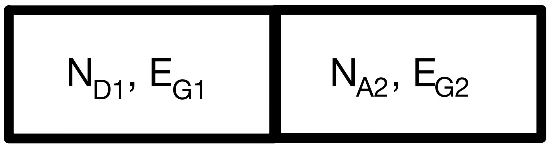
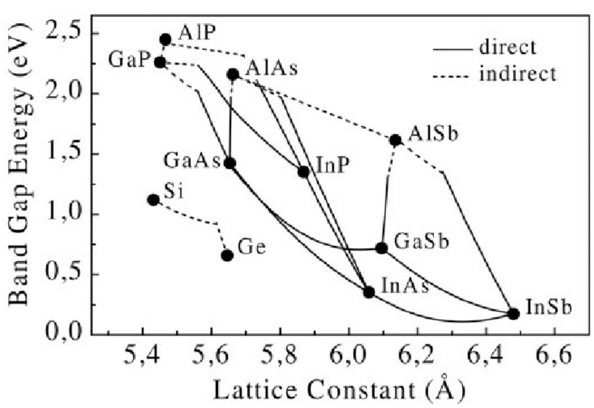
p-n Heterojunctions

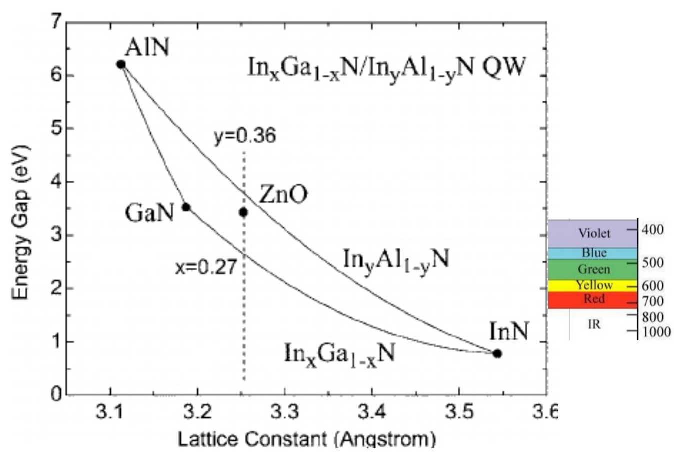
- In p-n homojunctions, control of current characteristics (e.g., J_n/J_p) is mostly limited to doping

- A method that allows for additional control over currents is to utilize a ***p-n heterostructure*** (i.e., different semiconductor materials for the p- and n- materials)

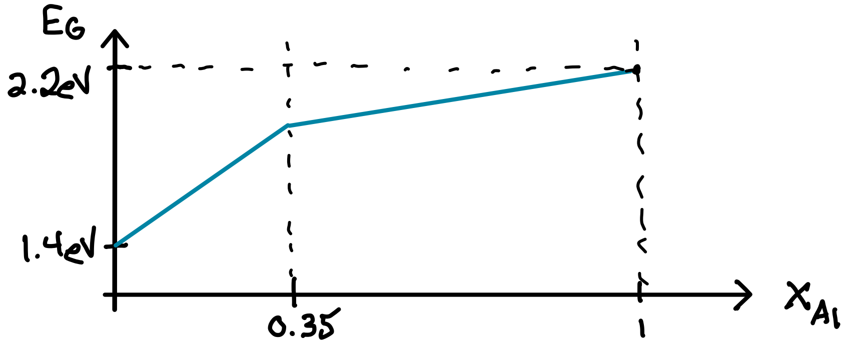


- Material considerations for epitaxial growth of heterostructures:
    - Lattice constant and structure
    - Chemical composition





Vegard's Law: $E_G(Al_xGa_{1-x}As) = E_G(GaAs) + Cx$

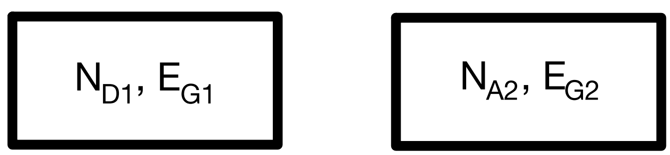


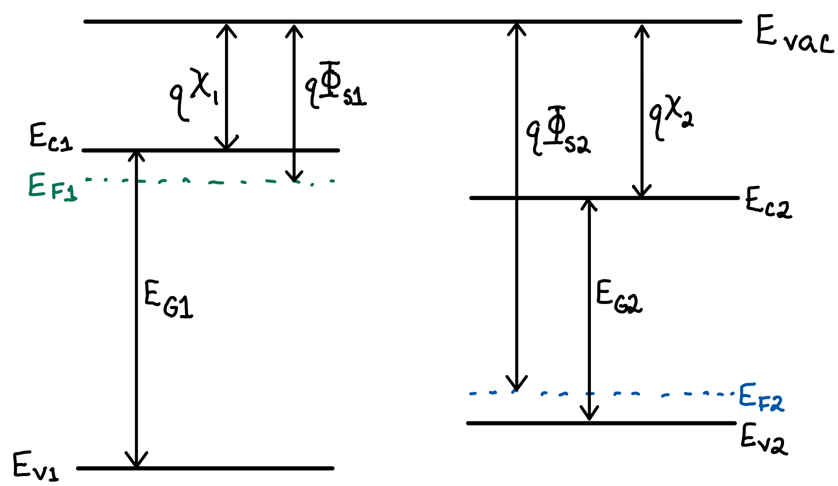
Consider the following p-n heterojunction:

