Bipolar Processes

- Comparison of MOS and Bipolar Process
- Parasitic Devices in CMOS Processes
- JFET

Special Bipolar Processes

- Thyristors
  - SCR
  - TRIAC
Exam Schedule

Exam 2  Friday March 24
Two-port representation of amplifiers

- Thevenin equivalent output port often more standard
- $R_{\text{IN}}$, $A_V$, and $R_{\text{OUT}}$ often used to characterize the two-port of amplifiers
Topical Coverage Change

Will have several additional lectures on amplifier structures but will temporarily suspend discussion of amplifiers to consider Thyristors

This is being done so that the Thyristor laboratory experiments can be conducted this week
Review from a Previous Lecture

vertical npn

lateral pnp

A-A’ Section

B-B’ Section
Review from Previous Lecture

B-B’ Section

p-channel JFET
Review from Previous Lecture

vertical npn

lateral pnp
Review from Previous Lecture

- Diode (capacitor)
- Resistor
- p-channel JFET

Diagram showing the components and their connections.
Will consider next the JFET but first some additional information about MOS Devices

Enhancement and Depletion MOS Devices

- Enhancement Mode n-channel devices
  \[ V_T > 0 \]

- Enhancement Mode p-channel devices
  \[ V_T < 0 \]

- Depletion Mode n-channel devices
  \[ V_T < 0 \]

- Depletion Mode p-channel devices
  \[ V_T > 0 \]
Enhancement and Depletion MOS Devices

- Depletion mode devices require only one additional mask step.
- Older n-mos and p-mos processes usually had a depletion device and an enhancement device.
- Depletion devices usually not available in CMOS because applications usually do not justify the small increasing costs in processing.
The JFET

With $V_{GS}=0$, channel exists under gate between D and S

Under sufficiently large reverse bias (depletion region widens and channel disappears - “pinches off”)
The JFET

Under smaller reverse bias (depletion region widens and channel thins)
The JFET

Under small reverse bias and large negative $V_{DS}$ (channel pinches off)
The JFET

n-channel

p-channel

Square-law model of p-channel JFET

\[ I_D = \begin{cases} 
0 & V_{GS} > V_P \\
\frac{2I_{DSS}}{V_P^2} \left( V_{GS} - V_P - \frac{V_{DS}}{2} \right) V_{DS} & \text{for } -0.3 < V_{GS} < V_P \\
I_{DSS} \left( 1 - \frac{V_{GS}}{V_P} \right)^2 & \text{for } V_{GS} + 0.3 > V_{DS} > V_{GS} - V_P \\
& \text{for } V_{DS} < V_{GS} - V_P 
\end{cases} \]

(I_{DSS} carries negative sign)

- Functionally identical to the square-law model of MOSFET
- Parameters \( I_{DSS} \) and \( V_P \) characterize the device
- \( I_{DSS} \) proportional to \( W/L \) where \( W \) and \( L \) are width and length of n+ diff
- \( V_P \) is negative for n-channel device, positive for p-channel device thus JFET is depletion mode device
- Must not forward bias GS junction by over about 300mV or excessive base current will flow (red constraint)
- Widely used as input stage for bipolar op amps
The JFET

n-channel JFET

p-channel JFET

Square-law model of n-channel JFET

\[
I_D = \begin{cases} 
0 & V_{GS} < V_P \\
\frac{2I_{DSS}}{V_P^2} \left( V_{GS} - V_P - \frac{V_{DS}}{2} \right) V_{DS} & 0.3 > V_{GS} > V_P \quad V_{GS} - 0.3 < V_{DS} < V_{GS} - V_P \\
I_{DSS} \left( 1 - \frac{V_{GS}}{V_P} \right)^2 & 0.3 > V_{GS} > V_P \quad V_{DS} > V_{GS} - V_P
\end{cases}
\]

- Functionally identical to the square-law model of MOSFET
- Parameters $I_{DSS}$ and $V_P$ characterize the device
- $I_{DSS}$ proportional to $W/L$ where $W$ and $L$ are width and length of n+ diff
- $V_P$ is negative for n-channel device, positive for p-channel device thus JFET is depletion mode device
- Must not forward bias GS junction by over about 300mV or excessive base current will flow (red constraint)
- Widely used as input stage for bipolar op amps
The Schottky Diode

- Metal-Semiconductor Junction
- One contact is ohmic, other is rectifying
- Not available in all processes
- Relatively inexpensive adder in some processes
- Lower cut-in voltage than pn junction diode
- High speed
The MESFET

- Metal-Semiconductor Junction for Gate
- Drain and Source contacts ohmic, other is rectifying
- Usually not available in standard CMOS processes
- Must not forward bias very much
- Lower cut-in voltage than pn junction diode
- High speed
Consider a Bulk-CMOS Process

Have formed a lateral pn-pn-pn device!
Will spend some time studying pn-pn-pn devices
MOS and Bipolar Area Comparisons

How does the area required to realize a MOSFET compare to that required to realize a BJT?

