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This program computes the values of  
the minimum empty potential well Vm and the surface potential Vs.

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As the density of the impurity atom in the buried channel Nd becomes larger,  
only the total dose of  $Q_d = Nd \cdot X_d$  influences the values of the buried channel  
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The density Nd of the buried channel region can be chosen effectively  
with an extra process freedom in the ion implattaion technology.

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The density Nd of the buried channel region can be  
made large as long as the width Xd is kept narrow.  
the PN+Psub double junction type Buried Channel CCD  
may also work perfectly.

This observation in 1975 led Hagiwara to his inventions of  
the double P+NP and the triple P+NPN junction type  
Pinned Buried Photodiodesdefined in JPA 1975-127646,  
JPA 1975-127647 and JPA1975-134985 Japanese Patents.

\*\*\*\*\*

$$Vs = V_{gg} + A - \sqrt{A \cdot A - B};$$

$$Vm = C * (Vs - V_{gg}) + D;$$

where

$$A = Esi \cdot Na / Cox / Cox + Qd * (1 + Na / Nd) / Cox;$$

$$B = (1 + Na / Nd) * Qd * Qd / Cox / Cox$$

$$- 2 * Esi * Na * (V_{gg} - V_{bar}) / Cox / Cox;$$

$$C = (1 + Na / Nd) * (1 + Cox / Cd);$$

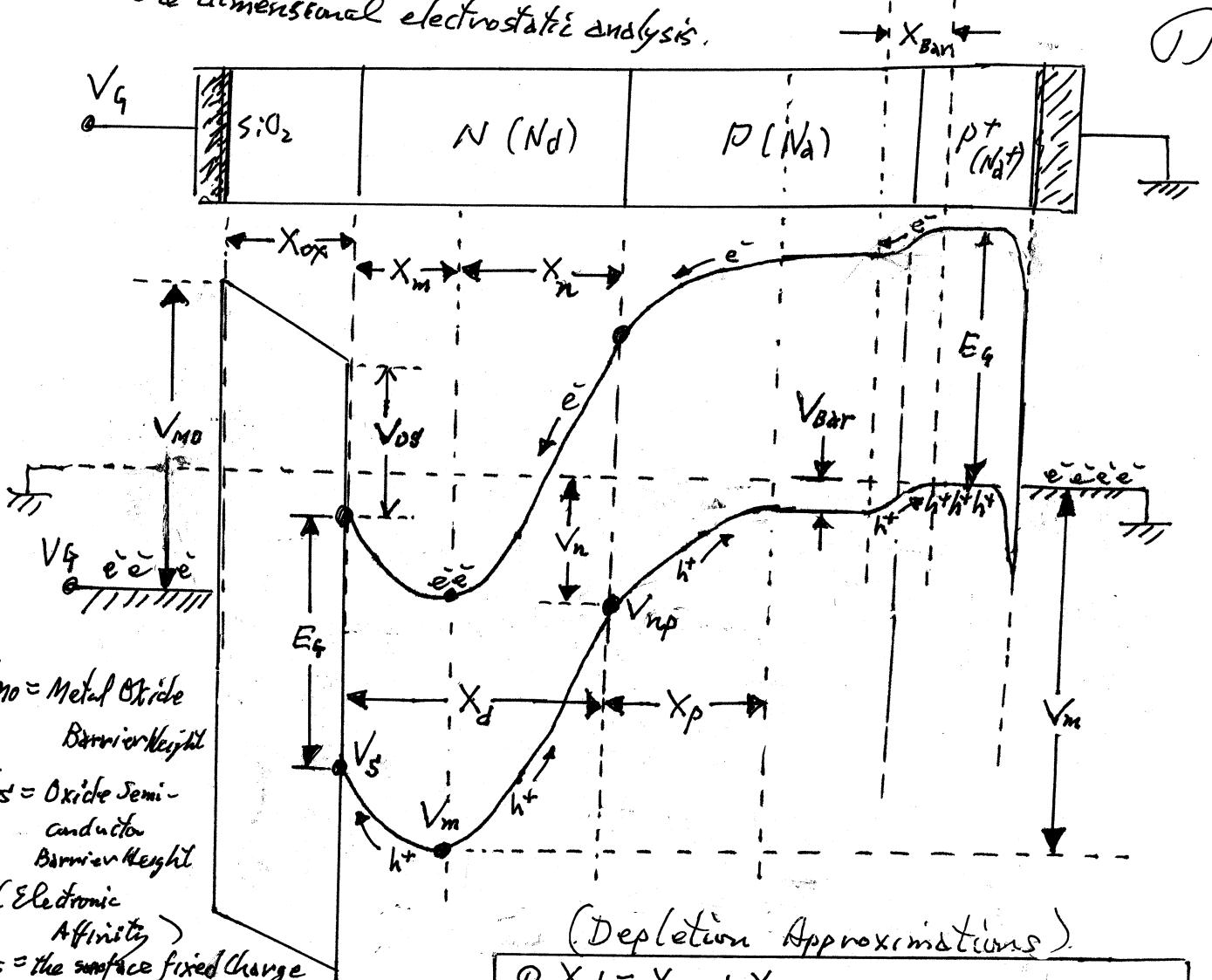
$$D = (1 + Na / Nd) * (V_{gg} - Nd * Xd * Xd / 2 / Esi)$$

$$- V_{bar} * Na / Nd$$

\*\*\*\*\*\*/

Buried Channel Charge Coupled Devices  
one dimensional electrostatic analysis.

Toshiaki Ochiai Nagahara



$X_d$  = the buried channel width

$V_m$  = the minimum potential

$V_s$  = the surface potential

$X_{ox}$  = oxide thickness

$E_{ox}$  = the electric field inside the oxide

$E_s$  = the electric field at the silicon surface in the inside of the silicon

$X_m$  = the depth of the minimum empty potential well.

$X_p$  = the depletion depth extended into the p-type silicon substrate.

$X_{bar}$  = barrier Potential width

$V_{bar}$  = Barrier Potential height

$E_{np}$  = the electric field at the pn junction.

(Depletion Approximations)

$$\textcircled{1} \quad X_d = X_m + X_n$$

$$\textcircled{2} \quad V_{np} = V_{Bar} + \frac{Na X_p}{2 \epsilon_{Si}}$$

$$\textcircled{3} \quad V_m = V_{np} + \frac{Nd X_n}{2 \epsilon_{Si}}$$

$$\textcircled{4} \quad V_m = V_s + \frac{Nd X_m}{2 \epsilon_{Si}}$$

$$\textcircled{5} \quad X_p Na = X_n Nd = E_{np} \epsilon_{Si}$$

$$\textcircled{6} \quad X_m Nd = E_s \epsilon_{Si} = E_{ox} \epsilon_{SiO_2} + Q_{ss}$$

$$\textcircled{7} \quad E_{ox} = \frac{(V_s - E_g - V_{os}) - (V_g - V_{Mo})}{X_{ox}}$$

$$\left\{ X_{bar} \approx (L_{debye}) \left( 1 + \sqrt{\frac{N_a^+}{N_d^-}} \right) \right.$$

$$L_{debye} = \sqrt{\frac{\epsilon_{Si} kT}{N_a^+}}$$

$$V_{bar} = kT \ln \left( \frac{N_a^+}{N_d^-} \right)$$

⑥, ⑤ and ③ give

$$V_m = V_{bar} + \frac{(N_d X_p)^2}{2 E_s N_a} + \frac{(N_d X_m)}{2 E_s N_d} = V_{bar} + \frac{(N_d X_p)^2}{2 E_s} \left( \frac{1}{N_a} + \frac{1}{N_d} \right)$$

Depletion Approximation : ②

$$① X_d = X_m + X_n$$

$$② V_{np} = V_{bar} + \frac{(N_d X_p)^2}{(2 E_s N_d)}$$

$$③ V_m = V_{np} + \frac{(N_d X_m)^2}{(2 E_s N_d)}$$

$$④ V_m = V_s + \frac{(N_d X_m)^2}{(2 E_s N_d)}$$

$$⑤ X_p \cdot N_a = X_n \cdot N_d = E_{xp} E_{si}$$

$$⑥ X_m N_d = E_s E_{si} \\ = E_{ox} E_{si} Q_2 + Q_{ss}$$

$$⑦ X_{ox} E_{ox} = (V_s - E_g - V_{os}) - (V_g - V_{mo})$$

$$⑧ V_{gg} = V_g + E_g + V_{os} - V_{mo} - \frac{Q_{ss}}{C_{ox}}$$

$$⑨ N_d X_m = E_s E_{si} = E_{ox} E_{si} Q_2 + Q_{ss}$$

$$⑩ N_d X_m = C_{ox} (V_s - V_{gg}) \leftarrow ⑧ + ⑥$$

$$⑤ \text{ and } ⑩ \text{ give } V_m = V_s + \frac{C_{ox}^2}{(2 E_s N_d)} (V_s - V_{gg})^2 \quad ⑪$$

③ and ② with ⑤ give

$$V_m = V_{bar} + \frac{(N_d X_n)^2}{(2 E_s)} \left( \frac{1}{N_d} + \frac{1}{N_a} \right) \quad ⑫$$

⑩ and ④ gives

$$(N_d X_n) = N_d X_d - N_d X_m = Q_d - C_{ox} (V_s - V_{gg}) \quad ⑬$$

$$\text{where } Q_d = N_d X_d \quad ⑭$$

$$V_m = V_{bar} + \frac{1}{(2 E_s)} \left( \frac{1}{N_d} + \frac{1}{N_a} \right) [Q_d - C_{ox} (V_s - V_{gg})]^2 \quad ⑮$$

