

On the depletion layer

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ABSTRACT

The main characteristics of the depletion layer, are obtained on the basis of a suggested model, according to which, the charge is distributed, not as a space charge but as surface charge on the lateral sides of the depletion layer.

Comparative discussions of the results obtained according to both models are given.

The dependences on the ratio " $\frac{N_d}{N_a}$ " and the applied voltage " V_a " are clarified. Both forward and backward biases are also considered. Graphical representations for the obtained relations, considering an illustrative example on a silicon cell are also given.

Key words: Depletion layer, charge, silicon cell.

INTRODUCTION

The study on the depletion layer of the p-n junction has aroused the interest of 1-5 many investigators. The main purpose is to increase the efficiency of the p-n junction as a solar energy converter. The depletion layer is an effective part of the indicated device. Thus the trend to determine the main characteristics of such a layer is predominant.

The present study is based on a model according to which the charges within the depletion layer are distributed on its lateral sides as surface charge distribution.

This model is in contrast with that model suggesting volume charge distribution in the depletion layer, for which Poisson's equation is required to find the potential. The application of both models will affect the estimated values of its

characteristics. This in turns will affect the expected values of the efficiency for such a device.

Derivation of the basic equations

Let us assume that the surface densities of the charge on the lateral sides of the depletion layer are given as:

$$\sigma_1 = -q(N_d - p + n)(x_0 - x_1) \quad , \left(\frac{C}{m^2}\right) \quad \text{for } x_1 < x < x_0 \dots (1)$$

and

$$\sigma_2 = +q(N_d + p - n)(x_2 - x_0) \quad , \left(\frac{C}{m^2}\right) \quad \text{for } x_0 < x < x_2 \dots (2)$$

Where

N_d, N_a , Donor and acceptor impurity densities, respectively.

, Densities of free electrons and holes, respectively.

, Magnitude of electron charge

According to Gauss theory, the intensity of the electric field (E), in the neighborhood of a charged plane surface is given according to the relation

$$E = \frac{\sigma}{\varepsilon} \quad \dots(3)$$

Where ε , is the permittivity of the medium ε_0 , F/m is the permittivity of free space, ε_r is the relative permittivity Moreover, one has to consider the relation

$$E = -\nabla \phi \quad \dots(4)$$

The boundary conditions imposed on the potentials fig (1) can be summarized as follows:

$$\text{at } x = x_1 \quad \phi = 0$$

$$\text{at } x = x_2 \quad \phi = v_{bi}$$

Where v_{bi} is the built in potential.

The system of equations (3), (4) and (5) makes it possible to obtain the following results:

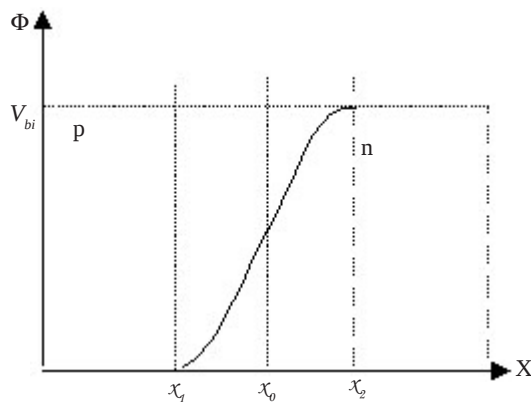


Fig. 1: The suggested potential distribution within the depletion layer

$$\phi_1 = \frac{qN_d(x_0 - x_1)(x - x_1)}{\varepsilon} \quad \text{for } x_1 < x < x_0 \dots(6)$$

$$\phi_2 = \frac{qN_d(x_2 - x_0)(x_2 - x)}{\varepsilon} + v_{bi} \quad \text{for } x_0 < x < x_2 \dots(7)$$

Equation (6) and (7) are subjected to the continuity condition at $x = x_0$, namely:

$$\text{at } x = x_0 \quad \begin{cases} \phi_1 = \phi_2 \\ \phi'_1 = \phi'_2 \end{cases} \quad \dots(8)$$

