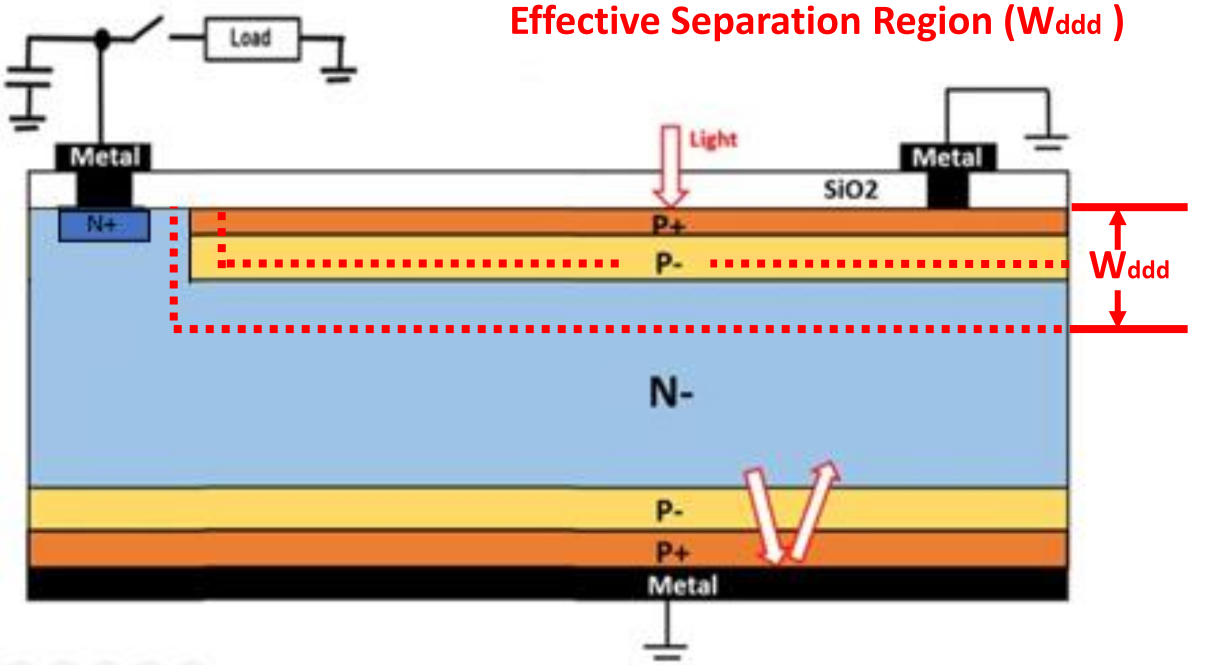
PNP Double Junction Type Solar Cell

See JPA 1975-134985 and JPA2020-131313 invented by Yoshiaki Hagiwara

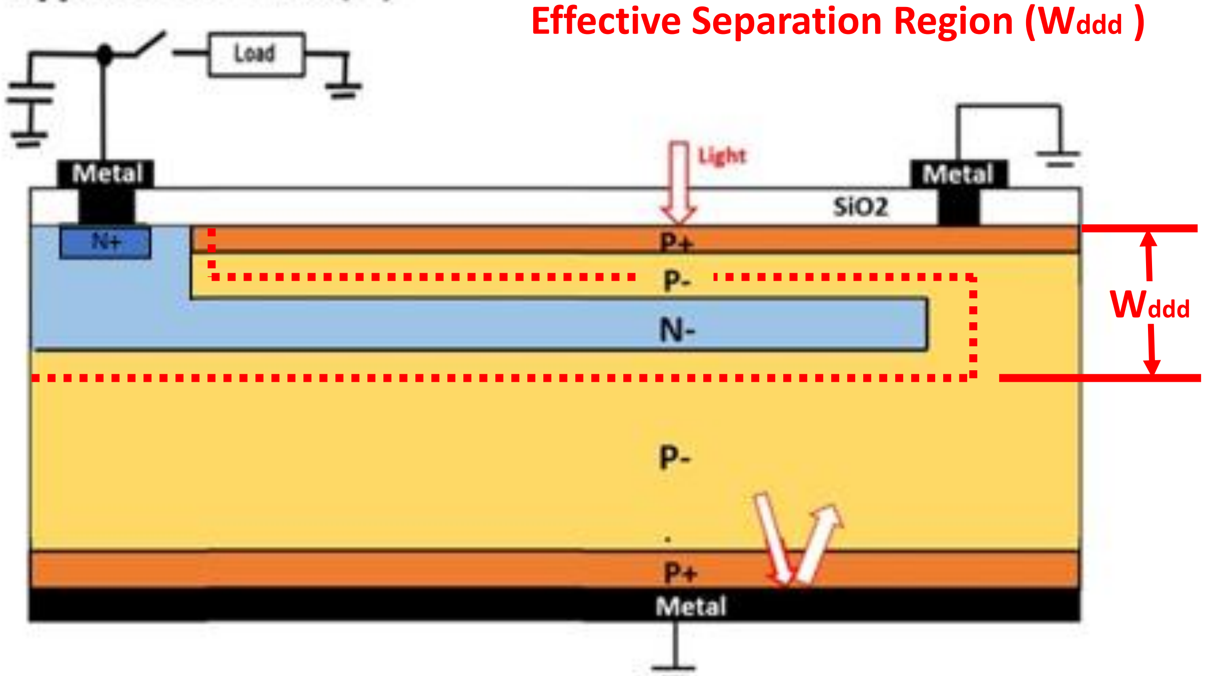
Double Junction Type Solar Cell (A)

Photo Electron and Hole Pairs Effective Separation Region (W_{ddd})