From ⑧

$$V_m = V_{Bar} + \frac{Q_d^2}{2\epsilon_{Si}} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) - \frac{2Q_d C_{ox}}{(2\epsilon_{Si})} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) (V_S - V_{GS}) \quad ③$$

$$+ \frac{C_{ox}^2}{(2\epsilon_{Si})} \left( \frac{1}{N_A} + \frac{1}{N_d} \right) (V_S - V_{GS})^2 \quad ④$$

$$C_{ox}^2 (V_S - V_{GS})^2 = (2\epsilon_{Si} N_d) (V_m - V_S) \quad ⑤$$

$$V_m = V_{Bar} + \frac{Q_d^2}{2\epsilon_{Si}} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) - \frac{Q_d C_{ox}}{\epsilon_{Si}} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) (V_S - V_{GS})$$

$$+ \frac{2\epsilon_{Si} N_d}{(2\epsilon_{Si})} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) (V_m - V_S) \quad ⑥$$

$$0 = V_{Bar} + \frac{Q_d^2}{2\epsilon_{Si}} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) - \frac{Q_d C_{ox}}{\epsilon_{Si}} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) (V_S - V_{GS})$$

$$+ \frac{N_d}{N_A} V_m - \left( \frac{1}{N_A} + \frac{1}{N_d} \right) (N_d) (V_S) \quad ⑦$$

$$V_m = \frac{Q_d C_{ox}}{\epsilon_{Si}} \frac{N_d}{N_A} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) (V_S - V_{GS})$$

$$+ \frac{N_d}{N_A} \left( \frac{1}{N_A} + \frac{1}{N_d} \right) (N_d) (V_S)$$

$$- \frac{N_d}{N_d} V_{Bar} - \frac{Q_d^2}{2\epsilon_{Si}} \frac{N_A}{N_d} \left( \frac{1}{N_d} + \frac{1}{N_A} \right) \quad ⑧$$

$$V_m = \left( \frac{C_{ox}}{C_d} \right) \left( 1 + \frac{N_A}{N_d} \right) (V_S - V_{GS}) + \left( 1 + \frac{N_A}{N_d} \right) (V_S)$$

$$- \frac{N_d}{N_d} V_{Bar} - \frac{X_d N_d}{2\epsilon_{Si}} \left( 1 + \frac{N_A}{N_d} \right) \quad ⑨$$

$$V_m = \left( 1 + \frac{C_{ox}}{C_d} \right) \left( 1 + \frac{N_A}{N_d} \right) (V_S - V_{GS}) + \left( 1 + \frac{N_A}{N_d} \right) V_{GS}$$

$$- \left( \frac{N_d}{N_d} \right) V_{Bar} - \frac{X_d N_d}{2\epsilon_{Si}} \left( 1 + \frac{N_A}{N_d} \right) \quad ⑩$$

$$(14) \rightarrow V_m = V_s + \frac{C_{ox}^2}{(2\epsilon_{si} N_d)} (V_s - V_{ss})^2 \quad (4)$$

$$(18) \rightarrow V_m = V_{Bdr} + \frac{1}{(2\epsilon_{si})} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) \left[ Q_d - C_{ox} (V_s - V_{ss}) \right]^2$$

$$(V_s - V_{ss}) + \frac{C_{ox}^2}{(2\epsilon_{si} N_d)} (V_s - V_{ss})^2 + V_{ss}$$

$$= V_{Bdr} + \frac{1}{(2\epsilon_{si})} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) \left[ Q_d^2 - 2Q_d C_{ox} (V_s - V_{ss}) + C_{ox}^2 (V_s - V_{ss})^2 \right]$$

$\leftarrow (25)$

$$\frac{C_{ox}^2}{2\epsilon_{si} N_d} (V_s - V_{ss})^2 = (V_s - V_{ss}) \left[ 1 + \frac{Q_d C_{ox}}{\epsilon_{si}} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) \right]$$

$$+ (V_{ss} - V_{Bdr}) - \frac{Q_d^2}{2\epsilon_{si}} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) \quad \leftarrow (26)$$

$$(V_s - V_{ss})^2 = \frac{2\epsilon_{si} N_d (V_s - V_{ss})}{C_{ox}^2} \left[ 1 + \frac{Q_d C_{ox}}{\epsilon_{si}} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) \right]$$

$$+ \frac{2\epsilon_{si} N_d}{C_{ox}^2} (V_{ss} - V_{Bdr}) - \frac{N_d Q_d^2}{C_{ox}^2} \left( \frac{1}{N_a} + \frac{1}{N_d} \right)$$

$\leftarrow (27)$

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$$(V_S - V_{GG})^2 = 2A(V_S - V_{GG}) \not\equiv B$$

$$(V_S - V_{GG} - A)^2 = A^2 \not\equiv B$$

$$V_S = V_{GG} + A - \sqrt{A^2 - B}$$

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$$A = \frac{\epsilon_{Si} N_A}{C_{ox}^2} \left[ 1 + \frac{Q_d C_{ox}}{\epsilon_{Si}} \left( \frac{1}{N_A} + \frac{1}{N_D} \right) \right]$$

$$B = \frac{N_A Q_d^2}{C_{ox}^2} \left( \frac{1}{N_A} + \frac{1}{N_D} \right) - \frac{2 \epsilon_{Si} N_A}{C_{ox}^2} (V_{GG} - V_{Bar})$$

$$A = \frac{\epsilon_{Si} N_A}{C_{ox}^2} + \frac{Q_d}{C_{ox}} \left( 1 + \frac{N_A}{N_D} \right)$$

$$B = \left( \frac{Q_d}{C_{ox}} \right)^2 \left( 1 + \frac{N_A}{N_D} \right) - \frac{2 \epsilon_{Si} N_A}{C_{ox}^2} (V_{GG} - V_{Bar})$$

$$V_S = V_{GG} + A - \sqrt{A^2 - B}$$

28

$$V_m = \left( 1 + \frac{C_{ox}}{C_d} \right) \left( 1 + \frac{N_A}{N_D} \right) (V_S - V_{GG})$$

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$$+ \left( 1 + \frac{N_A}{N_D} \right) \left( V_{GG} - \frac{X_d N_d}{2 \epsilon_{Si}} \right) - \left( \frac{N_d}{N_D} \right) V_{Bar}$$

$$V_S = V_{GG} + A - \sqrt{A^2 - B} \quad \text{--- (28)}$$

$$V_m = C (V_S - V_{GG}) + D \quad \text{--- (29)}$$

$$\left( C = \left( 1 + \frac{C_{ox}}{C_d} \right) \left( 1 + \frac{N_d}{N_a} \right) \right) \quad \text{--- (30)}$$

$$\left( D = \left( 1 + \frac{N_d}{N_a} \right) \left( V_{GG} - \frac{X_d^2 N_d}{2 E_{Si}} \right) - \left( \frac{N_d}{N_a} \right) V_{BdR} \right) \quad \text{--- (31)}$$

$$V_S' = V_{GG} + A - \sqrt{A^2 - B} \quad \text{--- (28')}$$

$$V_m = (C) \left[ A - \sqrt{A^2 - B} \right] + D \quad \text{--- (32)}$$

$$V_S = V_{GG} + A - \sqrt{A^2 - B} \quad \text{--- (28)}$$

$$A = \frac{E_{Si} N_a}{C_{ox}^2} + \frac{Q_d}{C_{ox}} \left( 1 + \frac{N_d}{N_a} \right) \quad \text{--- (29)}$$

$$B = \left( \frac{Q_d}{C_{ox}} \right)^2 \left( 1 + \frac{N_d}{N_a} \right) - \left( \frac{2 E_{Si} N_a}{C_{ox}^2} \right) (V_{GG} - V_{BdR}) \quad \text{--- (30)}$$

$$C = \left( 1 + \frac{C_{ox}}{C_d} \right) \left( 1 + \frac{N_d}{N_a} \right) \quad \text{--- (32)}$$

$$D = \left( 1 + \frac{N_d}{N_a} \right) \left( V_{GG} - \frac{Q_d}{2 C_d} \right) - \left( \frac{N_d}{N_a} \right) V_{BdR} \quad \text{--- (33)}$$

As  $N_d \rightarrow \infty$

$$A = \frac{E_{Si} N_a}{C_{ox}^2} + \frac{Q_d}{C_{ox}}$$

$$B = \left( \frac{Q_d}{C_{ox}} \right)^2 - \left( \frac{2 E_{Si} N_a}{C_{ox}^2} \right) (V_{GG} - V_{BdR})$$

$$C = \left( 1 + \frac{C_{ox}}{C_d} \right)$$

$$D = \left( 1 + \frac{N_d}{N_a} \right) \left( V_{GG} - \frac{Q_d}{2 C_d} \right)$$

Only the total charge  $Q_d$  influences the value of  $V_m$  and  $V_S$ .

