# HFET (Heterojunction FET) / HEMT (High Electron Mobility Transistor)

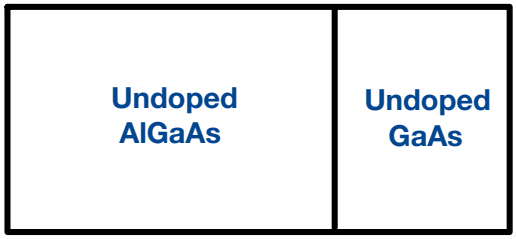
- In a MESFET (and JFET), higher doping leads to a higher channel charge density but also to a lower carrier mobility

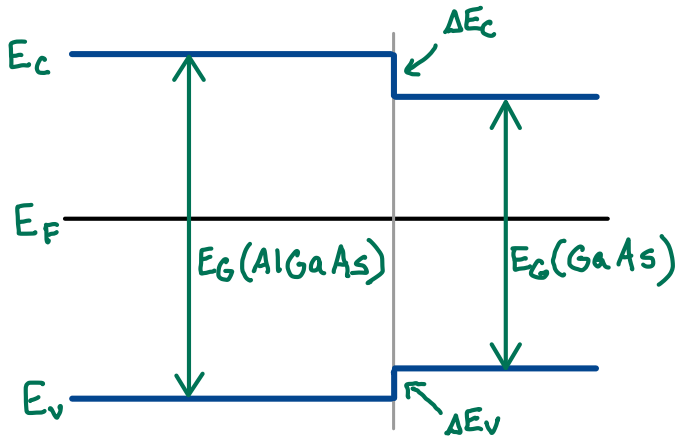
- In an HFET, the device channel consists of a **2-Dimensional Electron Gas (2DEG)** that is induced adjacent to a heterojunction

- A potential well that confines 2DEG is created in the narrow bandgap material

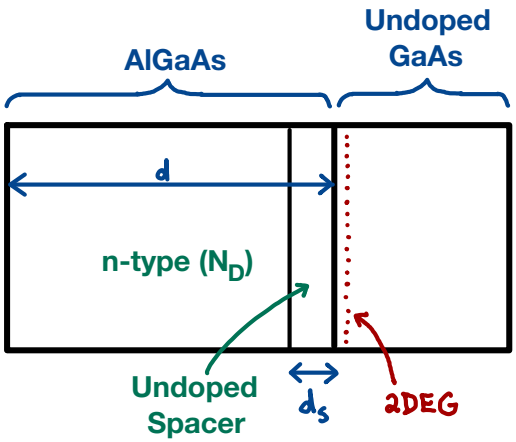
- 2DEG electrons are provided by dopants in the wide bandgap material, thereby spatially separating the 2DEG from the ionized donors, resulting in a very high mobility channel