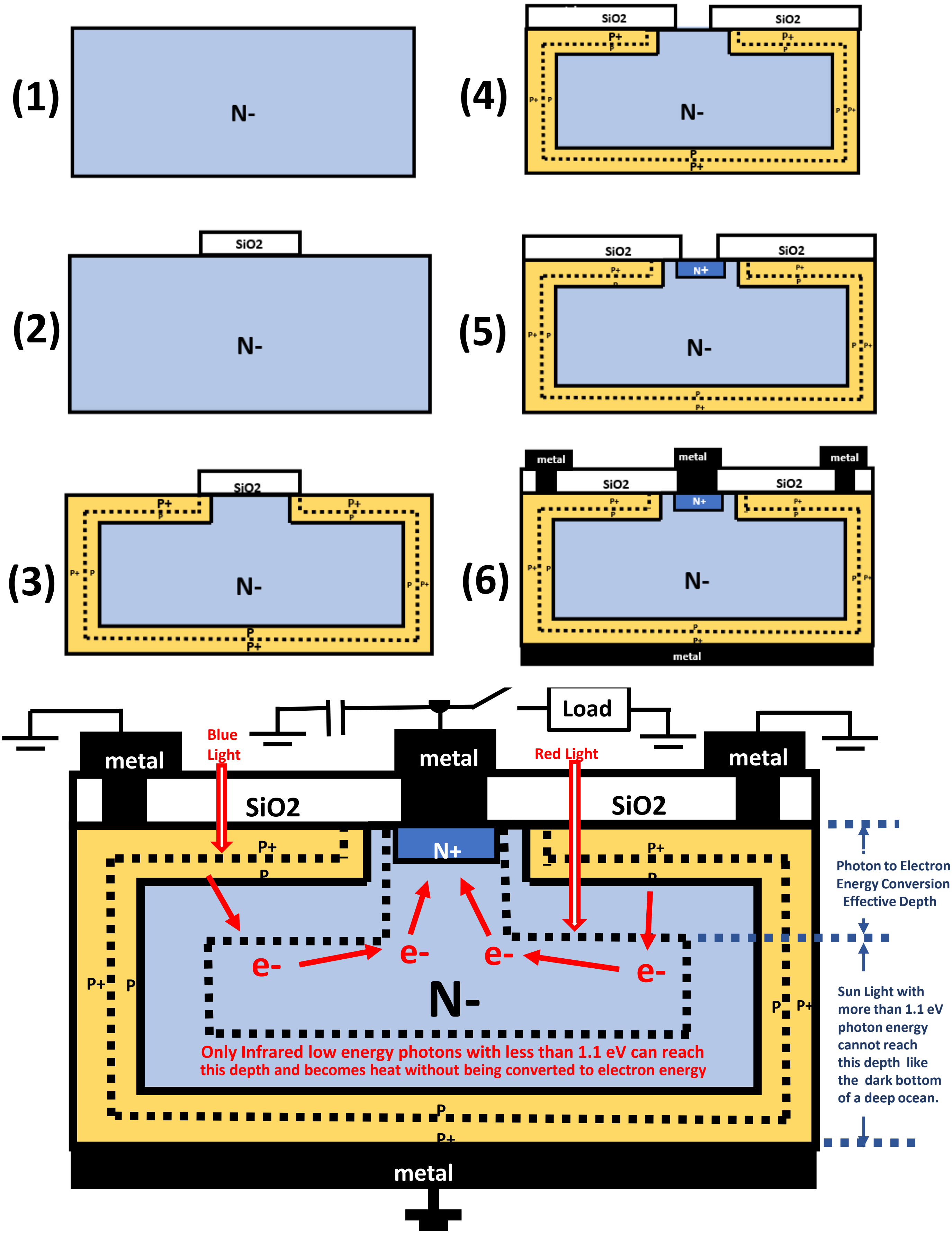


Double Junction Type Solar Cell (B)

Photo Electron and Hole Pairs Effective Separation Region (W_{ddd})

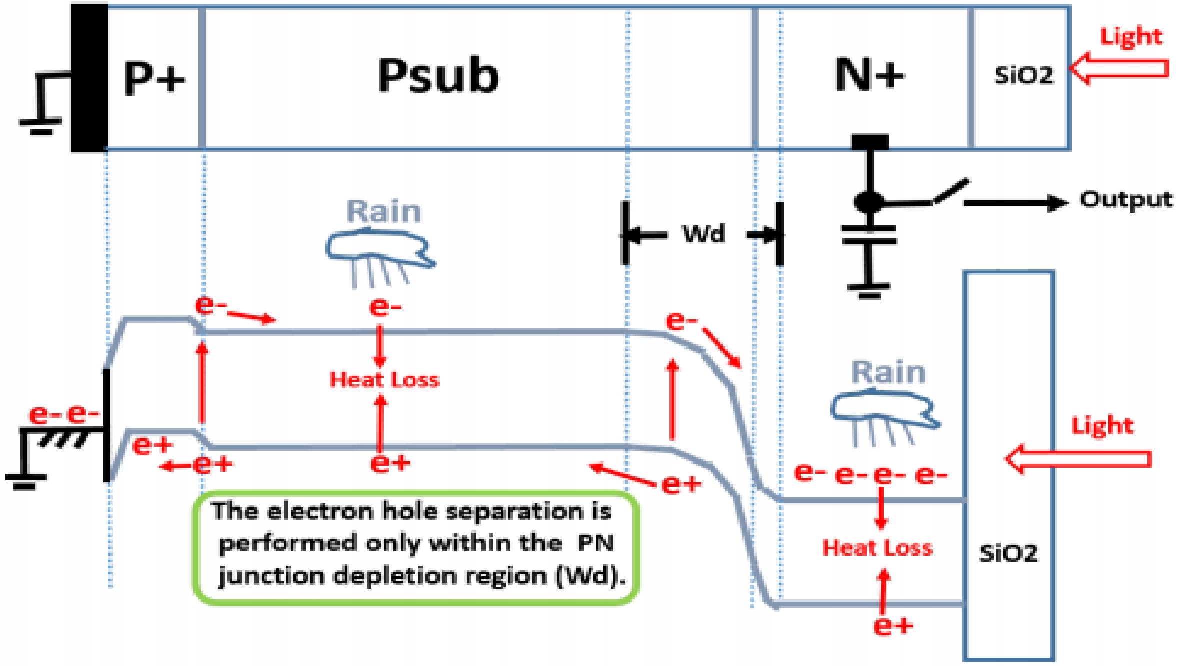


Double Junction type Pinned Photodiode Solar Cell
See JPA 2020-131313 by Yoshiaki Hagiwara