\*\*\*\*\*

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$$Vm = C * (Vs - V_{gg}) + D;$$

where

$$A = Esi \cdot Na / Cox / Cox + Qd * (1 + Na / Nd) / Cox;$$

$$B = (1 + Na / Nd) * Qd * Qd / Cox / Cox$$

$$- 2 * Esi * Na * (V_{gg} - V_{bar}) / Cox / Cox;$$

$$C = (1 + Na / Nd) * (1 + Cox / Cd);$$

$$D = (1 + Na / Nd) * (V_{gg} - Nd * Xd * Xd / 2 / Esi)$$

$$- V_{bar} * Na / Nd$$

\*\*\*\*\*\*/

```

#include <stdio.h>
#include <math.h>

FILE *fpA;

void main( void ) { int i, NEXTXm, Note=30 ; char c;

double Esi,Esio2,kT,Nd,Na,Naa,Xox,Xd,Cox,Cd,Qd,Vbar,Wbar,
Vs,Vgg,Vggg,A,B,C,D,Vm,Vmm,Xm,Xm1,Xm2,Xn,Xp,Vnp,
Vmmm,Vmmmm,Enp,Es,Eox,Ldebye,Xbar,Err,Err1,Err2;

fpA=fopen("A.txt","w");

/************* Buried Channel Charge Coupled Device *****/
/********** One Dimensional Electrotatic Potential Analysis ****/

Esi=648;
fprintf(fpA,"%n%n Esi = %f",Esi);
Esio2=216;
fprintf(fpA,"%n%n Esio2 = %f",Esio2);
kT=0.0259;
fprintf(fpA,"%n%n kT = %f",kT);
Nd= 1000;
fprintf(fpA,"%n%n Nd = %f",Nd);

Na=100;
fprintf(fpA,"%n%n Na = %f",Na);

Naa=10000;
fprintf(fpA,"%n%n Naa = %f",Naa);

Ldebye=sqrt(Esi*kT/Naa);

```

```

fprintf(fpA,"$n$n Ldebye=sqrt(Esi*kT/Naa)= %f",Ldebye);
Wbar= Ldebye*( 1 + log(Naa/Na));

fprintf(fpA,"$n$n Wbar= Ldebye*( 1 + log(Naa/Na))= %f",Wbar);

Xbar= Ldebye*( 1 + sqrt(Naa/Na));

fprintf(fpA,"$n$n Xbar= Ldebye*( 1 + sqrt(Naa/Na))= %f",Xbar);

Xox = 0.1 ;
fprintf(fpA,"$n$n Xox = %f",Xox);

Xd = 1.0 ;
fprintf(fpA,"$n$n Xd = %f",Xd);

/***********************/

Cox = Esio2/Xox ;
fprintf(fpA,"$n$n Cox = Esio2/Xox = %f",Cox);

Cd = Esi/Xd;
fprintf(fpA,"$n$n Cd = Esi/Xd = %f",Cd);

Qd = Nd*Xd;
fprintf(fpA,"$n$n Qd = Nd*Xd = %f",Qd);

Vbar = kT*log(Naa/Na) ;
fprintf(fpA,"$n$n Vbar = kT*log(Naa/Na)= %f",Vbar);

Vgg = 0;
/***********************/

MORE_Vgg:
NEXTXm = 0;

```

$$A = Esi * Na / Cox / Cox + Qd * (1 + Na / Nd) / Cox ;$$

```
fprintf(fpA,"%n%n A = Esi*Na/Cox/Cox + Qd*( 1 + Na/Nd )/ Cox = %f",A);
```

$$B = (1 + Na/Nd) * Qd * Qd / Cox / Cox$$

$$- 2 * E_{\text{Si}} * N_a * (V_{gg} - V_{\bar{b}}) / C_{ox} / C_{ox};$$

```
fprintf(fpA,"\$n\$n B = ( 1 + Na/Nd )*Qd*Qd/Cox/Cox\$n\$n");
```

```
fprintf(fpA," - 2*Esi*Na*( Vgg - Vbar )/Cox/Cox = %f", B);
```

$$C = A * A - B;$$

if( $C < 0$  )

```
{ printf(" \n\n Error : C = A*A - B < 0 "); goto FINAL; }
```

```
/*******/
```

$$Vs = Vgg + A - \sqrt{C};$$

```
fprintf(fpA,"\\n\\n Vs = Vgg + A - sqrt ( A*A - B )= %f",Vs);
```

$$C = (1 + Na/Nd) * (1 + Cox/Cd);$$

```
fprintf(fpA,"\\n\\n C = ( 1 + Na/Nd ) * ( 1 + Cox/Cd )= %f",C);
```

$$D = (1 + Na/Nd) * (Vgg - Nd * Xd * Xd / Esi) - Vbar * Na / Nd;$$

```
fprintf(fpA,"Yn D = ( 1 + Na/Nd ) * ( Vgg - Nd*Xg*Xg/2/Esi ) - Vbar*Na/Nd = %f",D);
```

$$V_m = C * (V_s - V_{gg}) + D ;$$

```
fprintf(fpA,"%n%n Vm = C*( Vs - Vgg ) + D = %f",Vm);
```

```
Xm = sqrt(2*Esi*(Vm - Vs)/Nd);  
fprintf(fpA,"$n$n Xm = sqrt(2*Esi*(Vm - Vs)/Nd) = %f",Xm);
```

```
Xn = Xd -Xm ;  
fprintf(fpA,"$n$n Xn = Xd -Xm = %f",Xn);
```

```
Xp = Xn*Nd/Na ;  
fprintf(fpA,"$n$n Xp = Xn*Nd/Na = %f",Xp);
```

```
Vnp = Vbar + Na*Xp*Xp/2/Esi;  
fprintf(fpA,"$n$n Vnp = Vbar + Na*Xp*Xp/2/Esi = %f",Vnp);
```

```
Vmmm = Vnp + Nd*Xn*Xn/2/Esi;  
fprintf(fpA,"$n$n Vmmm = Vnp + Nd*Xn*Xn/2/Esi = %f",Vmmm);
```

```
Vmmmm = Vs + Nd*Xm*Xm/2/Esi;  
fprintf(fpA,"$n$n Vmmmm = Vs + Nd*Xm*Xm/2/Esi = %f",Vmmmm);
```

```
Enp = Xp*Na/Esi;  
fprintf(fpA,"$n$n Enp = Xp*Na/Esi = %f",Enp);
```

```
Es = Xm*Nd/Esi;  
fprintf(fpA,"$n$n Es = Xm*Nd/Esi = %f",Es);
```

```
Eox = Xm*Nd/Esi*2;  
fprintf(fpA,"$n$n Eox = Xm*Nd/Esi*2= %f",Eox);
```

```
/***************** Summary *****/  
fprintf(fpA,"$n$n ***** Summary ***** ");  
printf("$n$n ***** Summary ***** ");  
fprintf(fpA,"$n$n Xm = %f",Xm);
```

```

printf("¥n¥n Xm = %f",Xm);
Xn = Xd - Xm ;
fprintf(fpA,"¥n¥n Xn = Xd - Xm = %f",Xn);
printf("¥n¥n Xn = Xd - Xm = %f",Xn);
Xp = Xn*Nd/Na;
fprintf(fpA,"¥n¥n Xp = Xn*Nd/Na = %f",Xp);
printf("¥n¥n Xp = Xn*Nd/Na = %f",Xp);
fprintf(fpA,"¥n¥n Vbar = %f",Vbar);
printf("¥n¥n Vbar = %f",Vbar);
Vnp = Vbar + Na*Xp*Xp/2/Esi ;
fprintf(fpA,"¥n¥n Vnp = Vbar + Na*Xp*Xp/2/Esi = %f",Vnp);
printf("¥n¥n Vnp = Vbar + Na*Xp*Xp/2/Esi = %f",Vnp);

Vm = Vnp + Nd*Xn*Xn/2/Esi ;
fprintf(fpA,"¥n¥n Vm = Vnp + Nd*Xn*Xn/2/Esi = %f",Vm);
printf("¥n¥n Vm = Vnp + Nd*Xn*Xn/2/Esi = %f",Vm);
Vs = Vm - Nd*Xm*Xm/2/Esi;
fprintf(fpA,"¥n¥n Vs = Vm - Nd*Xm*Xm/2/Esi = %f",Vs);
printf("¥n¥n Vs = Vm - Nd*Xm*Xm/2/Esi = %f",Vs);
Vggg = Vs - Nd*Xm/Cox;
fprintf(fpA,"¥n¥n Vgg = Vs - Nd*Xm/Cox = %f",Vgg);
printf("¥n¥n Vgg = Vs - Nd*Xm/Cox = %f",Vgg);
Err1 = Vggg - Vgg;
fprintf(fpA,"¥n¥n Err1 = Vggg - Vgg = %f",Err1);
printf("¥n¥n Err1 = Vggg - Vgg = %f",Err1);
fprintf(fpA,"¥n¥n ***** ¥n¥n");
printf("¥n¥n ***** ¥n¥n");

/**************** Numerical Calculation *****/
fprintf(fpA,"¥n¥n ***** Numerical Calculation ***** ");

```

```
printf("¥n¥n ***** Numerical Calculation ***** ");
```

```
Xm1 = 0; Xm2= Xd;
```