## Undoped Wide Bandgap Material (no 2DEG)

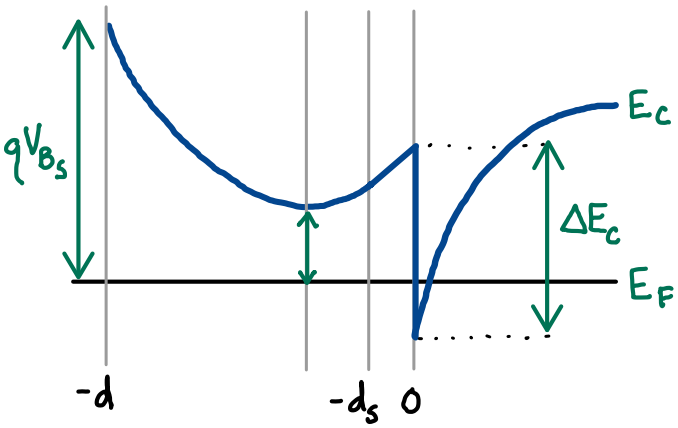


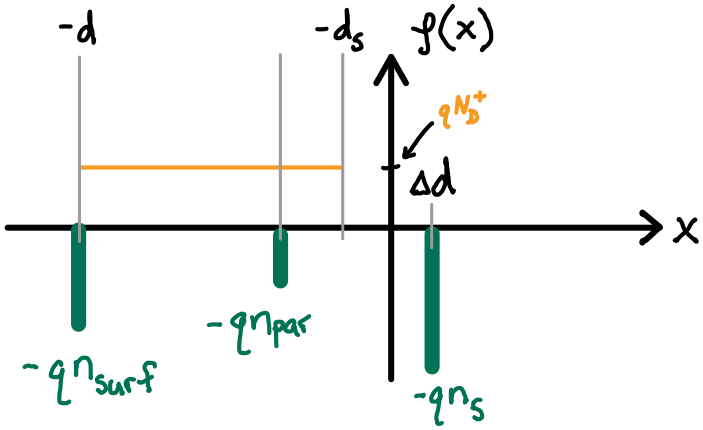



# Continuous Doping with Undoped Spacer in Wide Bandgap Material

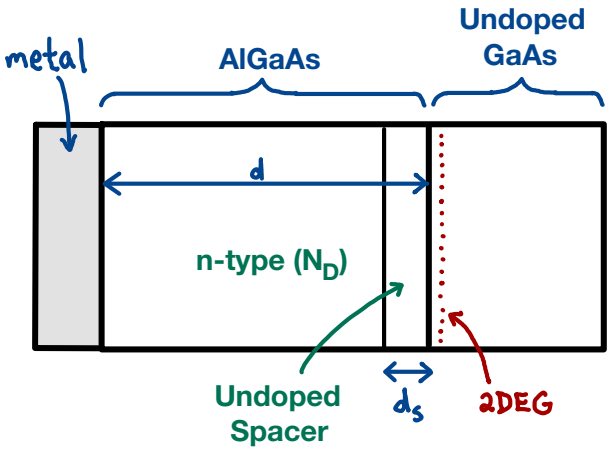


