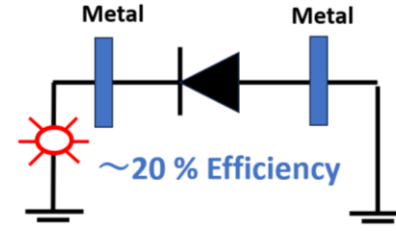
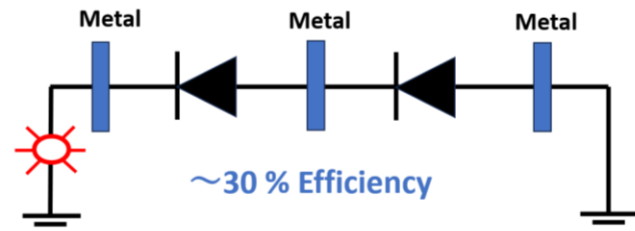


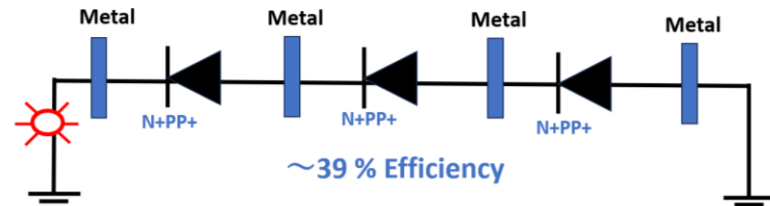
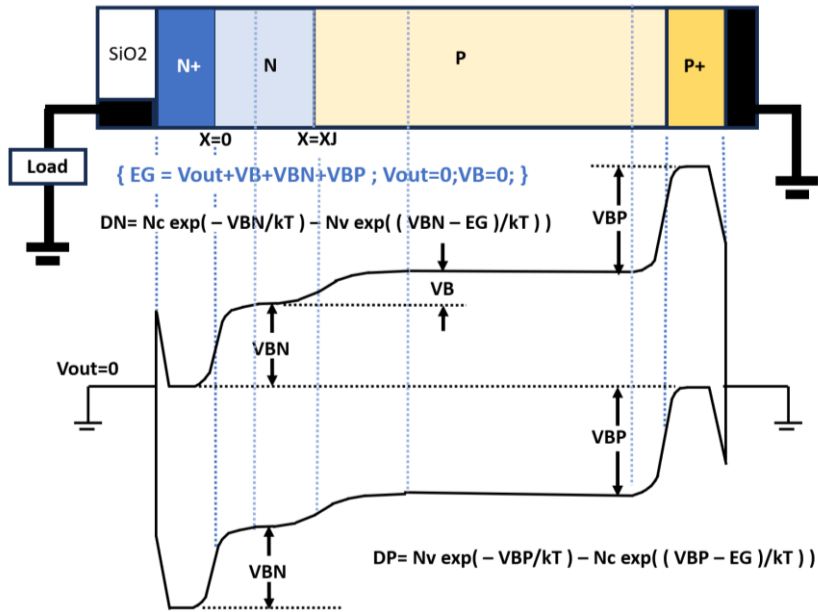
### (1) Single MN+PP+M Junction type



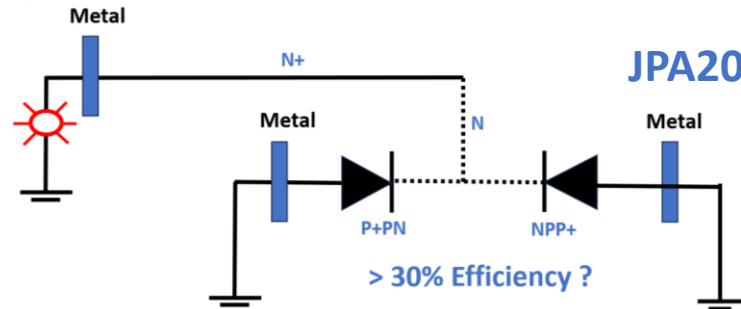
### (2) TANDEM型 Double MN+PP+MN+PP+M Junction Type