MORE:

```
/*****************************************/
```

```
Xm = Xm1;
```

```
if(NEXTXm ==Note) fprintf(fpA,"¥n¥n *****");
```

```
if(NEXTXm ==Note) fprintf(fpA,"¥n¥n Xm = %f",Xm);
```

```
Xn = Xd - Xm ;
```

```
if(NEXTXm ==Note) fprintf(fpA,"¥n¥n Xn = Xd - Xm = %f",Xn);
```

```
Xp = Xn*Nd/Na;
```

```
if(NEXTXm ==Note)fprintf(fpA,"¥n¥n Xp = Xn*Nd/Na = %f",Xp);
```

```
if(NEXTXm ==Note)fprintf(fpA,"¥n¥n Vbar = %f",Vbar);
```

```
Vnp = Vbar + Na*Xp*Xp/2/Esi ;
```

```
if(NEXTXm ==Note)fprintf(fpA,"¥n¥n Vnp = Vbar + Na*Xp*Xp/2/Esi = %f",Vnp);
```

```
Vm = Vnp + Nd*Xn*Xn/2/Esi ;
```

```
if(NEXTXm ==Note) fprintf(fpA,"¥n¥n Vm = Vnp + Nd*Xn*Xn/2/Esi = %f",Vm);
```

```
Vs = Vm - Nd*Xm*Xm/2/Esi;
```

```
if(NEXTXm ==Note) fprintf(fpA,"¥n¥n Vs = Vm - Nd*Xm*Xm/2/Esi = %f",Vs);
```

```
Vggg = Vs - Nd*Xm/Cox;
```

```
if(NEXTXm ==Note)fprintf(fpA,"¥n¥n Vgg = Vs - Nd*Xm/Cox = %f",Vgg);
```

```
Err1 = Vggg - Vgg;
```

```
if(NEXTXm ==Note)fprintf(fpA,"¥n¥n Err1 = Vggg - Vgg = %f",Err1);
```

```
if(NEXTXm ==Note)fprintf(fpA,"¥n¥n ***** ¥n¥n");
```

```
/*****************************************/
```

```
Xm = Xm2;
```

```
if(NEXTXm ==Note) fprintf(fpA,"¥n¥n Xm = %f",Xm);
```

```

Xn = Xd - Xm ;
if(NEXTXm ==Note) fprintf(fpA,"$n$n Xn = Xd - Xm = %f",Xn);
Xp = Xn*Nd/Na;
if(NEXTXm ==Note)fprintf(fpA,"$n$n Xp = Xn*Nd/Na = %f",Xp);

if(NEXTXm ==Note)fprintf(fpA,"$n$n Vbar = %f",Vbar);

Vnp = Vbar + Na*Xp*Xp/2/Esi ;
if(NEXTXm ==Note)fprintf(fpA,"$n$n Vnp = Vbar + Na*Xp*Xp/2/Esi = %f",Vnp);

Vm = Vnp + Nd*Xn*Xn/2/Esi ;
if(NEXTXm ==Note) fprintf(fpA,"$n$n Vm = Vnp + Nd*Xn*Xn/2/Esi = %f",Vm);
Vs = Vm - Nd*Xm*Xm/2/Esi;
if(NEXTXm ==Note) fprintf(fpA,"$n$n Vs = Vm - Nd*Xm*Xm/2/Esi = %f",Vs);
Vggg = Vs - Nd*Xm/Cox;
if(NEXTXm ==Note)fprintf(fpA,"$n$n Vgg = Vs - Nd*Xm/Cox = %f",Vgg);
Err2 = Vggg - Vgg;
if(NEXTXm ==Note)fprintf(fpA,"$n$n Err2 = Vggg - Vgg = %f",Err2);
if(NEXTXm ==Note)fprintf(fpA,"$n$n **** $n$n");
/*******/
Xm = (Xm1+Xm2)/2;
if(NEXTXm ==Note) fprintf(fpA,"$n$n Xm = %f",Xm);
Xn = Xd - Xm ;
if(NEXTXm ==Note) fprintf(fpA,"$n$n Xn = Xd - Xm = %f",Xn);
Xp = Xn*Nd/Na;
if(NEXTXm ==Note)fprintf(fpA,"$n$n Xp = Xn*Nd/Na = %f",Xp);

if(NEXTXm ==Note)fprintf(fpA,"$n$n Vbar = %f",Vbar);

Vnp = Vbar + Na*Xp*Xp/2/Esi ;
if(NEXTXm ==Note)fprintf(fpA,"$n$n Vnp = Vbar + Na*Xp*Xp/2/Esi = %f",Vnp);

```



```
goto MORE_Vgg;  
FINAL:  
fprintf(fpA,"$\n$ **** End of Computation ***** $\n");  
printf("$\n$ **** End of Computation ***** $\n");  
  
fclose(fpA) ;}  
  
/****************************************/
```

\*\*\*\*\*

This program computes the values of  
the minimum empty potential well Vm and the surface potential Vs.

\*\*\*\*\*

As the density of the impurity atom in the buried channel Nd becomes larger,  
only the total dose of  $Q_d = Nd \cdot X_d$  influences the values of the buried channel  
empty potentail well Vm and the surface potential Vs.

The density Nd of the buried channel region can be chosen effectively  
with an extra process freedom in the ion implattaion technology.

\*\*\*\*\*

The density Nd of the buried channel region can be  
made large as long as the width Xd is kept narrow.  
the PN+Psub double junction type Buried Channel CCD  
may also work perfectly.

This observation in 1975 led Hagiwara to his inventions of  
the double P+NP and the triple P+NPN junction type  
Pinned Buried Photodiodesdefined in JPA 1975-127646,  
JPA 1975-127647 and JPA1975-134985 Japanese Patents.

\*\*\*\*\*

$$Vs = V_{gg} + A - \sqrt{A \cdot A - B};$$

$$Vm = C * (Vs - V_{gg}) + D;$$

where

$$A = Esi \cdot Na / Cox / Cox + Qd * (1 + Na / Nd) / Cox;$$

$$B = (1 + Na / Nd) * Qd * Qd / Cox / Cox$$

$$- 2 * Esi * Na * (V_{gg} - V_{bar}) / Cox / Cox;$$

$$C = (1 + Na / Nd) * (1 + Cox / Cd);$$

$$D = (1 + Na / Nd) * (V_{gg} - Nd * Xd * Xd / 2 / Esi)$$

$$- V_{bar} * Na / Nd$$

\*\*\*\*\*\*/

Esi = 648.000000

Esio2 = 216.000000

kT = 0.025900

Nd = 1000.000000

Na = 100.000000

Naa = 10000.000000

Ldebye=sqrt(Esi\*kT/Naa)= 0.040967

Wbar= Ldebye\*( 1 + log(Naa/Na))= 0.229629

Xbar= Ldebye\*( 1 + sqrt(Naa/Na))= 0.450640

Xox = 0.100000

Xd = 1.000000

Cox = Esio2/Xox = 2160.000000

Cd = Esi/Xd = 648.000000

Qd = Nd\*Xd = 1000.000000

Vbar = kT\*log(Naa/Na)= 0.119274

\*\*\*\*\*

Vgg= 0.000000

\*\*\*\*\*

A = Esi\*Na/Cox/Cox + Qd\*( 1 + Na/Nd )/ Cox = 0.523148

B = ( 1 + Na/Nd )\*Qd\*Qd/Cox/Cox

- 2\*Esi\*Na\*( Vgg - Vbar )/Cox/Cox = 0.239081

Vs = Vgg + A - sqrt ( A\*A - B )= 0.337130

C = ( 1 + Na/Nd ) \* ( 1 + Cox/Cd )= 4.766667

D = ( 1 + Na/Nd ) \* ( Vgg - Nd\*Xd\*Xd/2/Esi ) - Vbar\*Na/Nd = -0.860693

Vm = C\*( Vs - Vgg ) + D = 0.746295

Xm = sqrt(2\*Esi\*(Vm - Vs)/Nd )= 0.728201

Xn = Xd -Xm = 0.271799

$$X_p = X_n * N_d / N_a = 2.717986$$

$$V_{np} = V_{bar} + N_a * X_p * X_p / 2 / E_{si} = 0.689293$$

$$V_{mm} = V_{np} + N_d * X_n * X_n / 2 / E_{si} = 0.746295$$

$$V_{mmmm} = V_s + N_d * X_m * X_m / 2 / E_{si} = 0.746295$$

$$E_{np} = X_p * N_a / E_{si} = 0.419442$$

$$E_s = X_m * N_d / E_{si} = 1.123768$$

$$E_{ox} = X_m * N_d / E_{so2} = 3.371303$$

\*\*\*\*\* Summary \*\*\*\*\*

$$X_m = 0.728201$$

$$X_n = X_d - X_m = 0.271799$$

$$X_p = X_n * N_d / N_a = 2.717986$$

$$V_{bar} = 0.119274$$

$$V_{np} = V_{bar} + N_a * X_p * X_p / 2 / E_{si} = 0.689293$$

$$V_m = V_{np} + N_d * X_n * X_n / 2 / E_{si} = 0.746295$$

$$V_s = V_m - N_d * X_m * X_m / 2 / E_{si} = 0.337130$$

$$V_{gg} = V_s - N_d * X_m / C_{ox} = 0.000000$$

$$Err1 = V_{ggg} - V_{gg} = 0.000000$$

\*\*\*\*\* Numerical Calculation \*\*\*\*\*

$$NOTE = 0 \quad X_m = 0.500000 \quad Err1 = 8.606928 \quad Err = 1.816805 \quad Err2 = -1.115294$$

$$NOTE = 1 \quad X_m = 0.750000 \quad Err1 = 1.816805 \quad Err = -0.131498 \quad Err2 = -1.115294$$

$$NOTE = 2 \quad X_m = 0.625000 \quad Err1 = 1.816805 \quad Err = 0.722090 \quad Err2 = -0.131498$$

$$NOTE = 3 \quad X_m = 0.687500 \quad Err1 = 0.722090 \quad Err = 0.265155 \quad Err2 = -0.131498$$

$$NOTE = 4 \quad X_m = 0.718750 \quad Err1 = 0.265155 \quad Err = 0.059294 \quad Err2 = -0.131498$$

$$NOTE = 5 \quad X_m = 0.734375 \quad Err1 = 0.059294 \quad Err = -0.037986 \quad Err2 = -0.131498$$

$$NOTE = 6 \quad X_m = 0.726562 \quad Err1 = 0.059294 \quad Err = 0.010183 \quad Err2 = -0.037986$$

$$NOTE = 7 \quad X_m = 0.730469 \quad Err1 = 0.010183 \quad Err = -0.014019 \quad Err2 = -0.037986$$

$$NOTE = 8 \quad X_m = 0.728516 \quad Err1 = 0.010183 \quad Err = -0.001948 \quad Err2 = -0.014019$$