Will consider a minimum-sized device in both processes
### TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5 \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$n^+$ buried collector diffusion (Yellow, Mask #1)</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Width</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>1.2</td>
<td>Overlap of p-base diffusion (for vertical npn)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>1.3</td>
<td>Overlap of $n^+$ emitter diffusion (for collector contact of vertical npn)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>1.4</td>
<td>Overlap of p-base diffusion (for collector and emitter of lateral pnp)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>1.5</td>
<td>Overlap of $n^+$ emitter diffusion (for base contact of lateral pnp)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>2.</td>
<td>Isolation diffusion (Orange, Mask #2)</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Width</td>
<td>$4\lambda$</td>
</tr>
<tr>
<td>2.2</td>
<td>Spacing</td>
<td>$24\lambda$</td>
</tr>
<tr>
<td>2.3</td>
<td>Distance to $n^+$ buried collector</td>
<td>$14\lambda$</td>
</tr>
<tr>
<td>3.</td>
<td>p-base diffusion (Brown, Mask #3)</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Width</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>3.2</td>
<td>Spacing</td>
<td>$5\lambda$</td>
</tr>
<tr>
<td>3.3</td>
<td>Distance to isolation diffusion</td>
<td>$14\lambda$</td>
</tr>
<tr>
<td>3.4</td>
<td>Width (resistor)</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>3.5</td>
<td>Spacing (as resistor)</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>4.</td>
<td>$n^+$ emitter diffusion (Green, Mask #4)</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Width</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>4.2</td>
<td>Spacing</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>4.3</td>
<td>p-base diffusion overlap of $n^+$ emitter diffusion (emitter in base)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>4.4</td>
<td>Spacing to isolation diffusion (for collector contact)</td>
<td>$12\lambda$</td>
</tr>
<tr>
<td>4.5</td>
<td>Spacing to p-base diffusion (for base contact of lateral pnp)</td>
<td>$6\lambda$</td>
</tr>
<tr>
<td>4.6</td>
<td>Spacing to p-base diffusion (for collector contact of vertical npn)</td>
<td>$6\lambda$</td>
</tr>
</tbody>
</table>
5. Contact (Black, Mask #5)
   5.1 Size (exactly) \(4\lambda \times 4\lambda\)
   5.2 Spacing \(2\lambda\)
   5.3 Metal overlap of contact \(\lambda\)
   5.4 n\(^+\) emitter diffusion overlap of contact \(2\lambda\)
   5.5 p-base diffusion overlap of contact \(2\lambda\)
   5.6 p-base to n\(^+\) emitter \(3\lambda\)
   5.7 Spacing to isolation diffusion \(4\lambda\)

6. Metalization (Blue, Mask #6)
   6.1 Width \(2\lambda\)
   6.2 Spacing \(2\lambda\)
   6.3 Bonding pad size \(100 \mu \times 100 \mu\)
   6.4 Probe pad size \(75 \mu \times 75 \mu\)
   6.5 Bonding pad separation \(50 \mu\)
   6.6 Bonding to probe pad \(30 \mu\)
   6.7 Probe pad separation \(30 \mu\)
   6.8 Pad to circuitry \(40 \mu\)
   6.9 Maximum current density \(0.8 \text{ mA/} \mu \text{ width}\)

