EE 130, Spring/2000
Midterm I Solutions
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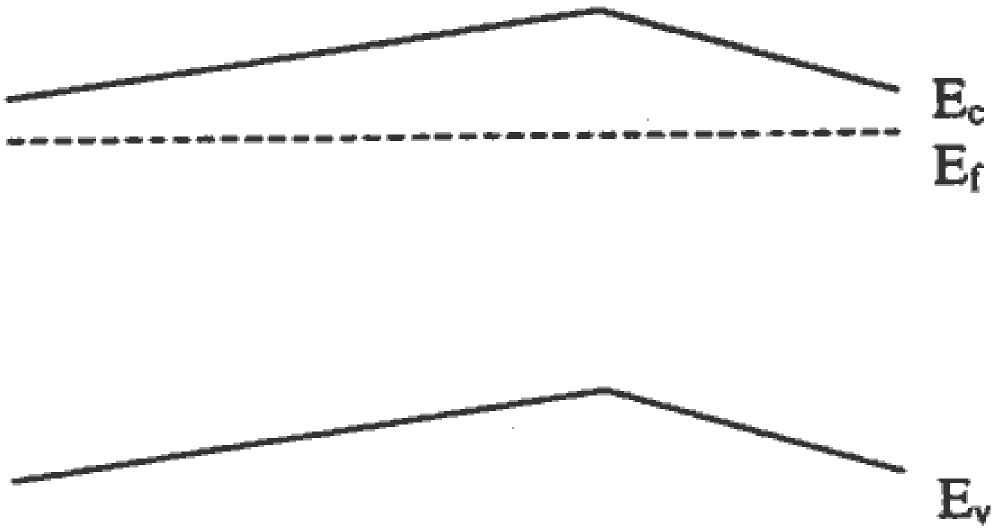
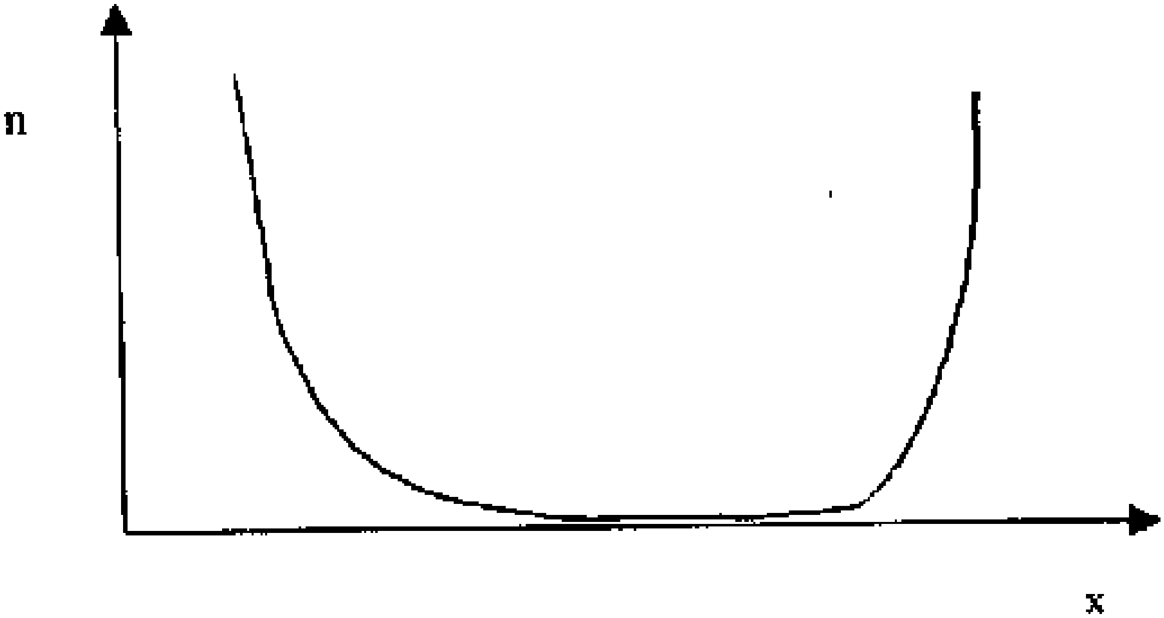
Problem #1