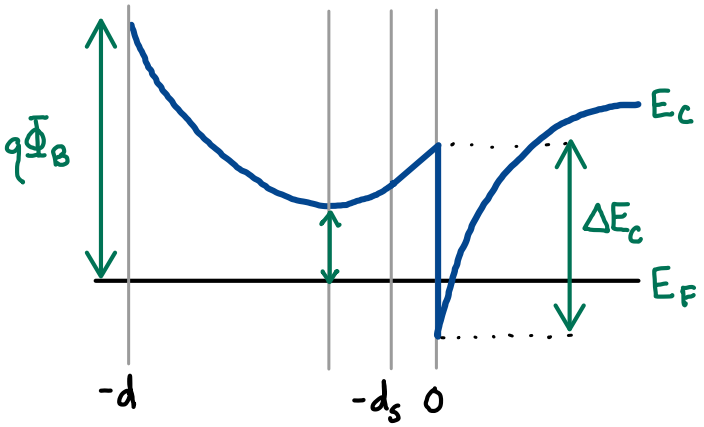

d is typically ~30 nm



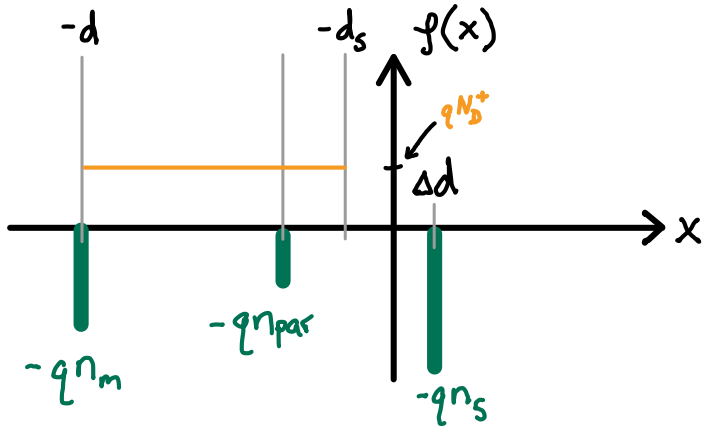




$$n_{surf} + n_{par} + n_s = N_D^+(d - d_s)$$



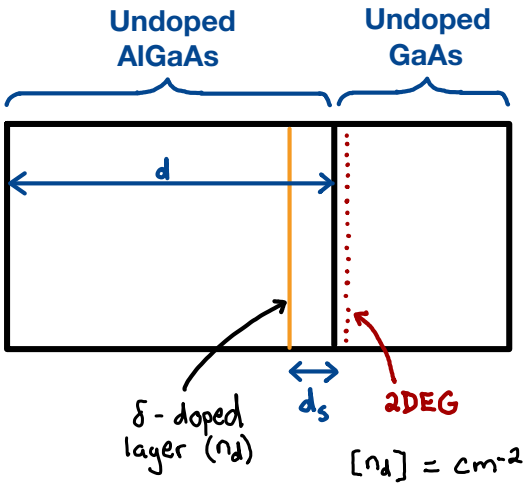



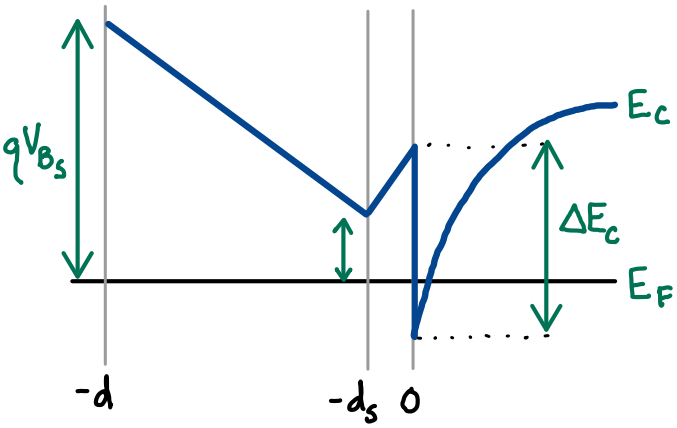

$$\Phi_B = \Phi_M - \chi$$

