COMPUTATION OF THE CAPACITANCE OF AN INTERGRATED $N^+P^+P^-$ JUNCTION

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SUMMARY:

An efficient and accurate numerical method is described here to calculate the capacitance of an N^+ P^+ P^- integrated junction which takes into account the sideways spread of the diffusion and depletion layer width variations. The theoretical results are compared with experimental results taken under same conditions. This method of analysis can be used for different devices with different boundary conditions.

NOTATIONS:

N^+ : Heavily doped n-Semiconductor

P^+ : Heavily doped p-Semiconductor

P^- : Lightly doped p-Semiconductor

W	:	Depletion layer width.
ϵ_s	:	Silicon permitivity
q	:	Electronic charge
N_A	:	Doping level of p-Semiconductor
N_D	:	Doping level of n-Semiconductor
V_R	:	Reverse Bias.
V_o	:	Built-in voltage of junction.
$N(y)$	:	Doping level of any diffusion at any depth y.
$N(0)$	:	Doping level of any diffusion at surface
y	:	Diffusion Depth.
D	:	Diffusion Constant.
T	:	Temperature
$N_D(0,y)$	:	Doping level of n-semiconductor at any depth and x=o
$N_D(0)$	:	Doping level of n-semiconductor at surface
D_N	:	Diffusion constant of electrons
$N_A(y)$	:	Doping level of p-semiconductor at any depth y
$N_A(0)$	:	Doping level of p-semiconductor at surface
D_P	:	Diffusion constant of holes
X_S	:	Side way's spread.
$N_D(X_S,y)$	:	Doping level of n-semiconductor at any y and $x = X_S$
N_{AS}	:	Doping level of p-substrate.
C	:	Capacitance
A	:	Area.

(1) INTRODUCTION

The capacitance - voltage characteristics of an integrated junction (1-3) is a useful tool in studying semiconductor devices both in understanding these devices and in considering them for actual applications. This paper deals with a special type of junction shown in fig.(1). This junction consists of P^- substrate with a P^+ layer at the top. Then a selective N^+ region is diffused through the P^+ layer into P^- substrate. Thereby two junctions are created i.e. $N^+ P^+$ and $N^+ P^-$. This junction combines the features of the normal PN junction and that of N^+P^- junction. The depletion layer will spread slowly inside the upper P^+ layer (fig.1) and will spread quickly inside the lightly deped subtrate.

Another point worth mentioning here is the sideway's spread of the N^+ region inside P^+,P^- layers. This spread will be wider in P^-layer than in P^+layer since the substrate is lightly doped. This spread will enlarge the capacitance value.

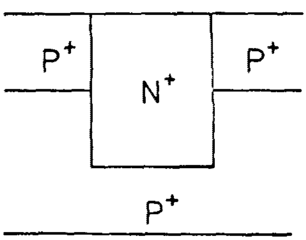


Fig1:$N^+ P^+ P^-$ junction

(2) NUMERICAL ANALYSIS

2.1 Assumptions.

Before describing the computation method two main assumptions have to be made namely.

(a) The junction model used i.e. abrupt approximation, linear representation, or any other model, and

(b) The diffusion distribution representation i.e. gussian function, complementary error function or any other function.

2.2 Analysis.

The computation method used (fig.2) is described below assuming an abrupt junction approximation, where the depletion layer width is given by (4);

$$W=(\frac{2\epsilon_S}{q}\ (\frac{N_A\ N_D}{N_A\ N_D})\ (V_R + V_o)\ \frac{1}{2} \qquad (1)$$

and guassian diffusion profile (5), where

$$N\ (y) = N\ (0) \qquad e^{-\ y^2/\ 4DT} \qquad (2)$$

After defining the required constants and functions, the N^+, P^+, P^- layers are subdivided into sub layers of thickness(y) as shown in fig (3). The value of y sets the accuracy limit i.e. as y is decreased, accuracy limit is increased and vice versa, then

(a) The dopings of N, P regions are calculated at any y (fig.3) along y-axis using this equation