NOTE = 9 Xm = 0.727539 Err1 = 0.010183 Err = 0.004110 Err2 = -0.001948  
 NOTE = 10 Xm = 0.728027 Err1 = 0.004110 Err = 0.001080 Err2 = -0.001948  
 NOTE = 11 Xm = 0.728271 Err1 = 0.001080 Err = -0.000434 Err2 = -0.001948  
 NOTE = 12 Xm = 0.728149 Err1 = 0.001080 Err = 0.000322 Err2 = -0.000434  
 NOTE = 13 Xm = 0.728210 Err1 = 0.000322 Err = -0.000056 Err2 = -0.000434  
 NOTE = 14 Xm = 0.728180 Err1 = 0.000322 Err = 0.000133 Err2 = -0.000056  
 NOTE = 15 Xm = 0.728195 Err1 = 0.000133 Err = 0.000039 Err2 = -0.000056  
 NOTE = 16 Xm = 0.728203 Err1 = 0.000039 Err = -0.000009 Err2 = -0.000056  
 NOTE = 17 Xm = 0.728199 Err1 = 0.000039 Err = 0.000015 Err2 = -0.000009  
 NOTE = 18 Xm = 0.728201 Err1 = 0.000015 Err = 0.000003 Err2 = -0.000009  
 NOTE = 19 Xm = 0.728202 Err1 = 0.000003 Err = -0.000003 Err2 = -0.000009  
 NOTE = 20 Xm = 0.728201 Err1 = 0.000003 Err = 0.000000 Err2 = -0.000003  
 NOTE = 21 Xm = 0.728202 Err1 = 0.000000 Err = -0.000001 Err2 = -0.000003  
 NOTE = 22 Xm = 0.728202 Err1 = 0.000000 Err = -0.000001 Err2 = -0.000001  
 NOTE = 23 Xm = 0.728201 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000001  
 NOTE = 24 Xm = 0.728201 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
 NOTE = 25 Xm = 0.728201 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
 NOTE = 26 Xm = 0.728201 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
 NOTE = 27 Xm = 0.728201 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
 NOTE = 28 Xm = 0.728201 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
 NOTE = 29 Xm = 0.728201 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000

\*\*\*\*\*

Xm = 0.728201

Xn = Xd - Xm = 0.271799

Xp = Xn\*Nd/Na = 2.717986

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 0.689293

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 0.746295

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 0.337130

Vgg = Vs - Nd\*Xm/Cox = 0.000000

Err1 = Vggg - Vgg = 0.000000

\*\*\*\*\*

Xm = 0.728201

Xn = Xd - Xm = 0.271799

Xp = Xn\*Nd/Na = 2.717986

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 0.689293

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 0.746295

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 0.337130

Vgg = Vs - Nd\*Xm/Cox = 0.000000

Err2 = Vggg - Vgg = -0.000000

\*\*\*\*\*

Xm = 0.728201

Xn = Xd - Xm = 0.271799

Xp = Xn\*Nd/Na = 2.717986

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 0.689293

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 0.746295

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 0.337130

Vgg = Vs - Nd\*Xm/Cox = 0.000000

Err = Vggg - Vgg = -0.000000

\*\*\*\*\*

NOTE = 30 Xm = 0.728201 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Vgg= 5.000000

\*\*\*\*\*

$$A = Esi*Na/Cox/Cox + Qd*( 1 + Na/Nd )/ Cox = 0.523148$$

$$B = ( 1 + Na/Nd )*Qd*Qd/Cox/Cox$$

$$- 2*Esi*Na*( Vgg - Vbar )/Cox/Cox = 0.100192$$

$$Vs = Vgg + A - \sqrt{ A*A - B } = 5.106625$$

$$C = ( 1 + Na/Nd ) * ( 1 + Cox/Cd ) = 4.766667$$

$$D = ( 1 + Na/Nd ) * ( Vgg - Nd*Xd*Xd/2/Esi ) - Vbar*Na/Nd = 4.639307$$

$$Vm = C*( Vs - Vgg ) + D = 5.147553$$

$$Xm = \sqrt{2*Esi*( Vm - Vs )/Nd} = 0.230310$$

$$Xn = Xd - Xm = 0.769690$$

$$Xp = Xn*Nd/Na = 7.696900$$

$$Vnp = Vbar + Na*Xp*Xp/2/Esi = 4.690437$$

$$Vm_{mm} = Vnp + Nd*Xn*Xn/2/Esi = 5.147553$$

$$Vm_{mmm} = Vs + Nd*Xm*Xm/2/Esi = 5.147553$$

$$Enp = Xp*Na/Esi = 1.187793$$

$$Es = Xm*Nd/Esi = 0.355417$$

$$Eox = Xm*Nd/Esi = 1.066250$$

\*\*\*\*\* Summary \*\*\*\*\*

$$Xm = 0.230310$$

$$Xn = Xd - Xm = 0.769690$$

$$Xp = Xn*Nd/Na = 7.696900$$

$$Vbar = 0.119274$$

$$Vnp = Vbar + Na*Xp*Xp/2/Esi = 4.690437$$

$$Vm = Vnp + Nd*Xn*Xn/2/Esi = 5.147553$$

$$Vs = Vm - Nd*Xm*Xm/2/Esi = 5.106625$$

$$Vgg = Vs - Nd*Xm/Cox = 5.000000$$

$$Err1 = Vg_{gg} - Vgg = -0.000000$$

\*\*\*\*\*

\*\*\*\*\* Numerical Calculation \*\*\*\*\*

NOTE = 0	Xm = 0.500000	Err1 = 3.606928	Err = -3.183195	Err2 = -6.115294
NOTE = 1	Xm = 0.250000	Err1 = 3.606928	Err = -0.270387	Err2 = -3.183195
NOTE = 2	Xm = 0.125000	Err1 = 3.606928	Err = 1.547708	Err2 = -0.270387
NOTE = 3	Xm = 0.187500	Err1 = 1.547708	Err = 0.608520	Err2 = -0.270387
NOTE = 4	Xm = 0.218750	Err1 = 0.608520	Err = 0.161531	Err2 = -0.270387
NOTE = 5	Xm = 0.234375	Err1 = 0.161531	Err = -0.056311	Err2 = -0.270387
NOTE = 6	Xm = 0.226562	Err1 = 0.161531	Err = 0.052139	Err2 = -0.056311
NOTE = 7	Xm = 0.230469	Err1 = 0.052139	Err = -0.002204	Err2 = -0.056311
NOTE = 8	Xm = 0.228516	Err1 = 0.052139	Err = 0.024938	Err2 = -0.002204
NOTE = 9	Xm = 0.229492	Err1 = 0.024938	Err = 0.011360	Err2 = -0.002204
NOTE = 10	Xm = 0.229980	Err1 = 0.011360	Err = 0.004576	Err2 = -0.002204
NOTE = 11	Xm = 0.230225	Err1 = 0.004576	Err = 0.001186	Err2 = -0.002204
NOTE = 12	Xm = 0.230347	Err1 = 0.001186	Err = -0.000509	Err2 = -0.002204
NOTE = 13	Xm = 0.230286	Err1 = 0.001186	Err = 0.000338	Err2 = -0.000509
NOTE = 14	Xm = 0.230316	Err1 = 0.000338	Err = -0.000086	Err2 = -0.000509
NOTE = 15	Xm = 0.230301	Err1 = 0.000338	Err = 0.000126	Err2 = -0.000086
NOTE = 16	Xm = 0.230309	Err1 = 0.000126	Err = 0.000020	Err2 = -0.000086
NOTE = 17	Xm = 0.230312	Err1 = 0.000020	Err = -0.000033	Err2 = -0.000086
NOTE = 18	Xm = 0.230310	Err1 = 0.000020	Err = -0.000006	Err2 = -0.000033
NOTE = 19	Xm = 0.230309	Err1 = 0.000020	Err = 0.000007	Err2 = -0.000006
NOTE = 20	Xm = 0.230310	Err1 = 0.000007	Err = 0.000000	Err2 = -0.000006
NOTE = 21	Xm = 0.230310	Err1 = 0.000000	Err = -0.000003	Err2 = -0.000006
NOTE = 22	Xm = 0.230310	Err1 = 0.000000	Err = -0.000001	Err2 = -0.000003
NOTE = 23	Xm = 0.230310	Err1 = 0.000000	Err = -0.000000	Err2 = -0.000001
NOTE = 24	Xm = 0.230310	Err1 = 0.000000	Err = 0.000000	Err2 = -0.000000
NOTE = 25	Xm = 0.230310	Err1 = 0.000000	Err = -0.000000	Err2 = -0.000000
NOTE = 26	Xm = 0.230310	Err1 = 0.000000	Err = -0.000000	Err2 = -0.000000

NOTE = 27 Xm = 0.230310 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 28 Xm = 0.230310 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 29 Xm = 0.230310 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Xm = 0.230310