7. Passivation (Purple, Mask #7)
   7.1 Minimum bonding pad opening \(90 \mu \times 90 \mu\)
   7.2 Minimum probe pad opening \(65 \mu \times 65 \mu\)
Consider Initially the Emitter in the BJT surrounded by a base region
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>n^+ buried collector diffusion (Yellow, Mask #1)</td>
<td>Dimension</td>
</tr>
<tr>
<td></td>
<td>1.1 Width</td>
<td>3λ</td>
</tr>
<tr>
<td></td>
<td>1.2 Overlap of p-base diffusion (for vertical npn)</td>
<td>2λ</td>
</tr>
<tr>
<td></td>
<td>1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)</td>
<td>2λ</td>
</tr>
<tr>
<td></td>
<td>1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)</td>
<td>2λ</td>
</tr>
<tr>
<td></td>
<td>1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)</td>
<td>2λ</td>
</tr>
<tr>
<td>2.</td>
<td>Isolation diffusion (Orange, Mask #2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.1 Width</td>
<td>4λ</td>
</tr>
<tr>
<td></td>
<td>2.2 Spacing</td>
<td>24λ</td>
</tr>
<tr>
<td></td>
<td>2.3 Distance to n^+ buried collector</td>
<td>14λ</td>
</tr>
<tr>
<td>3.</td>
<td>p-base diffusion (Brown, Mask #3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.1 Width</td>
<td>3λ</td>
</tr>
<tr>
<td></td>
<td>3.2 Spacing</td>
<td>5λ</td>
</tr>
<tr>
<td></td>
<td>3.3 Distance to isolation diffusion</td>
<td>14λ</td>
</tr>
<tr>
<td></td>
<td>3.4 Width (resistor)</td>
<td>3λ</td>
</tr>
<tr>
<td></td>
<td>3.5 Spacing (as resistor)</td>
<td>3λ</td>
</tr>
<tr>
<td>4.</td>
<td>n^+ emitter diffusion (Green, Mask #4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.1 Width</td>
<td>3λ</td>
</tr>
<tr>
<td></td>
<td>4.2 Spacing</td>
<td>3λ</td>
</tr>
<tr>
<td></td>
<td>4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)</td>
<td>2λ</td>
</tr>
<tr>
<td></td>
<td>4.4 Spacing to isolation diffusion (for collector contact)</td>
<td>12λ</td>
</tr>
<tr>
<td></td>
<td>4.5 Spacing to p-base diffusion (for base contact of lateral pnp)</td>
<td>6λ</td>
</tr>
<tr>
<td></td>
<td>4.6 Spacing to p-base diffusion (for collector contact of vertical npn)</td>
<td>6λ</td>
</tr>
</tbody>
</table>
5. Contact (Black, Mask #5)
   5.1 Size (exactly)  
   5.2 Spacing  
   5.3 Metal overlap of contact  
   5.4 n\textsuperscript{+} emitter diffusion overlap of contact  
   5.5 p-base diffusion overlap of contact  
   5.6 p-base to n\textsuperscript{+} emitter  
   5.7 Spacing to isolation diffusion  
   
\[4\lambda \times 4\lambda\]  
\[2\lambda\]  
\[\lambda\]  
\[2\lambda\]  
\[2\lambda\]  
\[3\lambda\]  
\[4\lambda\]  

6. Metalization (Blue, Mask #6)
   6.1 Width  
   6.2 Spacing  
   6.3 Bonding pad size  
   6.4 Probe pad size  
   6.5 Bonding pad separation  
   6.6 Bonding to probe pad  
   6.7 Probe pad separation  
   6.8 Pad to circuitry  
   6.9 Maximum current density  
   
\[2\lambda\]  
\[2\lambda\]  
\[100 \, \mu \times 100 \, \mu\]  
\[75 \, \mu \times 75 \, \mu\]  
\[50 \, \mu\]  
\[30 \, \mu\]  
\[30 \, \mu\]  
\[40 \, \mu\]  
\[0.8 \, \text{mA/\mu width}\]  

7. Passivation (Purple, Mask #7)
   7.1 Minimum bonding pad opening  
   7.2 Minimum probe pad opening  
   
\[90 \, \mu \times 90 \, \mu\]  
\[65 \, \mu \times 65 \, \mu\]
From design rules (left to right) 4.3, 5.1, 5.4, 5.6, 5.5
TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5 \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

