left\{\cosh\left(\frac{H'}{L_p}\right) - \exp(-\alpha H')\right\} + \sinh\left(\frac{H'}{L_p}\right) + \alpha L_p\exp(-\alpha H')}{\frac{S_pL_p}{D_p}\sinh\left(\frac{H'}{L_p}\right) + \cosh\left(\frac{H'}{L_p}\right)}\right] \quad (10)$$

3. Results and Discussions

Using Eq. (8), the excess minority carrier hole density in the n-type base region has been computed under different conditions. This minority carrier distribution helps in interpreting the photocurrent contribution from the base region of the solar cell for various values of doping concentration, back surface recombination velocity and so on.

The light generated excess minority carrier hole concentration is shown in **Fig.2**. The value of absorption coefficient α is taken as 100 cm^{-1}. It is observed from this figure that the value of minority carrier hole concentration is large near the rear surface for smaller values of S_p. There is a sharp fall in the hole density near the back of the cell, for larger values S_p, which is owing to the carrier lost due to recombination at the back surface for these large values of S_p. The value of excess hole concentration falls to zero near the junction, since the high field existing there sweeps the minority carriers across the depletion region.

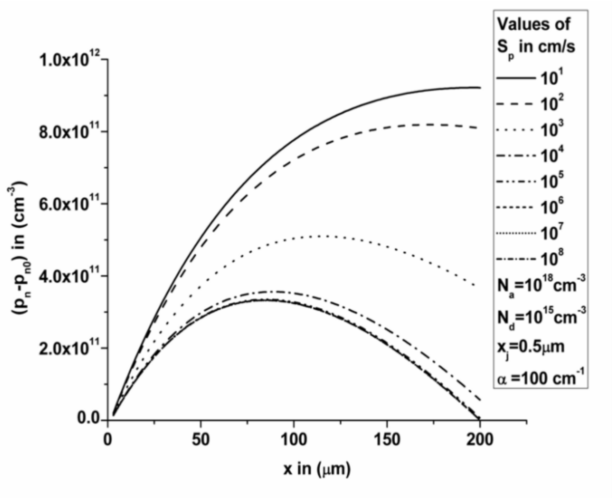

Fig.2. Variation of excess hole concentration with distance for different values of recombination velocity.

Fig.3 shows the distribution of light generated hole concentration in the entire base region corresponding to different values of absorption coefficient, α. It is observed that for α $=10^2$ cm^{-1}, the hole concentration is quite large, since most of the light photons corresponding to this wavelength are absorbed in this region and give rise to electron-hole pairs. Photons having wavelengths corresponding to larger values of α are absorbed mostly in the front region, whereas the photons of wavelength corresponding to smaller values of α are absorbed within this base region and contribute to photocurrent. It is observed that maximum excess minority carriers are obtained corresponding to α $=10^2$ cm^{-1}.

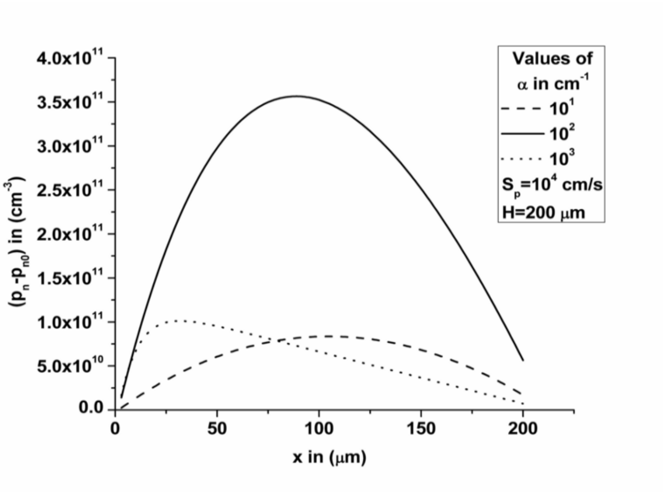

Fig.3. Variation of excess hole concentration with distance for different values of absorption coefficient.

Fig.4 shows the excess hole profile in the base of the cell. It is observed that the hole concentration increases for higher values of donor concentration N_d. This is expected, since the hole concentration in the base increases with the increase in the doping concentration.