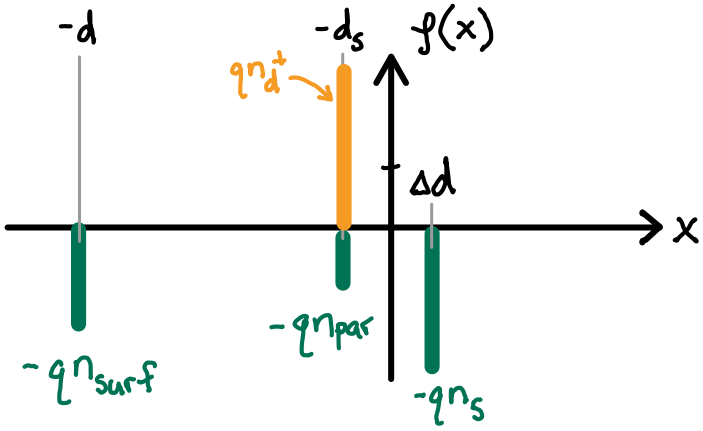



$$n_m + n_{par} + n_s = N_D^+(d - d_s)$$

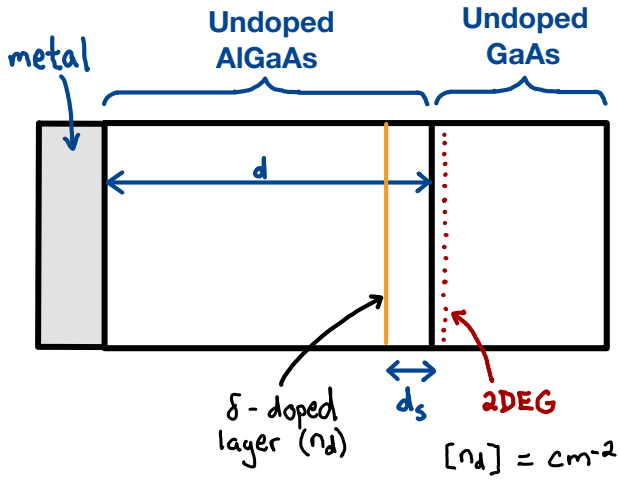
# Delta Doping in Wide Bandgap Material

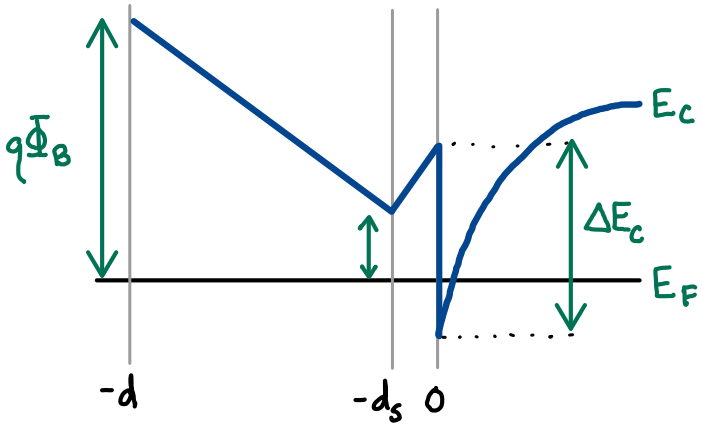


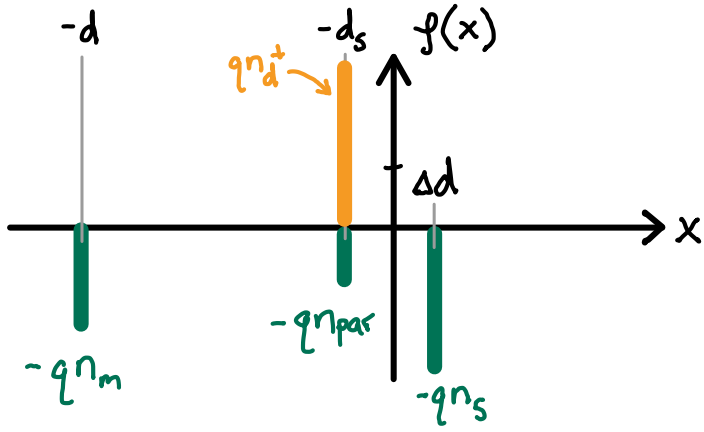