<table>
<thead>
<tr>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. n$^+$ buried collector diffusion (Yellow, Mask #1)</td>
</tr>
<tr>
<td>1.1 Width</td>
</tr>
<tr>
<td>1.2 Overlap of p-base diffusion (for vertical npn)</td>
</tr>
<tr>
<td>1.3 Overlap of n$^+$ emitter diffusion (for collector contact of vertical npn)</td>
</tr>
<tr>
<td>1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)</td>
</tr>
<tr>
<td>1.5 Overlap of n$^+$ emitter diffusion (for base contact of lateral pnp)</td>
</tr>
<tr>
<td>2. Isolation diffusion (Orange, Mask #2)</td>
</tr>
<tr>
<td>2.1 Width</td>
</tr>
<tr>
<td>2.2 Spacing</td>
</tr>
<tr>
<td>2.3 Distance to n$^+$ buried collector</td>
</tr>
<tr>
<td>3. p-base diffusion (Brown, Mask #3)</td>
</tr>
<tr>
<td>3.1 Width</td>
</tr>
<tr>
<td>3.2 Spacing</td>
</tr>
<tr>
<td>3.3 Distance to isolation diffusion</td>
</tr>
<tr>
<td>3.4 Width (resistor)</td>
</tr>
<tr>
<td>3.5 Spacing (as resistor)</td>
</tr>
<tr>
<td>4. n$^+$ emitter diffusion (Green, Mask #4)</td>
</tr>
<tr>
<td>4.1 Width</td>
</tr>
<tr>
<td>4.2 Spacing</td>
</tr>
<tr>
<td>4.3 p-base diffusion overlap of n$^+$ emitter diffusion (emitter in base)</td>
</tr>
<tr>
<td>4.4 Spacing to isolation diffusion (for collector contact)</td>
</tr>
<tr>
<td>4.5 Spacing to p-base diffusion (for base contact of lateral pnp)</td>
</tr>
<tr>
<td>4.6 Spacing to p-base diffusion (for collector contact of vertical npn)</td>
</tr>
</tbody>
</table>
Add n+ buried for collector

From design rule 1.2
TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5 \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

<table>
<thead>
<tr>
<th></th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>n$^+$ buried collector diffusion (Yellow, Mask #1)</td>
</tr>
<tr>
<td>1.1</td>
<td>Width</td>
</tr>
<tr>
<td>1.2</td>
<td>Overlap of p-base diffusion (for vertical npn)</td>
</tr>
<tr>
<td>1.3</td>
<td>Overlap of n$^+$ emitter diffusion (for collector contact of vertical npn)</td>
</tr>
<tr>
<td>1.4</td>
<td>Overlap of p-base diffusion (for collector and emitter of lateral pnp)</td>
</tr>
<tr>
<td>1.5</td>
<td>Overlap of n$^+$ emitter diffusion (for base contact of lateral pnp)</td>
</tr>
<tr>
<td>2.</td>
<td>Isolation diffusion (Orange, Mask #2)</td>
</tr>
<tr>
<td>2.1</td>
<td>Width</td>
</tr>
<tr>
<td>2.2</td>
<td>Spacing</td>
</tr>
<tr>
<td>2.3</td>
<td>Distance to n$^+$ buried collector</td>
</tr>
<tr>
<td>3.</td>
<td>p-base diffusion (Brown, Mask #3)</td>
</tr>
<tr>
<td>3.1</td>
<td>Width</td>
</tr>
<tr>
<td>3.2</td>
<td>Spacing</td>
</tr>
<tr>
<td>3.3</td>
<td>Distance to isolation diffusion</td>
</tr>
<tr>
<td>3.4</td>
<td>Width (resistor)</td>
</tr>
<tr>
<td>3.5</td>
<td>Spacing (as resistor)</td>
</tr>
<tr>
<td>4.</td>
<td>n$^+$ emitter diffusion (Green, Mask #4)</td>
</tr>
<tr>
<td>4.1</td>
<td>Width</td>
</tr>
<tr>
<td>4.2</td>
<td>Spacing</td>
</tr>
<tr>
<td>4.3</td>
<td>p-base diffusion overlap of n$^+$ emitter diffusion (emitter in base)</td>
</tr>
<tr>
<td>4.4</td>
<td>Spacing to isolation diffusion (for collector contact)</td>
</tr>
<tr>
<td>4.5</td>
<td>Spacing to p-base diffusion (for base contact of lateral pnp)</td>
</tr>
<tr>
<td>4.6</td>
<td>Spacing to p-base diffusion (for collector contact of vertical npn)</td>
</tr>
</tbody>
</table>
Add n-epi region from design rules 2.3 and 3.3
5. Contact (Black, Mask #5)
   5.1 Size (exactly)  
   5.2 Spacing  
   5.3 Metal overlap of contact  
   5.4 n⁺ emitter diffusion overlap of contact  
   5.5 p-base diffusion overlap of contact  
   5.6 p-base to n⁺ emitter  
   5.7 Spacing to isolation diffusion  
       \[ 4\lambda \times 4\lambda \]

