Devices in Semiconductor Processes
Quiz 11  A wire obtained with a ball bond is shown sitting on a bonding pad. What is a typical value for the dimension $d_1$ shown?
And the number is ....
And the number is .... 3
Quiz 11  A wire obtained with a ball bond is shown sitting on a bonding pad. What is a typical value for the dimension $d_1$ shown?

$d_1 = 25 \mu$m
Back-End Process Flow

- Wafer Probe
- Wafer Dicing
- Die Attach
- Wire Attach (bonding)
- Package
- Test
- Ship

Review from Last Time
Review from Last Time

Wafer Dicing

Gang of slitting blades

Rotary stage indexer

Silicon wafer

X axis

Y axis

www.renishaw.com
Review from Last Time

Die Attach

1. Eutectic
2. Pre-form
3. Conductive Epoxy
Review from Last Time

Electrical Connections (Bonding)

• Wire Bonding
• Bump Bonding
Basic Semiconductor Processes

MOS (Metal Oxide Semiconductor)

1. NMOS          n-ch
2. PMOS          p-ch
3. CMOS          n-ch & p-ch
   • Basic Device:  MOSFET
   • Niche Device:  MESFET
   • Other Devices: Diode
                   BJT
                   Resistors
                   Capacitors
                   Schottky Diode
Basic Semiconductor Processes

Bipolar

1. $T^2L$
2. ECL
3. I$^2$L
4. Linear ICs
   - Basic Device: BJT (Bipolar Junction Transistor)
   - Niche Devices: HBJT (Heterojunction Bipolar Transistor)
   - Other Devices: Diode
     Resistor
     Capacitor
     Schottky Diode
     JFET (Junction Field Effect Transistor)
Basic Semiconductor Processes

Other Processes

• Thin and Thick Film Processes
  – Basic Device: Resistor
• BiMOS or BiCMOS
  – Combines both MOS & Bipolar Processes
  – Basic Devices: MOSFET & BJT
• SiGe
  – BJT with HBT implementation
• SiGe / MOS
  – Combines HBT & MOSFET technology
• SOI / SOS (Silicon on Insulator / Silicon on Sapphire)
• Twin-Well & Twin Tub CMOS
  – Very similar to basic CMOS but more optimal transistor char.
Devices in Semiconductor Processes

- **Standard CMOS Process**
  - MOS Transistors
    - n-channel
    - p-channel
  - Capacitors
  - Resistors
  - Diodes
  - BJT (decent in some processes)
    - npn
    - pnp
  - JFET (in some processes)
    - n-channel
    - p-channel

- **Standard Bipolar Process**
  - BJT
    - npn
    - pnp
  - JFET
    - n-channel
    - p-channel
  - Diodes
  - Resistors
  - Capacitors

- **Niche Devices**
  - Photodetectors (photodiodes, phototransistors, photoresistors)
  - MESFET
  - HBT
  - Schottky Diode (not Shockley)
  - MEM Devices
  - ....
Basic Devices

- **Standard CMOS Process**
  - MOS Transistors
    - n-channel
    - p-channel
  - Capacitors
  - Resistors
  - Diodes
  - BJT (in some processes)
    - npn
    - pnp

- **Niche Devices**
  - Photodetectors
  - MESFET
  - Schottky Diode *(not Shockley)*
  - MEM Devices
  - Triac/SCR
  - ....

Primary Consideration in This Course

Some Consideration in This Course
Basic Devices and Device Models

• Resistor
• Diode
• Capacitor
• MOSFET
• BJT
Basic Devices and Device Models

- Resistor
  - Diode
  - Capacitor
  - MOSFET
  - BJT

Resistors were discussed when considering interconnects so will only be briefly reviewed here.
Resistors

- Generally thin-film devices
- Almost any thin-film layer can be used as a resistor
  - Diffused resistors
  - Poly Resistors
  - Metal Resistors
  - “Thin-film” adders (SiCr or NiCr)
- Subject to process variations, gradient effects and local random variations
- Often temperature and voltage dependent
  - Ambient temperature
  - Local Heating
- Nonlinearities often a cause of distortion when used in circuits
- Trimming possible resistors
  - Laser, links, switches
Resistor Model

Model:

$$R = \frac{V}{I}$$
Resistivity

- Volumetric measure of conduction capability of a material

\[ \rho = \frac{AR}{L} \]

for homogeneous material, \( \rho \perp A, R, L \)

units: ohm cm
Sheet Resistance

\[ R_{\square} = \frac{RW}{L} \]  
(for \( d \ll w, d \ll L \))  
units: ohms/\( \square \)

for homogeneous materials, \( R_{\square} \) is independent of \( W, L, R \)
Relationship between $\rho$ and $R_{\square}$

\[ R_{\square} = \frac{RW}{L} \]
\[ \rho = \frac{AR}{L} \]

\[ \rho = \frac{A}{W} R_{\square} = \frac{Wd}{W} R_{\square} = d \times R_{\square} \]

Number of squares, $N_S$, often used instead of $L / W$ in determining resistance of film resistors

\[ R = R_{\square} N_S \]
Example 1

\[ R = ? \]

\[ W \]

\[ L \]
Example 1

\[ \frac{L}{W} = N_s \]
Example 1

\[
\begin{array}{ccccccccc}
.4 & 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 \\
\end{array}
\]

\[R = ?\]
Example 1

\[ R = \, ? \]

\[ N_s = 8.4 \]

\[ R = R_{\Box}(8.4) \]
Corners in Film Resistors

Rule of Thumb: .55 squares for each corner
Example 2

Determine $R$ if $R_{\square} = 100 \, \Omega / \square$
Example 2

\[ N_s = 17.1 \]
\[ R = (17.1) R_\square \]
\[ R = 1710 \, \Omega \]
Resistivity of Materials used in Semiconductor Processing

- Cu: $1.7E-6 \ \Omega\text{cm}$
- Al: $2.7E-4 \ \Omega\text{cm}$
- Gold: $2.4E-6 \ \Omega\text{cm}$
- Platinum: $3.0E-6 \ \Omega\text{cm}$
- n-Si: $0.25$ to $5 \ \Omega\text{cm}$
- intrinsic Si: $2.5E5 \ \Omega\text{cm}$
- SiO$_2$: $E14 \ \Omega\text{cm}$
Temperature Coefficients

Used for indicating temperature sensitivity of resistors & capacitors

For a resistor:

\[
TCR = \left( \frac{1}{R} \frac{dR}{dT} \right)_{\text{op. temp}} \cdot 10^6 \text{ ppm/°C}
\]

This diff eqn can easily be solved if TCR is a constant

\[
R(T_2) = R(T_1) e^{\frac{T_2 - T_1}{10^6} TCR}
\]

\[
R(T_2) \approx R(T_1) \left[ 1 + (T_2 - T_1) \frac{TCR}{10^6} \right]
\]

Identical Expressions for Capacitors
End of Lecture 12