### (3) TANDEM型 Triple MN+PP+MN+PP+MN+PP+M Junction Type



### (4) Bipolar Transistor 型 Double MP+PNPP+M Junction Type



JPA2020-131313



Load

$$\{ EG = V_{out} + V_B + V_{BN} + V_{BP} ; V_{out} = 0 ; V_B = 0 ; \}$$

$$DN = N_c \exp(-V_{BN}/kT) - N_v \exp((V_{BN} - EG)/kT)$$

No Electric Field  
for Photo Electron and Hole Pair Separations

Intrinsic Silicon 内には電界がゼロとなり光電変換に寄与しない??

$$V_{BN} = (1/2)(EG + (kT) \ln(N_c / N_v))$$

V<sub>out</sub>=0

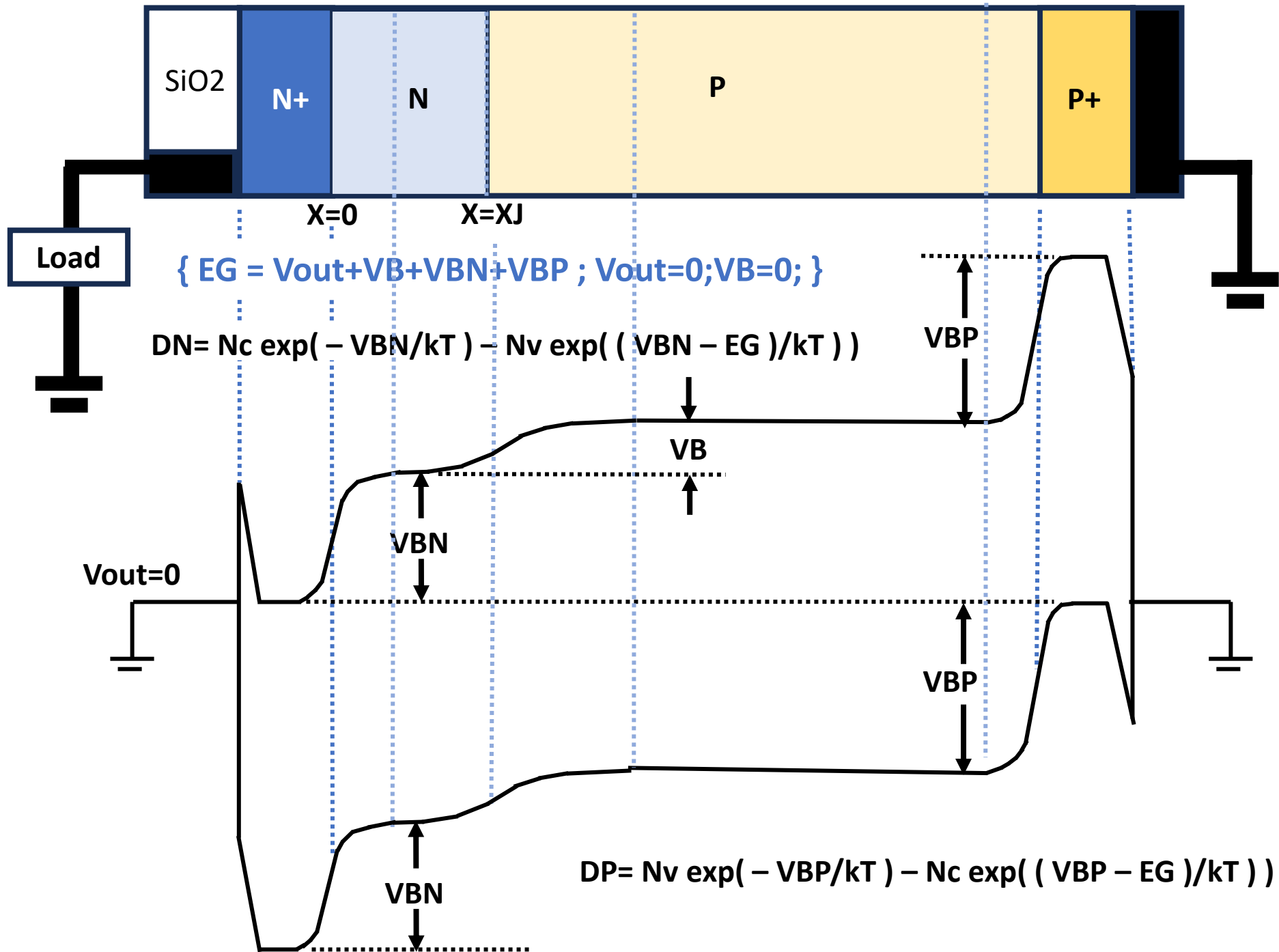
不純物原子濃度がゼロの  
純粋なシリコン結晶は  
高価であり存在しない。

No Electric Field  
for Photo Electron and Hole Pair Separations

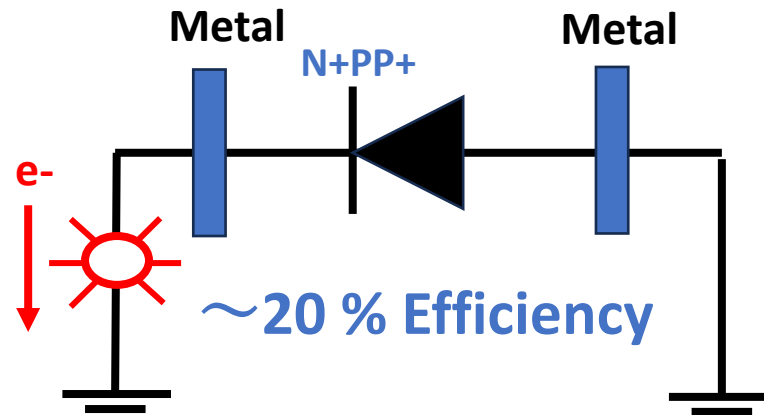
$$V_{BP} = (1/2)(EG - (kT) \ln(N_c / N_v))$$

$$DP = N_v \exp(-V_{BP}/kT) - N_c \exp((V_{BP} - EG)/kT)$$

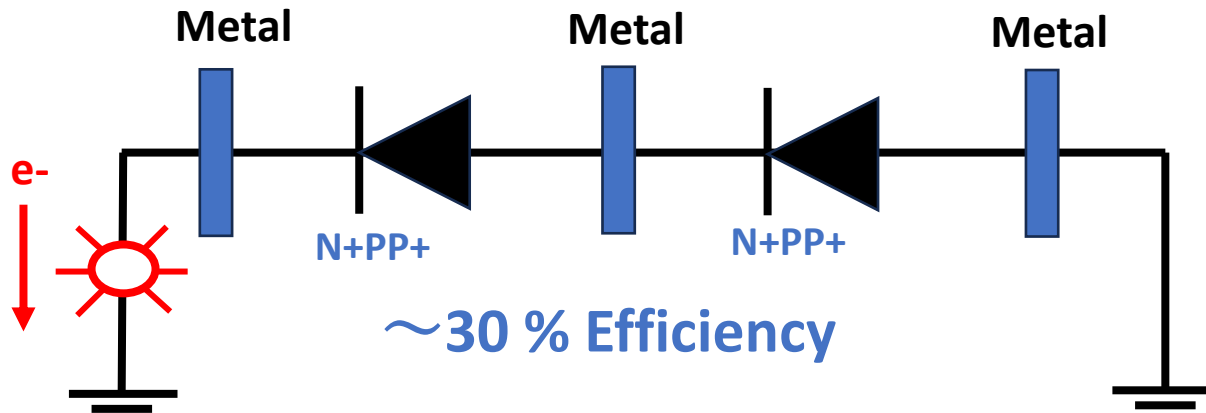
西澤教授が発明した  
P-I-N型の太陽電池  
は動作しない??