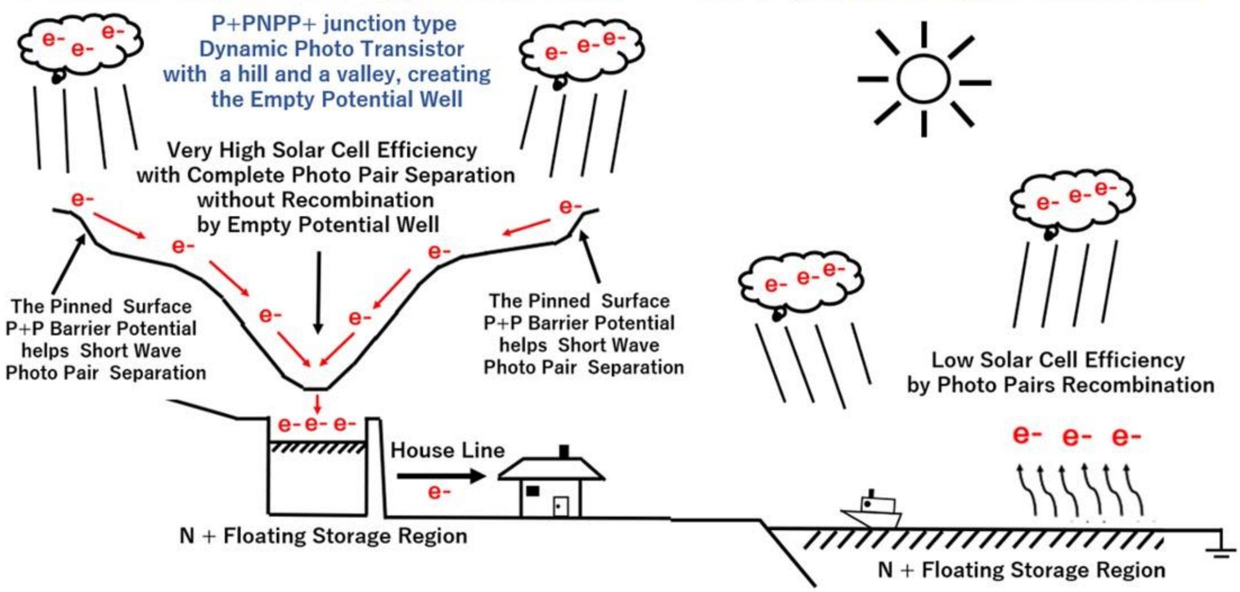
Single（単一）接合型 太陽電池

Classical N+PsubP+ Junction Photodiode



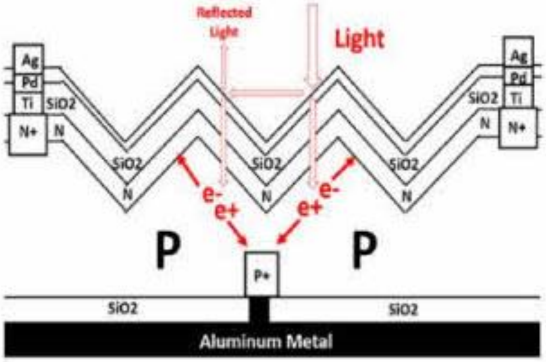
従来のN+P接合型太陽電池では効率良く光電変換ができない。N+P接合の狭い空乏層領域（Wd ）のみ可能。全体の空間に対して占める割合は非常に小さい。他の領域で、電子とHOLEを分離するバリア電界がない。すぐにその場で再結合し、熱になり無駄となる。太平洋の海上で海の水が蒸発してもそのまま雨となり海に戻る様なもので、人間には利用できない。

P+PNPP+ junction type Solar Cell　　N+P junction type Solar Cell

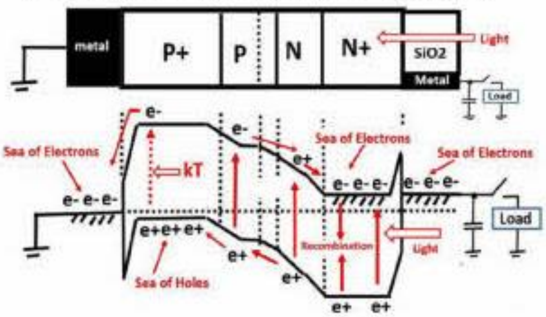


See Japanese Patent Applications JPA 1975-134985 and JPA 2020-131313 and http://www.aiplab.com by Yoshiaki Hagiwara (AIPS)

Conventional N+P Single junction Type Solar Cell

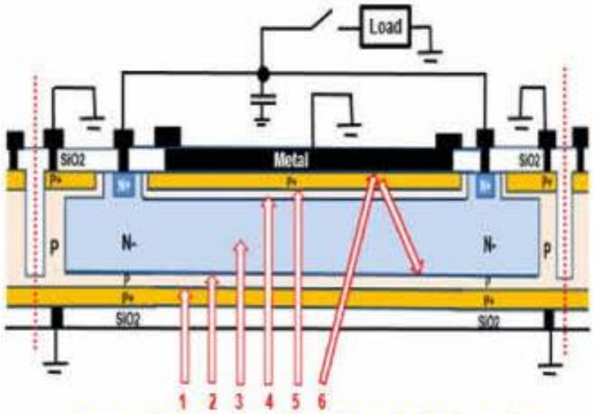


Poor Blue Light Sensitivity Problem

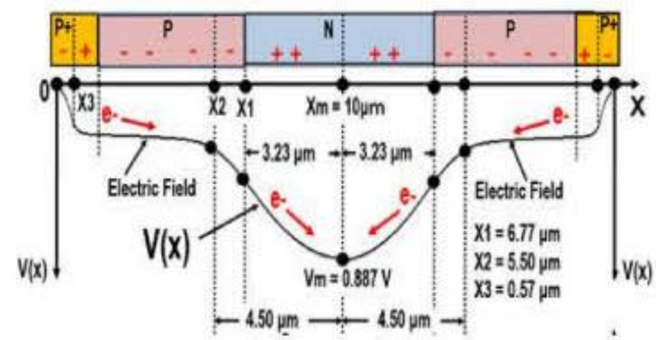


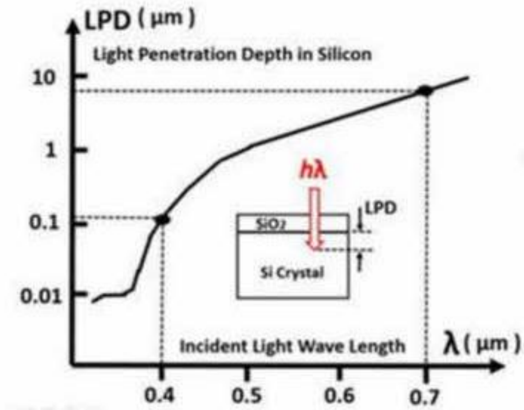
Single Junction N+P type Solar Cell also has a very poor short wave blue light sensitivity.

