(I.)

a) $\mathcal{E}_{cr} \approx 4\times10^{5}\ \mathrm{V/cm}$, at room temperature, a materials constant for silicon independent of doping.

b) $$V_{BR} = \frac{\epsilon}{2q}\,\frac{N_a+N_d}{N_aN_d}\,\mathcal{E}_{cr}^{2}$$

$$= \frac{\epsilon}{2q}\,\frac{\frac{N_d}{N_a}^{\to 0}+\frac{N_a}{N_a}^{\to 1}}{N_d}\,\mathcal{E}_{cr}^{2} = \frac{\epsilon}{2q}\,\frac{1}{N_d}\,\mathcal{E}_{cr}^{2}$$

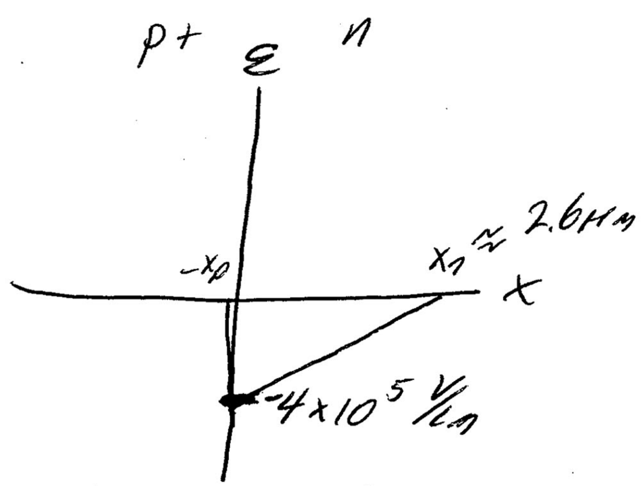
$$\underline{V_{BR} = 52\ \mathrm{V}}$$

c) $$W = \sqrt{\frac{2\epsilon}{q}\left(V_{bi}-V_a\right)\frac{N_a+N_d}{N_aN_d}}$$

$$W \approx \sqrt{\frac{2\epsilon}{q}\,|V_a|\,\frac{1}{N_d}}$$ since $|V_a| \gg |V_{bi}|$ and $N_a \gg N_d$

$$\underline{W \approx 2.6\ \mu\mathrm{m}}$$

d)



Both the curve at breakdown and the curve for one volt beyond breakdown are essentially identical. The voltage beyond breakdown will drop across the resistive bulk regions, primarily the n-region.

e) If the band gap increases, then we expect $\mathcal{E}_{cr}$ to increase because more energy is needed to form an electron-hole pair.

(2.) $I_{\text{forward bias}} = I_{ideal} + I_{recomb.}$ for low forward biases

(low-level injection)

At what voltage does

$I_{ideal} = I_{recomb.}$

$$\cancel{q} n_i^2 \cancel{A}\left(\frac{D_n}{N_a L_n} + \frac{D_p}{N_d L_p}\right) e^{qV_a/kT} = \cancel{q}\cancel{A}\frac{n_i}{2\tau_0} W e^{qV_a/2kT}$$

$$D_n = \frac{kT}{q}\mu_n(N_a = 3\times10^{16}) = (.026V)(1100\tfrac{cm^2}{V\text{-}s}) = 28.6\ \frac{cm^2}{V\text{-}s}$$

$$D_p = \frac{kT}{q}\mu_p(N_d = 7\times10^{16}) = (.026V)(360\tfrac{cm^2}{V\text{-}s}) = 9.4\ \frac{cm^2}{V\text{-}s}$$

$$L_n = \sqrt{D_n \tau_n} = 53\mu m$$

$$L_p = \sqrt{D_p \tau_p} = 31\mu m$$

$$V_{bi} = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2} = .79$$

$$W = \sqrt{\frac{2\epsilon}{q}(V_{bi} - V_a)\frac{N_a + N_d}{N_a N_d}}$$

(For this problem, we ignore the effect of V_a on W)

$\underline{W \sim 2.2\times10^{-5}\ cm}$

$$\tau_0 = \frac{\tau_n + \tau_p}{2} = 1\mu s$$

$$n_i^2\left(\frac{D_n}{N_a L_n}+\frac{D_p}{N_d L_p}\right)e^{qV_a/2kT} = \frac{n_i}{2\tau_0}W$$

$$\frac{qV_a}{2kT} = \ln\left[\frac{\frac{n_i}{2\tau_0}W}{n_i^2\left(\frac{D_n}{L_n N_a}+\frac{D_p}{N_d L_p}\right)}\right]$$

$$V_a = \frac{2kT}{q}\ln\left[\frac{\frac{n_i}{2\tau_0}W}{n_i^2\left(\frac{D_n}{L_n N_a}+\frac{D_p}{N_d L_p}\right)}\right]$$

$$\boxed{V_a \sim .44\,V}$$