微电子器件物理　第三周作业

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作业内容：pn 结作业（见 hw03-pnjunction.pdf）

Problem 1

SubProblem a

$$V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2} = 0.59524V$$

SubProblem b

$$x_p = x_n = \left[\frac{2K_s\epsilon_0}{q} \frac{N_A}{N_D(N_A + N_D)} \right]^{1/2} = 0.000062291cm$$

$$W = x_n + x_p = 0.00012458cm$$

SubProblem c

$$V(x = 0) = \frac{qN_A}{2K_S\epsilon_0} x_p^2 = 0.29762V$$

$$E(x = 0) = -\frac{qN_A}{K_S\epsilon_0} x_p = -9555.8V/cm$$

SubProblem d

如 **图 1**

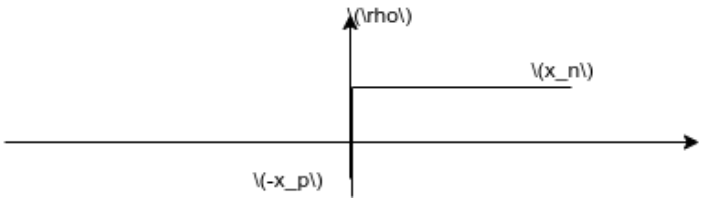

图 1: 草图

Problem 2

SubProblem a

$$V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$$

$$W \approx \left[\frac{2K_S \epsilon_0}{q} \frac{1}{N_D} V_{bi} \right]$$

$$E(0) = -\frac{qN_A}{K_S \epsilon_0} \left[\frac{2K_S \epsilon_0}{q} \frac{N_D}{N_A^2} \right]^{1/2}$$

$$V(x) = \begin{cases} \frac{qN_A}{2K_S \epsilon_0} (x + [\frac{2K_S \epsilon_0}{q} \frac{N_D}{N_A^2} V_{bi}]^{1/2})^2 \\ V_{bi} - \frac{qN_D}{2K_S \epsilon_0} (-x + [\frac{2K_S \epsilon_0}{q} \frac{1}{N_D} V_{bi}]^{1/2})^2 \end{cases}$$

$$\rho(x) = -qN_A, \text{ if } -x_p \leq x \leq 0; 0 \text{ else}$$

SubProblem b

$$V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2} = 0.83334V$$

SubProblem c

$$x_n = \left[\frac{2K_s \epsilon_0}{q} \frac{N_A}{N_D(N_A + N_D)} \right]^{1/2} = 0.00010423cm$$

$$x_p = \frac{N_D}{N_A} x_n = 0.000000010423cm$$

$$W = x_n + x_p = 0.00010424cm$$

SubProblem d

$$V(x = 0) = \frac{qN_A}{2K_S \epsilon_0} x_p^2 = 0.000083325V$$

$$E(x = 0) = -\frac{qN_A}{K_S \epsilon_0} x_p = -15989.04177V/cm$$

SubProblem e

如 **图 2**

Problem 3

SubProblem a

图 2: 草图

$$\rho = \begin{cases} qN_D, -x_n \leq x \leq 0 \\ 0{,}0 \leq x \leq x_i \\ -qN_A, x_i \leq x \leq x_i + x_p \end{cases}$$

如 **图 3**，由于掺杂浓度差距过大，图中大小仅作示意，不为真实大小。

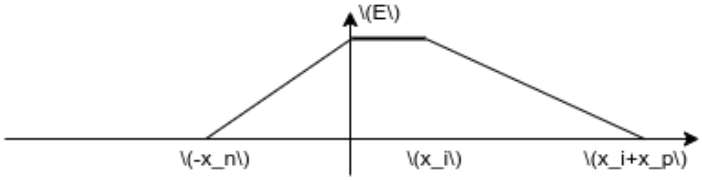

图 3: 电场

电场大小表示为

$$E = \begin{cases} \dfrac{qN_D}{K_S\epsilon_0}(x + x_n), -x_n \leq x \leq 0 \\ \text{const}, 0 \leq x \leq x_i \\ -\dfrac{qN_A}{K_S\epsilon_0}(x - x_i - x_p), x_i \leq x \leq x_i + x_p \end{cases}$$