PNP Double Junction Type Solar Cell proposed by Hagiwara in 2020



Completely depleted Buried N region In the PNP Double Junction Type Solar Cell proposed by Hagiwara in 2020





Drift Field Transistor

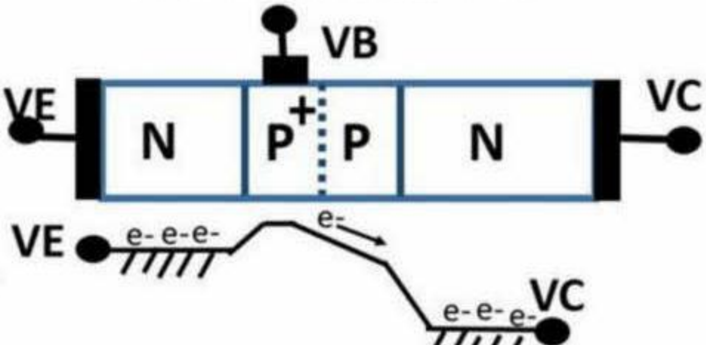
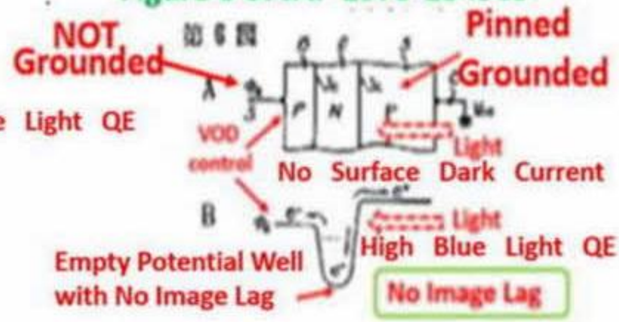


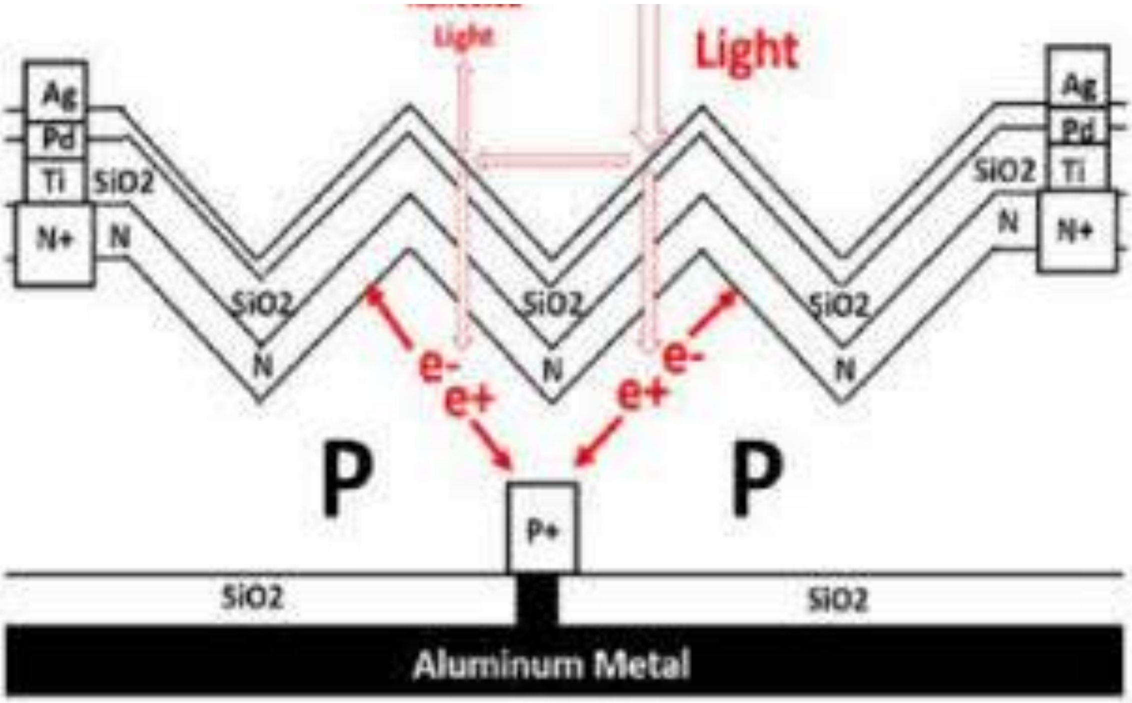
Figure 7 of JAP 1975-127647

Figure 6 of JAP 1975-134985

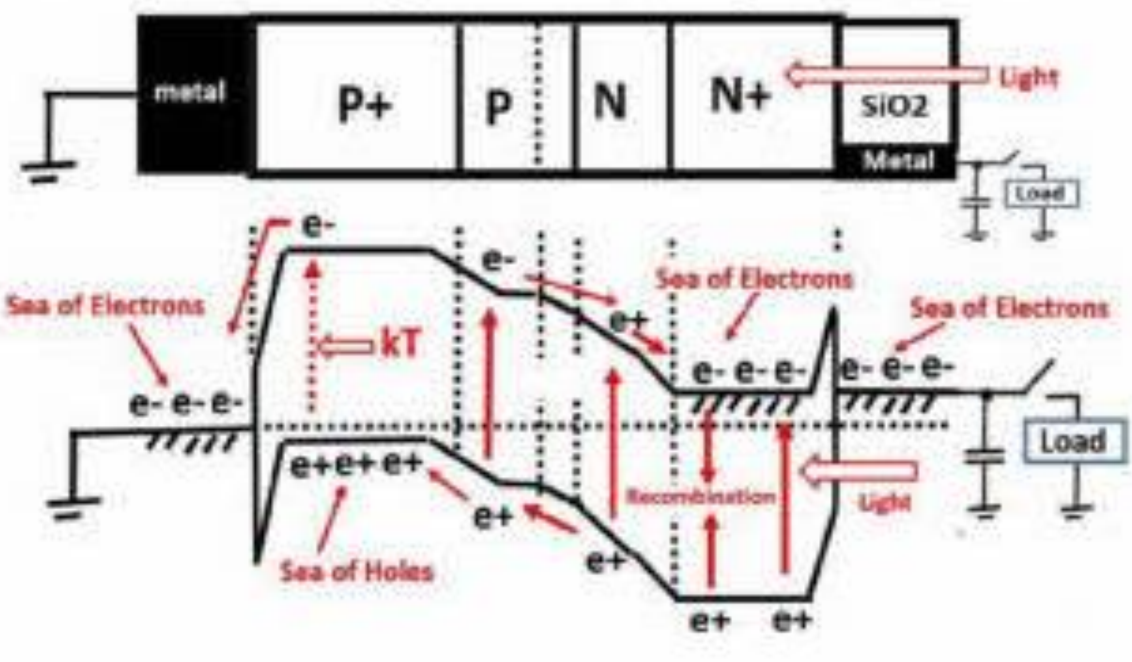


Hagiwara invented PNP junction type PPD in 1975 with (1) blue light 100% QE, (2) No Surface Dark Current and (3) No Image Lag, Complete Charge Transfer features.

