Chapter 18  Electrical properties

- Electrical conduction of semiconductor
- Factors influence carrier mobility
- Semiconductor devices
- Electrical conduction of ionic crystals and polymers

Temperature dependence of electric conductivity

- Carrier concentration vs T for intrinsic semiconductor
Temperature dependence of electric conductivity

- Carrier concentration vs T for extrinsic semiconductor
  - for $T < 100K$: “freeze-out” thermal energy insufficient to excite electrons.
  - for $150K < T < 450K$: “extrinsic”
  - for $T >> 450K$: “intrinsic”

Factors that affect carrier mobility

- Influence of dopant content
Factors that affect carrier mobility

- Influence of temperature

Hole mobilities for silicon with acceptor concentrations

Semiconductor devices

- Advantages of SC devices
  - small size
  - low power consumption
  - no warm up time

- A rectifier(diode): an electronic device that allows the current to flow in one direction
Semiconductor devices

- Allows flow of electrons in one direction only
  No applied potential: no net current flow
- Forward bias: positive terminal is connected to the positive side
  Carrier flow through p-type and n-type regions; holes and electrons recombine at p-n junction; current flows.
- Reverse bias: negative terminal is connected to the positive side
  Carrier flow away from p-n junction; carrier conc. greatly reduced at junction; little current flow.

Semiconductor devices (cont.)

- Current-voltage characteristics of a p-n junction for forward and reverse bias

The current-voltage characteristics of a p-n junction for forward and reverse biases
To convert alternating current to direct current
(a) input voltage
(b) output current after a rectifier

Voltage versus time for the input to a p-n rectifying junction

**p-n-p junction transistor**

Forward-biasing voltage

Input voltage

Load

Output voltage

Reverse-biasing voltage

Emitter

Collector

Base

Input voltage

Output voltage

Time

Time
Semiconductor devices (cont.)

- **p-n-p junction transistor**
  - Schematic cross-sectional view of MOSFET transistor

  ![Schematic of p-n-p junction transistor](image1.png)

- **Metal-oxide-semiconductor field-effect transistor (MOSFET)**
  - Schematic cross-sectional view of MOSFET transistor

  ![Schematic of MOSFET transistor](image2.png)
Integrated circuit

- The limits with individual transistor
- Integrated circuit
  - 1958-59
  - Jack Kilby at Texas Instruments
  - Moore’s law: the number of transistors per unit area has been doubling every 1.5 years
  - Gordon Moore: one of the early integrated circuit pioneers and founders of Intel Corporation
  - The Nobel Prize in Physics 2000 was awarded to Jack Kilby for the invention of the integrated circuit.

Electrical conduction in other materials

- Electrical conduction in ionic ceramics
- Electrical conduction in polymers

<table>
<thead>
<tr>
<th>Material</th>
<th>Electrical Conductivity [S·m⁻¹]</th>
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<tbody>
<tr>
<td>Graphite</td>
<td>$3 \times 10^5$ to $2 \times 10^7$</td>
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<tr>
<td>Ceramics</td>
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<tr>
<td>Concrete (dry)</td>
<td>$10^{-13}$</td>
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<tr>
<td>Soda-lime glass</td>
<td>$10^{-14}$ to $10^{-12}$</td>
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<tr>
<td>Potash</td>
<td>$10^{-11}$ to $10^{-10}$</td>
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<tr>
<td>Beryllium glass</td>
<td>$&lt;10^{-10}$</td>
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<tr>
<td>Aluminum-oxide</td>
<td>$&lt;10^{-10}$</td>
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<tr>
<td>Fused silica</td>
<td>$&lt;10^{-10}$</td>
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<tr>
<td>Polymers</td>
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<tr>
<td>Polyethylene</td>
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<tr>
<td>Poly(methyl methacrylate)</td>
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<td>Styrene</td>
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Electrical conduction in conducting polymers
## Summary

- Electrical **conductivity** and **resistivity** are:
  -- material parameters.
  -- geometry independent.
- Electrical **resistance** is:
  -- a geometry and material dependent parameter.
- Conductors, semiconductors, and insulators...
  -- differ in accessibility of energy states for conductance electrons.
- For metals, conductivity is increased by
  -- reducing deformation
  -- reducing imperfections
  -- decreasing temperature.
- For pure semiconductors, conductivity is increased by
  -- increasing temperature
  -- doping (e.g., adding B to Si ($p$-type) or P to Si ($n$-type)).