**Forward Biased Diode**

- Minority carrier injection
- $\lambda = 1/(26 \text{ mV})$ at 300 K
- $\tau_r = \text{minority carrier lifetime}$
- (above equations don't include current that charges depletion region capacitance)

Diode Stored Charge

The diode equation:

$$q(t) = Q_0 \left( e^{\lambda \beta(t)} - 1 \right)$$

Charge control equation:

$$\frac{dq(t)}{dt} = i(t) - \frac{q(t)}{\tau_L}$$

With:

- $\lambda = 1/(26 \text{ mV})$ at 300 K
- $\tau_r = \text{minority carrier lifetime}$

In equilibrium: $dq/dt = 0$, and hence

$$i(t) = \frac{q(t)}{\tau_L} = \frac{Q_0}{\tau_L} \left( e^{\lambda \beta(t)} - 1 \right) = I_0 \left( e^{\lambda \beta(t)} - 1 \right)$$

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Chapter 4: Switch realization
Diode Reverse Recovery

Energy loss shows up in MOSFET

\[ E = \int i_d \text{d}t = V \left( i_{L_{\text{err}}} + Q_t \right) \]

\[ P_{\text{diode}} = V \left( i_{L_{\text{err}}} + Q_t \right) f_s \]

Datasheet RR Characteristics

Fig. 10 - Typical Stored Charge vs. \( \frac{\text{d}i}{\text{d}t} \)

Fig. 9 - Typical Reverse Recovery Time vs. \( \frac{\text{d}i}{\text{d}t} \)
Types of Power Diodes

- **Standard recovery**
  Reverse recovery time not specified, intended for 50/60Hz

- **Fast recovery and ultra-fast recovery**
  Reverse recovery time and recovered charge specified
  Intended for converter applications

- **Schottky diode**
  A majority carrier device
  Essentially no recovered charge
  Model with equilibrium i-v characteristic, in parallel with
depletion region capacitance
  Restricted to low voltage (few devices can block 100V or more)

Paralleling Diodes

Attempts to parallel diodes, and share the current so that \( i_1 = i_2 = i/2 \), generally don't work.

- **Reason**: thermal instability caused by temperature dependence of the diode equation.
- Increased temperature leads to increased current, or reduced voltage.
- One diode will hog the current.

To get the diodes to share the current, heroic measures are required:
- Select matched devices
- Package on common thermal substrate
- Build external circuitry that forces the currents to balance
Schottky Diode

<table>
<thead>
<tr>
<th>$L$</th>
<th>$C_{out}$</th>
<th>$f_s$</th>
<th>Diode</th>
<th>$\eta$ (Sim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22uH</td>
<td>22uF</td>
<td>202k</td>
<td>Si (FR)</td>
<td>93.9%</td>
</tr>
<tr>
<td>22uH</td>
<td>22uF</td>
<td>202k</td>
<td>Si Schottky</td>
<td>96.9%</td>
</tr>
</tbody>
</table>

Simulation Waveforms
Switching Transition

Power MOSFET