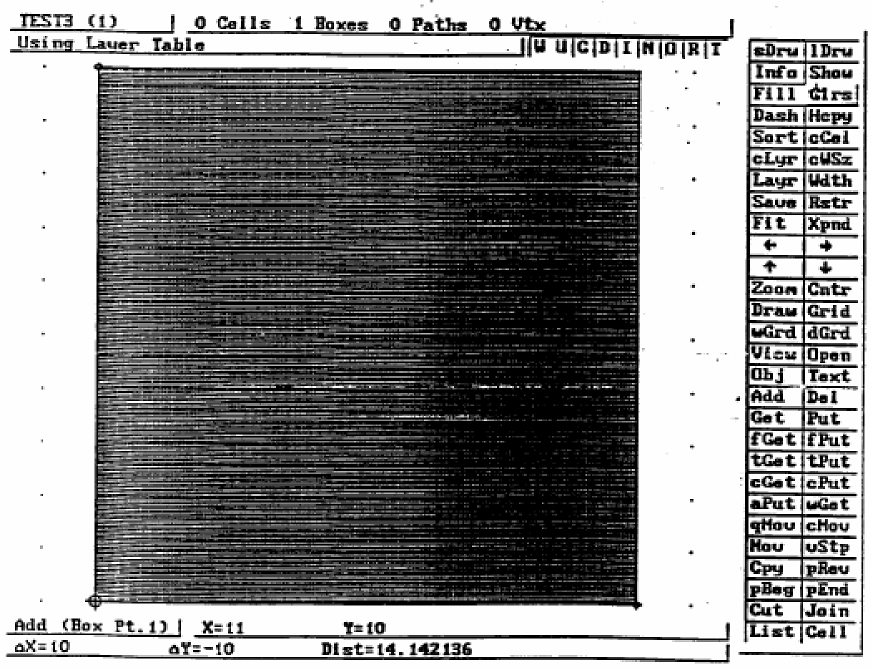
ENEE 408D HW1_Solution Spring, 2003

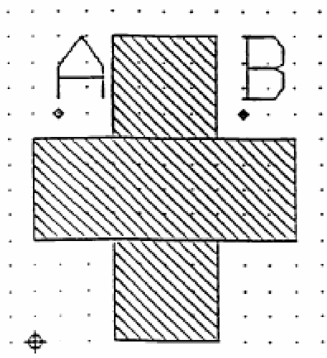
Problem 1.1



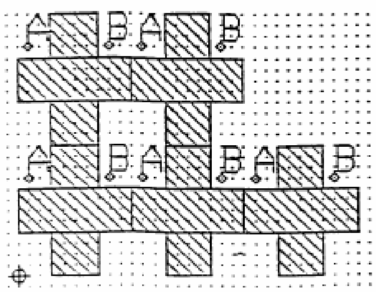
- *It's useful to use the "Print Screen" button on the keyboard to copy the screen to the clipboard.*

Dist = 14.142136 μm.

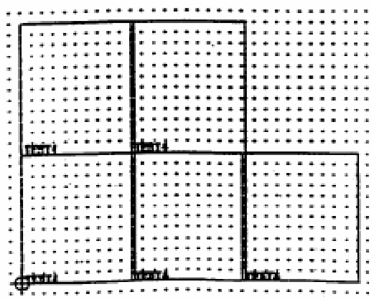
1.6 The results are as follows:



(a)



(b)



(c)

Problem 1.7: The result is the same as Problem 1.6 (a)

4. Qualitative Description

(a) Equilibrium:

Mobile electrons diffuse from n-side to p-side, due to concentration difference, leaving behind n-side field positive charge. As a result, the electric field is established between fixed ions and electrons. The electric field will try to pull the electrons back to the n-side, this movement will cause a drift current. While the electrons flow due to the diffusion from n to p is balanced by the electrons flow due to drift from p to n, the equilibrium is established.

Holes will experience the analogues events.

In the equilibrium, there is a depletion region (DR) in the middle of the n-p junction, which has the built-in voltage drop, named ϕ_0 .

