EE 330
Lecture 25

Bipolar Processes

JFET
Thyristors
SCR
TRIAC
Relative Magnitude of Small Signal MOS Parameters

Consider:

\[ i_d = g_m v_{gs} + g_{mb} v_{bs} + g_o v_{ds} \]

3 alternate equivalent expressions for \( g_m \)

\[ g_m = \frac{\mu C_{OX} W}{L} V_{EBQ} \quad g_m = \sqrt{2 \mu C_{OX} W} \sqrt{I_{DQ}} \quad g_m = \frac{2 I_{DQ}}{V_{EBQ}} \]

If \( \mu C_{OX}=100\mu A/V^2, \lambda=.01V^{-1}, \gamma = 0.4V^{0.5}, V_{EBQ}=1V, W/L=1, V_{BSQ}=0V \)

\[ I_{DQ} \approx \frac{\mu C_{OX} W}{2L} V_{EBQ}^2 = \frac{10^{-4} W}{2L} (1V)^2 = 5E-5 \]

\[ g_m = \frac{\mu C_{OX} W}{L} V_{EBQ} = 1E-4 \]

\[ g_o = \lambda I_{DQ} = 5E-7 \]

\[ g_{mb} = g_m \left( \frac{\gamma}{2 \sqrt{\phi - V_{BSQ}}} \right) = .26 g_m \]

- Often the \( g_o \) term can be neglected in the small signal model because it is so small
- Be careful about neglecting \( g_o \) prior to obtaining a final expression
Relative Magnitude of Small Signal BJT Parameters

\[ g_m = \frac{I_{CQ}}{V_t} \]
\[ g_\pi = \frac{I_{CQ}}{\beta V_t} \]
\[ g_o \approx \frac{I_{CQ}}{V_{AF}} \]

\[ \begin{bmatrix} g_m \\ g_\pi \\ g_o \end{bmatrix} = \begin{bmatrix} \frac{I_Q}{V_t} \\ \frac{I_Q}{\beta V_t} \\ \frac{I_Q}{\beta V_t} \end{bmatrix} \]

\[ g_m \gg g_\pi \gg g_o \]

Often the \( g_o \) term can be neglected in the small signal model because it is so small.
Large and Small Signal Model Summary

Large Signal Model

\[ I_D = \begin{cases} 
0 & V_{GS} \leq V_T \\
\mu C_{ox} \cdot \frac{W}{L} \left( V_{GS} - V_T - \frac{V_{DS}}{2} \right) V_{DS} & V_{GS} > V_T, V_{DS} < V_{GS} - V_T \\
\mu C_{ox} \cdot \frac{W}{2L} \left( V_{GS} - V_T \right)^2 \cdot (1 + \lambda V_{DS}) & V_{GS} > V_T, V_{DS} \geq V_{GS} - V_T
\end{cases} \]

\[ V_T = V_{T0} + \gamma \left( \sqrt{\phi} - V_{BS} - \sqrt{\phi} \right) \]

Small Signal Model

\[ i_D = g_m v_{gs} + g_{mb} v_{bs} + g_o v_{ds} \]

where

\[ g_m = \frac{\mu C_{ox} W}{L} V_{EBQ} \]
\[ g_{mb} = g_m \left( \frac{\gamma}{2\sqrt{\phi} - V_{BSQ}} \right) \]
\[ g_o = \lambda I_{DQ} \]
**Review from Last Lecture**

**Large and Small Signal Model Summary**

**Large Signal Model**

\[ I_C = \beta I_B \left( 1 + \frac{V_{CE}}{V_{AF}} \right) \]
\[ I_B = \frac{J_S A_E e^{V_{BE}/V_t}}{\beta} \]

- For \( V_{BE} > 0.4V \)
- For \( V_{BC} < 0 \)

- \( V_{BE} = 0.7V \)
- \( V_{CE} = 0.2V \)
- \( I_C < \beta I_B \)
- \( I_C = I_B = 0 \)