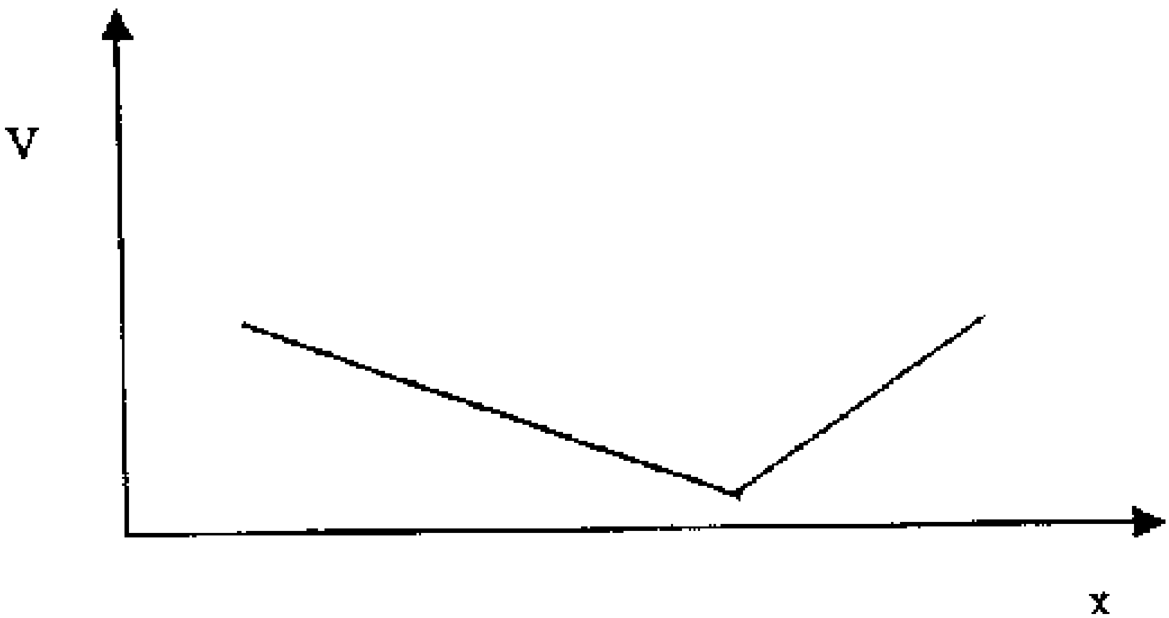
A n-type silicon sample has the energy band diagram shown below.



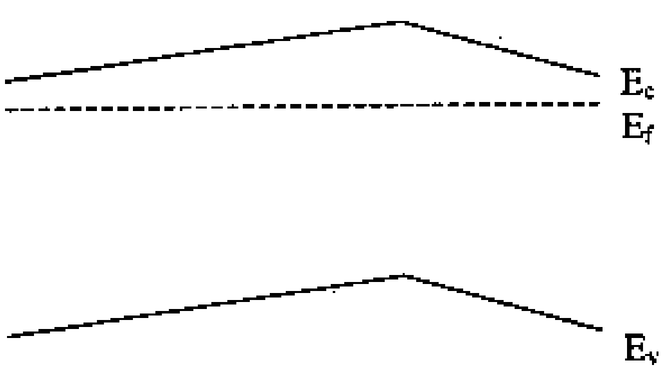
Qualitatively sketch the items on the following linear-linear axes: (5 points each)