# (1) Single MN+PP+M Junction type

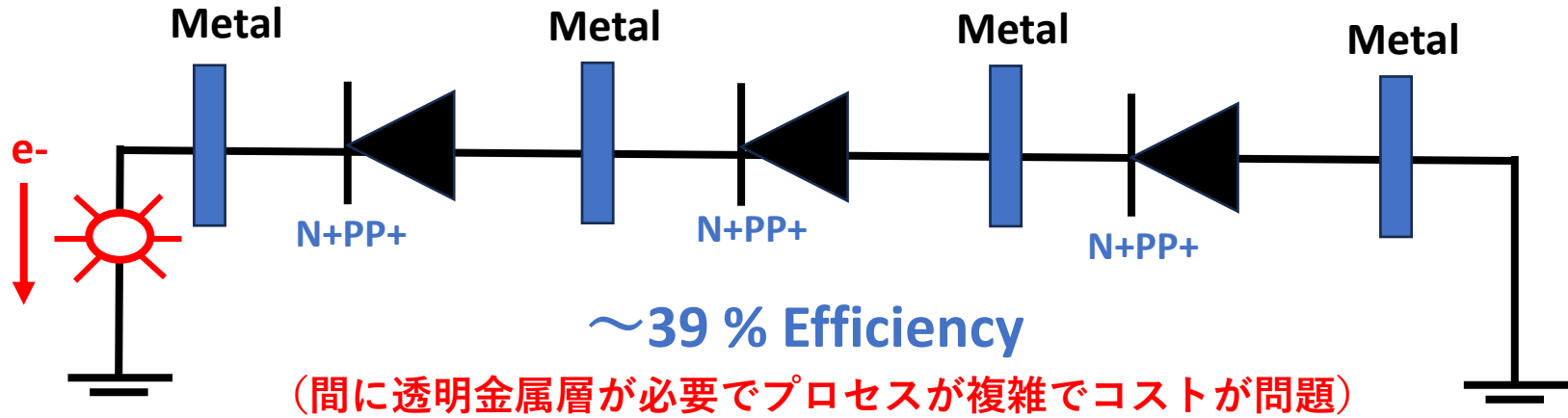


# (2) TANDEM型 Double MN+PP+MN+PP+M Junction Type

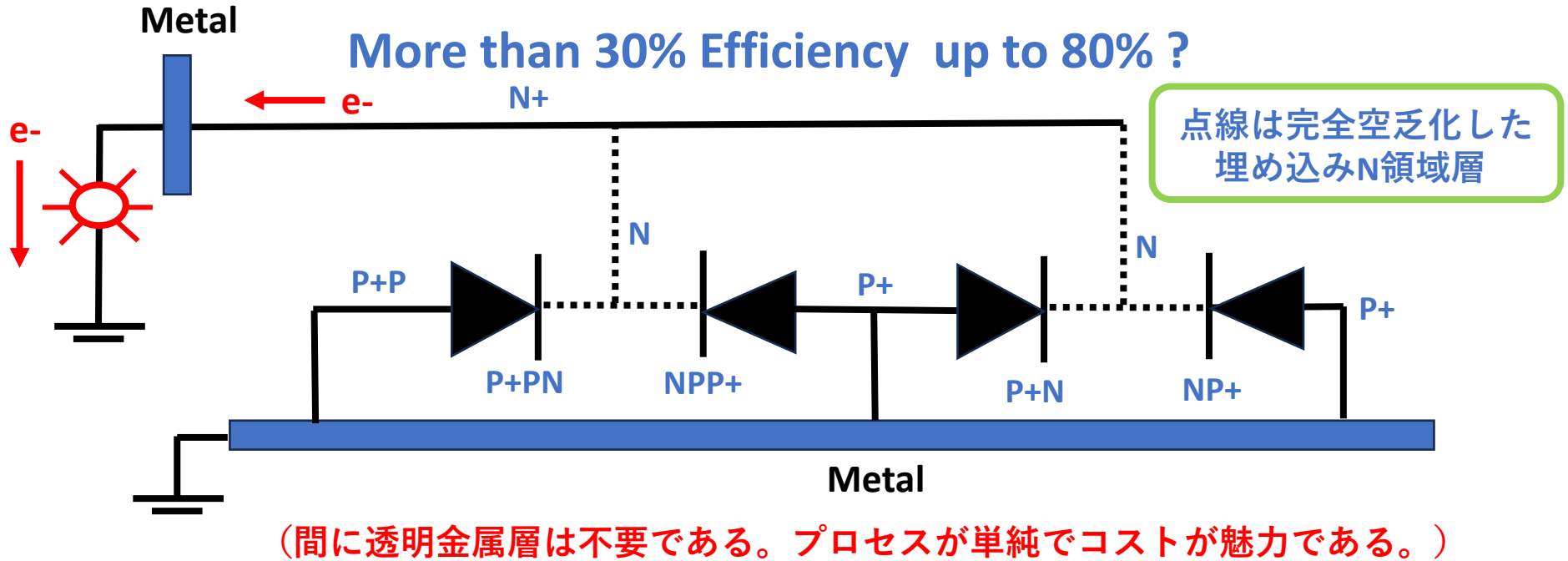


(間に透明金属層が必要でプロセスが複雑でコストが問題)

