Chapter 1: Semiconductor Diodes

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The Zener region is in the diode’s reverse-bias region. At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.

- The maximum reverse voltage that won’t take a diode into the zener region is called the peak inverse voltage (PIV) or peak reverse voltage (PRV).
- The voltage that causes a diode to enter the zener region of operation is called the zener voltage ($V_Z$).
The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the $p-n$ junction. This energy comes from the external voltage applied across the diode.

The forward bias voltage required for a:

- gallium arsenide diode $\approx 1.2$ V
- silicon diode $\approx 0.7$ V
- germanium diode $\approx 0.3$ V
Comparison Ge, Si, GaAs
Temperature Effects

As temperature increases it adds energy to the diode.

- It reduces the required forward bias voltage for forward-bias conduction.
- It increases the amount of reverse current in the reverse-bias condition.

Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.
Temperature Effects

The diagram shows the relationship between temperature and current. As the temperature increases, the current also increases. The graph includes temperature points at 125°C, 25°C, and 75°C, with corresponding current values. The equation for the temperature effect is given as:

\[(100°C)(-2.5 \text{ mV/°C}) = -0.35 \text{ V}\]

The diagram also illustrates the effect of increasing and decreasing temperature on the current flow.
Semiconductors react differently to DC and AC currents. There are three types of resistance:

- **DC (static) resistance**
- **AC (dynamic) resistance**
- **Average AC resistance**
DC (Static) Resistance

For a specific applied DC voltage $V_D$, the diode has a specific current $I_D$, and a specific resistance $R_D$.

$$R_D = \frac{V_D}{I_D}$$
The dynamic resistance is the resistance offered by the diode to the AC signal. It is equal to the slope of the $VI$ characteristics ($dV/dI$ or $\Delta V / \Delta I$),

$$r_D = \frac{\text{change in voltage}}{\text{resulting change in current}} = \frac{dV}{dI} = \frac{\Delta V}{\Delta I}$$
AC (Dynamic) Resistance

\[ I_D = I_s \left(e^{V_D/nV_T} - 1\right), \quad \frac{dI_D}{dV_D} = \frac{I_s}{nV_T} e^{V_D/nV_T} \]

\[ \frac{dI_D}{dV_D} = \frac{1}{nV_T} \left(I_D + I_s\right), \quad \text{since } I_D \gg I_s, \quad \frac{dI_D}{dV_D} \approx \frac{I_D}{nV_T} \]

\[ \frac{dV_D}{dI_D} = r_D = \frac{nV_T}{I_D} \]

for \ n=1, and at room temperature of 27°C, \ T=273+27=300K

\[ V_T = \frac{KT}{q} = \left(1.38 \times 10^{-23}\right) \frac{1.6 \times 10^{-19}}{26mV} \approx 26mV \]

\[ r_D = \frac{26mV}{I_D} \]
AC (Dynamic) Resistance

In the forward bias region:  \[ r_d' = \frac{26 \text{ mV}}{I_D} + r_B \]

- The resistance depends on the amount of current \((I_D)\) in the diode.
- \(r_D = 26 \text{ mV}/I_D\) is the resistance of the p-n junction and does not include the resistance of the semiconductor material itself (the body resistance).
- \(r_B\) is added to account for body resistance and it ranges from a typical 0.1 \(\Omega\) to 2 \(\Omega\).

In the reverse bias region:

\[ r_d' = \infty \]

The resistance is effectively infinite. The diode acts like an open.
**Average AC Resistance**

\[ r_{av} = \frac{\Delta V_d}{\Delta I_d} \mid \text{pt. to pt.} \]

AC resistance can be calculated using the current and voltage values for two points on the diode characteristic curve.
Diode Equivalent Circuit
Diode Specification Sheets

Data about a diode is presented uniformly for many different diodes.

1. Forward Voltage ($V_F$) at a specified current and temperature
2. Maximum forward current ($I_F$) at a specified temperature
3. Reverse saturation current ($I_R$) at a specified voltage and temperature
4. Reverse voltage rating, PIV or PRV or V(BR), at a specified temperature
5. Maximum power dissipation at a specified temperature
6. Capacitance levels
7. Reverse recovery time, $t_{rr}$ (is the time required for a diode to stop conducting once it is switched from forward bias to reverse bias)
8. Operating temperature range
Diode Specification Sheets

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Characteristic</th>
<th>BAY73</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>( V_T ) Forward Voltage</td>
<td>0.85</td>
<td>1.00</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.81</td>
<td>0.94</td>
<td>V</td>
</tr>
<tr>
<td></td>
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<td>0.78</td>
<td>0.88</td>
<td>V</td>
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<td></td>
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<td>0.69</td>
<td>0.80</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.67</td>
<td>0.75</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.60</td>
<td>0.68</td>
<td>V</td>
</tr>
<tr>
<td>F</td>
<td>( I_R ) Reverse Current</td>
<td>500</td>
<td>nA</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>( \mu \text{A} )</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.2</td>
<td>nA</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
<td>nA</td>
<td>V</td>
</tr>
<tr>
<td>G</td>
<td>( C ) Capacitance</td>
<td>125</td>
<td>V</td>
<td>I_R = 100 ( \mu \text{A} )</td>
</tr>
<tr>
<td>H</td>
<td>( t_r ) Reverse Recovery Time</td>
<td>8.0</td>
<td>pF</td>
<td>V</td>
</tr>
</tbody>
</table>

**NOTES:**
1. These ratings are limiting values above which the serviceability of the diode may be impaired.
2. These are steady state limits. The factory should be consulted on applications involving pulses or low duty-cycle operation.
The anode is abbreviated A

The cathode is abbreviated K

Anode (+)  Cathode (−)
Diode Testing - Ohmmeter

An ohmmeter set on a low Ohms scale can be used to test a diode. The diode should be tested out of circuit.
Other Types of Diodes

Zener diode
Light-emitting diode
Diode arrays
A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener voltage" ($V_Z$).

Common Zener voltages are between 1.8 V and 200 V.

Zener diode is used as regulator (circuits will be shown in chapter 2).
**Light-Emitting Diode (LED)**

- An LED emits photons when it is forward biased.
- These can be in the infrared or visible spectrum.
- The forward bias voltage is usually in the range of 2 V to 5 V.

**Light-Emitting Diodes**

<table>
<thead>
<tr>
<th>Color</th>
<th>Construction</th>
<th>Typical Forward Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amber</td>
<td>AlInGaP</td>
<td>2.1</td>
</tr>
<tr>
<td>Blue</td>
<td>GaN</td>
<td>5.0</td>
</tr>
<tr>
<td>Green</td>
<td>GaP</td>
<td>2.2</td>
</tr>
<tr>
<td>Orange</td>
<td>GaAsP</td>
<td>2.0</td>
</tr>
<tr>
<td>Red</td>
<td>GaAsP</td>
<td>1.8</td>
</tr>
<tr>
<td>White</td>
<td>GaN</td>
<td>4.1</td>
</tr>
<tr>
<td>Yellow</td>
<td>AlInGaP</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Multiple diodes can be packaged together in an integrated circuit (IC).

A variety of combinations exist.