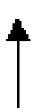


$n \propto \exp \frac{-(E_c - E_f)}{kT}$

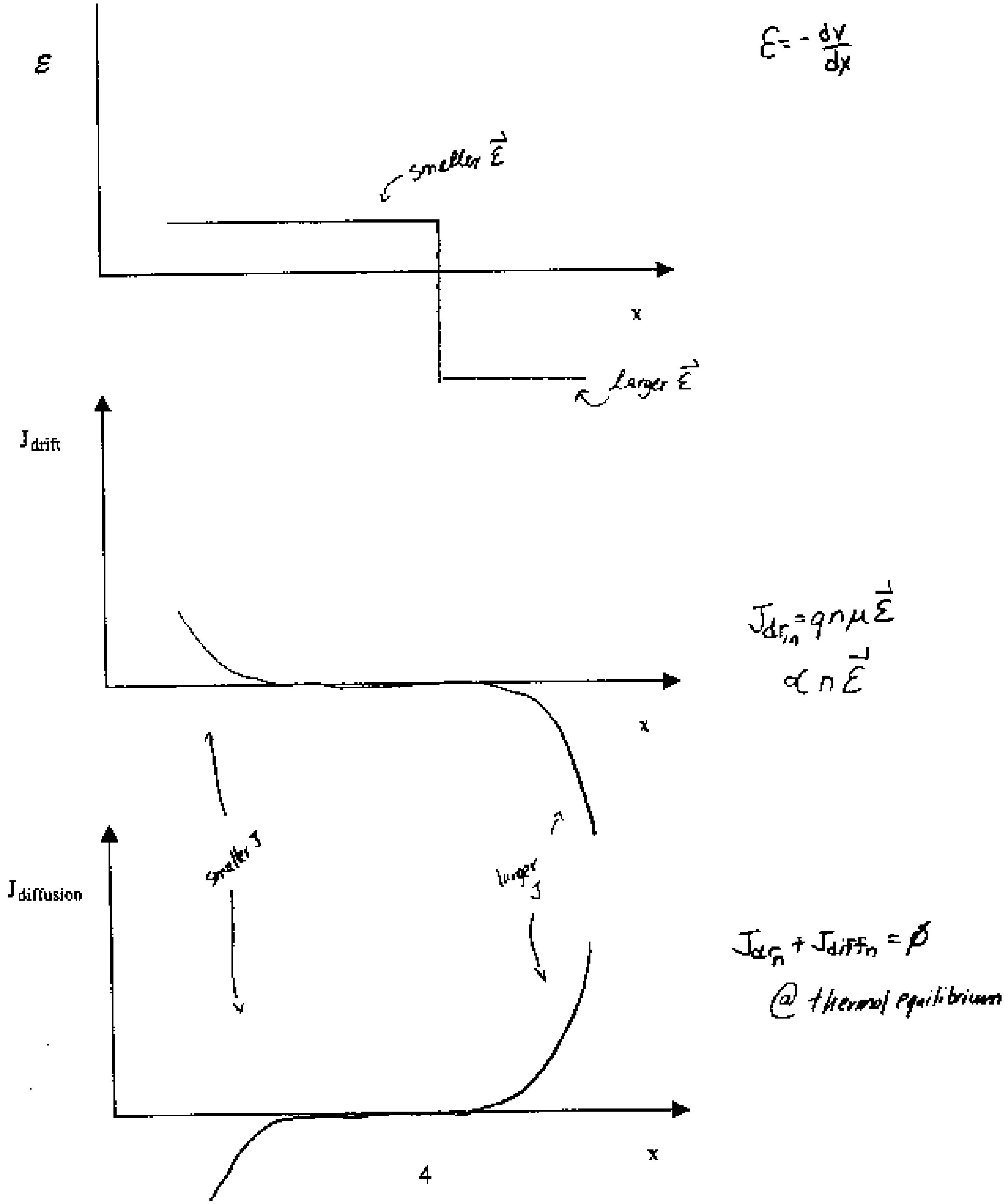


$V = -E/q$





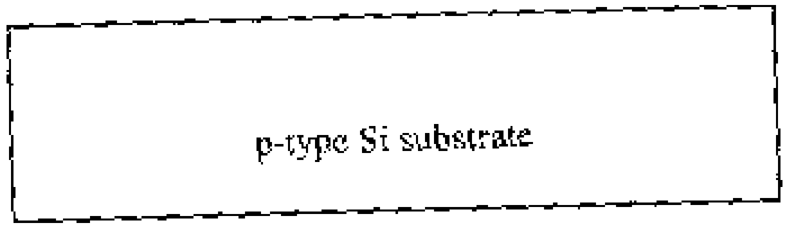
$E = -dV$


ℰ
$\mathcal{E} = -\frac{dV}{dx}$
smaller $\vec{\mathcal{E}}$
x
larger $\vec{\mathcal{E}}$
J drift
$J_{dr,n} = qn\mu\vec{\mathcal{E}}$
$\propto n\vec{\mathcal{E}}$
x
smaller J
larger J
J diffusion
$J_{dr_n} + J_{diff_n} = \emptyset$
@ thermal equilibrium
x
4

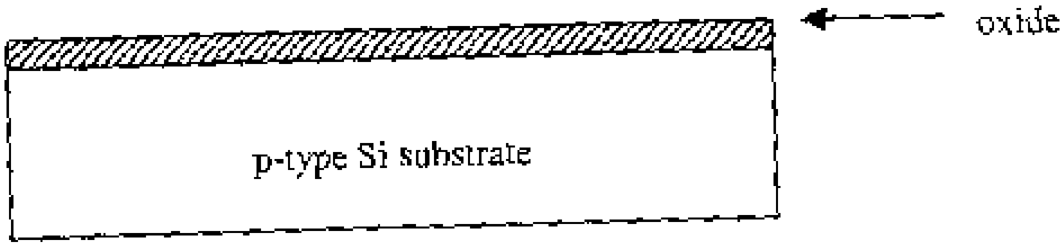
Problem #2

Shallow n+p junctions are often found in state-of-the-art processes. The following is a simplified process. You may assume infinite selectivity and 100% step coverage in this process. Please fill in the missing steps and answer the questions.

-Start with a p-type silicon wafer.

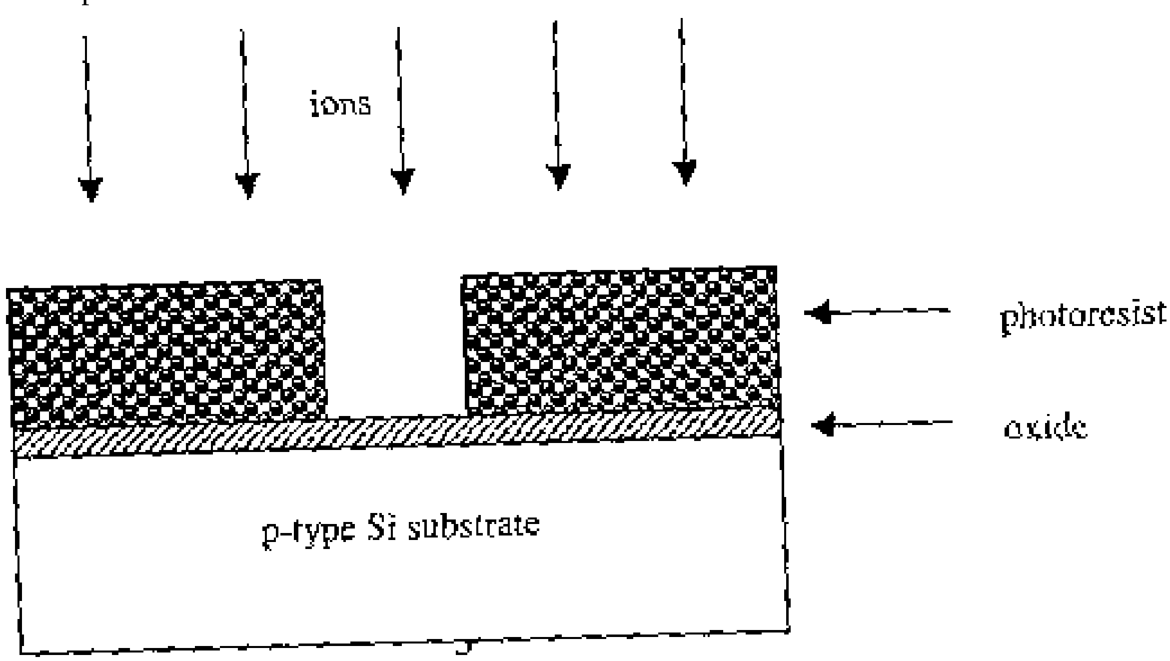


-Grow a 30nm thick oxide layer.



