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.

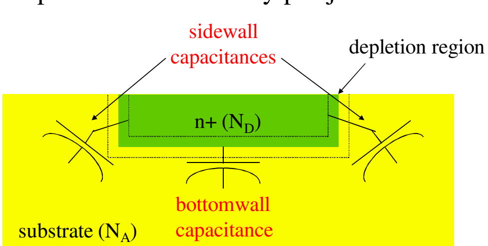
Metal migration problems and solutions

- 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 accomodate maximum current flow:

  I_{max} = 1.5 mA/µm of metal width.
- Mainly applies to V_{DD}/V_{SS} lines.

Diffusion wire capacitance

- Capacitances formed by p-n junctions:

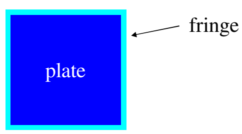


Depletion region capacitance

- Zero-bias depletion capacitance:
  - $C_{j0} = \varepsilon_{si}/x_d$.
- Depletion region width:
  - $x_{d0} = \mathrm{sqrt}[(1/N_A + 1/N_D)2\varepsilon_{si}V_{bi}/q]$.
- Junction capacitance is function of voltage across junction:
  - $C_j(V_r) = C_{j0}/\mathrm{sqrt}(1 + V_r/V_{bi})$

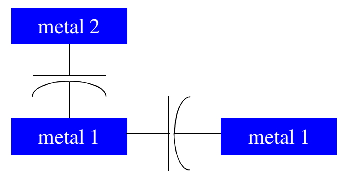
Poly/metal wire capacitance

- Two components:
  - parallel plate;
  - fringe.



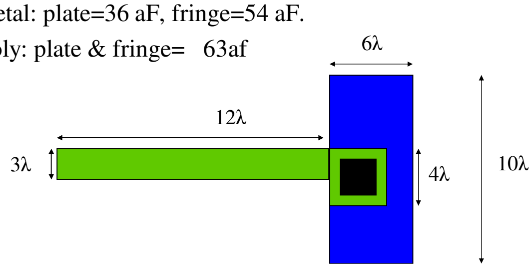
Metal coupling capacitances

- Can couple to adjacent wires on same layer, wires on above/below layers:



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= 63af



N-diffusion layer capacitance calculation

- Bottom wall capacitance
  - Area of n-diffusion layer:
  - $3 \times 12 \times \lambda^2 + 4 \times 4\lambda^2 = 36\lambda^2 + 16\lambda^2 = 52\lambda^2 = 52(.09\mu m)^2 = 0.4212\mu m^2$
  - Bottom wall capacitance : 0.4212x940aF= 0.39fF
- Side wall capacitance:
  - Perimeter of side wall (counter clockwise)

$$0.27\mu m + 1.08\mu m + 0.09\mu m + 0.36\mu m + 0.36\mu m + 1.44\mu m = 3.6\mu m$$

  - Side wall capacitance: 3.6x200af = 0.72fF
- Total n-diffusion capacitance: 0.42 + 0.72 = **1.11fF**

Typical parameters for our 180 nm process.

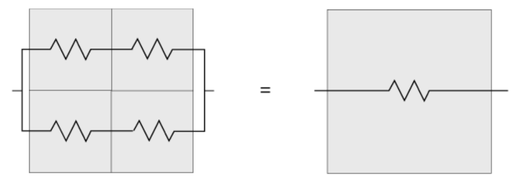
p-type transconductance	k'_p	$-30 \mu A/V^2$
n-type threshold voltage	V_{tn}	0.5V
p-type threshold voltage	V_{tp}	-0.5V
n-diffusion bottomwall capacitance	$C_{ndiff,bot}$	$940 aF/\mu m^2$
n-diffusion sidewall capacitance	$C_{ndiff,side}$	$200 aF/\mu m$
p-diffusion bottomwall capacitance	$C_{pdiff,bot}$	$1000 aF/\mu m^2$
p-diffusion sidewall capacitance	$C_{pdiff,side}$	$200 aF/\mu m$
n-type source/drain resistivity	R_{ndiff}	$7 \Omega/\square$
p-type source/drain resistivity	R_{pdiff}	$7 \Omega/\square$
poly-substrate plate capacitance	$C_{poly,plate}$	$63 aF/\mu m^2$
poly-substrate fringe capacitance	$C_{poly,fringe}$	$63 aF/\mu m$

poly resistivity	R_{poly}	$8 \Omega/\square$
metal 1-substrate plate capacitance	$C_{metal1,plate}$	$36 aF/\mu m^2$
metal 1-substrate fringe capacitance	$C_{metal1,fringe}$	$54 aF/\mu m$
metal 2-substrate capacitance	$C_{metal2,plate}$	$36 aF/\mu m^2$
metal 2-substrate fringe capacitance	$C_{metal2,fringe}$	$51 aF/\mu m$
metal 3-substrate capacitance	$C_{metal3,plate}$	$37 aF/\mu m^2$
metal 3-substrate fringe capacitance	$C_{metal3,fringe}$	$54 aF/\mu m$
metal 1 resistivity	R_{metal1}	$0.08 \Omega/\square$
metal 2 resistivity	R_{metal2}	$0.08 \Omega/\square$
metal 3 resistivity	R_{metal3}	$0.03 \Omega/\square$
metal current limit	$I_{m,max}$	$1 mA/\mu m$

- What will be metal wire capacitance?

Wire resistance

- Resistance of any size square is constant:

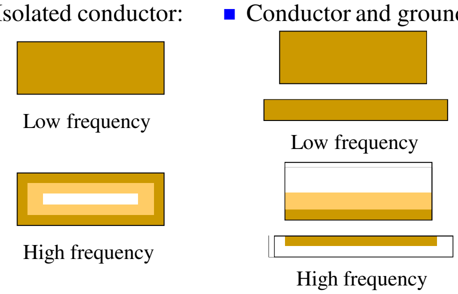


Skin effect

- 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:
- Conductor and ground:



Skin depth

- Skin depth is depth at which conductor's current is reduced to 1/3 = 37% of surface value:
  - $\delta = 1/\mathrm{sqrt}(\pi f \mu \sigma)$
  - f = signal frequency
  - μ = magnetic permeability
  - σ = wire conducitvity

Effect on resistance

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