Metal migration

- Current-carrying capacity of metal wire depends on cross-section. Height is fixed, so width determines current limit.
- Metal migration: when current is too high, electron flow pushes around metal grains. Higher resistance increases metal migration, leading to destruction of wire.

Metal migration problems and solutions

- Marginal wires will fail after a small operating period—infant mortality.
  - Under high currents, electron collisions with metal grains cause the metal to move; this process is called metal migration (also known as electromigration)
- Normal wires must be sized to accommodate maximum current flow:
  \[ I_{\text{max}} = 1.5 \text{ mA}/\mu\text{m of metal width}. \]
- Mainly applies to \( V_{DD}/V_{SS} \) lines.

Diffusion wire capacitance

- Capacitances formed by p-n junctions:
  - sidewall capacitances
  - depletion region capacitance
  - bottomwall capacitance

Depletion region capacitance

- Zero-bias depletion capacitance:
  \[ C_{dj} = \varepsilon_s/x_d. \]
- Depletion region width:
  \[ x_{d0} = \sqrt{[1/N_A + 1/N_D]2\varepsilon_s V_{bi}/q}. \]
- Junction capacitance is function of voltage across junction:
  \[ C_j(V_r) = C_{dj}/\sqrt{1 + V_r/V_{bi}}. \]
Poly/metal wire capacitance

- Two components:
  - parallel plate;
  - fringe.

Example: parasitic capacitance measurement

- n-diffusion: bottom wall=940 aF/um^2, sidewall=200 aF/um.
- metal: plate=36 aF, fringe=54 aF.
- Poly: plate & fringe = 63 aF

N-diffusion layer capacitance calculation

- Bottom wall capacitance:
  - Area of n-diffusion layer:
    - 3x12λ^2 + 4x4λ^2 + 36λ^2 + 16λ^2 = 52λ^2 = 52(0.09µm)^2 = 0.4212µm^2
  - Bottom wall capacitance: 0.4212x940aF= 0.399F

- Side wall capacitance:
  - Perimeter of side wall (counter clockwise)
    - 0.27µm + 1.08µm + 0.09µm + 0.36µm + 0.36µm + 1.44µm = 3.6µm
  - Side wall capacitance: 3.6x200aF = 0.72F

- Total n-diffusion capacitance: 0.42 + 0.72 = 1.11F
Typical parameters for our 180 nm process.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage hysteresis</td>
<td>0.3 V</td>
</tr>
<tr>
<td>Voltage threshold voltage</td>
<td>0.9 V</td>
</tr>
<tr>
<td>Voltage threshold voltage</td>
<td>-0.9 V</td>
</tr>
<tr>
<td>Capacitance of metal wire</td>
<td>20 fF/µm²</td>
</tr>
<tr>
<td>Conductance of metal wire</td>
<td>100 µS/µm²</td>
</tr>
<tr>
<td>Skin effect of copper conductor</td>
<td>20 Ω/µm²</td>
</tr>
<tr>
<td>Skin effect at low frequency</td>
<td>50 Ω/µm²</td>
</tr>
<tr>
<td>Skin effect at high frequency</td>
<td>100 Ω/µm²</td>
</tr>
</tbody>
</table>

What will be metal wire capacitance?

Wire resistance

- Resistance of any size square is constant:

Skin effect

- At low frequencies, most of copper conductor's cross section carries current.
- As frequency increases, current moves to skin of conductor.
  - Back EMF induces counter-current in body of conductor.
- Skin effect most important at gigahertz frequencies.

Skin effect, cont'd

- Isolated conductor:
  - Low frequency
  - High frequency
- Conductor and ground:
  - Low frequency
  - High frequency
Skin depth

- Skin depth is depth at which conductor’s current is reduced to $1/3 = 37\%$ of surface value:
  \[ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]
  - $f =$ signal frequency
  - $\mu =$ magnetic permeability
  - $\sigma =$ wire conductivity

Effect on resistance

- Low frequency resistance of wire:
  \[ R_{dc} = \frac{1}{\sigma wt} \]
- High frequency resistance with skin effect:
  \[ R_{hf} = \frac{1}{2} \sigma \delta (w + t) \]
- Resistance per unit length:
  \[ R_{ac} = \sqrt{R_{dc}^2 + \kappa R_{hf}^2} \]
  - Typically $\kappa = 1.2$. 