Characteristics of Finer Feature Size Processes

Bipolar Process
How does the inverter delay compare between a 0.5μ process and a 0.13μ process?
INTRODUCTION: This report contains the lot average results obtained by MOSIS from measurements of MOSIS test structures on each wafer of this fabrication lot. SPICE parameters obtained from similar measurements on a selected wafer are also attached.

COMMENTS: American Microsystems, Inc. C5

<table>
<thead>
<tr>
<th>TRANSISTOR PARAMETERS</th>
<th>W/L</th>
<th>N-CHANNEL</th>
<th>P-CHANNEL</th>
<th>UNITS</th>
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<tr>
<td>MINIMUM</td>
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<td>P+</td>
<td>POLY</td>
<td>PLY2 HR</td>
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<tr>
<th>CAPACITANCE PARAMETERS</th>
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<th>POLY</th>
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<tr>
<th>CIRCUIT PARAMETERS</th>
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<tr>
<td>Ring Oscillator Freq.</td>
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<tr>
<td>Ring Oscillator Power</td>
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<tr>
<td>DIV256 (31-stg,5.0V)</td>
<td>0.48 uW/MHz/gate</td>
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</table>
INTRODUCTION: This report contains the lot average results obtained by MOSIS from measurements of MOSIS test structures on each wafer of this fabrication lot. SPICE parameters obtained from similar measurements on a selected wafer are also attached.

COMMENTS: 8RF IBM-BURLIN

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<thead>
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<th>N-CHANNEL</th>
<th>P-CHANNEL</th>
<th>UNITS</th>
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<td>uA/um</td>
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<td>K' (Uo*Cox/2)</td>
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PROCESS PARAMETERS

N+   P+   POLY   M1   M2   M3   M4   UNITS
Sheet Resistance  7.1  7.1  6.8  0.07  0.05  0.05  0.04 ohms/sq
Contact Resistance 20.2 13.6 11.2 0.84  1.46  1.73 ohms
Gate Oxide Thickness 31 angstrom

PROCESS PARAMETERS

M5   M6   M7   N+BLK PPLY+BLK M8   N_W   POLY_NON TaN UNITS
Sheet Resistance  0.04  0.09  0.01  74.0 337.7  0.01  541 1653.0 ohms/sq
Contact Resistance 2.26 2.31 2.54 2.79 ohms

COMMENTS: BLK is silicide block.

CAPACITANCE PARAMETERS

N+   D_N_W   P+   POLY   R_W   N_W   UNITS
Area (substrate) 933 509 1068 1014  aF/um^2
Area (N+active)  10975  aF/um^2
Area (P+active)  10347  aF/um^2
Area (r well) 1209  aF/um^2
Area (d well) 1548  aF/um^2
Area (N+ HA varactor) 2261  aF/um^2
Fringe (substrate) 31 21 aF/um
Overlap (N+active) 393 aF/um
Overlap (P+active) 384 aF/um

CIRCUIT PARAMETERS

Inverters

Vin  1.0  0.51 volts
Vin  1.5  0.52 volts
Vol (100 uA) 2.0  0.01 volts
Voh (100 uA) 2.0  1.18 volts
Vin  2.0  0.54 volts
Gain  2.0  -16.99

Ring Oscillator Freq.

D1024_THK (31-stg,2.5V) 276.12 MHz
DIV1024 (31-stg,1.2V) 415.18 MHz

Ring Oscillator Power

D1024_THK (31-stg,2.5V) 0.03 uW/MHz/gate
DIV1024 (31-stg,1.2V) 0.00 uW/MHz/gate

COMMENTS: DEEP_SUBMICRON
How does the inverter delay compare between a 0.5u process and a 0.13u process?