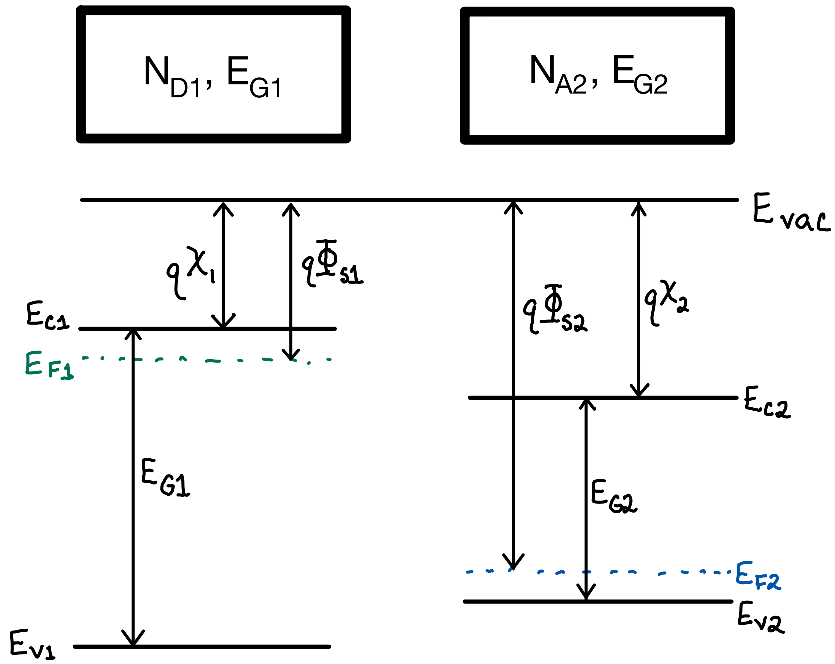
- Material 1: n-type (N_{D1}), wide bandgap (E_{G1})
- Material 2: p-type (N_{A2}), narrower bandgap (E_{G2})

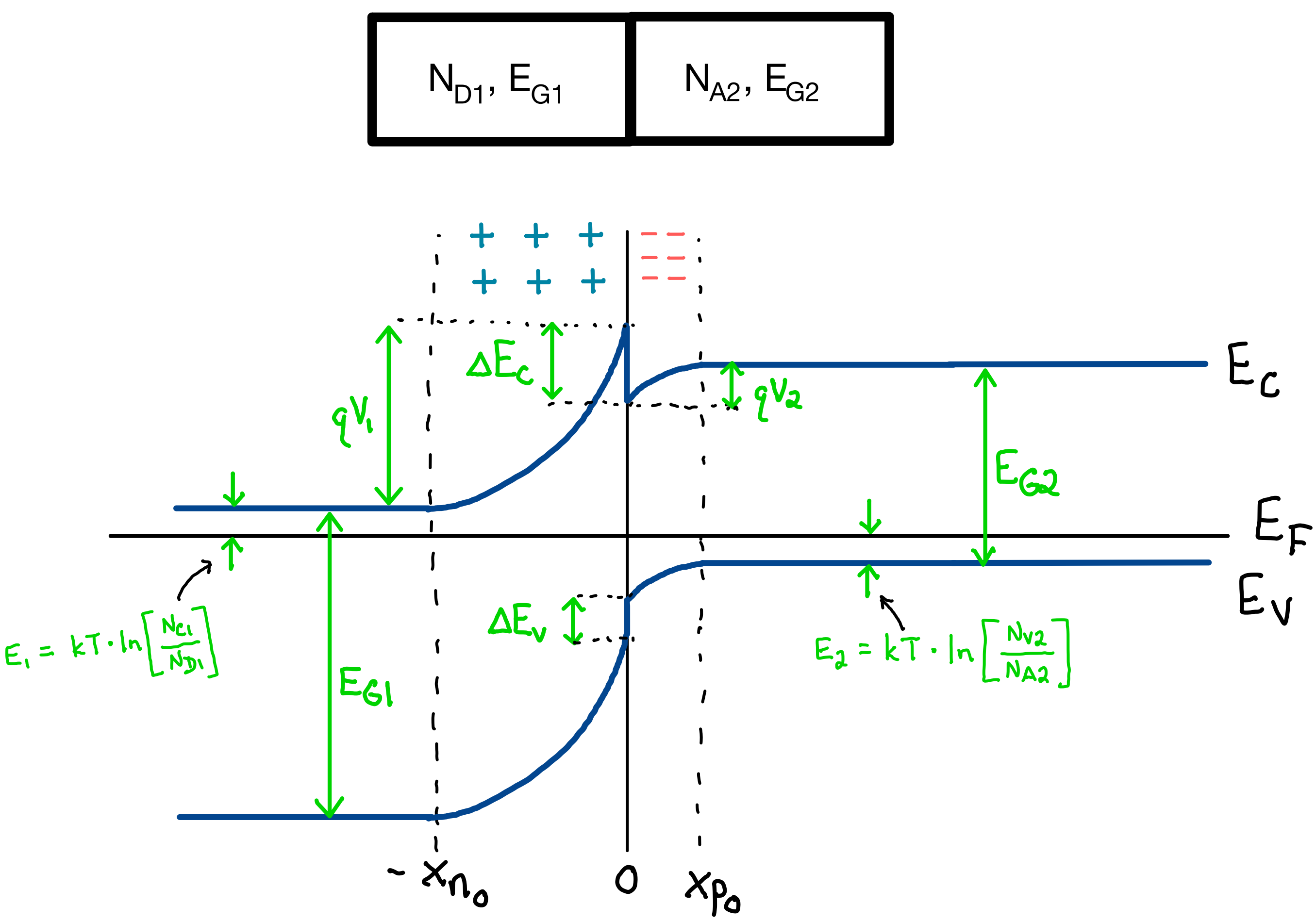
$\chi_1 < \chi_2$ (common for many materials, including $Al_xGa_{1-x}As/GaAs$)