(b) Forward Bias:

Forward bias voltage is applied from p to n, so the total voltage across the n-p junction is reduced, which will cause the drift current goes down. However, the electron concentration hasn't changed. So now the total current, which is defined as the drift current plus the diffusion current, is no longer zero(They are not in balance now.)

As a result, in FB (Forward Bias) we have a net current flow that is mainly diffusion current.

(c) Reverse Bias:

Reverse bias voltage is applied from n to p, so that the total voltage across the n-p junction is increased, which will cause the drift current goes up. However, since we do not have much free carriers, we can't pull the electrons back to the n-side, as what happened in equilibrium.

As a result, in RB (Reverse Bias) the current due to e flowing from p to n is very small net drift current.

5. Derive the expression $\phi(x)$ on the p-side of a NP junction.

ANS: For n-p junction, at p-side, using Poisson's Equation:

$$\frac{d^2\phi}{dx^2} = \frac{qN_A}{\varepsilon}, \text{ for } 0 < x < x_p$$

notice that $E = -\frac{d\phi}{dx}$,so $\frac{dE}{dx} = -\frac{d^2\phi}{dx^2} = -\frac{qN_A}{\varepsilon}$

$$\int_x^{x_p} dE = \int_x^{x_p} -\frac{qN_A}{\varepsilon} dx$$

$$E(x_p) - E(x) = -\frac{qN_A}{\varepsilon}(x_p - x)$$

Boundary condition: $E(x_p) = 0$

So, $-E(x) = -\frac{qN_A}{\varepsilon}(x_p - x) = \frac{d\phi}{dx}$

$$\int_x^{x_p} d\phi = \int_x^{x_p} -\frac{qN_A}{\varepsilon}(x_p - x')dx'$$

$$\phi(x_p) - \phi(x) = -\frac{qN_A}{\varepsilon}(x_p x - \frac{1}{2}x'^2)\,|_x^{x_p} = -\frac{qN_A}{\varepsilon}(\frac{1}{2}x_p^2 - xx_p + \frac{1}{2}x^2)$$

$$= -\frac{qN_A}{\varepsilon}(x_p - x)^2$$

Define $\phi(x_p) = \phi_p$

So, $\phi(x) = \phi(x_p) + \dfrac{qN_A}{\varepsilon}(x_p - x)^2$

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6. Derive the expression $x_{d0} = x_n + x_p = \sqrt{\dfrac{2\varepsilon}{q}\phi_0\left(\dfrac{1}{N_A} + \dfrac{1}{N_D}\right)}$

ANS: results in class: $\phi(x) = \phi_p + qN_A\dfrac{x_p^2}{2\varepsilon}$ for p-side potential

$\phi(x) = \phi_n - qN_D\dfrac{x_n^2}{2\varepsilon}$ for n-side potential

At the interface , $\phi(x) = \phi(x)$

So, $\phi(x) = \phi_p + qN_A\dfrac{x_p^2}{2\varepsilon} = \phi_n - qN_D\dfrac{x_n^2}{2\varepsilon}$ ----------------------(1)

In Equilibrium, the total charge is zero,

So, $x_p N_A = x_n N_D$ ---(2)

From (1)&(2), we have

$$x_n = \sqrt{\frac{2\varepsilon\phi_0}{q}\frac{N_A}{N_D(N_A + N_D)}}$$

$$x_p = \sqrt{\frac{2\varepsilon\phi_0}{q}\frac{N_D}{N_A(N_A + N_D)}}$$

where $\phi_0 = \phi_n - \phi_p$

Thus, in equilibrium, $x_{d0} = x_n + x_p = \sqrt{\dfrac{2\varepsilon}{q}\phi_0\left(\dfrac{1}{N_A} + \dfrac{1}{N_D}\right)}$

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COMMENTS

While building your Mathematical Model for the device (The 5 equations given in the lecture), you need to be careful about the directions of the physical variable. Sign problem is a common mistake in the analysis. In order to avoid this mistake, it is helpful to think about the actual physical process in the device, and always pay attention to the positive direction of the axis.