Assume n-channel and p-channel devices are minimum sized

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<td>ucoxp</td>
<td>4.00E-05</td>
<td>5.00E-05</td>
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<tr>
<td>Cox</td>
<td>2.50E-15</td>
<td>1.05E-14</td>
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<tr>
<td>Rpd</td>
<td>3.50E+03</td>
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<tr>
<td>Rpu</td>
<td>9.62E+03</td>
<td>2.35E+04</td>
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<tr>
<td>TLH</td>
<td>1.20E-11</td>
<td>8.35E-12</td>
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Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT
Bipolar Junction Transistors

- Operation
- Modeling
Carriers in Doped Semiconductors

n-type

p-type
Carriers in Doped Semiconductors

Current carriers are dominantly electrons
Small number of holes are short-term carriers

Current carriers are dominantly holes
Small number of electrons are short-term carriers
Carriers in Doped Semiconductors

<table>
<thead>
<tr>
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<th>Majority Carriers</th>
<th>Minority Carriers</th>
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<tr>
<td>n-type</td>
<td>electrons</td>
<td>holes</td>
</tr>
<tr>
<td>p-type</td>
<td>holes</td>
<td>electrons</td>
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</table>
Carriers in MOS Transistors

Consider n-channel MOSFET

Saturation Region

Channel

Triode Region
Carriers in MOS Transistors

Consider n-channel MOSFET

Carriers in electrically induced n-channel are electrons
Carriers in MOS Transistors

Consider p-channel MOSFET

Saturation Region

Channel

Triode Region
Carriers in MOS Transistors

Consider p-channel MOSFET

Saturation Region

Triode Region

Carriers in electrically induced p-channel are holes
Carriers in channel of MOS transistors are Majority carriers
Bipolar Transistors

With proper doping and device sizing these form Bipolar Transistors

- Bipolar Devices Show Basic Symmetry
- Electrical Properties not Symmetric
- Designation of C and E critical

npn transistor

pnp transistor

npn stack
	pnp stack
Bipolar Transistors

In contrast to a MOSFET which has 4 terminals, a BJT only has 3 terminals
Bipolar Operation

Consider npn transistor

Under **forward bias** current flow into base and out of emitter

Current flow is governed by the diode equation

Carriers in emitter are electrons (majority carriers)

When electrons pass into the base they become minority carriers

Quickly recombine with holes to create holes base region

Dominant current flow in base is holes (majority carriers)
Bipolar Operation

Consider npn transistor

Under forward BE bias and reverse BC bias current flows into base region.

Carriers in emitter are electrons (majority carriers).

When electrons pass into the base they become minority carriers.

When minority carriers are present in the base they can be attracted to collector...
If no force on electron is applied by collector, electron will contribute to base current.
If no force on electron is applied by collector, electron will contribute to base current. Electron will recombine with a hole so dominant current flow in base will be by majority carriers.
Bipolar Operation

Consider npn transistor

When minority carriers are present in the base they can be attracted to collector with reverse-bias of BC junction and can move across BC junction.
Bipolar Operation

Consider npn transistor

When minority carriers are present in the base they can be attracted to collector with reverse-bias of BC junction and can move across BC junction.

Will contribute to collector current flow as majority carriers.
Bipolar Operation
Consider npn transistor

So, what will happen?
Bipolar Operation
Consider npn transistor

So, what will happen?

Some will recombine with holes and contribute to base current and some will be attracted across BC junction and contribute to collector.

Size and thickness of base region and relative doping levels will play key role in percent of minority carriers injected into base contributing to collector current.
Bipolar Operation

Consider npn transistor

Under forward BE bias and reverse BC bias current flows into base region.

Carriers in emitter are electrons (majority carriers).

When electrons pass into the base they become minority carriers.

When minority carriers are present in the base they can be attracted to collector.