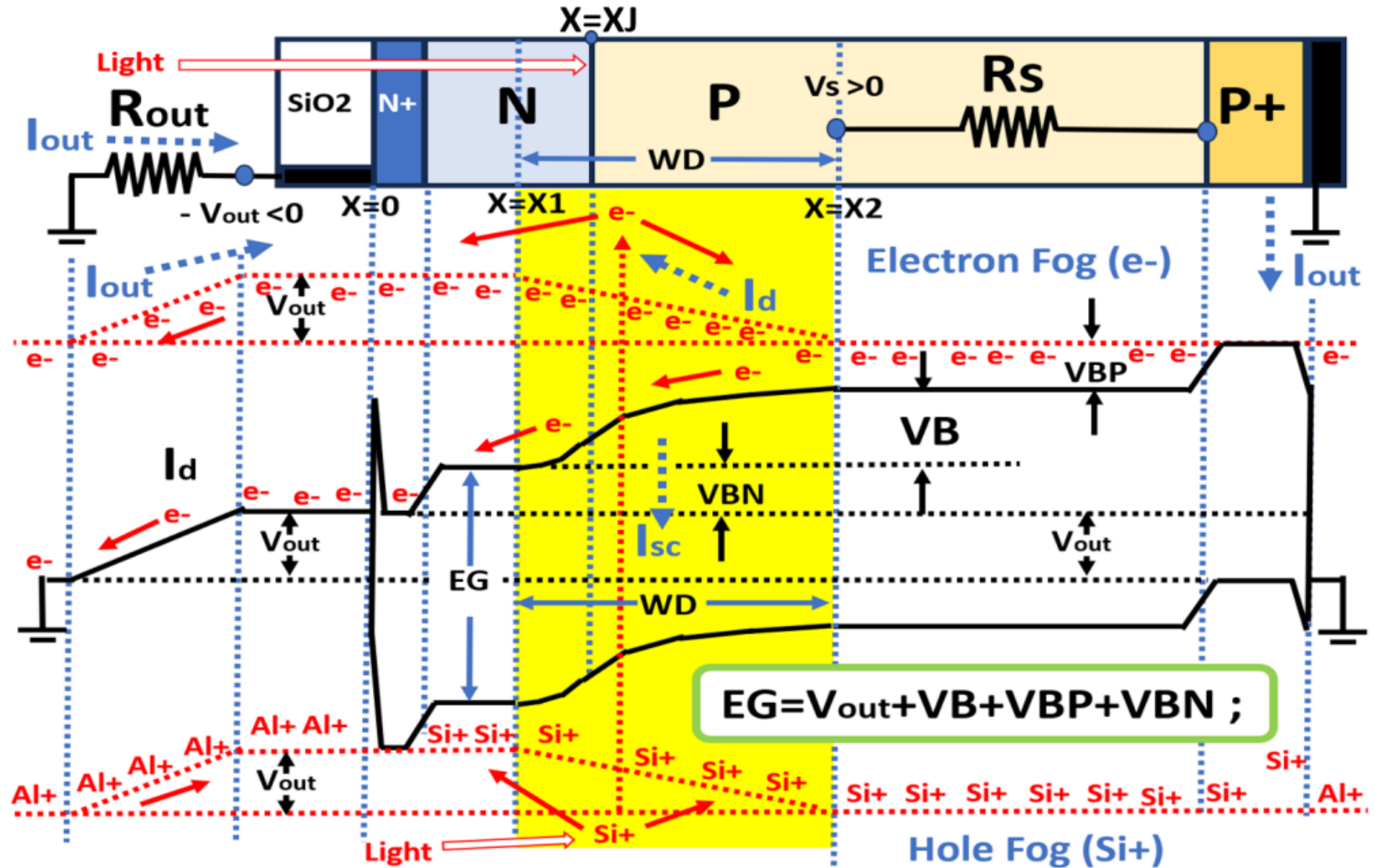
### (3) TANDEM型 Triple MN+PP+MN+PP+MN+PP+M Junction Type



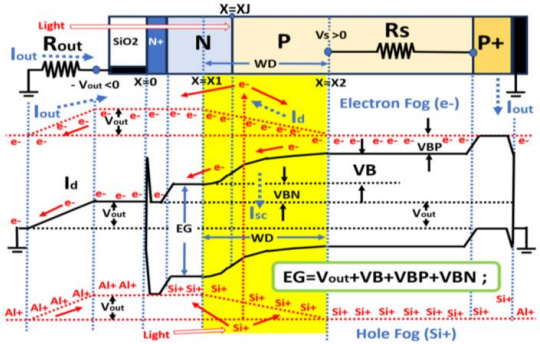
### (4) Bipolar Transistor 型 Double MP+PNPP+M Junction Type



# Band Diagram of Photo Electron Fog ( $e^-$ ) and Hole Fog ( $Si^+$ ) with Band Bending Effects of $\{ V_{BP}=(kT) \ln(P^+/P) ; V_{BN}=(kT) \ln(N^+/N) ; \}$



Band Diagram of Photo Electron Fog (e-) and Hole Fog (Si+) with Band Bending Effects of {  $VBP=(kT) \ln(P+/P)$  ;  $VBN=(kT) \ln(N+/N)$  ; }



/\*\*\*\*\*\*  
C2025\_06\_26  
\*\*\*\*\*

\*\*\*\*\*  
重要な関係式  
\*\*\*\*\*

EG=1.11 eV;  
kT=0.0259 eV;  
Esi=648 e/(V · μm);  
NC=10400000 e/(μm)\*\*3;  
NV=28000000e/(μm)\*\*3;

\*\*\*\*\*

```
{ DP = Nv exp( - VBP/kT ) - Nc exp( (VBP-EG)/kT) ; }
{ DN = Nc exp( - VBN/kT ) - Nv exp( (VBN-EG)/kT) ; }
{ EG = Vout + VBP + VBN + VB ; }
{ DPN = (DP*DN)/( DP + DN ) ; }
{ WD = sqrt( 2*Esi*VB/DPN ) ; }
```

\*\*\*\*\*

```
( 1 ) if { DP=0 ; }, { VBPP=(EG+kT*ln(NV/NC))/2=0.567826 ; }
( 2 ) if { DN=0 ; }, { VBNN=(EG+kT*ln(NC/NV))/2=0.542174 ; }
```

\*\*\*\*\*

\*\*\*\*\* C-Code \*\*\*\*\*

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

```
double EG=1.11, kT=0.0259, Esi=648, NC=10400000, NV=28000000;
```

```
double Vout, VBPP=0.567826, VBNN=0.542174, E, D, DDD, DPN;
```

```
double DNP, VB, VBWD, VBWD_max;
```

```
double WD, VBN, VBP, DP, DN, WD_max, VBN_max, VBP_max,
```

```
DP_max, DN_max, VB_max, VBP_max, VBN_max;
```

```
int i, j, i_max, j_max;
```

```
char c;
```

```
FILE *fpBB;
```

```
void main(void) {
```

```
fpBB=fopen( "BB.txt", "w" );
```

```
Vout=0.3;
```

```
VBN=0;
```

```
DN=NC*exp(-VBN/kT)-NV*exp((VBN-EG)/kT);
```

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

```
i=1;
```

```
NEXT_i;
```

```
VBP=i*VBPP/100;
```

```
DP=NV*exp(-VBP/kT)-NC*exp((VBP-EG)/kT);
```

```
DPN=DP*DN/(DP+DN);
```

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

```
VB=EG-VBP-VBN-Vout;
```

```
WD=sqrt(2*Esi*VB/DPN);
```

```
E=VB/WD;
```

```
D=kT/E;
```

```
printf( " %n VBP=%f DP=%f VB=EG-VBP-VBN-Vout=%f WD=%f E=VB/WD=%f D=kT/E=%f D*D*DP=%f", VBP, DP, VB, WD, E, D, DDD );
```

```
fprintf(fpBB, " %n VBP=%f DP=%f VB=EG-VBP-VBN-Vout=%f WD=%f E=VB/WD=%f D=kT/E=%f D*D*DP=%f", VBP, DP, VB, WD, E, D, DDD );
```

```
i=i+5;
```

```
if(i<100) goto NEXT_i;
```

```
printf( " %n");
```

```
fprintf(fpBB, " %n");
```