Conventional N+P Single junction Type Solar Cell

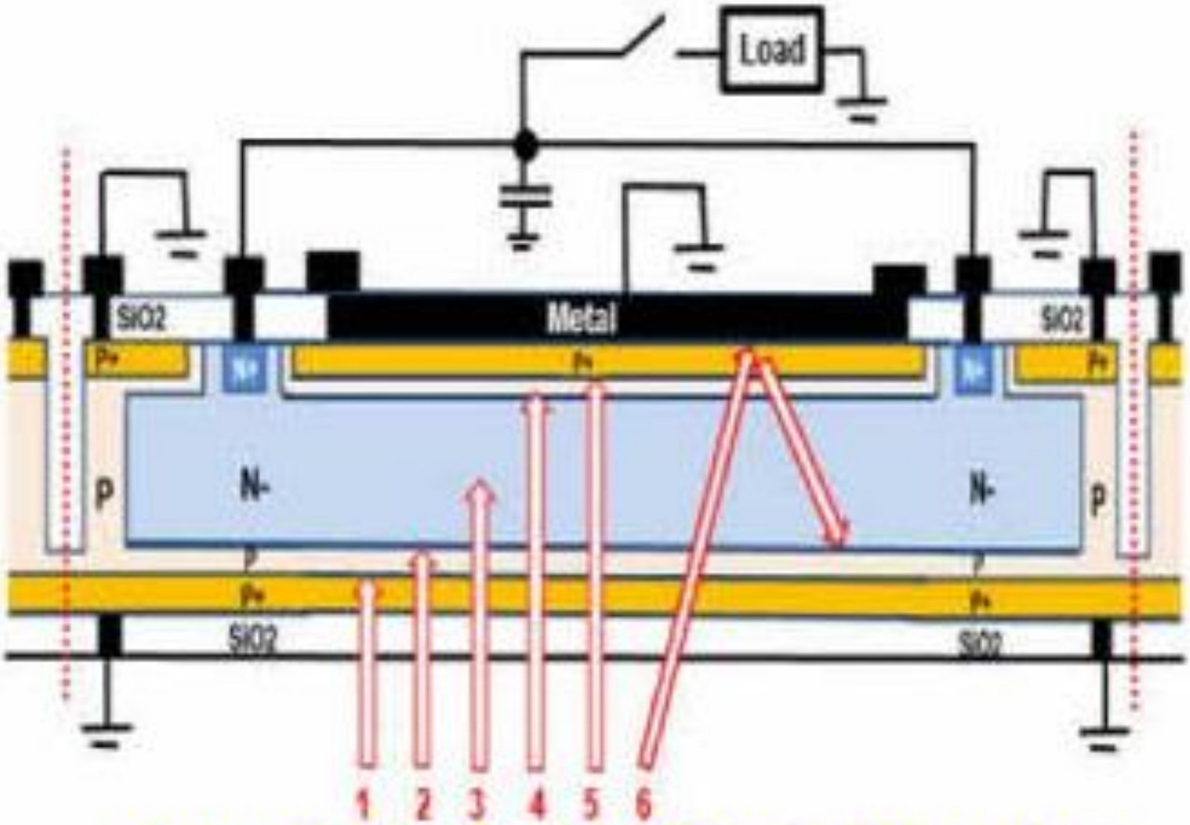


Poor Blue Light Sensitivity Problem

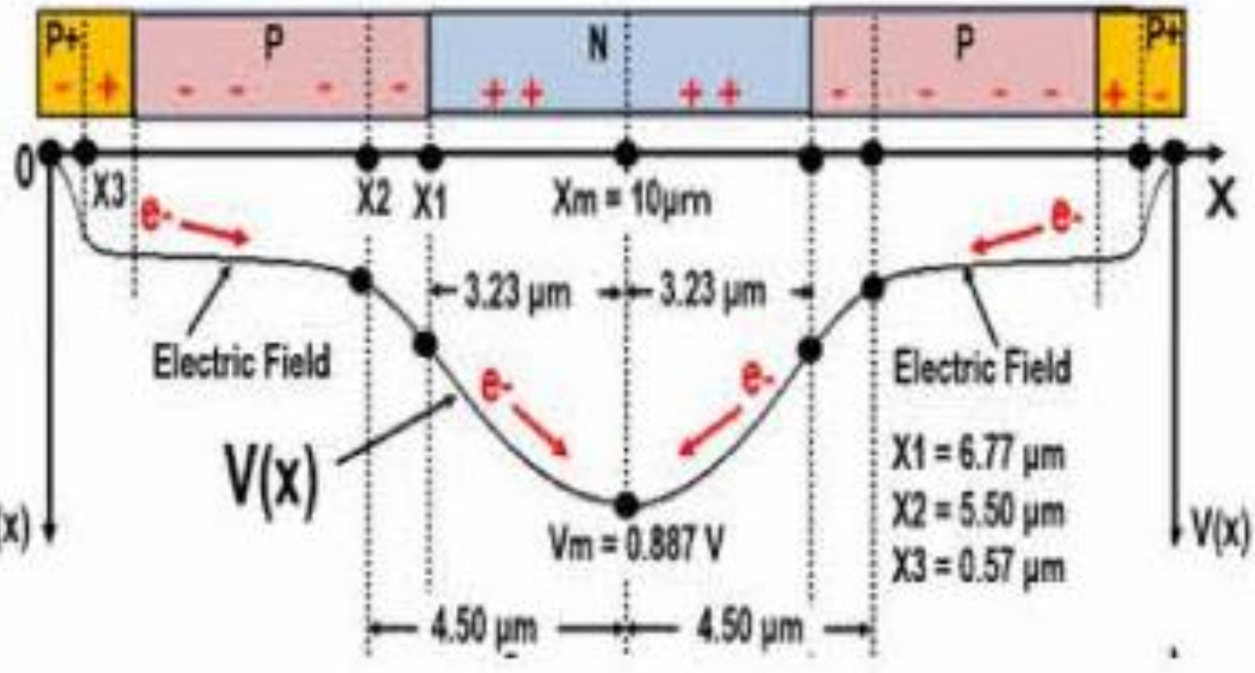


Single Junction N+P type Solar Cell also has a very poor short wave blue light sensitivity.