**Small Signal Model**

**Forward Active**

\[ i_b = g_\pi v_{be} \]
\[ i_c = g_m v_{be} + g_0 v_{ce} \]

where

\[ g_m = \frac{I_{CQ}}{V_t} \]
\[ g_\pi = \frac{I_{CQ}}{\beta V_t} \]
\[ g_o \approx \frac{I_{CQ}}{V_{AF}} \]
Small Signal MOSFET Model Summary

An equivalent Circuit:

\[
g_m = \frac{\mu C_{OX} W}{L} (V_{GSQ} - V_T)
\]

\[
g_o = \lambda I_{DQ}
\]

\[
g_{mb} = g_m \left( \frac{\gamma}{2 \sqrt{\phi - V_{BSQ}}} \right)
\]

Alternate equivalent representations for \(g_m\)

\[
g_m = \sqrt{\frac{2\mu C_{OX} W}{L}} \sqrt{I_{DQ}}
\]

\[
g_m = \frac{2I_{DQ}}{V_{GSQ} - V_T} = \frac{2I_{DQ}}{V_{EBQ}}
\]

\[g_{mb} < g_m\]
\[g_o << g_m, g_{mb}\]
Small Signal Model Simplifications

Review from Last Lecture

Simplification that is often adequate
Small Signal Model Simplifications

Even further simplification that is often adequate
Review from Previous Lecture

A-A’ Section

vertical npn

lateral pnp

B-B’ Section
A - A' Section

B - B' Section

Review from Previous Lecture

p-channel JFET

B-B' Section
Review from Previous Lecture

vertical npn

lateral pnp
Diode (capacitor)

Resistor

n-channel JFET
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 depletion device and 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 (channel disappears - “pinches off”)
The JFET

Under smaller reverse bias (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

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

(V_{GS} > V_P)

-0.3 < V_{GS} < V_P

V_{DS} < V_{GS} - V_P

(I_{DSSp} 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

Square-law model of n-channel JFET

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

- 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
The Thyristor

A bipolar device in CMOS Processes

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>Dimension</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\textsuperscript{+} emitter diffusion overlap of contact  \[2\lambda\]
   5.5 p-base diffusion overlap of contact  \[2\lambda\]
   5.6 p-base to n\textsuperscript{+} 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  \[0.8 \, \text{mA/\mu width}\]

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
<table>
<thead>
<tr>
<th></th>
<th>Design rules for a typical bipolar process ((\lambda = 2.5 \ \mu))</th>
<th>Dimension</th>
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<tbody>
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<td>1.</td>
<td>n(^{+}) buried collector diffusion (Yellow, Mask #1)</td>
<td></td>
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<tr>
<td>1.1</td>
<td>Width</td>
<td>3(\lambda)</td>
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<tr>
<td>1.2</td>
<td>Overlay of p-base diffusion (for vertical npn)</td>
<td>2(\lambda)</td>
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<td>Overlay of p-base diffusion (for collector and emitter of lateral pnp)</td>
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<td></td>
</tr>
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<td>Width</td>
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<td>2.3</td>
<td>Distance to n(^{+}) buried collector</td>
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<td>p-base diffusion (Brown, Mask #3)</td>
<td></td>
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<td>3.1</td>
<td>Width</td>
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</tr>
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<td>3.2</td>
<td>Spacing</td>
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<td>3(\lambda)</td>
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<td>4.2</td>
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<td>p-base diffusion overlap of n(^{+}) emitter diffusion (emitter in base)</td>
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<td>4.6</td>
<td>Spacing to p-base diffusion (for collector contact of vertical npn)</td>
<td>6(\lambda)</td>
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</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 \(65 \mu \times 65 \mu\)
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>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>
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<td>1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)</td>
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<td>1.5 Overlap of n$^+$ emitter diffusion (for base contact of lateral pnp)</td>
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<tr>
<td>Isolation diffusion (Orange, Mask #2)</td>
</tr>
<tr>
<td>2.1 Width</td>
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<tr>
<td>2.2 Spacing</td>
</tr>
<tr>
<td>2.3 Distance to n$^+$ buried collector</td>
</tr>
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<td>p-base diffusion (Brown, Mask #3)</td>
</tr>
<tr>
<td>3.1 Width</td>
</tr>
<tr>
<td>3.2 Spacing</td>
</tr>
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<td>3.3 Distance to isolation diffusion</td>
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<td>n$^+$ emitter diffusion (Green, Mask #4)</td>
</tr>
<tr>
<td>4.1 Width</td>
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<td>4.3 p-base diffusion overlap of n$^+$ emitter diffusion (emitter in base)</td>
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<td>4.4 Spacing to isolation diffusion (for collector contact)</td>
</tr>
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</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)

