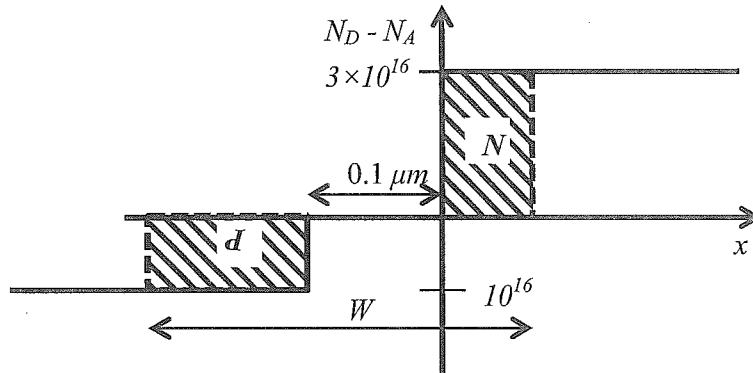P1 (40 points): For the P-I-N junction doping profile as shown in the following figure, the impurity profile at the donor side is given by $N_D = 3 \times 10^{16}$ cm^{-3}. On the acceptor side, the impurity profile is given by the following function.

$$N_A = \text{undoped} \qquad 0 > x > -0.1 \ \mu m$$
$$N_A = 10^{16} \ cm^{-3} \qquad -0.1 \ \mu m > x$$

Assume that the semiconductor has a dielectric constant $\varepsilon = 1.6 \times 10^{-8}$ F/cm and electronic charge is $q = 1.6 \times 10^{-19}$ C. The thickness of the depletion region is $W = 0.5 \ \mu m$.

(a) Find the depth of the depletion region in both P and N sides when no external voltage is applied (W_p and W_n, respectively) (10 points).

(b) Find expressions for the electric field distribution. Determine the maximum field and plot the electric field along x in the semiconductor. (20 points)

(c) Roughly draw the potential across the junction. No derivation is needed. (10 points)
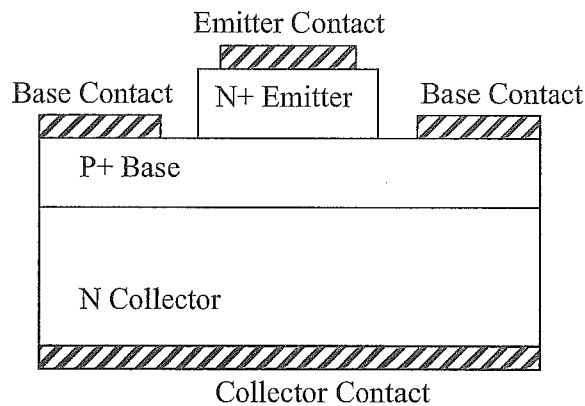
P2 (27 points): For the NPN Si bipolar junction transistor with the cross-section shown below, estimate the common-emitter current gain in the forward biased active region. Assume an electron mobility of 1500 cm^2/V.Sec in P-type base and N-type collector regions and a hole mobility of 500 cm^2/V.Sec in N-type emitter region. State any assumption that you make.

N+ Emitter doping: 1×10^{19} cm^{-3}, Thickness: 1 μm
P+ Base doping: 1×10^{18} cm^{-3}, Thickness: 1 μm
N Collector doping: 1×10^{16} cm^{-3}, Thickness: 5 μm

Emitter Contact

Base Contact   N+ Emitter   Base Contact

P+ Base

N Collector

Collector Contact

P3 (33 points): Draw the band structure of an NPN Si/Si$_{0.8}$Ge$_{0.2}$ double heterojunction bipolar transistor at zero applied bias and under active region (9 points). What is a typical doping in different regions of such a device (3 points). Explain in what ways this transistor may be superior to a Si bipolar junction transistor. In your discussion, consider common-emitter current gain β, collector-emitter saturation voltage $V_{ce,sat}$, reverse collector-base breakdown voltage $V_{cb,br}$, cutoff frequency f_T, maximum oscillation frequency f_{max}, high current effects, and specifically emitter current crowding and the effect of strain (21 points).

Use equations to prove your points if necessary. Assume that the bandgap values of Si and Ge are 1.1 eV and 0.6 eV, respectively. Further assume that SiGe is a random alloy and conduction and valence band discontinuities between Si and Si$_{0.8}$Ge$_{0.2}$ are identical. State any other assumption that you make.

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