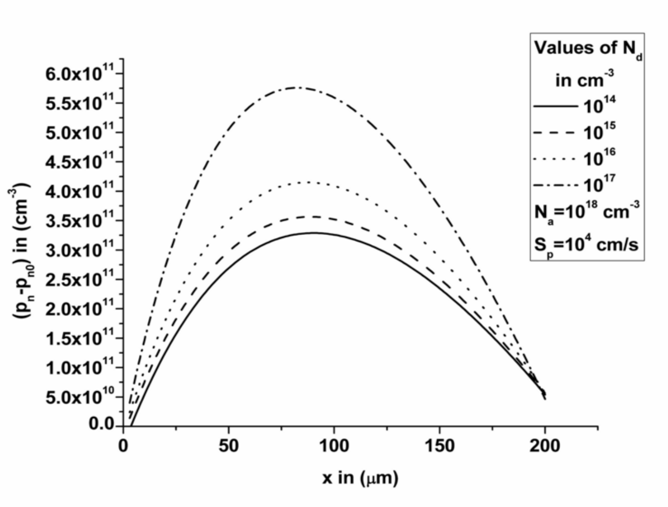

Fig.4. Variation of excess minority carrier density with distance for different values of donor concentration.

In Fig.5 the spectral response corresponding to n-type base region has been plotted for different values of base thickness H', taking different values of S_p. It is observed that there is an improvement in the spectral response as S_p is decreased. Also, as the thickness of this region is increased, more and more photons are absorbed here, giving rise to an improvement in the spectral response.

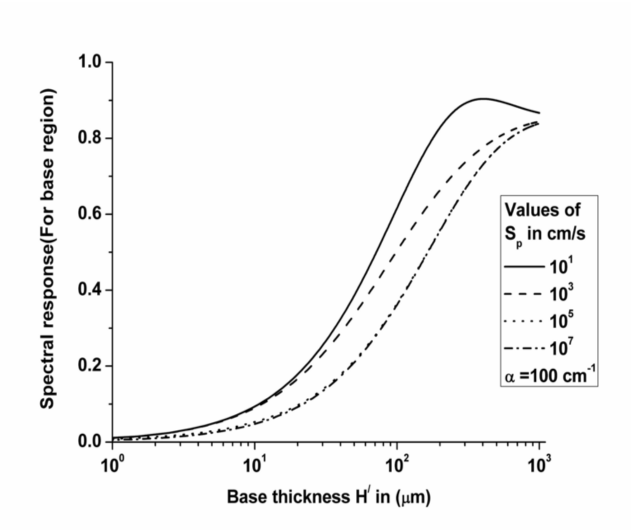

Fig. 5. Spectral response versus base thickness for different values of back surface recombination velocity.

4. Conclusion

The light generated excess hole concentration and the photocurrent contribution from the base region of the p^+ n junction solar cell has been studied in this paper. It is observed that the excess hole concentration and the photocurrent depends on the absorption coefficient as well as on the doping concentration. The excess carrier concentration and also the photocurrent increases for lower values of recombination velocity at the back surface.

Acknowledgements

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References

[1] D.M. Chapin, C.S. Fuller and G.L. Pearson, “A new silicon p-n junction photocell for converting solar radiation into electrical power”. J. Appl. Phys. vol. 25, pp. 676 - 677, May 1954.

[2] B. Dale and P. Smith, “Spectral response of solar cells”, J. Appl. Phys. vol. 25, pp.1377-1381, July 1961.

[3] R. Gereth, H. Fischer, E. Link, S. Mattes and W. Pschunder, “Contribution to Silicon solar cell technology, Energy Conversion, vol. 12, pp. 103-107, Sept. 1972.

[4] A.W. Blakers and M.A. Green, “20% efficiency silicon solar cells”, Appl. Phys. Lett., vol. 48, pp.215-217, Jan 1986.

[5] W. Wang, J. Zhao and M.A. Green, “24% efficiency silicon solar cells”, Appl. Phys. Lett. vol. 57, pp. 602-604, August 1990.

[6] P. Doshi and A. Rohatgi, “18% efficient silicon photovoltaic devices by rapid thermal diffusion and oxidation”, IEEE Trans. Electron Dev. vol. 45, pp. 1710-1716, August 1998.

[7] V. Perraki, “Modeling of recombination velocity and doping influence in epitaxial silicon solar cells”, Solar Energy Materials and Solar Cells, vol. 94, pp. 1597-1603, June 2010.

[8] A. Kassis and M. Saad, “Analysis of multi-crystalline silicon solar cells at low illumination levels using a modified two-diode model”, Solar Energy Materials & Solar Cells, vol. 94, pp. 2108-2112, 2010.

[9] A. Chatterjee, A. K. Biswas and A. Sinha, “Analytical Study of the minority carrier distribution and photocurrent of a Schottky - barrier silicon solar cell”, International Journal of Renewable Energy Research, vol. 4, No.2, pp. 504-507, June 2014.

[10] H. J. Hovel, Semiconductors and Semimetals, vol.11, Solar cells, Academic Press, New York, 1975, pp. 15-20.

[11] S. M. Sze and K. K. Ng, Physics of Semiconductor devices, John Wiley & Sons, 2007, pp. 725 - 730.