$$n_{surf} + n_{par} + n_s = n_d^+$$



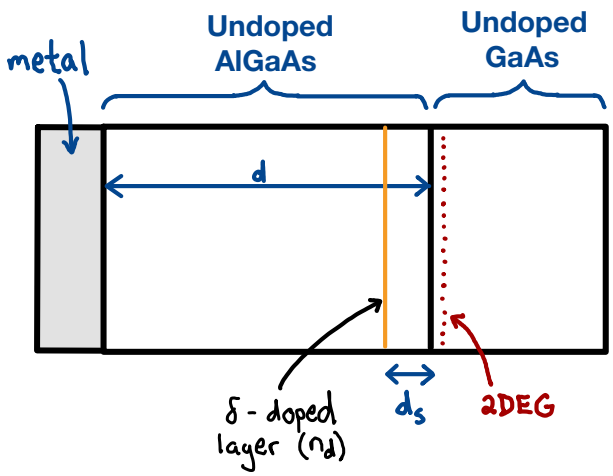



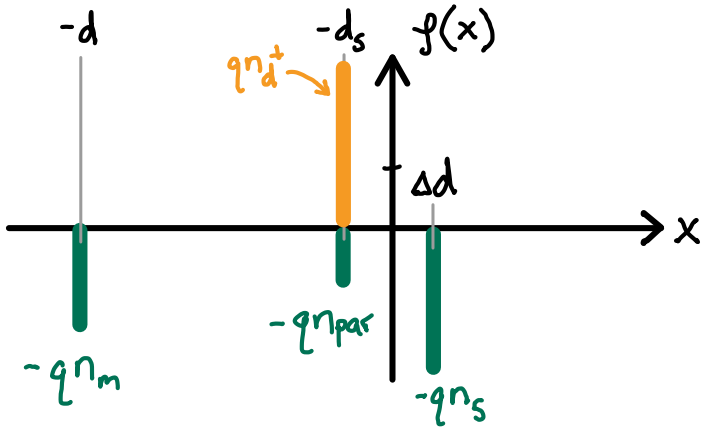

$$\Phi_B = \Phi_M - \chi$$

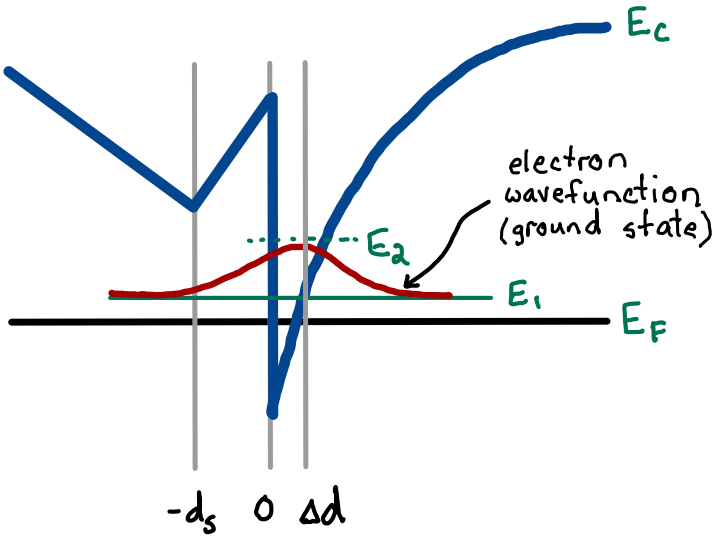



$$n_m + n_{par} + n_s = n_d^+$$