Fill in the next processing step(s): (2pts)
Lithography module = (i) spin on resist, (ii) stepper exposure, (iii) develop pattern

-Ion Implant

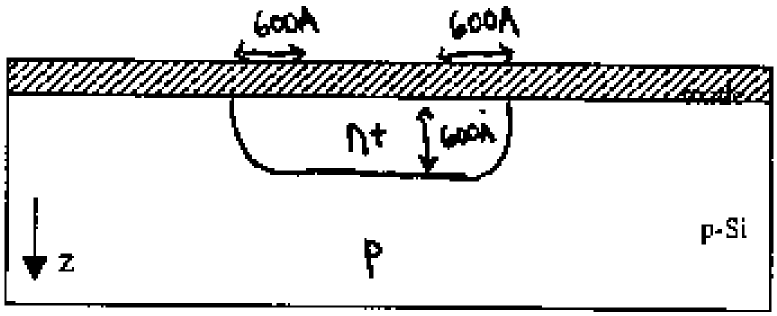


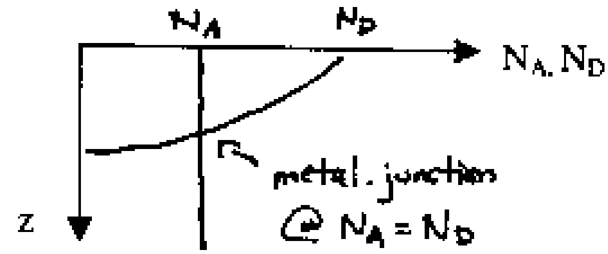
-If the junction depth is to be kept as small as possible, which ion species would you use to make a p-n junction? List three reasons to support your answer (4pts)
Arsenic: (1) donor ion (Group IV), (2) reduced Rp and delta Rp, (3) reduced diffusivity

-Strip photoresist. RTA until the junction depth reaches 0.06um.

Paying attention to the relative dimensions, sketch the p-n junction profile inside the silicon sample shown below. (3pts)

In the accompanying axes, qualitatively draw the Na and Nd profiles along the p-n junction and indicate the position of the metallurgical junction. Assume that the implanted peak is at the Si-SiO2 interface (3pts)





-Deposit 4000A oxide as a passivation layer. ***If you wanted to deposit oxide at the lowest possible temperature, what process technology would you use? (2pts)***
PECVD

-Fill in the next processing step(s): (1pt)
Lithography module

-Dry etch a contact hole over the center of the n-region.

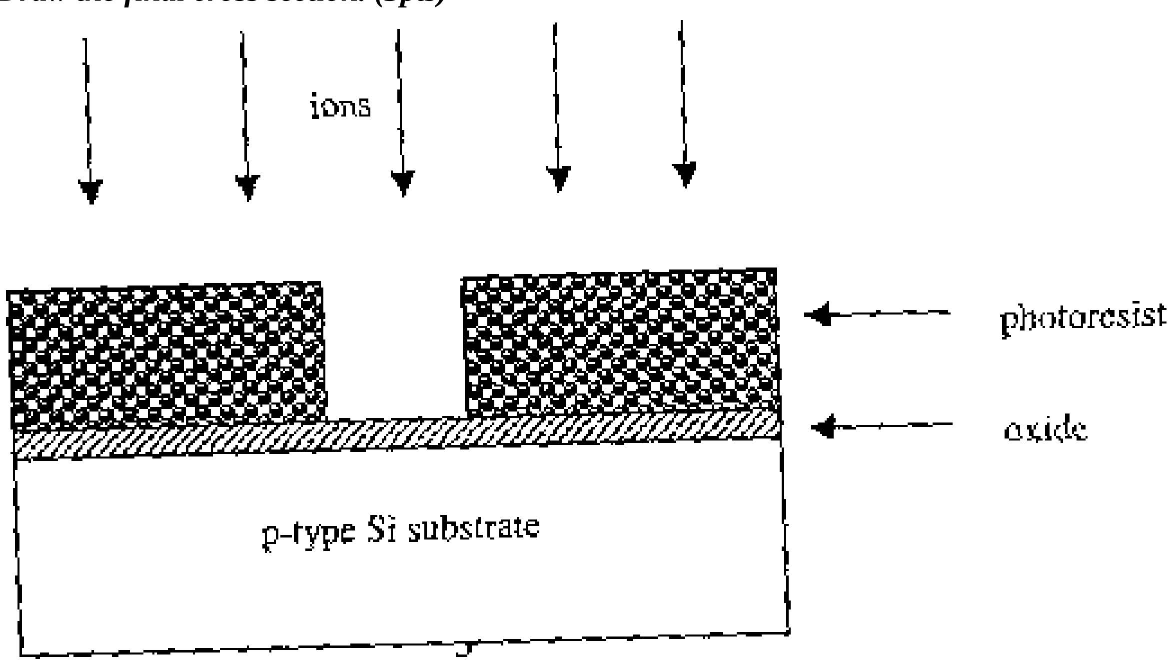
-Strip photoresist. Deposit 4000A aluminum.
What process technology would you use to deposit aluminum? (2pts)
Sputter

-Fill in the next processing step(s): (1pt) Lithography module

-Etch a very fine (i.e. thin) aluminum line.
What processing technology would you use? (2pts) Dry Etch
What chemial(s) are involved? (2ts) To remove Al, use plasmas containing Cl

-Remove photoresist

-Draw the final cross section. (3pts)



Problem #3

Consider a silicon p-n junction with doping levels Na = 10^15cm^-3 and Nd = 3.5x10^15cm^-3 .

a) Calculate the ration of Xn to Wdep. (5pts)
eqtn1: Xn+Xp = Wdep
eqtn2: Xn*Nd = Xp*Na
Therefore, Xp = Np/Na * Xn
Plug Xp into eqtn1 to get
Xn*(1+Nd/Na) = Wdep
Xn/Wdep = Na/(Nd+Na) = 10^15/(4.5*10^15) = .22

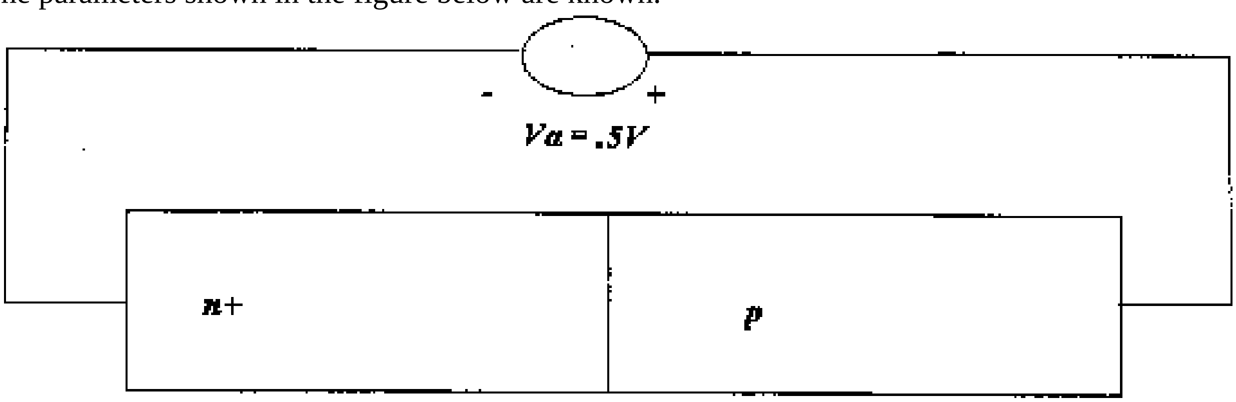
b) What is the built-voltage PHIbi? (5pts)
PHIbi=K*T/q*ln(Na*Nd/Ni^2) =(.026)*ln(10^15*3.5x10^15/10^20) =.63 V

c) Calculate how much of PHIbi exists on the N-side. (5pts)
(i) PHIn/PHIp = 1/2*Emax*Xn/(1/2*Emax*Xp) Therefore, PHIp = Xp/Xn * PHIn
(ii) PHIbi = PHIn+PHIp = PHIn + Xp/Xn *PHIn PHIn/PHIbi = (1 + Xp/Xn)^-1
(iii) Xp*Na = Xn*Nd PHIn/PHIbi = (!+ Nd/Na)^-1 = (1+3.5)^-1 = 1/4.5 = .22
*NOTE that this is the same expression as in part a!

d) Under a 2V reverse bias, the donor ion charge on the N-side of the depletion region is 10^-6 C/cm^2. What is the acceptor ion charge on the P-side? (5pts)
(i) Qn-side = q*Nd*Xn = q*Na*Xp = |Qp-side| *charge neutrality Therefore, Qp-side = -10^-6 C/cm^2

Problem #4

The parameters shown in the figure below are known.



Write down the expressions and numerical answers for the following items:

(3pts) a) Potential barrier across the depletion region
PHI = PHIbi-Va = (K*T/q * ln(10^19*10^15/Ni^2))-.5 = .34V

(2pts) b) Depletion width
Wdep = (2*Esi*(PHIi-Va)/(q*N))^1/2 = (2(11.7)(8.85E-14)(.34)/((1.6E-19)(10^15)))^1/2 = 6um

(3pts) c) Np' (0p) and Pn' (0n)
Np' = Np0*(e^(q*Va/(K*T))-1) ~ Ni^2/Na * e^(q*Va/(K*T)) = 10^20/10^15 * e^.5/.026 = 2.3*10^13/cm^3
Pn' = Pn0*(e^(q*Va/(K*T))-1) ~ Ni^2/Na * e^(q*Va/(K*T)) = 10^20/10^15 * e^.5/.026 = 2.3*10^13/cm^3

(3pts) d) Pp'(0p) and Nn'(0n)
Pp' = Np' = 2.3*10^13/cm^3
Nn' = Pn' = 2.3 * 10^9/cm^3

(3pts) e) Itotal
(i) Itotal ~ downloaded by current in p-side = -A*q*Dn*Np0*e^(q*Va/(K*T))/Ln
(ii) Dn > K*T/q * Un = .026*1400 = 36.4cm^2/s
    Ln = (Dn*TAUn)^.5 = .0134cm
(iii) Therefore, Itotal = -[(10^-4cm^2)*(1.6E-19)*(36.4)*(10^5)*e^(.5/.026)]/.0134 = -.98uA
(iv) verify: check the hole component term:
   |Ih| = A*q*Dp*Pinfinity*e^(q*Va/(K*T))/Lp
Lp = (Dp*TAUp)^.5 = 5E-4cm
Therefore, |Ih| = [(10^-4)*(1.6E-19)*(2.6)*(10)*e^(.5/.026)]/5E-4 = 1.9E-10A << |Ie|

(3pts) f) Junction depletion capacitance Cj
Cj = Esi*A/Wdep = (11.7)*(8.85E-14)*(10^-4)/(.6E-4) = 1.73pF

(3pts) g) Junction diffusion capacitance Cdiff
Cdiff = Itotal*TAUe/(l*c*T/q) = 188pF

(3pts) h) What is the total charge Q in the excess carrier distribution?
Qtotal = Itotal*TAUe = total charge is dominated by e- injection into p-side = (-.98uA)*(5usec) = -4.9*10^-12C

(3pts) i) What is the total rate of recombination?
R = rate of recombination = Qtotal/(q*TAUe) = 4.9*10^-12/((1.6E-19)*(5E-6)) = 6.13*10^12/sec

(4pts) k) If the capacitance of this diode were 5pF at a 2V reverse bias and 10pF at 0 bias, how should Na be changed?
We still have a N+P diode; depletion cap. dominates in this region.
5pF = Esi*A/Wdep = Esi*A/(2*Esi*(PHIbi+2)/(q*N))^.5 AND 10pF = Esi*A/(2*Esi*PHIbi/(q*N))^.5
5pF/10pF = 1/2 = PHIbi^.5/(PHIbi+2)^.5
1/4 = PHIbi/(PHIbi+2)
PHIbi+2 = 4*PHIbi
PHIbi = 2/3 = .67V = K*T/q*ln(Na*Nd/Ni^2)
Therefore, Na = 1.55*10^12cm^-3