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

```
c=getchar();
```

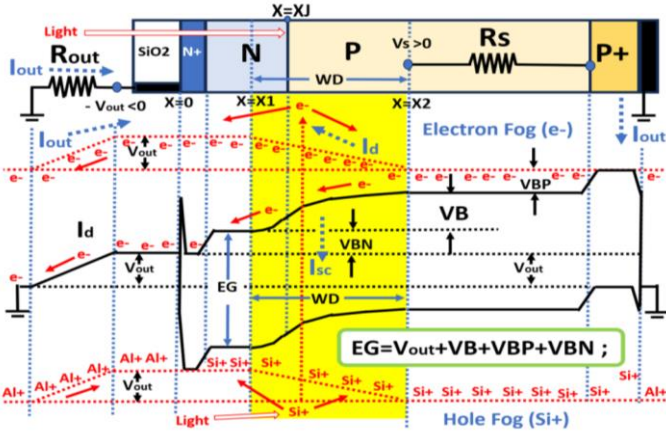
```
if(c=='!') printf(" %n %n Good-bye !!");
```

```
fclose(fpBB); }
```

```
/****** End of C-code *****
```

Band Diagram of Photo Electron Fog (e-) and Hole Fog (Si+) with

Band Bending Effects of { VBP=(kT) ln(P+/P) ; VBN=(kT) ln(N+/N) ; }



Vout = 0.3 volt , VBN= 0 volt の場合  
すなわちN+PP+ 接合での計算値で  
VB = 0.492 volt , WD= 2.21 μm となる。

```
***** 重要関係式 *****
EG=1.11 eV;
kT=0.0259 eV;
Esi=648 e/(V-μm);
NC=10400000 e/(μm)**3;
NV=28000000e/(μm)**3;
[ DP = Nv exp(-VBP/kT) - Nc exp(-(VBP-EG)/kT); ]
[ DN = Nc exp(-VBN/kT) - Nv exp(-(VBN-EG)/kT); ]
[ EG = Vout + VBP + VBN + VB ; ]
[ DPN = (DP+DN)/(DP + DN) ; ]
[ WD = sqrt(2*Esi*VB/DPN) ; ]
(1) if [ DP=0 ; ], [ VBP=(EG+kT*ln(NV/NC))/2=0.567826 ; ]
(2) if [ DN=0 ; ], [ VBN=(EG+kT*ln(NC/NV))/2=0.542174 ; ]
```

```
***** C-Code *****
#include <stdio.h>
#include <math.h>
double EG=1.11,kT=0.0259,Esi=648,NC=10400000,NV=28000000;
double Vout,VBP=0,VB=0,VBN=0,WD=0,D=0,DPN;
double DNP,VB,VBN,WD,max;
double WD,VBN,VB,DP,DN,WD_max,VBN_max,VBP_max;
DP_max,DN_max,VB_max,VBP_max,VBN_max;
int i,j,i_max,j_max;
char c;
FILE *fpBB;
void main(void){
fpBB=fopen("BB.txt","w");
Vout=0.3;
VBN=0;
DN=Nc*exp(-VBN/kT)-Nv*exp(-(VBN-EG)/kT);
```

```
*****
i=1;
NEXT_i:
VBP=i*VBPP/100;
DP=Nv*exp(-VBP/kT)-Nc*exp(-(VBP-EG)/kT);
DPN=DP/DN/(DP+DN);
/*****
VB=EG-VBP-VBN-Vout;
WD=sqrt(2*Esi*VB/DPN);
E=VB/WD;
D=kT/E;
```

```
printf(" %n VBP=%f DP=%f VB=EG-VBP-VBN-Vout=%f WD=%f E=VB/WD=%f D=kT/E=%f D*D*DP=%f",VBP,DP,VB,WD,E,D,DDD);
fprintf(fpBB," %n VBP=%f DP=%f VB=EG-VBP-VBN-Vout=%f WD=%f E=VB/WD=%f D=kT/E=%f D*D*DP=%f",VBP,DP,VB,WD,E,D,DDD);
i=i+5;
if(i<100) goto NEXT_i;
printf(" %n");
fprintf(fpBB," %n");
/*****
c=getchar();
if(c=='!') printf(" %n %n Good-bye !!");
fclose(fpBB); ]
/***** End of C-code *****
```

