Chapter 0 Overheads

after Cressler and Niu, Silicon-Germanium Heterojunction Bipolar Transistors, 2003
Fermi-Dirac Distribution Function

Energy band diagram

Density of states

Occupancy factors

Carrier distributions

(a) \( E_F \) above midgap

(b) \( E_F \) near midgap

(c) \( E_F \) below midgap

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graphs and tables of intrinsic carrier concentrations for different temperatures:

- **Si**
  - $T(\text{C})$, $n_i (\text{cm}^{-3})$
  - 0: $8.86 \times 10^8$
  - 5: $1.44 \times 10^9$
  - 10: $2.30 \times 10^9$
  - 15: $3.62 \times 10^9$
  - 20: $5.62 \times 10^9$
  - 25: $8.60 \times 10^9$
  - 30: $1.30 \times 10^{10}$
  - 35: $1.93 \times 10^{10}$
  - 40: $2.85 \times 10^{10}$
  - 45: $4.15 \times 10^{10}$
  - 50: $5.97 \times 10^{10}$
  - 300 K: $1.00 \times 10^{10}$

- **GaAs**
  - $T(\text{C})$, $n_i (\text{cm}^{-3})$
  - 0: $1.02 \times 10^5$
  - 5: $1.89 \times 10^5$
  - 10: $3.45 \times 10^5$
  - 15: $6.15 \times 10^5$
  - 20: $1.08 \times 10^6$
  - 25: $1.85 \times 10^6$
  - 30: $3.13 \times 10^6$
  - 35: $5.20 \times 10^6$
  - 40: $8.51 \times 10^6$
  - 45: $1.37 \times 10^7$
  - 50: $2.18 \times 10^7$
  - 300 K: $2.25 \times 10^6$

Graphs showing the intrinsic carrier concentration as a function of temperature for Ge, Si, and GaAs.

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after Pierret, Semiconductor Device Fundamentals, 1996
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Scattering Mechanisms:
- Optical Phonon
- Non-Polar Scattering
- Piezoelectric Scattering
- Deformation Potential Scattering
- Lattice Scattering
- Carrier-Carrier Scattering & Coupled Scattering Mechanisms
- Crystal Defect Scattering
- Impurity Scattering
- Alloy Scattering
- Interface Scattering

Graph showing absorption coefficient ($a$) vs. wavelength ($\lambda$) for different materials: GaAs, Si, Ge, GaP, InP.
## Milestones in Electronics

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1884</td>
<td>American Institute of Electrical Engineers (AIEE) formed</td>
</tr>
<tr>
<td>1895</td>
<td>Marconi makes first radio transmissions</td>
</tr>
<tr>
<td>1904</td>
<td>Fleming invents diode vacuum tube—Age of Electronics begins</td>
</tr>
<tr>
<td>1906</td>
<td>Pickard creates solid-state point-contact diode (silicon)</td>
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<tr>
<td>1910–1911</td>
<td>“Reliable” tubes fabricated</td>
</tr>
<tr>
<td>1912</td>
<td>Institute of Radio Engineers (IRE) founded</td>
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<tr>
<td>1907–1927</td>
<td>First radio circuits developed from diodes and triodes</td>
</tr>
<tr>
<td>1920</td>
<td>Armstrong invents super heterodyne receiver</td>
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<tr>
<td>1925</td>
<td>TV demonstrated</td>
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<tr>
<td>1925</td>
<td>Lilienfeld files patent application on the field-effect device</td>
</tr>
<tr>
<td>1927–1936</td>
<td>Multigrid tubes developed</td>
</tr>
<tr>
<td>1933</td>
<td>Armstrong invents FM modulation</td>
</tr>
<tr>
<td>1935</td>
<td>Hell receives British patent on a field-effect device</td>
</tr>
<tr>
<td>1940</td>
<td>Radar developed during World War II—TV in limited use</td>
</tr>
<tr>
<td>1947</td>
<td>Bardeen, Brattain, and Shockley at Bell Laboratories invent bipolar transistors</td>
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<tr>
<td>1950</td>
<td>First demonstration of color TV</td>
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<tr>
<td>1952</td>
<td>Shockley describes the unipolar field-effect transistor</td>
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<tr>
<td>1952</td>
<td>Commercial production of silicon bipolar transistors begins at Texas Instruments</td>
</tr>
<tr>
<td>1956</td>
<td>Bardeen, Brattain, and Shockley receive Nobel Prize for invention of bipolar transistors</td>
</tr>
<tr>
<td>1958</td>
<td>Integrated circuit developed simultaneously by Kilby at Texas Instruments and Noyce and Moore at Fairchild Semiconductor</td>
</tr>
<tr>
<td>1961</td>
<td>First commercial digital IC available from Fairchild Semiconductor</td>
</tr>
<tr>
<td>1963</td>
<td>AIEE and IRE merge to become the Institute of Electrical and Electronic Engineers (IEEE): Your Professional Society!</td>
</tr>
<tr>
<td>1967</td>
<td>First semiconductor RAM (64 bits) discussed at the IEEE International Solid-State Circuits Conference (ISSCC)</td>
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<tr>
<td>1968</td>
<td>First commercial IC operational amplifier—the μA-700—introduced by Fairchild Semiconductor</td>
</tr>
<tr>
<td>1970</td>
<td>One-transistor dynamic memory cell invented by Dennard at IBM</td>
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<tr>
<td>1971</td>
<td>4004 microprocessor introduced by Intel</td>
</tr>
<tr>
<td>1972</td>
<td>First 8-bit microprocessor—the 8008—introduced by Intel</td>
</tr>
<tr>
<td>1974</td>
<td>First commercial 1-kilobit memory chip developed</td>
</tr>
<tr>
<td>1974</td>
<td>8080 microprocessor introduced</td>
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<tr>
<td>1978</td>
<td>First 16-bit microprocessor developed</td>
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<tr>
<td>1984</td>
<td>Megabit memory chip introduced</td>
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<tr>
<td>1995</td>
<td>Experimental gigabit memory chip presented at the IEEE ISSCC</td>
</tr>
</tbody>
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The Old Days

after Jaeger, Introduction to Microelectronic Fabrication, 2002
Today!

John D. Cressler
ECE 8853

after Jaeger, Introduction to Microelectronic Fabrication, 2002
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A Feel for the Numbers

Features:
- heavily-doped polysilicon emitter contact
- emitter widths < 30 nm
- base widths < 100 nm using ion-implantation
- selectively ion-implanted collector (epi < 0.5 μm)
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after Pierret, Semiconductor Device Fundamentals, 1996
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\[ I_E = I_{PE} + I_{AE} + I_R \]
\[ I_B = I_{PB} + I_R + (I_{AB} - I_{AC}) - I_{CO} \]
\[ I_C = I_{AC} + I_{CO} \]

\[ I_E + I_B + I_C = 0 \]
"Gummel Characteristics"

Collector and Base Currents (A)

- $A_E = 0.8 \times 2.5 \, \mu m^2$
- $R_{BI} = 5 - 8 \, k\Omega$
- $V_{CB} = 0.0 \, V$

SiGe HBT

Si BJT

4.51x

Emitter–Base Voltage (V)