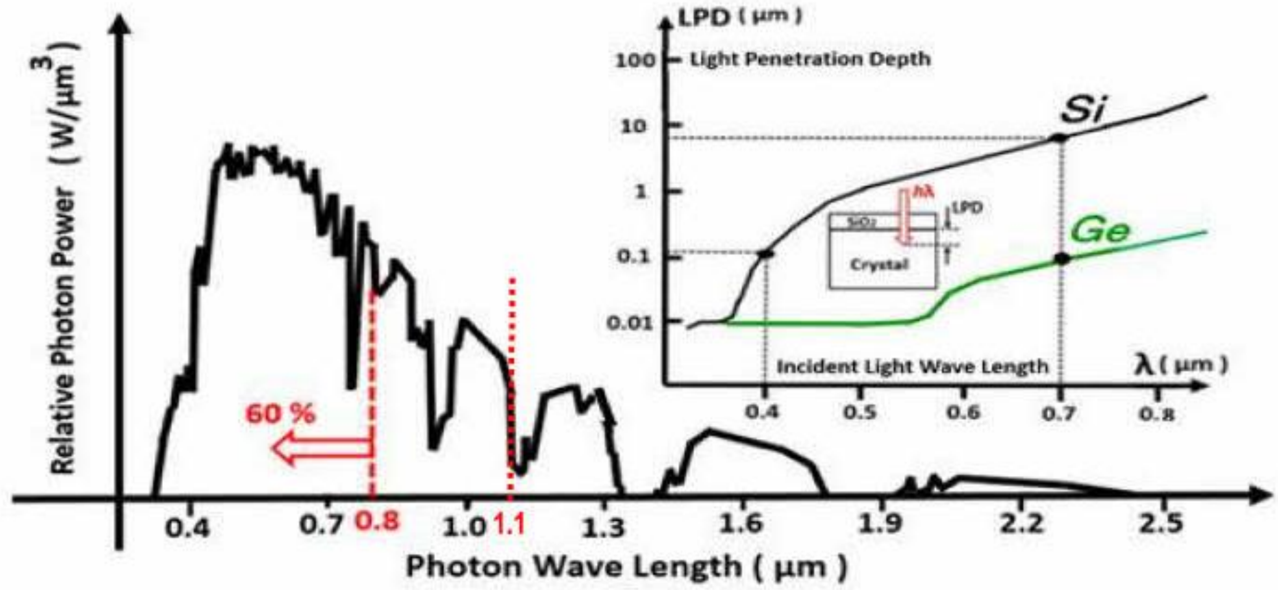
PNP Double Junction Type Solar Cell proposed by Hagiwara in 2020



Completely depleted Buried N region In the PNP Double Junction Type Solar Cell proposed by Hagiwara in 2020



Sun Light Spectrum



$E = \hbar\,\omega = h\,f = h\,c\,/\,\lambda$

$E\,(eV) = 1.24\,/\,\lambda\,(\mu m)$

For Silicon, E_G = 1.10 eV and λ = 1.12 µm

The light energy of the wave length more than λ = 1.12 µm can not be converted to electrical energy in the silicon crystal.

Difference of the static and dynamic photo transistors are illustrated in these figures.

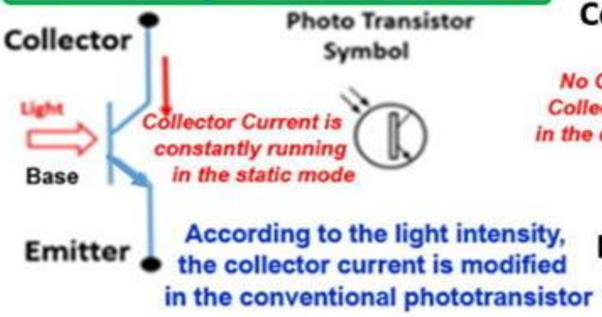
Sony Hole Accumulation Diode (HAD) is the P+NPNsub junction dynamic photo transistor with the surface P+ hole collecting and accumulation region is pinned and grounded, which is now widely called as Pinned Photodiode with the vertical overflow drain (VOD) function. Only Pinned Photodiode with the VOD function can realize the electrical shutter function.

SONY HAD Sensor 1975 was hinted by SONY PNP Bipolar Transistor Process Technology

Conventional Static Phototransistor

(by John Northrup Shive , 1950)

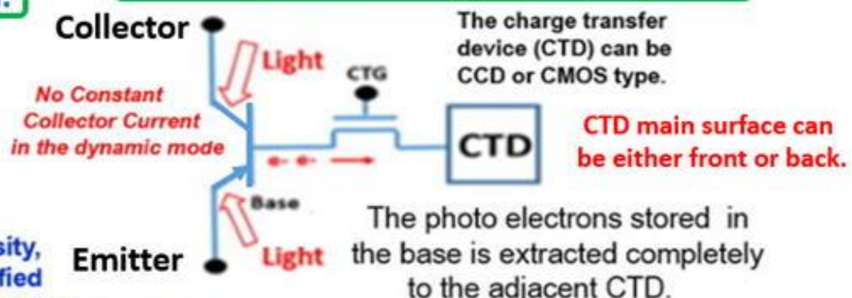
No memory function is involved.