Minority carriers either recombine with holes and contribute to base current or are attracted into collector region and contribute to collector current.
Bipolar Operation

Consider npn transistor

Under forward BE bias and reverse BC bias current flows into base region

Efficiency at which minority carriers injected into base region and contribute to collector current is termed $\alpha$

$\alpha$ is always less than 1 but for a good transistor, it is very close to 1

For good transistors $0.99 < \alpha < 0.999$

Making the base region very thin makes $\alpha$ large
Bipolar Transistors

principle of operation of pnp and npn transistors are the same

minority carriers in base of pnp are holes

npn usually have modestly superior properties because mobility of electrons is larger than mobility of holes
In contrast to MOS devices where current flow in channel is by majority carriers, current flow in the critical base region of bipolar transistors is by minority carriers.
Bipolar Operation

\[ I_C + I_B = -I_E \]
\[ I_C = -\alpha I_E \]

\[ I_C = \frac{\alpha}{1-\alpha} I_B \]
\[ \beta = \frac{\alpha}{1-\alpha} \]
\[ I_C = \beta I_B \]

\( \beta \) is typically very large
often 50<\( \beta <999 \)
$I_C = \beta I_B$

$\beta$ is typically very large

Bipolar transistor can be thought of a current amplifier with a large current gain

In contrast, MOS transistor is inherently a transconductance amplifier

Current flow in base is governed by the diode equation

$\quad I_B = \tilde{I}_S e^{\frac{V_{BE}}{V_t}}$

Collector current thus varies exponentially with $V_{BE}$

$\quad I_C = \beta \tilde{I}_S e^{\frac{V_{BE}}{V_t}}$
Bipolar Operation

\[ I_C = \beta I_B \]

\( \beta \) is typically very large

Collector current thus varies exponentially with \( V_{BE} \)

\[ I_C = \beta I_S e^{V_{BE}/V_t} \]

This exponential relationship (in contrast to the square-law relationship for the MOSFET) provides a very large gain for the BJT and this property is very useful for many applications!!
Bipolar Models

following convention, pick $I_C$ and $I_B$ as dependent variables and $V_{BE}$ and $V_{CE}$ as independent variables.
Summary:

\[
I_B = \tilde{I}_S e^{\frac{V_{BE}}{V_t}}
\]

\[
I_C = \beta \tilde{I}_S e^{\frac{V_{BE}}{V_t}}
\]

\[
V_t = \frac{kT}{q}
\]

This has the properties we are looking for but the variables we used in introducing these relationships are not standard.

It can be shown that \( \tilde{I}_S \) is proportional to the emitter area \( A_E \).

Define \( \tilde{I}_S = \beta^{-1} J_S A_E \) and substitute this into the above equations.
Simple dc model

\[ I_B = \tilde{I}_S \frac{V_{BE}}{V_t} \]
\[ I_C = \beta \tilde{I}_S \frac{V_{BE}}{V_t} \]
\[ V_t = \frac{kT}{q} \]

\[ I_B = \frac{J_S A_E}{\beta} \frac{V_{BE}}{V_t} \]
\[ I_C = J_S A_E \frac{V_{BE}}{V_t} \]
\[ V_t = \frac{kT}{q} \]

\( J_S \) is termed the saturation current density

Process Parameters : \( J_S, \beta \)
Design Parameters: \( A_E \)
Environmental parameters and physical constants: \( k, T, q \)
At room temperature, \( V_t \) is around 26mV
\( J_S \) very small – around .25fA/u^2
Transfer Characteristics

$J_S = 0.25 \text{fA/} \mu^2$

$A_E = 400 \mu^2$

$V_{BE}$ close to 0.6V for a two decade change in $I_C$ around 1mA
Transfer Characteristics

\[ J_S = 0.25 \text{fA/}\mu^2 \]
\[ A_E = 400 \text{u}^2 \]

\[ V_{BE} \text{ close to 0.6V for a four decade change in } I_C \text{ around 1mA} \]
Simple dc model

Output Characteristics

\[ I_C = J_S A_E e^{\frac{V_{BE}}{V_t}} \]
Simple dc model

Better Model of Output Characteristics

\[ I_C \]

\[ V_{CE} \] or \[ I_B \]

\[ \text{V}_{BE} \] or \[ I_B \]
Simple dc model

Typical Output Characteristics

Forward Active region of BJT is analogous to Saturation region of MOSFET
Saturation region of BJT is analogous to Triode region of MOSFET
End of Lecture 18