**E = VB/WD = (空乏層内の電界の平均値)**  
**基板濃度DP = 130 μm<sup>3</sup>の時**  
**D=kT/E = 0.1164 μm となる。**  
**Dの2乗がDPに反比例??**

VBP=0.005678	DP=22487659.056015	VB=EG-VBP-VBN-Vout=0.804322	WD=0.012107	E=VB/WD=66.433130	D=kT/E=0.000390	D*D*DP=3.418018
VBP=0.034070	DP=7514071.653819	VB=EG-VBP-VBN-Vout=0.775930	WD=0.015183	E=VB/WD=51.105316	D=kT/E=0.000507	D*D*DP=1.929935
VBP=0.062461	DP=2510767.024619	VB=EG-VBP-VBN-Vout=0.747539	WD=0.021886	E=VB/WD=34.155317	D=kT/E=0.000758	D*D*DP=1.443741
VBP=0.090852	DP=838952.746573	VB=EG-VBP-VBN-Vout=0.719148	WD=0.034649	E=VB/WD=20.755303	D=kT/E=0.001248	D*D*DP=1.306408
VBP=0.119243	DP=280329.359148	VB=EG-VBP-VBN-Vout=0.690757	WD=0.057267	E=VB/WD=12.061981	D=kT/E=0.002147	D*D*DP=1.292501
VBP=0.147635	DP=93669.816234	VB=EG-VBP-VBN-Vout=0.662365	WD=0.096161	E=VB/WD=6.888094	D=kT/E=0.003760	D*D*DP=1.324345
VBP=0.176026	DP=31299.020909	VB=EG-VBP-VBN-Vout=0.633974	WD=0.162265	E=VB/WD=3.907024	D=kT/E=0.006629	D*D*DP=1.375429
VBP=0.204417	DP=10458.317836	VB=EG-VBP-VBN-Vout=0.605583	WD=0.274079	E=VB/WD=2.209515	D=kT/E=0.011722	D*D*DP=1.437036
VBP=0.232809	DP=3494.563369	VB=EG-VBP-VBN-Vout=0.577191	WD=0.462742	E=VB/WD=1.247329	D=kT/E=0.020764	D*D*DP=1.506713
VBP=0.261200	DP=1167.680437	VB=EG-VBP-VBN-Vout=0.548800	WD=0.780498	E=VB/WD=0.703141	D=kT/E=0.036835	D*D*DP=1.584306
VBP=0.289591	DP=390.171091	VB=EG-VBP-VBN-Vout=0.520409	WD=1.314787	E=VB/WD=0.395812	D=kT/E=0.065435	D*D*DP=1.670614
VBP=0.317983	DP=130.372553	VB=EG-VBP-VBN-Vout=0.492017	WD=2.211579	E=VB/WD=0.222473	D=kT/E=0.116418	D*D*DP=1.766971
VBP=0.346374	DP=43.562946	VB=EG-VBP-VBN-Vout=0.463626	WD=3.713888	E=VB/WD=0.124836	D=kT/E=0.207473	D*D*DP=1.875160
VBP=0.374765	DP=14.556206	VB=EG-VBP-VBN-Vout=0.435235	WD=6.225017	E=VB/WD=0.069917	D=kT/E=0.370439	D*D*DP=1.997476
VBP=0.403156	DP=4.863827	VB=EG-VBP-VBN-Vout=0.406844	WD=10.411834	E=VB/WD=0.039075	D=kT/E=0.662826	D*D*DP=2.136866
VBP=0.431548	DP=1.625170	VB=EG-VBP-VBN-Vout=0.378452	WD=17.372354	E=VB/WD=0.021785	D=kT/E=1.188906	D*D*DP=2.297172
VBP=0.459939	DP=0.542921	VB=EG-VBP-VBN-Vout=0.350061	WD=28.907189	E=VB/WD=0.012110	D=kT/E=2.138760	D*D*DP=2.483481
VBP=0.488330	DP=0.181065	VB=EG-VBP-VBN-Vout=0.321670	WD=47.983319	E=VB/WD=0.006704	D=kT/E=3.863492	D*D*DP=2.702679
VBP=0.516722	DP=0.059460	VB=EG-VBP-VBN-Vout=0.293278	WD=79.951846	E=VB/WD=0.003668	D=kT/E=7.060708	D*D*DP=2.964316
VBP=0.545113	DP=0.016753	VB=EG-VBP-VBN-Vout=0.264887	WD=143.149341	E=VB/WD=0.001850	D=kT/E=13.996789	D*D*DP=3.282040