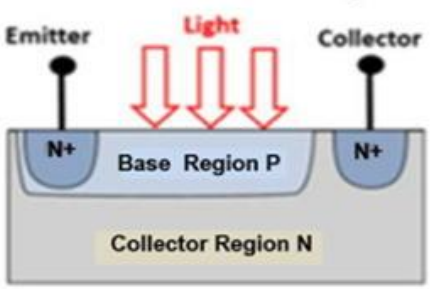


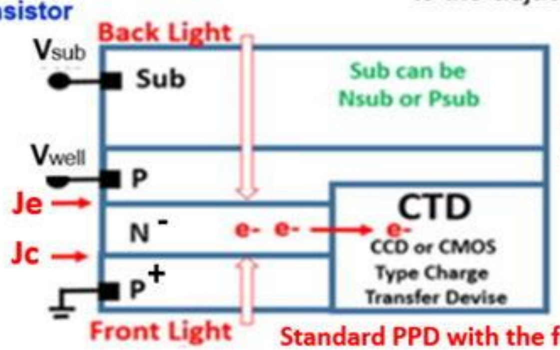
Dynamic Phototransistor Operation

by Yoshiaki Hagiwara at Sony in 1975

Dynamic Memory function is involved.



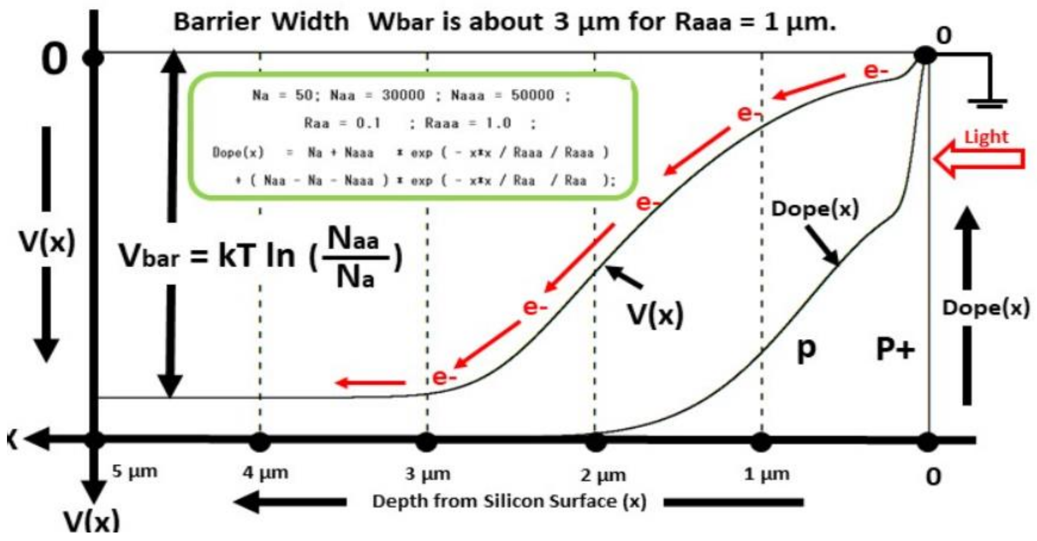




Complete Charge Extraction from the N base region for low image lag and high speed high quality action pictures

Standard PPD with the front CTD main surface

Double_Gaussian_Doping_Profile_Dope(x)



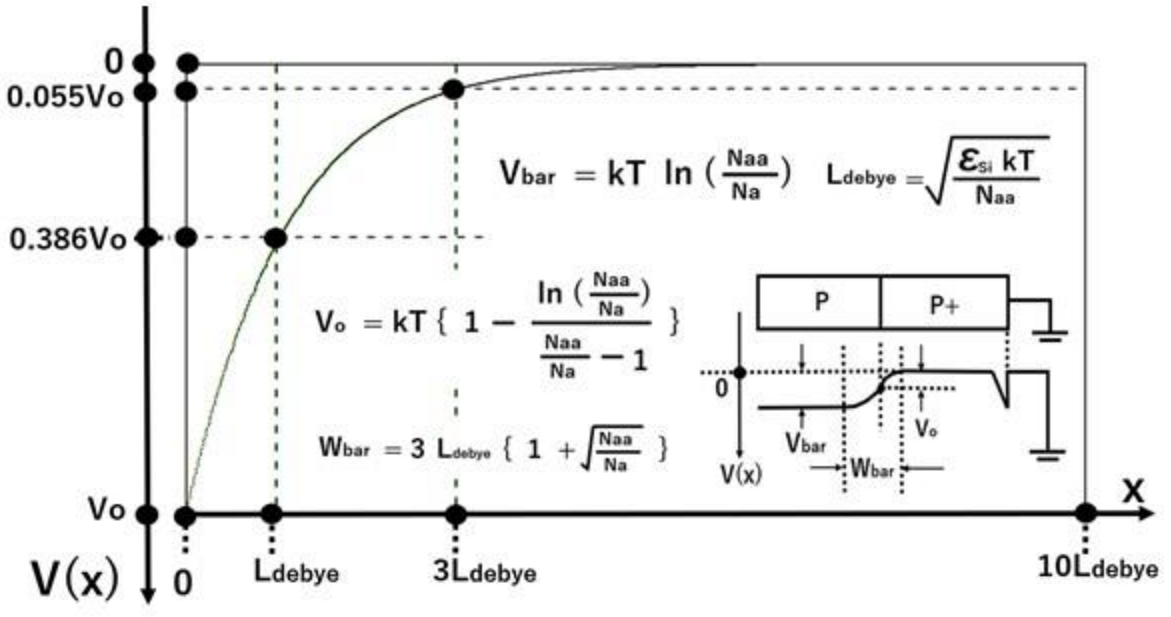

```
******************************************************************************
            Numerical Computation of Double Gaussian Doping Profile
******************************************************************************
  Esi =648; kT = 0.0259 ; Substrate Doping Denisty Na = 50 ;
  For P+PNsub Single Junction type Soalr Cell
  Wddd = sqrt ( Esi*Eg/Na)= 3.775712

  For P+PNPP+ jucntion type,
  2*Wddd = 7.551424
  Ldebye = sqrt ( Esi*kT/Na ) = 0.579365

  First Gausian Doping   Naa = 50000; Raa = 0.1 ;
  Seond Gausian Doping   Naaa = 30000;  Raaa = 1 ;
  Xsub = 5    ;
 NP = 1000 ;  dx = Xsub/NP = 0.005000   ;
 E6 = 100000 ;
******************************************************************************
Compute YY(x)  with  V[0] = kT ln ( Naa/Na ) and V[NP] = 0 ;
   For  ( i = 0 to i = NP =1000 ) {
   x = i*Xsubb/NP;
    D[i] = Na + ( Naa - Na - Naaa) *exp ( - ( Xsub - X[i] )*( Xsub - X[i] )/Raa/Raa)
            + Naaa*exp ( - ( Xsub - X[i] )*( Xsub - X[i] )/Raaa/Raaa) ;

  YY[i+1]+YY[i-1]-2*YY[i] = Esi*dx*dx*( D[i] - Naa*exp( -YY[i]/kT ) ; }


 At x  =   4.995000,    Dope(x)  = 49949.437301 ;
*********************************************************************************
```