# 2-D Electron Gas (2DEG)



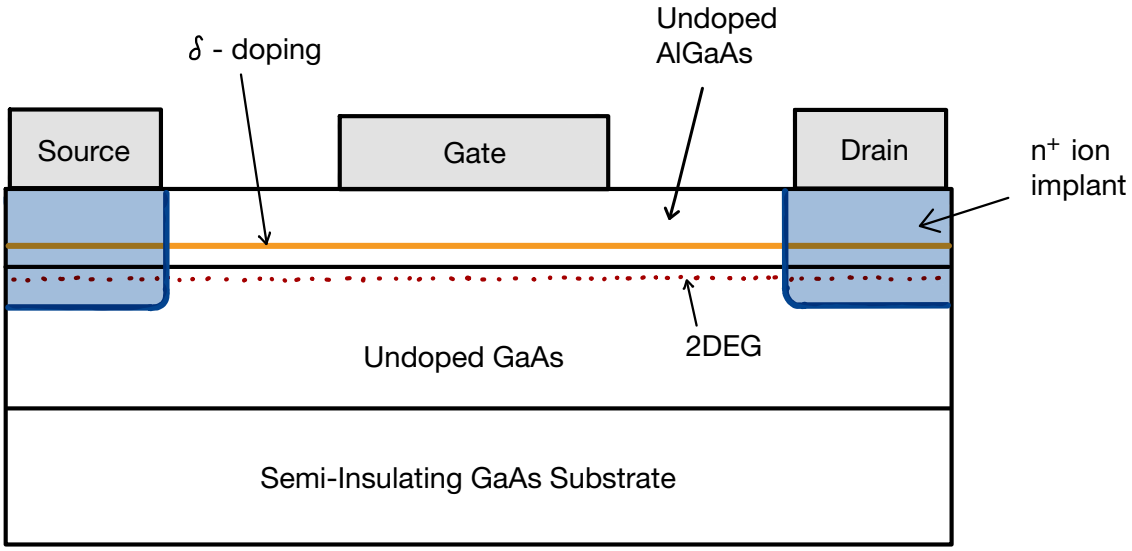

## 2DEG Properties:

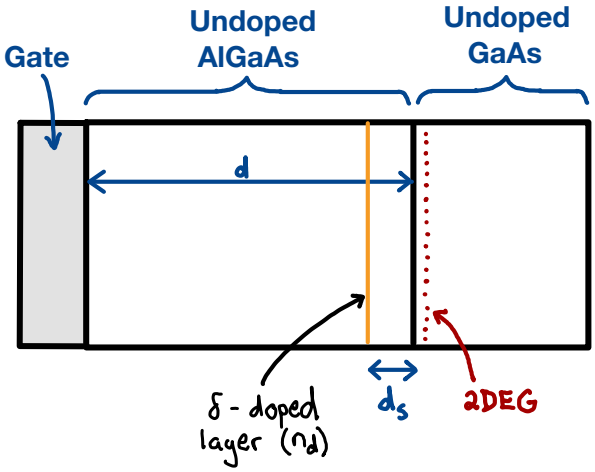
- High mobility due to reduced ionized impurity scattering

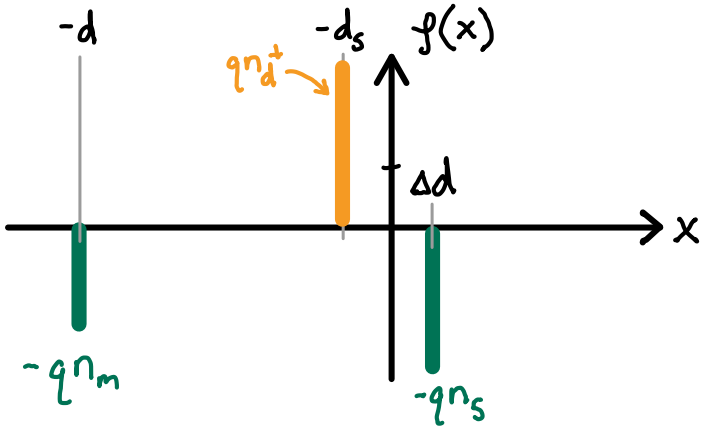
- Charge density is temperature independent

- Mobility increases with decreasing temperature

# HFET Device

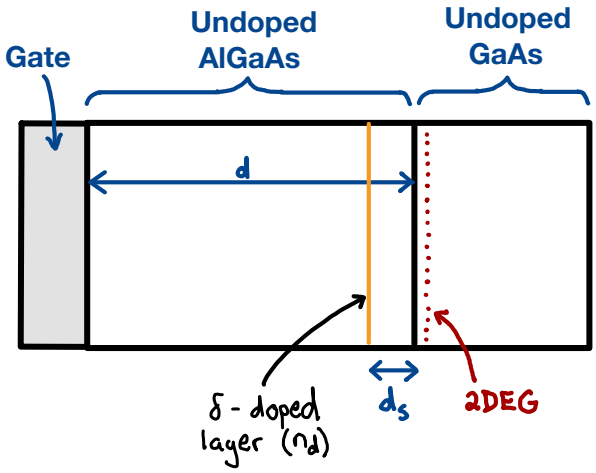


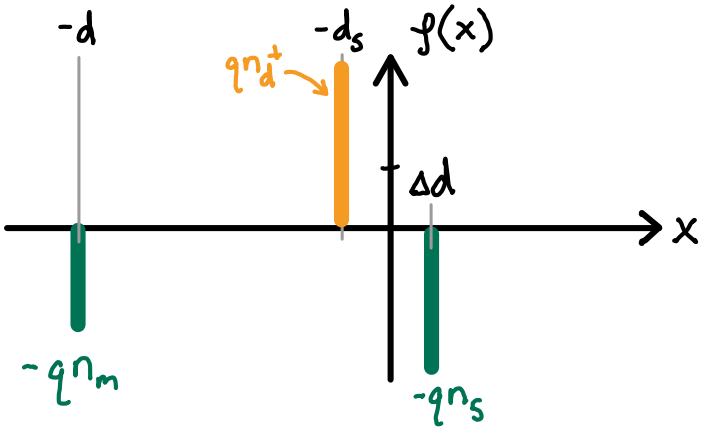



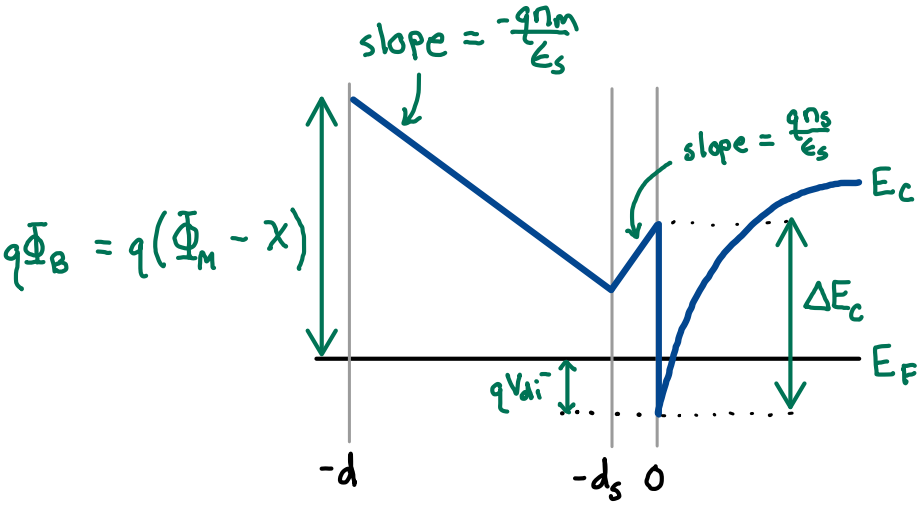



# Charge Control in HFET Channel

## $V_G = 0V$:

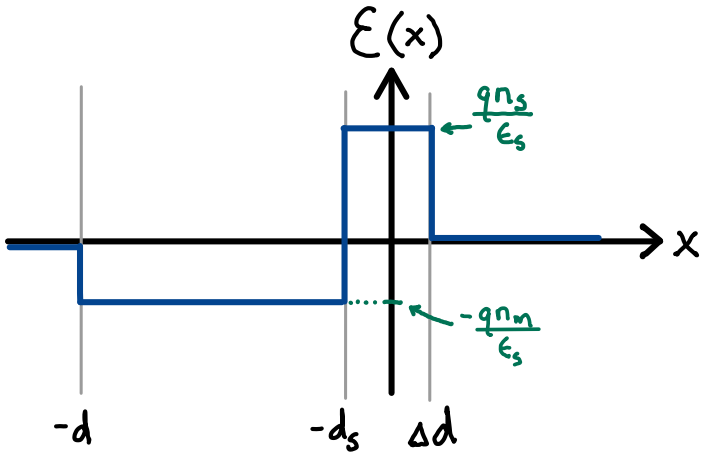


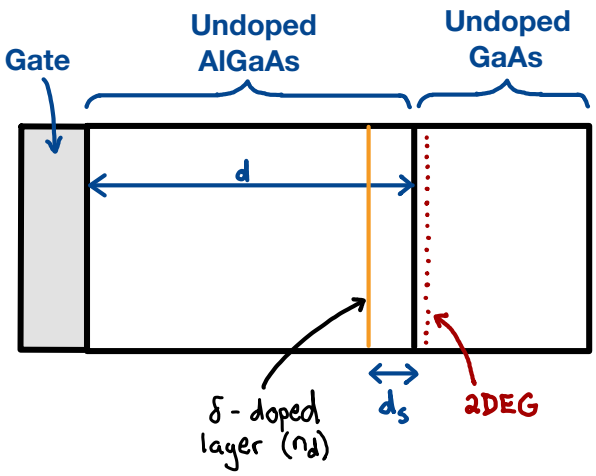



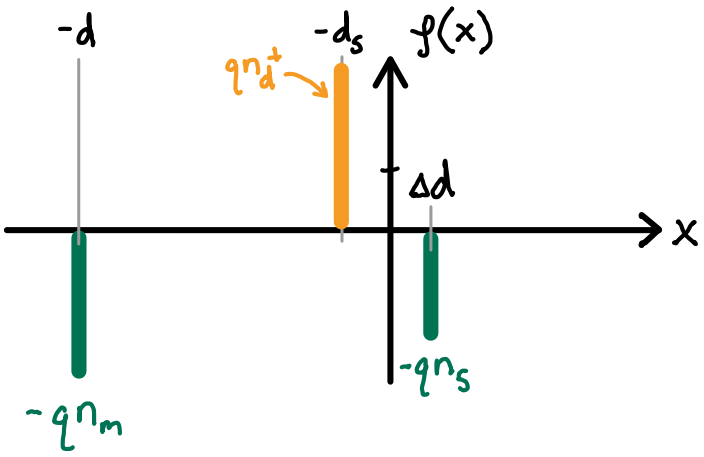

- $V_{di}^- = a \cdot n_s$
- $\Delta d$ and a are material dependent
- $\Delta d$ is typically ~80Å for AlGaAs/GaAs