Xn = Xd - Xm = 0.769690

Xp = Xn\*Nd/Na = 7.696900

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 4.690437

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 5.147553

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 5.106625

Vgg = Vs - Nd\*Xm/Cox = 5.000000

Err1 = Vgg - Vgg = 0.000000

\*\*\*\*\*

Xm = 0.230310

Xn = Xd - Xm = 0.769690

Xp = Xn\*Nd/Na = 7.696900

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 4.690437

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 5.147553

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 5.106625

Vgg = Vs - Nd\*Xm/Cox = 5.000000

Err2 = Vgg - Vgg = -0.000000

\*\*\*\*\*

Xm = 0.230310

Xn = Xd - Xm = 0.769690

Xp = Xn\*Nd/Na = 7.696900

$$V_{\bar{}} = 0.119274$$

$$V_{np} = V_{\bar{}} + Na \cdot X_p \cdot X_p / 2 / E_{si} = 4.690437$$

$$V_m = V_{np} + Nd \cdot X_n \cdot X_n / 2 / E_{si} = 5.147553$$

$$V_s = V_m - Nd \cdot X_m \cdot X_m / 2 / E_{si} = 5.106625$$

$$V_{gg} = V_s - Nd \cdot X_m / Cox = 5.000000$$

$$Err = V_{ggg} - V_{gg} = -0.000000$$

\*\*\*\*\*

NOTE = 30 Xm = 0.230310 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

$$V_{gg} = 6.000000$$

\*\*\*\*\*

$$A = E_{si} \cdot Na / Cox / Cox + Qd * (1 + Na / Nd) / Cox = 0.523148$$

$$B = (1 + Na / Nd) * Qd * Qd / Cox / Cox$$

$$- 2 * E_{si} * Na * (V_{gg} - V_{\bar{}}) / Cox / Cox = 0.072415$$

$$V_s = V_{gg} + A - \sqrt{A \cdot A - B} = 6.074518$$

$$C = (1 + Na / Nd) * (1 + Cox / Cd) = 4.766667$$

$$D = (1 + Na / Nd) * (V_{gg} - Nd \cdot X_d \cdot X_d / 2 / E_{si}) - V_{\bar{}} \cdot Na / Nd = 5.739307$$

$$V_m = C * (V_s - V_{gg}) + D = 6.094508$$

$$X_m = \sqrt{2 * E_{si} * (V_m - V_s) / Nd} = 0.160958$$

$$X_n = X_d - X_m = 0.839042$$

$$X_p = X_n \cdot Nd / Na = 8.390418$$

$$V_{np} = V_{\bar{}} + Na \cdot X_p \cdot X_p / 2 / E_{si} = 5.551305$$

$$V_{mm} = V_{np} + Nd \cdot X_n \cdot X_n / 2 / E_{si} = 6.094508$$

$$V_{mmmm} = V_s + Nd \cdot X_m \cdot X_m / 2 / E_{si} = 6.094508$$

$$E_{np} = X_p \cdot Na / E_{si} = 1.294818$$

$$E_s = X_m \cdot Nd / E_{si} = 0.248392$$

$$E_{ox} = X_m \cdot Nd / Esio_2 = 0.745177$$

\*\*\*\*\* Summary \*\*\*\*\*

$$Xm = 0.160958$$

$$Xn = Xd - Xm = 0.839042$$

$$Xp = Xn*Nd/Na = 8.390418$$

$$Vbar = 0.119274$$

$$Vnp = Vbar + Na*Xp*Xp/2/Esi = 5.551305$$

$$Vm = Vnp + Nd*Xn*Xn/2/Esi = 6.094508$$

$$Vs = Vm - Nd*Xm*Xm/2/Esi = 6.074518$$

$$Vgg = Vs - Nd*Xm/Cox = 6.000000$$

$$Err1 = Vg - Vgg = -0.000000$$

\*\*\*\*\* Numerical Calculation \*\*\*\*\*

$$\text{NOTE} = 0 \quad Xm = 0.500000 \quad Err1 = 2.606928 \quad Err = -4.183195 \quad Err2 = -7.115294$$

$$\text{NOTE} = 1 \quad Xm = 0.250000 \quad Err1 = 2.606928 \quad Err = -1.270387 \quad Err2 = -4.183195$$

$$\text{NOTE} = 2 \quad Xm = 0.125000 \quad Err1 = 2.606928 \quad Err = 0.547708 \quad Err2 = -1.270387$$

$$\text{NOTE} = 3 \quad Xm = 0.187500 \quad Err1 = 0.547708 \quad Err = -0.391480 \quad Err2 = -1.270387$$

$$\text{NOTE} = 4 \quad Xm = 0.156250 \quad Err1 = 0.547708 \quad Err = 0.070578 \quad Err2 = -0.391480$$

$$\text{NOTE} = 5 \quad Xm = 0.171875 \quad Err1 = 0.070578 \quad Err = -0.162335 \quad Err2 = -0.391480$$

$$\text{NOTE} = 6 \quad Xm = 0.164062 \quad Err1 = 0.070578 \quad Err = -0.046349 \quad Err2 = -0.162335$$

$$\text{NOTE} = 7 \quad Xm = 0.160156 \quad Err1 = 0.070578 \quad Err = 0.011997 \quad Err2 = -0.046349$$

$$\text{NOTE} = 8 \quad Xm = 0.162109 \quad Err1 = 0.011997 \quad Err = -0.017206 \quad Err2 = -0.046349$$

$$\text{NOTE} = 9 \quad Xm = 0.161133 \quad Err1 = 0.011997 \quad Err = -0.002612 \quad Err2 = -0.017206$$

$$\text{NOTE} = 10 \quad Xm = 0.160645 \quad Err1 = 0.011997 \quad Err = 0.004691 \quad Err2 = -0.002612$$

$$\text{NOTE} = 11 \quad Xm = 0.160889 \quad Err1 = 0.004691 \quad Err = 0.001039 \quad Err2 = -0.002612$$

$$\text{NOTE} = 12 \quad Xm = 0.161011 \quad Err1 = 0.001039 \quad Err = -0.000786 \quad Err2 = -0.002612$$

$$\text{NOTE} = 13 \quad Xm = 0.160950 \quad Err1 = 0.001039 \quad Err = 0.000126 \quad Err2 = -0.000786$$

$$\text{NOTE} = 14 \quad Xm = 0.160980 \quad Err1 = 0.000126 \quad Err = -0.000330 \quad Err2 = -0.000786$$

$$\text{NOTE} = 15 \quad Xm = 0.160965 \quad Err1 = 0.000126 \quad Err = -0.000102 \quad Err2 = -0.000330$$

NOTE = 16 Xm = 0.160957 Err1 = 0.000126 Err = 0.000012 Err2 = -0.000102  
NOTE = 17 Xm = 0.160961 Err1 = 0.000012 Err = -0.000045 Err2 = -0.000102  
NOTE = 18 Xm = 0.160959 Err1 = 0.000012 Err = -0.000016 Err2 = -0.000045  
NOTE = 19 Xm = 0.160958 Err1 = 0.000012 Err = -0.000002 Err2 = -0.000016  
NOTE = 20 Xm = 0.160958 Err1 = 0.000012 Err = 0.000005 Err2 = -0.000002  
NOTE = 21 Xm = 0.160958 Err1 = 0.000005 Err = 0.000002 Err2 = -0.000002  
NOTE = 22 Xm = 0.160958 Err1 = 0.000002 Err = -0.000000 Err2 = -0.000002  
NOTE = 23 Xm = 0.160958 Err1 = 0.000002 Err = 0.000001 Err2 = -0.000000  
NOTE = 24 Xm = 0.160958 Err1 = 0.000001 Err = 0.000000 Err2 = -0.000000  
NOTE = 25 Xm = 0.160958 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 26 Xm = 0.160958 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 27 Xm = 0.160958 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 28 Xm = 0.160958 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 29 Xm = 0.160958 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Xm = 0.160958