6. Metalization (Blue, Mask #6)
   6.1 Width  
   6.2 Spacing  
   6.3 Bonding pad size  
   6.4 Probe pad size  
   6.5 Bonding pad separation  
   6.6 Bonding to probe pad  
   6.7 Probe pad separation  
   6.8 Pad to circuitry  
   6.9 Maximum current density  
       \[ 100 \mu \times 100 \mu \]
       \[ 75 \mu \times 75 \mu \]
       \[ 50 \mu \]
       \[ 30 \mu \]
       \[ 30 \mu \]
       \[ 40 \mu \]
       \[ 0.8 \text{mA/\mu width} \]

7. Passivation (Purple, Mask #7)
   7.1 Minimum bonding pad opening  
   7.2 Minimum probe pad opening  
       \[ 90 \mu \times 90 \mu \]
       \[ 65 \mu \times 65 \mu \]
Add contact to n-epi region from design rules 2.3 and 3.3
**TABLE 2C.2**

Design rules for a typical bipolar process ($\lambda = 2.5 \mu$)

(See Table 2C.3 in color plates for graphical interpretation)

<table>
<thead>
<tr>
<th>Dimension</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $n^+$ buried collector diffusion (Yellow, Mask #1)</td>
<td></td>
</tr>
<tr>
<td>1.1 Width</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>1.2 Overlap of p-base diffusion (for vertical npn)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>1.3 Overlap of $n^+$ emitter diffusion (for collector contact of vertical npn)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>1.5 Overlap of $n^+$ emitter diffusion (for base contact of lateral pnp)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>2. Isolation diffusion (Orange, Mask #2)</td>
<td></td>
</tr>
<tr>
<td>2.1 Width</td>
<td>$4\lambda$</td>
</tr>
<tr>
<td>2.2 Spacing</td>
<td>$24\lambda$</td>
</tr>
<tr>
<td>2.3 Distance to $n^+$ buried collector</td>
<td>$14\lambda$</td>
</tr>
<tr>
<td>3. p-base diffusion (Brown, Mask #3)</td>
<td></td>
</tr>
<tr>
<td>3.1 Width</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>3.2 Spacing</td>
<td>$5\lambda$</td>
</tr>
<tr>
<td>3.3 Distance to isolation diffusion</td>
<td>$14\lambda$</td>
</tr>
<tr>
<td>3.4 Width (resistor)</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>3.5 Spacing (as resistor)</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>4. $n^+$ emitter diffusion (Green, Mask #4)</td>
<td></td>
</tr>
<tr>
<td>4.1 Width</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>4.2 Spacing</td>
<td>$3\lambda$</td>
</tr>
<tr>
<td>4.3 p-base diffusion overlap of $n^+$ emitter diffusion (emitter in base)</td>
<td>$2\lambda$</td>
</tr>
<tr>
<td>4.4 Spacing to isolation diffusion (for collector contact)</td>
<td>$12\lambda$</td>
</tr>
<tr>
<td>4.5 Spacing to p-base diffusion (for base contact of lateral pnp)</td>
<td>$6\lambda$</td>
</tr>
<tr>
<td>4.6 Spacing to p-base diffusion (for collector contact of vertical npn)</td>
<td>$6\lambda$</td>
</tr>
</tbody>
</table>
5. Contact (Black, Mask #5)
   5.1 Size (exactly) $4\lambda \times 4\lambda$
   5.2 Spacing $2\lambda$
   5.3 Metal overlap of contact $\lambda$
   5.4 $n^+$ emitter diffusion overlap of contact $2\lambda$
   5.5 p-base diffusion overlap of contact $2\lambda$
   5.6 p-base to $n^+$ emitter $3\lambda$
   5.7 Spacing to isolation diffusion $4\lambda$

6. Metalization (Blue, Mask #6)
   6.1 Width $2\lambda$
   6.2 Spacing $2\lambda$
   6.3 Bonding pad size $100 \mu \times 100 \mu$
   6.4 Probe pad size $75 \mu \times 75 \mu$
   6.5 Bonding pad separation $50 \mu$
   6.6 Bonding to probe pad $30 \mu$
   6.7 Probe pad separation $30 \mu$
   6.8 Pad to circuitry $40 \mu$
   6.9 Maximum current density $0.8 \text{mA/}\mu\text{width}$

7. Passivation (Purple, Mask #7)
   7.1 Minimum bonding pad opening $90 \mu \times 90 \mu$
   7.2 Minimum probe pad opening $65 \mu \times 65 \mu$
But, there are some rather strict rules relating to the epi contact from (left to right) rules 4.4, 5.4, 4.6

Note: 26\(\lambda\) required Between p-base and isolation diffusion
Consider a structure with a collector contact on both sides of epi.

Note: 26\(\lambda\) required between p-base and isolation diffusion.

Note: Not to vertical scale.
Note: Not to vertical Scale

Note: 26\(\lambda\) required Between p-base and isolation diffusion
Note: Not to vertical Scale
Major contributor to large size of BJT is the isolation diffusion which diffuses laterally a large distance beyond the drawn edges of the isolation mask.
Comparison with Area for n-channel MOSFET in Bulk CMOS

Bounding Area = 208\lambda^2
Minimum-Sized MOSFET

Bounding Area = 168\lambda^2
Active Area = 6\lambda^2
Note: Not to vertical Scale
Area Comparison between BJT and MOSFET

- BJT Area = $3600 \lambda^2$
- n-channel MOSFET Area = $168 \lambda^2$
- Area Ratio = 21:1
Thyristors

The good and the bad!
Thyristors

The good

SCRs
Triacs

The bad

Parasitic Device that can destroy integrated circuits
The SCR

Silicon Controlled Rectifier

- Widely used to switch large resistive or inductive loads
- Widely used in the power electronics field
- Widely used in consumer electronic to interface between logic and power

Usually made by diffusions in silicon

Consider first how this 4-layer 3-junction device operates
Operation of the SCR

Not actually separated but useful for describing operation
Variation of Current Gain ($\beta$) with Bias for BJT

Note that current gain gets very small at low base current levels.
Consider a small positive bias (voltage or current) on the gate \( V_{GC} < 0.5 \) V and a positive and large voltage \( V_F \).

Will have \( V_{C1} \geq V_F - 0.5 \) V.

Thus \( Q_1 \) has a large positive voltage on its collector.

Since \( V_{BE1} \) is small, \( I_{C1} \) will be small as will \( I_{C2} \) so diode equation governs BE junction of \( Q_1 \).

\( I_F \) will be very small.
Now let bias on the gate increase ($V_{GC}$ around 0.6V) so $Q_1$ and $Q_2$ in FA

From diode equation, base voltage $V_{BE1}$ will increase and collector current $I_{C1}$ will increase

Thus base current $I_{B2}$ will increase as will the collector current of $I_{C2}$

Under assumption of operation in FA region get expression

$$I_{B1} = I_G + \beta_1 \beta_2 I_{B1}$$

This is regenerative feedback (actually can show pole in RHP)
Very Approximate Analysis Showing RHP Pole

\[ V_G = I_G \frac{R_{BE}}{sR_{BE}C_B + 1 - \beta_1\beta_2} \]

\[ p = \frac{\beta_1\beta_2 - 1}{R_{BE}C_B} \]
Operation of the SCR

\[ V_{C1} \approx V_F - 0.6V \]

Under assumption of operation in FA region get expression

\[ I_{B1} = I_G + \beta_1\beta_2 I_{B1} \]

What will happen with this is regenerative feedback?

If \( I_G \) is small (and thus \( \beta_1 \) and \( \beta_2 \) are small) \( I_F \) will be very small.

If \( I_G \) larger, it can be removed and current will continue to flow.

\( I_{C1} \) will continue to increase and drive \( Q_1 \) into SAT.

This will try to drive \( V_A \) towards 0.9V (but forced to be \( V_F \)!) 

The current in \( V_F \) will go towards \( \infty \).

The SCR will self-destruct because of excessive heating!

Too bad the circuit self-destructed because the small gate current was able to control a lot of current!
Operation of the SCR

Consider a modified application by adding a load (depicted as $R_L$)

All operation is as before, but now, after the triggering occurs, the voltage $V_F$ will drop to approximately 0.8 V and the voltage $V_{CC} - .8$ will appear across $R_L$

If $V_{CC}$ is very large, the SCR has effectively served as a switch putting $V_{CC}$ across the load and after triggering occurs, $I_G$ can be removed!

But, how can we turn it off? Will discuss that later
End of Lecture 27