The approximation of V(x) = kT ln(Naa/Dope(x)) was found to be very near the true value within 0.000052 volt accuracy.

```
***** Approximation by V(x) = kT ln ( Naa/Dope(x) )  ******************  E6 = 1000000 ; ***********************************
dx = 0.005000  XXX =  4.995000   Dope = 49949.437301
XX[999]=4.995000 E6*Y[998]  = 104.590834 E6*Y[999]  = 26.204730 E6*Y[1000]  = 0.000000  ErrorV( ):E6*Error = 52.181374
***** REAL VALUE otained by Numerical Computation **********
dx = 0.005000  XXX =  4.995000   Dope = 49949.437301
XX[999]=4.995000 E6*YY[998]  = 104.592487 E6*YY[999]  = 26.206400 E6*YY[1000]  = 0.000000  ErrorV( ):E6*Error = -0.000000
******************  ErrorV = YY[1000]+YY[998]-2*YY[999] - Esi*dx*dx*( Dope - Naa*exp( - YY[999]/kT ) ) ; ****************
```

Calculation of Barrier Potential of P+P Doping Profile

Yoshiaki Hagiwara (AIPS) April 27, 2021



Conclusion

Barrier Potential is well know and give as

$$V_{bar} = kT \ln\left(\frac{N_{aa}}{N_a}\right)$$

But the actual Barrier Width was found to be about three time of the value estimate by the simple calculation of the Debye Length .

$$W_{bar} = 3\, L_{debye} \left\{ 1 + \sqrt{\frac{N_{aa}}{N_a}} \right\}$$

****** Na+/Na Potential Barrier Computation **********

Na = 50 μm^{-3}

Naa = 5000 μm^{-3}

Ldebye_Na = sqrt(Esi*kT/Na) = 0.579365 μm

Ldebye_Naa = sqrt(Esi*kT/Naa) = 0.057937 μm

Ldebye_Na + Ldebye_Naa = 0.637302 μm

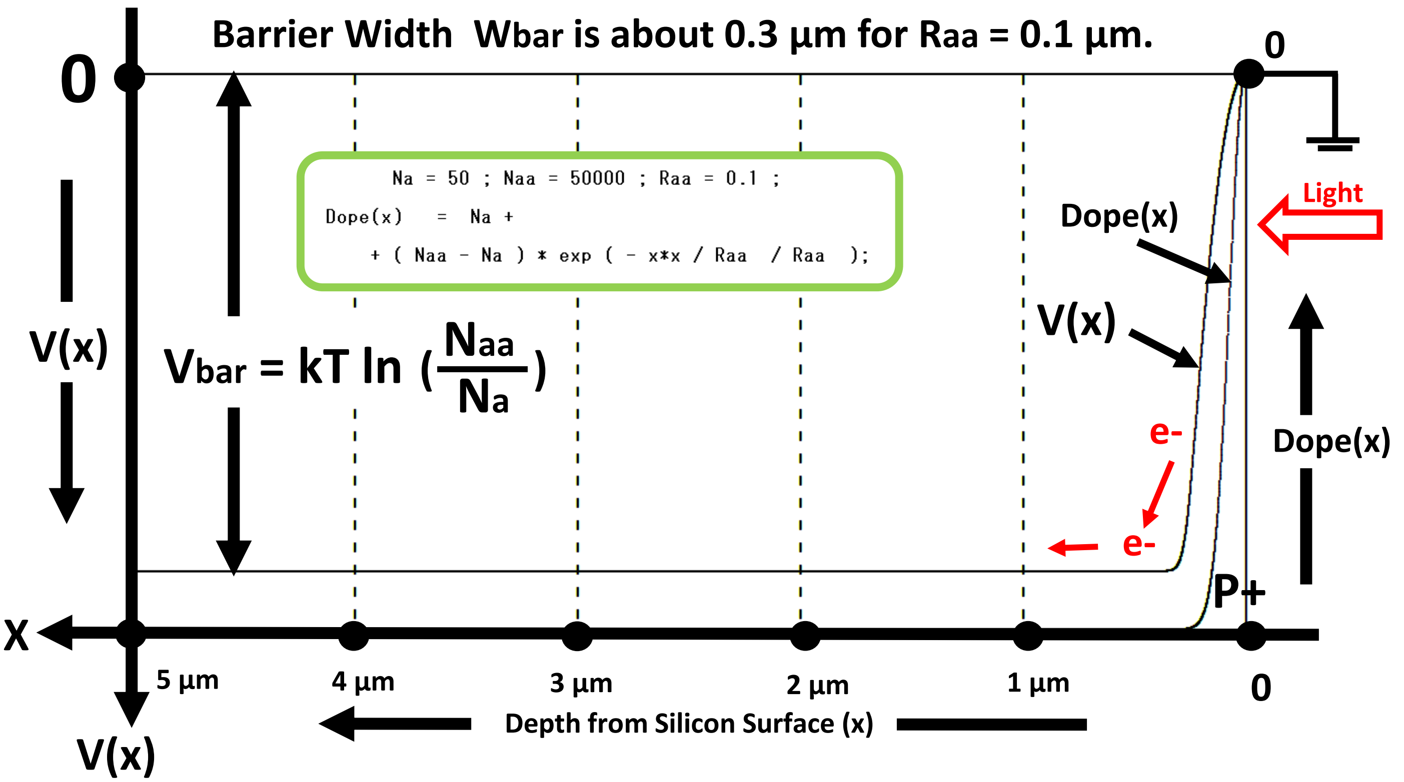
Wbar = 3 (Ldebye_Na + Ldebye_Naa) = 1.911905 μm

****

Barrier_Width_Wbar_of_Double_Gaussian_Doping_Profile for P+PN junction type Pinned Photodiode Solar Cell

See JPA 1975-127647 and JPA 2020-131313 by Hagiwara(AIPS)

(A) Single_Gaussian_Doping_Profile_Dope(x)



(B) Double_Gaussian_Doping_Profile_Dope(x)

The approximation of V(x) = kT ln(Naa/Dope(x)) was found to be very near the true value within 0.000052 volt accuracy.