连续性得到：$x_n N_D = x_p N_P$

设在 P 侧中性区电势为 0，那么 N 侧的中性区电势为 V_{bi}。由于 $x_p > x_i$ 近似忽略后者。

$$V_{bi} = \frac{1}{2}(x_i + x_i + x_n + x_p) \cdot \frac{qN_A x_p}{K_S\epsilon_0} \approx (\frac{N_A + N_D}{2N_D})\frac{qN_A}{K_S\epsilon_0}x_p^2 \approx \frac{N_A q}{2K_S\epsilon_0}x_p^2$$

解得 $x_p = \sqrt{\frac{2K_S\epsilon_0 V_{bi}}{N_A q}}$

SubProblem c

由电场表示**图 3**可知本征层的存在扩展了电场最大值的空间，增大了 V_{bi}

SubProblem d

最大电场大小没有变化，但是分布变广了。

Problem 4

$$I_0 = qA(\frac{D_N}{L_N}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D})$$

$$L = \sqrt{\tau D}, \frac{D}{\mu} = \frac{kT}{q}$$

$$I = I_0(\exp(aV_A/kT) - 1)$$

带入 MATLAB

```
T=300;          % Temperature in Kelvin
k=8.617e-5;     % Boltzmann constant (eV/K)
e0=8.85e-14;    % permittivity of free space (F/cm)
q=1.602e-19;    % charge on an electron (coul)
KS=11.8;        % Dielectric constant of Si at 300K
ni=1.0e10;      % intrinsic carrier conc. in Silicon at 300K (
   cm^-3)
EG=1.12;        % Silicon band gap (eV)

NA = 1e16;
ND = 1e19;

NDref = 1.3e17;
NAref = 2.35e17;
unmin = 92;
upmin = 54.3;
un0 = 1268;
up0 = 406.9;
an = 0.91;
ap = 0.88;

```

```
un = unmin + un0 / (1 + (ND/NDref)^an);
up = upmin + up0 / (1 + (NA/NAref)^ap);

Dn = k * T * un;
Dp = k * T * up;

tp = 1e-6;
tn = tp;

Ln = sqrt(tn * Dn);
Lp = sqrt(tp * Dp);

J0 = q * (Dn*ni^2/Ln/NA + Dp*ni^2/Lp/ND);


Vbi=k*T*log((NA*ND)/ni^2);
xN=sqrt(2*KS*e0/q*NA*Vbi/(ND*(NA+ND)));    % Depletion width
   n-side
xP=sqrt(2*KS*e0/q*ND*Vbi/(NA*(NA+ND)));    % Depletion width
   p-side

W = xN + xP;

J = J0 * e^(VA / k / T) - J0
```

在 0.5，0.6，-0.5，-0.6 分别得到 0.00069784，0.033400，-2.7784e-12，-2.7784e-12

Problem 5

SubProblem a 正偏，存在少子的积累问题。

SubProblem b $N_A = 1e16cm^{-3}$

SubProblem c $N_D = 1e14cm^{-3}$

SubProblem d $n_i^2 = 1e23cm^{-6}, n_i = 3.1623e11cm^{-3}$

SubProblem e $np = n_i^2 \exp(qV_A/kT)$ 即 $1e26 = 1e20 \exp(V_A/0.026)$，$V_A = 0.6V$

Problem 6

SubProblem a 正偏，空穴的能量相对变高了。

SubProblem b 即费米能级的偏移，$0.5V$

SubProblem c 带隙为导带价带的差距，$1.25eV$

SubProblem d 内建电势为 $0.25eV$