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<tr>
<td></td>
<td>Dimension</td>
</tr>
<tr>
<td></td>
<td>3\lambda</td>
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<tr>
<td></td>
<td>2\lambda</td>
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<td>2\lambda</td>
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<tr>
<td></td>
<td>2\lambda</td>
</tr>
<tr>
<td></td>
<td>2\lambda</td>
</tr>
</tbody>
</table>

| 2. | Isolation diffusion (Orange, Mask #2) |
| 2.1 | Width |
| 2.2 | Spacing |
| 2.3 | Distance to n$^+$ buried collector |
|   | 4\lambda |
|   | 24\lambda |
|   | 14\lambda |

| 3. | p-base diffusion (Brown, Mask #3) |
| 3.1 | Width |
| 3.2 | Spacing |
| 3.3 | Distance to isolation diffusion |
| 3.4 | Width (resistor) |
| 3.5 | Spacing (as resistor) |
|   | 3\lambda |
|   | 5\lambda |
|   | 14\lambda |
|   | 3\lambda |

| 4. | n$^+$ emitter diffusion (Green, Mask #4) |
| 4.1 | Width |
| 4.2 | Spacing |
| 4.3 | p-base diffusion overlap of n$^+$ emitter diffusion (emitter in base) |
| 4.4 | Spacing to isolation diffusion (for collector contact) |
| 4.5 | Spacing to p-base diffusion (for base contact of lateral pnp) |
| 4.6 | Spacing to p-base diffusion (for collector contact of vertical npn) |
|   | 3\lambda |
|   | 3\lambda |
|   | 2\lambda |
|   | 12\lambda |
|   | 6\lambda |
|   | 6\lambda |
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  
   \[ 4\lambda \times 4\lambda \]  
   \[ 2\lambda \]  
   \[ \lambda \]  
   \[ 2\lambda \]  
   \[ 2\lambda \]  
   \[ 3\lambda \]  
   \[ 4\lambda \]  

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  
   \[ 100 \mu \times 100 \mu \]  
   \[ 75 \mu \times 75 \mu \]  
   \[ 50 \mu \]  
   \[ 30 \mu \]  
   \[ 30 \mu \]  
   \[ 40 \mu \]  
   \[ 0.8 \text{mA}/\mu \text{ width} \]  

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>Step</th>
<th>Description</th>
<th>Dimension</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 \[65 \mu \times 65 \mu\]
But, there are some rather strict rules relating to the epi contact from (left to right) 

rules 4.4, 5.4, 4.6

Note: 26λ required between p-base and isolation diffusion
Consider a structure with a collector contact on both sides of epi.

Note: Not to vertical Scale

Note: 26λ required Between p-base and isolation diffusion.
Note: 26λ required Between p-base and isolation diffusion

Note: Not to vertical Scale
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
- SCR
- TRIAC

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

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 \((V_{GC} < 0.5V)\) and a positive and large voltage \(V_F\).

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

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

Since \(V_{B_{E1}}\) 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 well 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

\[ V_G s C_B + I_{B1} = I_{C2} + I_G \]

\[ I_{C2} = \beta_1 \beta_2 I_{B1} \]

\[ I_{B1} R_{BE} = V_G \]

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

\[ p = \frac{\beta_1 \beta_2 - 1}{R_{BE} C_B} \]
End of Lecture 25