This gives, the following results:

$$(x_0 - x_1) = \left[\frac{V_{bi}}{\frac{qN_d}{\varepsilon} \left(1 - \frac{N_s}{N_d}\right)} \right]^{\frac{1}{2}} \quad \dots(9)$$

and

$$(x_2 - x_0) = \left[\frac{V_{bi}}{\frac{qN_d}{\varepsilon} \left(\frac{N_d}{N_s} - 1\right)} \right]^{\frac{1}{2}} \quad \dots(10)$$

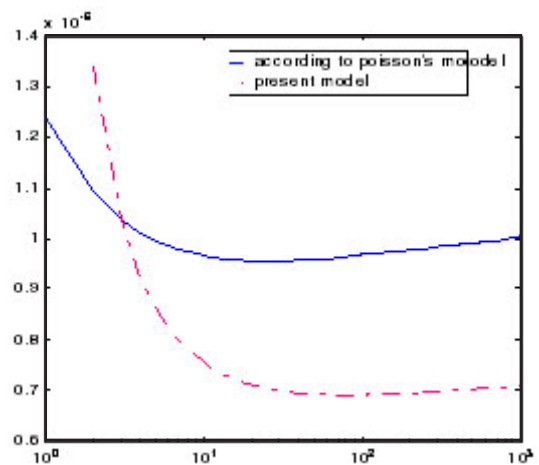


Fig. 2: The thickness of the depletion layer as a function as a function of the doping ratio

It is revealed, that to get real quantities, in equation (9) and (10) the following Conditions must be fulfilled.

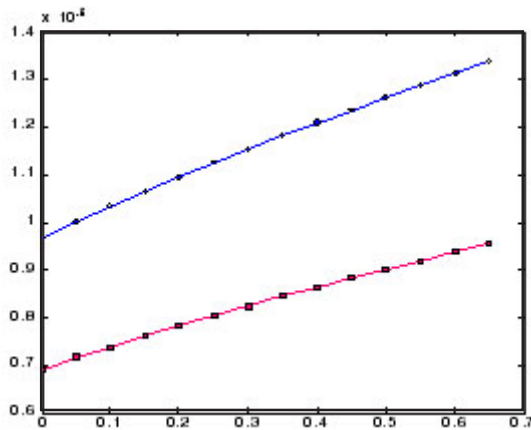
- i) $N_d \neq N_a$
- ii) for n^+p device, (and $N_a > N_d$ for p^+n device)

These restrictions are not revealed in the treatment according to the model considering volume charge distribution within the depletion layer.

Equations (9) and (10) make it possible to find the thickness of the depletion layer in the form:

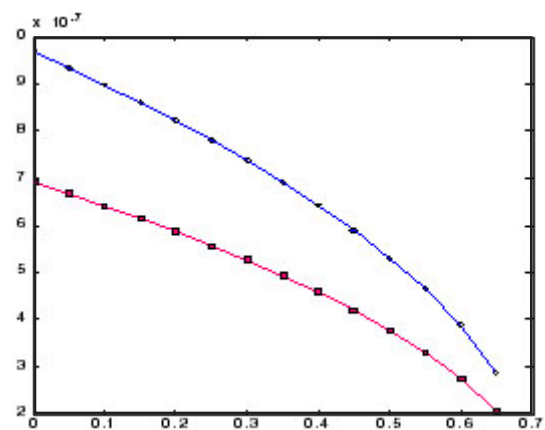
$$d = x_2 - x_1 = (x_2 - x_0) + (x_0 - x_1) \quad \dots(11)$$

$$d = \frac{\left[V_b \frac{qN_s}{\varepsilon} \left(1 - \frac{N_s}{N_d}\right) \right]^{\frac{1}{2}} + \left[V_b \frac{qN_s}{\varepsilon} \left(\frac{N_d}{N_s} - 1\right) \right]^{\frac{1}{2}}}{\left[\left(\frac{qN_d}{\varepsilon}\right) \left(\frac{N_d}{N_s} - 1\right) \left(\frac{qN_s}{\varepsilon}\right) \left(1 - \frac{N_s}{N_d}\right) \right]^{\frac{1}{2}}} \quad \dots(12)$$



(Backward bias)

Fig. 3: The thickness of the depletion layer as a function of the applied voltage-comparative study



(Forward bias)

Fig. 4: The thickness of the depletion layer as a function of the applied voltage -comparative study

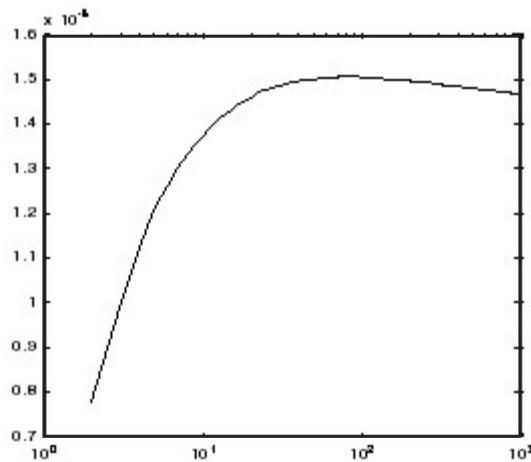
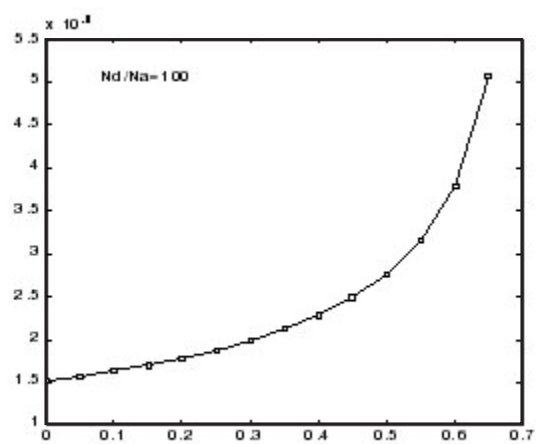


Fig. 5: The capacity as a function of the doping ratio



(Forward bias)