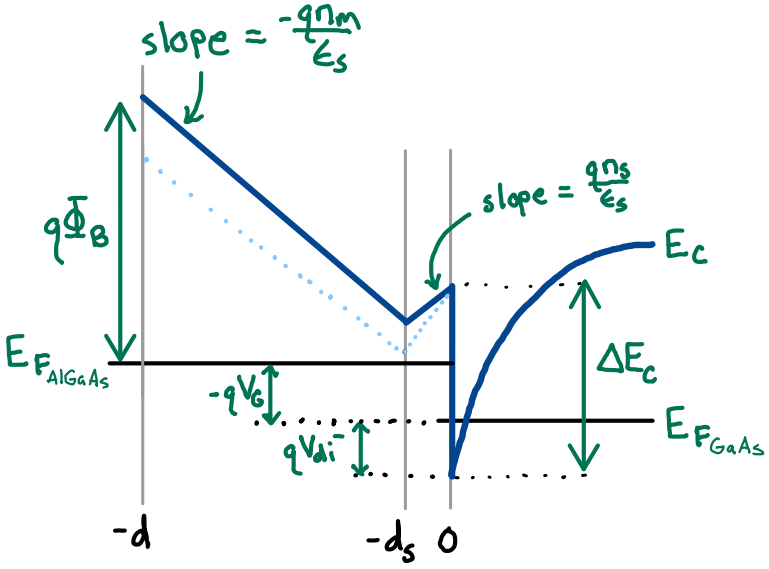
- $q\Phi_B - \frac{qn_m}{\epsilon_s}(d-d_s) + \frac{qn_s}{\epsilon_s}(d) - \Delta E_c + qV_{di}^- = 0$
- $n_m + n_s = n_d^+$



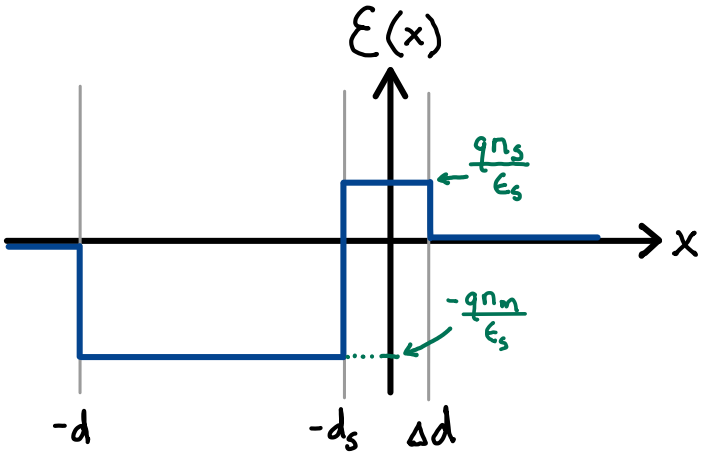
# $V_G < 0V$:




- $(-qV_G) + q\Phi_B - \frac{qn_m}{\epsilon_s}(d-d_s) + \frac{qn_s}{\epsilon_s}(d) - \Delta E_C + qV_{di} = 0$
- $n_m + n_s = n_d^+$



# Final Notes on HFETs

- Lever Rule: $n_s$ increases as dopants are brought closer to channel (but channel mobility decreases)