Xn = Xd - Xm = 0.839042

Xp = Xn\*Nd/Na = 8.390418

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 5.551305

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 6.094508

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 6.074518

Vgg = Vs - Nd\*Xm/Cox = 6.000000

Err1 = Vgg - Vgg = 0.000000

\*\*\*\*\*

Xm = 0.160958

Xn = Xd - Xm = 0.839042

Xp = Xn\*Nd/Na = 8.390418

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 5.551305

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 6.094508

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 6.074518

Vgg = Vs - Nd\*Xm/Cox = 6.000000

Err2 = Vgg - Vgg = -0.000000

\*\*\*\*\*

Xm = 0.160958

Xn = Xd - Xm = 0.839042

Xp = Xn\*Nd/Na = 8.390418

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 5.551305

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 6.094508

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 6.074518

Vgg = Vs - Nd\*Xm/Cox = 6.000000

Err = Vgg - Vgg = 0.000000

\*\*\*\*\*

NOTE = 30 Xm = 0.160958 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000

\*\*\*\*\*

Vgg= 7.000000

\*\*\*\*\*

A = Esi\*Na/Cox/Cox + Qd\*( 1 + Na/Nd )/ Cox = 0.523148

B = ( 1 + Na/Nd )\*Qd\*Qd/Cox/Cox

- 2\*Esi\*Na\*( Vgg - Vbar )/Cox/Cox = 0.044637

Vs = Vgg + A - sqrt ( A\*A - B )= 7.044560

C = ( 1 + Na/Nd ) \* ( 1 + Cox/Cd )= 4.766667

$$D = (1 + Na/Nd) * (Vgg - Nd*Xd*Xd/2/Esi) - Vbar*Na/Nd = 6.839307$$

$$Vm = C*(Vs - Vgg) + D = 7.051707$$

$$Xm = \sqrt{2*Esi*(Vm - Vs)/Nd} = 0.096249$$

$$Xn = Xd - Xm = 0.903751$$

$$Xp = Xn*Nd/Na = 9.037515$$

$$Vnp = Vbar + Na*Xp*Xp/2/Esi = 6.421486$$

$$Vm_{mm} = Vnp + Nd*Xn*Xn/2/Esi = 7.051707$$

$$Vm_{mmm} = Vs + Nd*Xm*Xm/2/Esi = 7.051707$$

$$Enp = Xp*Na/Esi = 1.394678$$

$$Es = Xm*Nd/Esi = 0.148532$$

$$Eox = Xm*Nd/Esi = 0.445595$$

\*\*\*\*\* Summary \*\*\*\*\*

$$Xm = 0.096249$$

$$Xn = Xd - Xm = 0.903751$$

$$Xp = Xn*Nd/Na = 9.037515$$

$$Vbar = 0.119274$$

$$Vnp = Vbar + Na*Xp*Xp/2/Esi = 6.421486$$

$$Vm = Vnp + Nd*Xn*Xn/2/Esi = 7.051707$$

$$Vs = Vm - Nd*Xm*Xm/2/Esi = 7.044560$$

$$Vgg = Vs - Nd*Xm/Cox = 7.000000$$

$$Err1 = Vgg - Vgg = -0.000000$$

\*\*\*\*\*

\*\*\*\*\* Numerical Calculation \*\*\*\*\*

NOTE = 0 Xm = 0.500000 Err1 = 1.606928 Err = -5.183195 Err2 = -8.115294

NOTE = 1 Xm = 0.250000 Err1 = 1.606928 Err = -2.270387 Err2 = -5.183195

NOTE = 2 Xm = 0.125000 Err1 = 1.606928 Err = -0.452292 Err2 = -2.270387

NOTE = 3 Xm = 0.062500 Err1 = 1.606928 Err = 0.547177 Err2 = -0.452292

NOTE = 4 Xm = 0.093750 Err1 = 0.547177 Err = 0.039907 Err2 = -0.452292

NOTE = 5 Xm = 0.109375 Err1 = 0.039907 Err = -0.208076 Err2 = -0.452292  
NOTE = 6 Xm = 0.101562 Err1 = 0.039907 Err = -0.084556 Err2 = -0.208076  
NOTE = 7 Xm = 0.097656 Err1 = 0.039907 Err = -0.022442 Err2 = -0.084556  
NOTE = 8 Xm = 0.095703 Err1 = 0.039907 Err = 0.008703 Err2 = -0.022442  
NOTE = 9 Xm = 0.096680 Err1 = 0.008703 Err = -0.006877 Err2 = -0.022442  
NOTE = 10 Xm = 0.096191 Err1 = 0.008703 Err = 0.000911 Err2 = -0.006877  
NOTE = 11 Xm = 0.096436 Err1 = 0.000911 Err = -0.002983 Err2 = -0.006877  
NOTE = 12 Xm = 0.096313 Err1 = 0.000911 Err = -0.001036 Err2 = -0.002983  
NOTE = 13 Xm = 0.096252 Err1 = 0.000911 Err = -0.000062 Err2 = -0.001036  
NOTE = 14 Xm = 0.096222 Err1 = 0.000911 Err = 0.000424 Err2 = -0.000062  
NOTE = 15 Xm = 0.096237 Err1 = 0.000424 Err = 0.000181 Err2 = -0.000062  
NOTE = 16 Xm = 0.096245 Err1 = 0.000181 Err = 0.000059 Err2 = -0.000062  
NOTE = 17 Xm = 0.096249 Err1 = 0.000059 Err = -0.000002 Err2 = -0.000062  
NOTE = 18 Xm = 0.096247 Err1 = 0.000059 Err = 0.000029 Err2 = -0.000002  
NOTE = 19 Xm = 0.096248 Err1 = 0.000029 Err = 0.000014 Err2 = -0.000002  
NOTE = 20 Xm = 0.096248 Err1 = 0.000014 Err = 0.000006 Err2 = -0.000002  
NOTE = 21 Xm = 0.096248 Err1 = 0.000006 Err = 0.000002 Err2 = -0.000002  
NOTE = 22 Xm = 0.096249 Err1 = 0.000002 Err = 0.000000 Err2 = -0.000002  
NOTE = 23 Xm = 0.096249 Err1 = 0.000000 Err = -0.000001 Err2 = -0.000002  
NOTE = 24 Xm = 0.096249 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000001  
NOTE = 25 Xm = 0.096249 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 26 Xm = 0.096249 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 27 Xm = 0.096249 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 28 Xm = 0.096249 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 29 Xm = 0.096249 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Xm = 0.096249

Xn = Xd - Xm = 0.903751

Xp = Xn\*Nd/Na = 9.037515

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 6.421486

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 7.051707

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 7.044560

Vgg = Vs - Nd\*Xm/Cox = 7.000000

Err1 = Vggg - Vgg = 0.000000

\*\*\*\*\*

Xm = 0.096249

Xn = Xd - Xm = 0.903751

Xp = Xn\*Nd/Na = 9.037515

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 6.421486

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 7.051707

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 7.044559

Vgg = Vs - Nd\*Xm/Cox = 7.000000

Err2 = Vggg - Vgg = -0.000000

\*\*\*\*\*

Xm = 0.096249

Xn = Xd - Xm = 0.903751

Xp = Xn\*Nd/Na = 9.037515

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 6.421486

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 7.051707

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 7.044560

Vgg = Vs - Nd\*Xm/Cox = 7.000000

Err = Vggg - Vgg = -0.000000

\*\*\*\*\*

NOTE = 30 Xm = 0.096249 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Vgg= 3.000000

\*\*\*\*\*

A = Esi\*Na/Cox/Cox + Qd\*( 1 + Na/Nd )/ Cox = 0.523148

B = ( 1 + Na/Nd )\*Qd\*Qd/Cox/Cox

- 2\*Esi\*Na\*( Vgg - Vbar )/Cox/Cox = 0.155748

Vs = Vgg + A - sqrt ( A\*A - B )= 3.179730

C = ( 1 + Na/Nd ) \* ( 1 + Cox/Cd )= 4.766667

D = ( 1 + Na/Nd ) \* ( Vgg - Nd\*Xd\*Xd/2/Esi ) - Vbar\*Na/Nd = 2.439307

Vm = C\*( Vs - Vgg ) + D = 3.296020

Xm = sqrt(2\*Esi\*(Vm - Vs)/Nd) = 0.388217

Xn = Xd - Xm = 0.611783

Xp = Xn\*Nd/Na = 6.117831

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.007225

Vmmmm = Vnp + Nd\*Xn\*Xn/2/Esi = 3.296020

Vmmmm = Vs + Nd\*Xm\*Xm/2/Esi = 3.296020

Enp = Xp\*Na/Esi = 0.944110

Es = Xm\*Nd/Esi = 0.599100

Eox = Xm\*Nd/Esi = 1.797301

\*\*\*\*\* Summary \*\*\*\*\*

Xm = 0.388217

Xn = Xd - Xm = 0.611783

Xp = Xn\*Nd/Na = 6.117831

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.007225

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 3.296020

$V_s = V_m - N_d \cdot X_m \cdot X_m / 2 / E_{si} = 3.179730$

$V_{gg} = V_s - N_d \cdot X_m / C_{ox} = 3.000000$

$Err_1 = V_{ggg} - V_{gg} = 0.000000$

\*\*\*\*\* Numerical Calculation \*\*\*\*\*

NOTE = 0  $X_m = 0.500000$  Err1 = 5.606928 Err = -1.183195 Err2 = -4.115294

NOTE = 1  $X_m = 0.250000$  Err1 = 5.606928 Err = 1.729613 Err2 = -1.183195

NOTE = 2  $X_m = 0.375000$  Err1 = 1.729613 Err = 0.152646 Err2 = -1.183195

NOTE = 3  $X_m = 0.437500$  Err1 = 0.152646 Err = -0.545416 Err2 = -1.183195

NOTE = 4  $X_m = 0.406250$  Err1 = 0.152646 Err = -0.203920 Err2 = -0.545416

NOTE = 5  $X_m = 0.390625$  Err1 = 0.152646 Err = -0.027521 Err2 = -0.203920

NOTE = 6  $X_m = 0.382812$  Err1 = 0.152646 Err = 0.062092 Err2 = -0.027521

NOTE = 7  $X_m = 0.386719$  Err1 = 0.062092 Err = 0.017168 Err2 = -0.027521

NOTE = 8  $X_m = 0.388672$  Err1 = 0.017168 Err = -0.005206 Err2 = -0.027521

NOTE = 9  $X_m = 0.387695$  Err1 = 0.017168 Err = 0.005973 Err2 = -0.005206

NOTE = 10  $X_m = 0.388184$  Err1 = 0.005973 Err = 0.000382 Err2 = -0.005206

NOTE = 11  $X_m = 0.388428$  Err1 = 0.000382 Err = -0.002413 Err2 = -0.005206

NOTE = 12  $X_m = 0.388306$  Err1 = 0.000382 Err = -0.001016 Err2 = -0.002413

NOTE = 13  $X_m = 0.388245$  Err1 = 0.000382 Err = -0.000317 Err2 = -0.001016

NOTE = 14  $X_m = 0.388214$  Err1 = 0.000382 Err = 0.000032 Err2 = -0.000317

NOTE = 15  $X_m = 0.388229$  Err1 = 0.000032 Err = -0.000142 Err2 = -0.000317

NOTE = 16  $X_m = 0.388222$  Err1 = 0.000032 Err = -0.000055 Err2 = -0.000142

NOTE = 17  $X_m = 0.388218$  Err1 = 0.000032 Err = -0.000011 Err2 = -0.000055

NOTE = 18  $X_m = 0.388216$  Err1 = 0.000032 Err = 0.000011 Err2 = -0.000011

NOTE = 19  $X_m = 0.388217$  Err1 = 0.000011 Err = -0.000000 Err2 = -0.000011

NOTE = 20  $X_m = 0.388216$  Err1 = 0.000011 Err = 0.000005 Err2 = -0.000000

NOTE = 21  $X_m = 0.388217$  Err1 = 0.000005 Err = 0.000002 Err2 = -0.000000

NOTE = 22  $X_m = 0.388217$  Err1 = 0.000002 Err = 0.000001 Err2 = -0.000000

NOTE = 23 Xm = 0.388217 Err1 = 0.000001 Err = 0.000000 Err2 = -0.000000  
NOTE = 24 Xm = 0.388217 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 25 Xm = 0.388217 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 26 Xm = 0.388217 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 27 Xm = 0.388217 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 28 Xm = 0.388217 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 29 Xm = 0.388217 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Xm = 0.388217