$N_{A2} > N_{D1}$

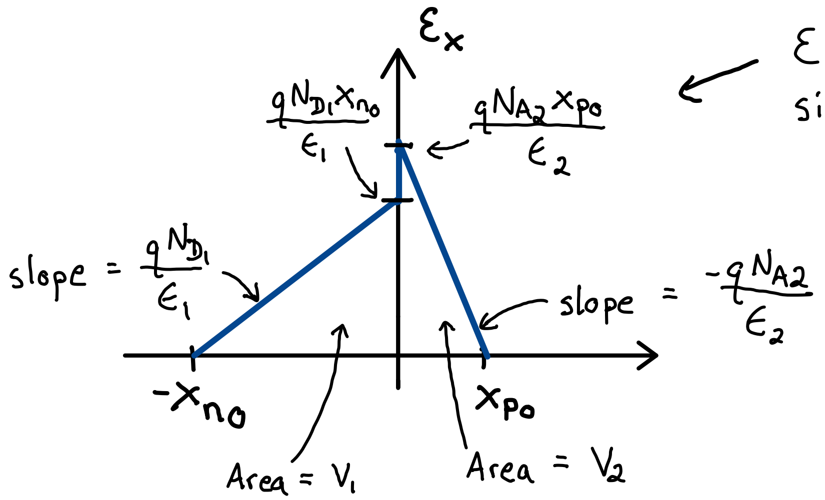








$$\Delta E_c + \Delta E_v = \Delta E_G = E_{G1} - E_{G2}$$



$\mathcal{E}$-field discontinuous since $\epsilon_1 \neq \epsilon_2$

- $\epsilon_1 \mathcal{E}_1(0) = \epsilon_2 \mathcal{E}_2(0)$
- $N_{D1} x_{n_0} = N_{A2} x_{p_0}$

- $\Delta E_C + \Delta E_V = \Delta E_G = E_{G1} - E_{G2}$

- $\frac{\Delta E_C}{\Delta E_G}$ depends on material system:
  - AlGaAs / GaAs: $\Delta E_C \approx (0.6) \Delta E_G$
  - AlGaN / GaN: $\Delta E_C \approx (0.7) \Delta E_G$
  - InGaAsP / InP: $\Delta E_C \approx (0.4) \Delta E_G$
  - Si / SiGe: $\Delta E_C \approx 0$

<u>Unknowns:</u> x_{n_0}, x_{p_0}, V_1, V_2

- $N_{D1} x_{n_0} = N_{A2} x_{p_0}$ (1)
- $V_1 = \dfrac{q N_{D1} x_{n_0}^2}{2\epsilon_1}$ (2)
- $V_2 = \dfrac{q N_{A2} x_{p_0}^2}{2\epsilon_2}$ (3)
- $E_1 + qV_1 - \Delta E_c + qV_2 - E_{G2} + E_2 = 0$ (4)

Graded Junction: