Bohr & Pauli - What is a semiconductor. How do diodes & transistors work?

- 1900 people knew about atomic spectra but didn't know why.
  - Even knew that \( \frac{1}{\alpha} = R \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \)

Bohr guessed that electron energies were quantized - only some values allowed.

Pauli said no two Fermions (such as electrons) can have the same energy.

When atoms come together, to form a crystal the discrete energies split up into bands.

For hypothetical room temp, the electron is at its lowest energy.

Some for silicon - at room temp, almost all of the low energies are filled.

- At least 3 empty \( 4N \) states
- \{ almost compl. \( 14N \) states \}
- \( N \) atoms

\( \text{N atoms} \)
why almost? thermal excitation

\[ N_i = 10^{10} \text{ e}_C \]

\[ N = 5 \times 10^{22} \frac{e}{cc} \]

\[ \% \text{ excited} = \frac{N_i}{N} = \frac{10^{10}}{5 \times 10^{22}} = 5 \times 10^{-12} \]

\[ \frac{e}{cc} \]

not may!

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<table>
<thead>
<tr>
<th>Metals</th>
<th>Top layer half full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulators</td>
<td>Two adjacent bands completely full &amp; completely empty at ( T = 0 ) Kohn</td>
</tr>
<tr>
<td>Difference: size of band gap</td>
<td></td>
</tr>
<tr>
<td>( (10^7 - 40) )</td>
<td></td>
</tr>
<tr>
<td>( N_i = 10^{10} \text{ e}_300K )</td>
<td></td>
</tr>
<tr>
<td>( 5 \times 10^{-16} )</td>
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</tbody>
</table>

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Electrons in a full band can’t move.

- No available energy state to go to.

- Empty

- Gap

- Full

\( T = 0 \) \n
\( T = 300K \)

Electron–hole pair

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Doping

- Boron, Phosphorus, Arsenic also have energies allowed for their \( e^- \)

- These happen to lie up just inside the band gap.

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Boron accepts an electron, creating a hole in the valence band.

Phosphorus donates an electron to the conduction band.
Electrons in conduction band, or holes in valence band, can move either by drift in an electric field, or diffusion due to concentration gradients.

\[ v_{\text{Drift}} = \mu \frac{E}{v_{\text{m}}} \]

\[ I = ab \cdot v \cdot n \cdot \frac{\mu e}{s} \]

Assume a density \( n \) [conduction band electrons/cc]

moving w/ velocity \( v (\text{cm/s}) \)

\[ I_{\text{Drift}} = \frac{ab \cdot v \cdot n \cdot \mu e}{s} \]

\[ \frac{E}{s} = \frac{A}{s} \]

\[ \frac{E}{s} = A \]

\[ I = I_n + I_p = ab q \frac{V}{L} (n \cdot n_p + p \cdot p) \]

Intrinsic (undoped) silicon

\[ n = p = 10^{10} \text{cm}^{-3} \]

Thermal excitation

doping \( \Rightarrow n, p \approx 10^{20} \text{cm}^{-3} \)

10 order of magnitude change due to addition of 0-1% dopants

\[ R = \frac{V}{I} = \frac{L}{ab} \frac{1}{g(e_n + e_p)} \]

\[ = \frac{L}{A} \rho \]

\[ \rho = \frac{1}{g(e_n + e_p)} \]
Reduces potential barrier \( \Rightarrow \) big diffusion current

\[ I_D = e \]

Increase potential barrier \( \Rightarrow \) only tiny "leakage" current

Take 105 or 130 for more detail

Lasers & LEDs

Population inversion

\[
\begin{array}{c|c|c}
- & + & + \\
\end{array}
\]

Forward bias \( \Rightarrow \) minority carriers show up on both sides

\( \Rightarrow \) recombine and (maybe) emit photon

Clean ends of crystal \( \Rightarrow \) mirrors

Stimulated emission \( \Rightarrow \) LASERS

Roughly additive to diode I/V curve
photo excitation of ehp

hydrogen:

absorption/excitation

re-emission/decay

very well defined wavelengths

\[ E = h \nu = \frac{hc}{\lambda} \]

1eV \( \Rightarrow \lambda = 1.2 \text{\mu m} \)

Solar cells

Semiconductor

[p]

metal

Diodes

big diffusion current

\[ I_n = A \beta D_n \frac{dn}{dx} \]

\[ I_p = -A \beta D_p \frac{dp}{dx} \]

leaves behind fixed charge (donor/acceptor atoms)

\Rightarrow creates E-field to balance diffusion

solution of this differential eqn leads to ideal diode