Xn = Xd - Xm = 0.611783

Xp = Xn\*Nd/Na = 6.117831

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.007225

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 3.296020

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 3.179730

Vgg = Vs - Nd\*Xm/Cox = 3.000000

Err1 = Vgg - Vgg = 0.000000

\*\*\*\*\*

Xm = 0.388217

Xn = Xd - Xm = 0.611783

Xp = Xn\*Nd/Na = 6.117831

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.007225

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 3.296020

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 3.179730

Vgg = Vs - Nd\*Xm/Cox = 3.000000

Err2 = Vgg - Vgg = -0.000000

\*\*\*\*\*

Xm = 0.388217

Xn = Xd - Xm = 0.611783

Xp = Xn\*Nd/Na = 6.117831

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.007225

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 3.296020

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 3.179730

Vgg = Vs - Nd\*Xm/Cox = 3.000000

Err = Vgg - Vgg = -0.000000

\*\*\*\*\*

NOTE = 30 Xm = 0.388217 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Vgg= 4.000000

\*\*\*\*\*

A = Esi\*Na/Cox/Cox + Qd\*( 1 + Na/Nd )/ Cox = 0.523148

B = ( 1 + Na/Nd )\*Qd\*Qd/Cox/Cox

- 2\*Esi\*Na\*( Vgg - Vbar )/Cox/Cox = 0.127970

Vs = Vgg + A - sqrt ( A\*A - B )= 4.141423

C = ( 1 + Na/Nd ) \* ( 1 + Cox/Cd )= 4.766667

D = ( 1 + Na/Nd ) \* ( Vgg - Nd\*Xd\*Xd/2/Esi ) - Vbar\*Na/Nd = 3.539307

Vm = C\*( Vs - Vgg ) + D = 4.213426

Xm = sqrt(2\*Esi\*(Vm - Vs)/Nd) = 0.305475

Xn = Xd - Xm = 0.694525

Xp = Xn\*Nd/Na = 6.945254

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.841230

Vmm = Vnp + Nd\*Xn\*Xn/2/Esi = 4.213426

Vmmmm = Vs + Nd\*Xm\*Xm/2/Esi = 4.213426

Enp = Xp\*Na/Esi = 1.071798

Es = Xm\*Nd/Esi = 0.471411

Eox = Xm\*Nd/Esi = 1.414234

\*\*\*\*\* Summary \*\*\*\*\*

Xm = 0.305475

Xn = Xd - Xm = 0.694525

Xp = Xn\*Nd/Na = 6.945254

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.841230

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 4.213426

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 4.141423

Vgg = Vs - Nd\*Xm/Cox = 4.000000

Err1 = Vgg - Vgg = -0.000000

\*\*\*\*\* Numerical Calculation \*\*\*\*\*

NOTE = 0 Xm = 0.500000 Err1 = 4.606928 Err = -2.183195 Err2 = -5.115294

NOTE = 1 Xm = 0.250000 Err1 = 4.606928 Err = 0.729613 Err2 = -2.183195

NOTE = 2 Xm = 0.375000 Err1 = 0.729613 Err = -0.847354 Err2 = -2.183195

NOTE = 3 Xm = 0.312500 Err1 = 0.729613 Err = -0.089011 Err2 = -0.847354

NOTE = 4 Xm = 0.281250 Err1 = 0.729613 Err = 0.312766 Err2 = -0.089011

NOTE = 5 Xm = 0.296875 Err1 = 0.312766 Err = 0.109994 Err2 = -0.089011

NOTE = 6 Xm = 0.304688 Err1 = 0.109994 Err = 0.010020 Err2 = -0.089011

NOTE = 7 Xm = 0.308594 Err1 = 0.010020 Err = -0.039613 Err2 = -0.089011

NOTE = 8 Xm = 0.306641 Err1 = 0.010020 Err = -0.014826 Err2 = -0.039613

NOTE = 9 Xm = 0.305664 Err1 = 0.010020 Err = -0.002410 Err2 = -0.014826

NOTE = 10 Xm = 0.305176 Err1 = 0.010020 Err = 0.003803 Err2 = -0.002410

NOTE = 11 Xm = 0.305420 Err1 = 0.003803 Err = 0.000696 Err2 = -0.002410

NOTE = 12 Xm = 0.305542 Err1 = 0.000696 Err = -0.000857 Err2 = -0.002410  
NOTE = 13 Xm = 0.305481 Err1 = 0.000696 Err = -0.000081 Err2 = -0.000857  
NOTE = 14 Xm = 0.305450 Err1 = 0.000696 Err = 0.000308 Err2 = -0.000081  
NOTE = 15 Xm = 0.305466 Err1 = 0.000308 Err = 0.000114 Err2 = -0.000081  
NOTE = 16 Xm = 0.305473 Err1 = 0.000114 Err = 0.000016 Err2 = -0.000081  
NOTE = 17 Xm = 0.305477 Err1 = 0.000016 Err = -0.000032 Err2 = -0.000081  
NOTE = 18 Xm = 0.305475 Err1 = 0.000016 Err = -0.000008 Err2 = -0.000032  
NOTE = 19 Xm = 0.305474 Err1 = 0.000016 Err = 0.000004 Err2 = -0.000008  
NOTE = 20 Xm = 0.305475 Err1 = 0.000004 Err = -0.000002 Err2 = -0.000008  
NOTE = 21 Xm = 0.305475 Err1 = 0.000004 Err = 0.000001 Err2 = -0.000002  
NOTE = 22 Xm = 0.305475 Err1 = 0.000001 Err = -0.000000 Err2 = -0.000002  
NOTE = 23 Xm = 0.305475 Err1 = 0.000001 Err = 0.000001 Err2 = -0.000000  
NOTE = 24 Xm = 0.305475 Err1 = 0.000001 Err = 0.000000 Err2 = -0.000000  
NOTE = 25 Xm = 0.305475 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 26 Xm = 0.305475 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 27 Xm = 0.305475 Err1 = 0.000000 Err = 0.000000 Err2 = -0.000000  
NOTE = 28 Xm = 0.305475 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000  
NOTE = 29 Xm = 0.305475 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\*

Xm = 0.305475

Xn = Xd - Xm = 0.694525

Xp = Xn\*Nd/Na = 6.945254

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.841230

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 4.213426

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 4.141423

Vgg = Vs - Nd\*Xm/Cox = 4.000000

Err1 = Vgg - Vgg = 0.000000

\*\*\*\*\*

Xm = 0.305475

Xn = Xd - Xm = 0.694525

Xp = Xn\*Nd/Na = 6.945254

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.841230

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 4.213426

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 4.141423

Vgg = Vs - Nd\*Xm/Cox = 4.000000

Err2 = Vggg - Vgg = -0.000000

\*\*\*\*\*

Xm = 0.305475

Xn = Xd - Xm = 0.694525

Xp = Xn\*Nd/Na = 6.945254

Vbar = 0.119274

Vnp = Vbar + Na\*Xp\*Xp/2/Esi = 3.841230

Vm = Vnp + Nd\*Xn\*Xn/2/Esi = 4.213426

Vs = Vm - Nd\*Xm\*Xm/2/Esi = 4.141423

Vgg = Vs - Nd\*Xm/Cox = 4.000000

Err = Vggg - Vgg = -0.000000

\*\*\*\*\*

NOTE = 30 Xm = 0.305475 Err1 = 0.000000 Err = -0.000000 Err2 = -0.000000

\*\*\*\*\* End of Computation \*\*\*\*\*

\*\*\*\*\*

This program computes the values of  
the minimum empty potential well Vm and the surface potential Vs.

\*\*\*\*\*

As the density of the impurity atom in the buried channel Nd becomes larger,  
only the total dose of  $Q_d = Nd \cdot X_d$  influences the values of the buried channel  
empty potentail well Vm and the surface potential Vs.

The density Nd of the buried channel region can be chosen effectively  
with an extra process freedom in the ion implattnaion technology.

\*\*\*\*\*

The density Nd of the buried channel region can be  
made large as long as the width Xd is kept narrow.  
the PN+Psub double junction type Buried Channel CCD  
may also work perfectly.

This observation in 1975 led Hagiwara to his inventions of  
the double P+NP and the triple P+NPN junction type  
Pinned Buried Photodiodesdefined in JPA 1975-127646,  
JPA 1975-127647 and JPA1975-134985 Japanese Patents.

\*\*\*\*\*

$$Vs = V_{gg} + A - \sqrt{A \cdot A - B};$$

$$Vm = C * (Vs - V_{gg}) + D;$$

where

$$A = Esi \cdot Na / Cox / Cox + Qd * (1 + Na / Nd) / Cox;$$

$$B = (1 + Na / Nd) * Qd * Qd / Cox / Cox$$

$$- 2 * Esi * Na * (V_{gg} - V_{bar}) / Cox / Cox;$$

$$C = (1 + Na / Nd) * (1 + Cox / Cd);$$

$$D = (1 + Na / Nd) * (V_{gg} - Nd * Xd * Xd / 2 / Esi)$$

$$- V_{bar} * Na / Nd$$

\*\*\*\*\*\*/