Microwave Solid State Devices

[Chapter 10]

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Purposes for Microwave Semiconductor Devices

It has been developed since 1960 for;
- Detection
- Mixing
- Frequency Multiplication
- Phase Shifting
- Attenuating
- Switching
- Limiting
- Amplification
- Oscillation

In most low power applications, solid state devices have replaced electron beam devices because of the advantages of their;
- Small size
- Light weight
- Low cost and
- High Reliability
- Capability of being incorporated into microwave integrated circuits
Classification of Microwave Diodes and its Application

Crystal Diodes and Schottky Diodes: For Mixing and Detection

PIN Diode: For Attenuation, Modulation, Switching, Phase shifting and limiting

Varactor Diode: For Frequency Multiplication, Parametric amplification and tuning.

Tunnel Diode and Gun Diode: For Oscillation

Read Diodes (IMPATT, TRAPATT and BARITT): For Amplification and Oscillation

- IMPATT - Impact Ionization Avalanche Transit Time effect
- TRAPATT - Trapped Plasma Avalanche Triggered Transit effect
- BARITT - Barrier Injected Transit Time effect
Crystal Diode

Tungsten Wire almost 0.08 mm diameter, P type spring
Wafer almost 1.6 mm square with suitably doped
$L_s$ and $R_s$ is Series Lead Inductance and Resistance
$R_j$ and $C_j$ is the effective Resistance and Capacitance ($R_j$ is small for forward bias and large for reverse bias)
$C_c$ is the case capacitance
$L_s$ and $C_c$ can be tuned out by matching element
**Schottky Diode**

$L_s$ is the inductance of gold whisker wire (0.4 – 0.9 nH)

$R_s$ is bulk resistance of heavy doped Si substrate (4-6 ohm)

$R_j$ is the resistance of metallic Junction

$C_j$ is the barrier Capacitance (0.3 – 0.5 pF)

$C_c$ is the case capacitance
Avalanche Transit–Time Devices (ATTD)

Avalanche transit time devices (W T Read, 1958) are p-n junction diode with the highly doped p and n regions. They could produce a negative resistance at microwave frequencies by using a carrier impact ionization avalanche breakdown and carriers drift in the high field intensity region under reverse biased condition. There are three types of this devices:

- Impact Ionization Avalanche Transit Time effect (IMPATT)
- Trapped Plasma Avalanche Triggered Transit (TRAPATT) effect and
- Barrier Injected Transit Time (BARITT) effect.

The IMPATT diodes have an efficiency of the order of 3% CW power and 60 % pulsed power and can be operated from 500 MHz to 100 GHz. The power outputs lie between 1W (CW) and over 400 W (pulsed). TRAPATT is suitable for low frequency (1-3 GHz) applications with pulsed power output of several hundred watts and efficiency 20-60%. BARITT has the advantage of low–noise figures (<15) but with low power and smaller bandwidth.
## Comparison among Gunn, IMPATT, TRAPATT and BARITT

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Gunn</th>
<th>IMPATT</th>
<th>TRAPATT</th>
<th>BARITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>1-100 GHz</td>
<td>0.5-100 GHz</td>
<td>1-10 GHz</td>
<td>4-8 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2% of center frequency</td>
<td>1/10th of Center frequency</td>
<td>Narrow</td>
<td></td>
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<tr>
<td>Power Output</td>
<td>A few watts (CW), 100-200W (Pulsed)</td>
<td>1 W (CW), 400W (Pulsed)</td>
<td>Several 100 W (Pulsed)</td>
<td>Low (mW)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>3% CW, 60% Pulsed</td>
<td>20-60% Pulsed</td>
<td>Low (2%)</td>
<td></td>
</tr>
<tr>
<td>Noise Figure</td>
<td>High (30dB)</td>
<td>High (60dB)</td>
<td>Less noisy than IMPATT (&lt;15dB)</td>
<td></td>
</tr>
<tr>
<td>Applications</td>
<td>Oscillator</td>
<td>Oscillator, Amplifier</td>
<td>Oscillator</td>
<td>Local Oscillator</td>
</tr>
<tr>
<td>Basic Semiconductors</td>
<td>GaAs</td>
<td>Si, Ge, GaAs</td>
<td>Si</td>
<td>Si/metal</td>
</tr>
<tr>
<td>Harmonics</td>
<td>Less</td>
<td>Strong</td>
<td>Less</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>Constructions</td>
<td>GaAs single Crystal</td>
<td>Reverse bias p-n</td>
<td>p-n-p or p-n-i-p</td>
<td></td>
</tr>
</tbody>
</table>
Characteristics of Tunnel Diode

Fig. 10.32 Tunnel diodes and I-V characteristics (a) Symbol, (b) Energy level diagram (c) I-V characteristics
## Comparison between Tunnel Diode and Normal Diode

<table>
<thead>
<tr>
<th><strong>Tunnel Diode</strong></th>
<th><strong>Normal p-n Diode</strong></th>
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<tbody>
<tr>
<td>Doping levels at p and n are very high</td>
<td>Doping is normal in both p and n sides</td>
</tr>
<tr>
<td>Tunneling currents consists of majority carrier-electrons from n side to p side.</td>
<td>Currents consists of minority carrier-holes from p side to n side.</td>
</tr>
<tr>
<td>Majority carrier current responds much faster to voltage changes-suitable to microwaves.</td>
<td>Majority carrier current dose not responds so fast to voltage changes-suitable for low frequency applications only.</td>
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<tr>
<td>Low power device.</td>
<td>Lower power device</td>
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<tr>
<td>Shows negative resistance characteristics-useful for reflection amplifiers and oscillators.</td>
<td>Does not show negative resistance characteristics-used as detector and mixers.</td>
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<tr>
<td>It is a low noise device.</td>
<td>Moderate noise characteristics.</td>
</tr>
<tr>
<td>Preferred semiconductors are Ge and GaAs</td>
<td>Preferred semiconductors are Ge and Si.</td>
</tr>
<tr>
<td>At a small values of reverse voltage a large current flows due to considerable overlap between conduction band and valance band-useful as frequency converter.</td>
<td>Current is extremely small (Leakage current) up to considerable reverse bias voltage and then increases abruptly to extremely high at particular voltage called breakdown voltage.</td>
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</table>
Fig. 11.19 (a) Rotational and vibrational losses due to polarisation change in food molecules in microwaves (b) Microwave oven (c) Choke in microwave oven
Fig. 11.19 (a) Rotational and vibrational losses due to polarisation change in food molecules in microwaves (b) Microwave oven (c) Choke in oven door
Fig. 10.25  Types of IMPATT diodes and doping profile
Construction and package of $p^+ n n^+$ IMPATT diode
Fig. 10.27  IMPATT diode operation
Fig. 10.31  TRAPATT diode