Fig. 6: The capacity as a function of the applied voltage

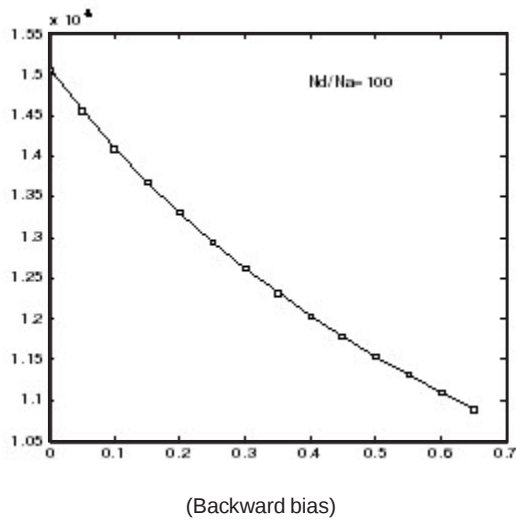


Fig. 7: The capacity of the depletion layer as function of the applied voltage

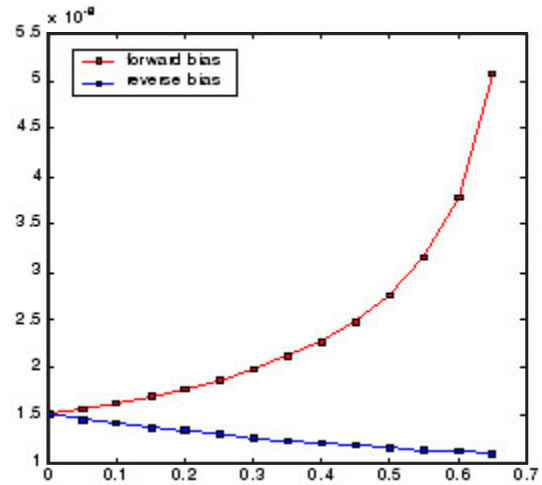


Fig. 8: The capacity as a function of the applied voltage-comparative study

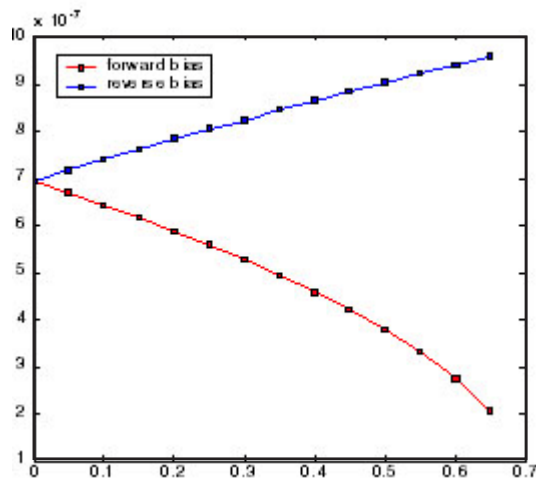


Fig. 9: The thickness as a function of the applied voltage-comparative study

Where, the built in potential V_{bi} is given in literatures as

$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

Where

n_i , m^{-3} Intrinsic density
 T , $^{\circ}K$ Absolute temperature
 k , $J/^{\circ}K$ Boltzmann constant

The capacity of the depletion layer as a parallel plate condenser can be obtained through the relation:

$$C = \frac{s \sqrt{q\epsilon} (N_d - N_a)}{\left[V_{bi} \left(\left[\frac{N_d^2 - N_d N_a}{N_a} \right] + \left[\frac{N_d N_d - N_a^2}{N_d} \right] \right) \right]^{\frac{1}{2}}} \dots (13)$$

Where, s , m^2 is the surface lateral area of one side.

Computations and discussion

Let us consider a n^+p junction made of silicon having the following specifications

$$\epsilon = \epsilon_0 \epsilon_r = 1.044 \times 10^{-10} \frac{F}{m} \quad T = 300^{\circ}K$$

$$q = 1.6 \times 10^{-19} C, \quad N_a = 10^{21} m^{-3}, \quad N_d = 10^{23} m^{-3}, \quad n_i = 10^{10} m^{-3}$$

This gives

$$(x_0 - x_1) = 0.684 \mu m$$

$$(x_2 - x_0) = 0.00684 \mu m$$

This result shows that the metallurgical surface is nearer to the side with higher doping concentration.

Moreover, the obtained expressions and computations reveal that for higher values of the ratio $\frac{N_d}{N_a}$, one obtains smaller values for the thickness of the depletion layer than those obtained according to the other model and vice versa. At a critical ratio one gets equal values for the thickness according to both models. The thickness "d" as a function of shows asymptotic behaviour. The asymptotic value of the thickness in case of our model is smaller than that according the other model, as shown in fig (2).

The thickness as a function of the applied voltage V_a is also studied for the forward and backward biases, and compared with corresponding values according to Poisson's model. The obtained results are illustrated graphically in figures (3), (4) and (9).

The thickness of the depletion layer as a function of the applied voltage –comparative study

Computations for capacity reveal that it does increase with $\frac{N_d}{N_a}$ ratio and it shows asymptotic behaviour, as shown in fig (5).

The dependence of the capacity on the applied voltage reveals that for forward bias, it increases with V_a while, it decreases with for backward bias, as shown in figures (6), (7) and (8).

CONCLUSIONS

As a result of this study, the following conclusions can be given

- The introduced model that assumes surface charge on the lateral sides of the depletion layer gives smaller values for the thickness of the depletion layer and the capacity of the equivalent condenser than that obtained for the model that assumes volume charge distribution in the space of the depletion layer, for the same parameters.
- Asymptotic behavior for the thickness as a function of the ratio $\frac{N_d}{N_a}$ is clarified.
- The condition $\frac{N_d}{N_a} \neq 1$ is established.
- Moreover, two other conditions are obtained namely:
 - i) $\frac{N_d}{N_a} > 1$ for n^+p device.
 - ii) $\frac{N_d}{N_a} < 1$ for p^+n device, such conditions are not established when the model of volume charge distribution in the depletion layer is considered.

For forward bias, the capacity of the depletion layer increases with the increase of the applied voltage and vice versa for the case of backward bias. This article is of importance in the efficiency evaluation of the solar energy converter. Further, studies are required to reveal the effect of the obtained results on the efficiency of the solar energy converter.

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