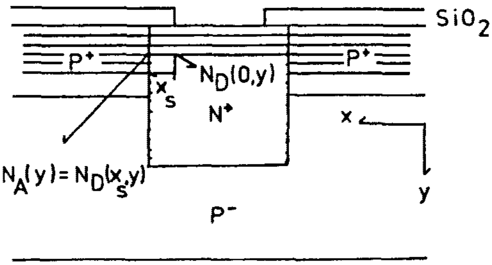


Fig3: Sideways spread calculation

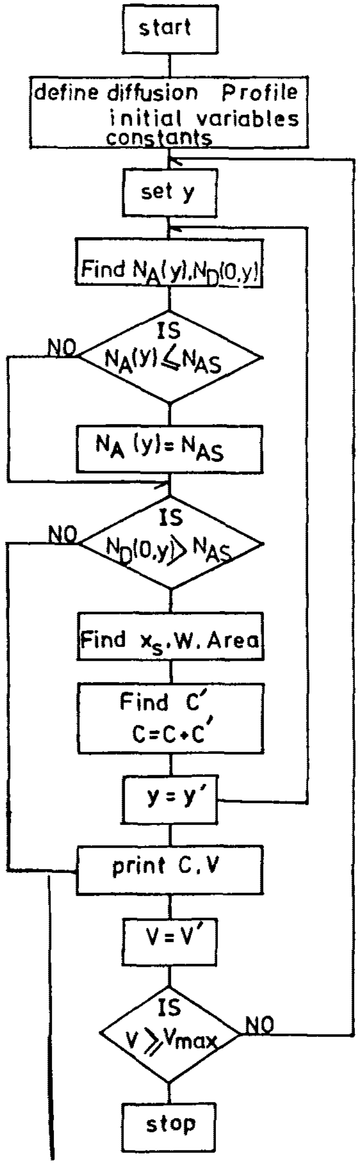


Fig 2 Computer programme flow chart

$$N_D(0,y) = N_D(0,0)\ e^{-y^2/4\ D_N T} \tag{3}$$

for N-diffusion, and

$$N_A(y) = N_A(0)\ e^{-y^2/4\ D_p T} \tag{4}$$

for P-diffusion

(b) A test is made to check if the P^+ doping is more than substrate doping, if not then its value is fixed to that of substrate.

(c) A test is made to check if N^+doping is more than substrate doping, if not calculation ends.

(d) The sideway's spread (X_S) is calculated now for any y by applying guassian function equation (3) along the x-axis for the N-diffusion (fig 3) to find the point where N diffusion ends inside P^+layer i.e. where

$$N_D(X_S,y) = N_A(y) \tag{5}$$

The $N_D(0,0)$ value in equation (3) now takes the value of $N_D(0,Y)$ calculated from (1) above.

Thus equation (3) becomes:

$$N_D(X_S,y) = N_A(y) = N_D(0,Y)\ e^{-X_S^{2}/4D_N T} \tag{6}$$

or by mathematical manipulation

$$X_S = 4\ D_N\ T\ \text{In}\ \frac{N_D\ (\ 0,y\ )}{N_A\ (y)} \tag{7}$$

(e) The depletion layer thickness is calculated using this equation:

$$W = \left(\frac{2\epsilon s}{q} \left(\frac{N_A\ (y)\ + N_D(0,y)}{N_A\ (y)\ \ N_D(0,Y)} \right) (V_R+V_o) \right)^{\frac{1}{2}} \tag{8}$$

if P^+ doping is greater than substrate doping, and

$$W = \frac{2\epsilon_s}{q} \frac{1}{N_{AS}} (V_R + V_o)^{\frac{1}{2}} \qquad (9)$$

if P^+ doping is less than substrate doping, after defining the built-in voltage (V_o) using dopings found in (1) above

(f) The area is calculated now using the side-way's spread from (4) above.

(g) The differential capacitance is found now using this relation.:

$$C = \frac{\epsilon_s A}{W} \qquad (10)$$

(h) The differential capacitance associated with different y^s are added to give total acapacitance at a certain bias.

(i) The whole process is repeated for different voltage.

(3) Theoretical Results

The numerical analysis described before was applied to a junction with the following characteristics: Area = $4000\mu m^2$, $N_A(0) = 5x10^{19}/cm^3$.

$N_D(0) = 1.15 \times 10^{21}/cm^3$, N_A (substrate) $= 10^{13}/cm^3$,
D_PT product for p^+ diff$=1.4 \times 10^{-11} cm^2$, and
D_NT product for N^+ diff$=7.77 \times 10^{-10} cm^2$.

The theoretical results achieved using this computation method are plotted in figs (4,5).

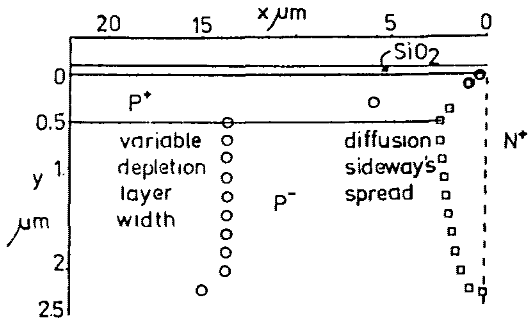
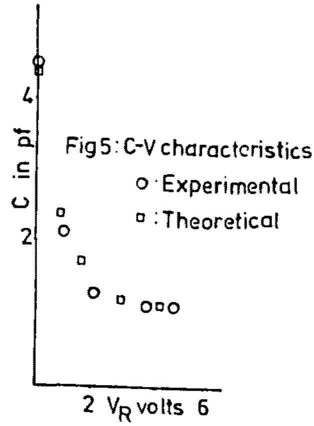


Fig4: Theoretical X_s and W variations with diffusion depth



The sideway's spread is **plotted** in fig(4) along with the depletion layer width. The sideway's spread in as expected before, thereby increasing the area and capacitance of junction. The depletion layer starts with 0.01μm at the surface to reach about 10 μm at the bottom, thereby indication that the dominating capacitance value is that at the surface.

The calculated capacitance-voltage variations is shown in fig (5).The shape, as seen, is midway between normal N^+P^+ junction and that of lightly doped regions.

(4) Experimental Results:

The results achieved for a junction processed under the same conditions assumed for theoretical model are plotted in fig (5).They are in good agreement with the theoretical results.
The measurements were taken at 100 KH_z.

(5) Conclusion:

A study is presented for the capacitance of the $N^+P^+P^-$ junction from the theoretical and experimental sides. A numerical analysis is presented which takes into account sideway's spread and depletion layer width variations. This method of analysis assumes gaussian diffusion profiles and abrupt junction.

The model gave accurate results enough for most applications. It can be used for any other structure and under different conditions.

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