pn Junctions

- ubiquitous IC structure -- pn junctions are everywhere!

Thermal Equilibrium

- Thought experiment: bring p and n Si blocks together
  holes flood from p side to n side of junction and electrons go the other way

- what can balance out this transport and prevent the p & n sides from mixing?

- thermal equilibrium: no hole current, no electron current ... no voltage applied between metal interconnects (could short them together)
Charge in pn Junction in Thermal Equilibrium

- Answer: a charged region at the junction!

Qualitative Electrostatics in Equilibrium

- From the charge density, we can find the electric field and the potential
Qualitative Electrostatics in Equilibrium

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\[ E_\phi \]

\[ \phi_\phi \]

The Barrier Potential Across the Junction

- The n-side is at a higher potential than the p-side of the junction in thermal equilibrium (no applied voltage), due to the charged layer (called the depletion region) and the built-in field

- To quantify the potential \( \phi_\phi(x) \), we need to pick a reference where \( \phi_\phi = 0 \)

  Conventional choice: intrinsic (pure/compensated) silicon \( \rightarrow \phi_\phi = 0 \)

**n-type silicon** in thermal equilibrium (subscript is “\( \alpha \)“)

\[
\phi_\phi = \frac{V_{th} \ln \left( \frac{n_\alpha}{n_i} \right)}{10} = \frac{26 \text{mV} \ln(10) \log \left( \frac{n_\alpha}{10^{10}} \right)}{10} = \frac{60 \text{mV} \log \left( \frac{n_\alpha}{10^{10}} \right)}{10}
\]

**p-type silicon** in thermal equilibrium

\[
\phi_\phi = \frac{V_{th} \ln \left( \frac{n_i}{p_\alpha} \right)}{10} = \frac{26 \text{mV} \ln(10) \log \left( \frac{p_\alpha}{10^{10}} \right)}{10} = \frac{-60 \text{mV} \log \left( \frac{p_\alpha}{10^{10}} \right)}{10}
\]
The 60 mV Rule

Examples:

Measuring the Built-In Potential Barrier

- Can $\phi_B$ be measured externally?