EECS 427
Lecture 2: Design rules & layout intro

Reading: 2.3, Insert A, Weste 1.5, 3.3 (handouts)

With thanks to Irwin/Narayanan

Last Time

- Course intro/logistics
  - eecs427w09@umich.edu
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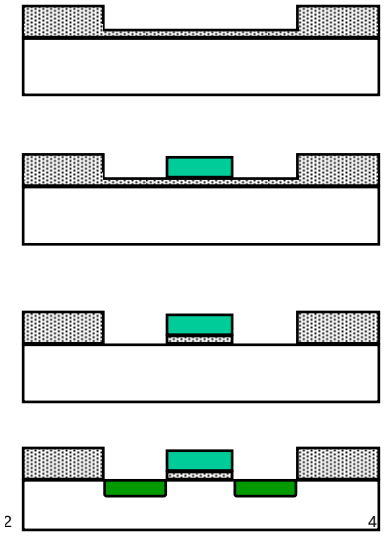
- Processing flow: helps you to picture how the layout relates to the physical silicon implementation
- HW1 posted, due Fri 9/14 at 5pm to my admin Nicole Frizzell (2417 EECS)
- CAD1 → due Monday at 7pm
  - Best to start right after you do the CAD tutorial
  - Class accounts set up
  - Tutorial tonight 7-9pm in1620 CSE

Outline

- Design rules introduction
  - What are they and why do we have them?
- You will quickly memorize our own design rules!

Self-Aligned Gates

1. Create thin oxide in the “active” regions, thick elsewhere
2. Deposit polysilicon
3. Etch thin oxide from active region (poly acts as a mask for the diffusion)
4. Implant dopant



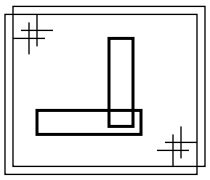
Design Rules

- Interface between the circuit designer and process engineer
- Guidelines for constructing process masks
- Unit dimension: minimum feature size (transistor gate length)
  - scalable design rules: lambda parameter
  - absolute dimensions: micron rules
- Rules constructed to ensure that design works even when small fab errors (within some tolerance) occur
- A complete set includes
  - set of layers
  - intra-layer: relations between objects in the same layer
  - inter-layer: relations between objects on different layers

Why Have Design Rules?

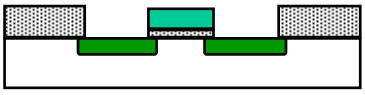
- To be able to tolerate some level of fabrication errors such as

1. Mask misalignment



2. Dust

3. Process parameters (e.g., lateral diffusion)



4. Rough surfaces

Typical CMOS Process Layers

Layer

Well (p,n)

Active Area (n+,p+)

Select (p+,n+)

Polysilicon

Metal1

Metal2

Contact To Poly

Contact To Diffusion

Via

Key points:

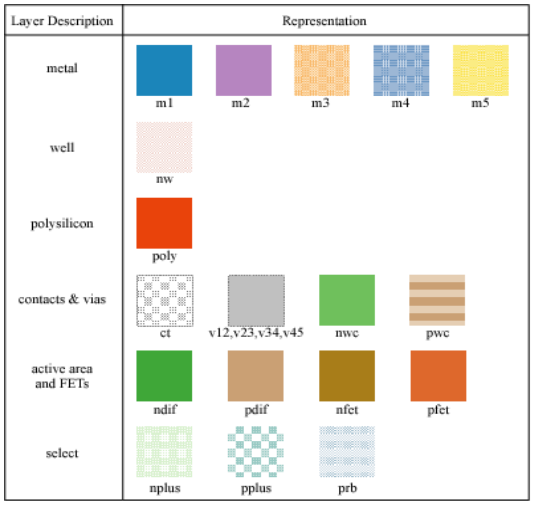
Active area determines where transistors may go

Poly overlapping with active = transistor

Select is where n+ and p+ ion implantation occurs; it can also be used to place an opposite type region (e.g., put n+ select within n-well to create a well plug, more later)

All contacts/vias are the same size (eases processing)

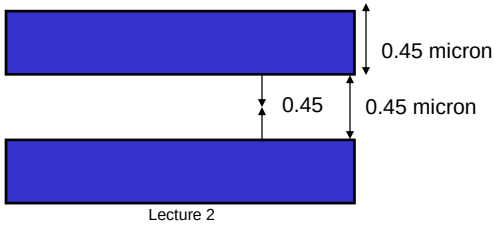
Layers in the book's 0.25 μm CMOS process



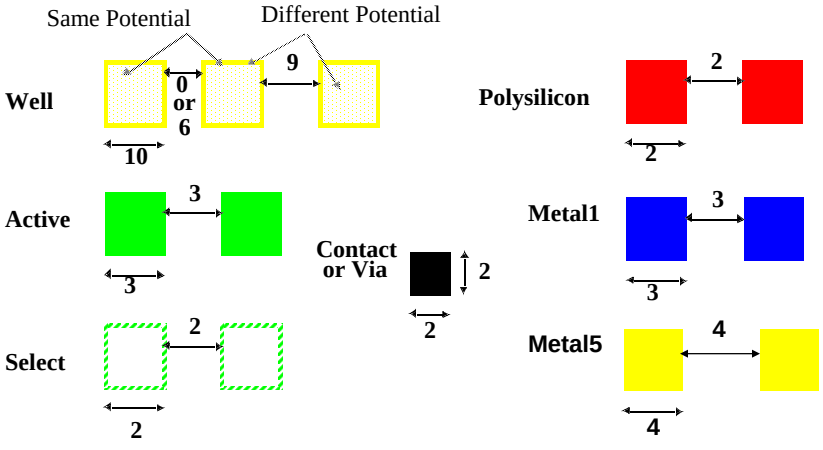
The book's process is NOT the same as the one we will be using

Intra-Layer Design Rule Origins

- Minimum dimensions (e.g., widths) of objects on each layer to maintain that object after fab
  - minimum line width is set by the resolution of the patterning process (photolithography)
- Minimum spaces between objects (that are *not* related) on the same layer to ensure they will not short after fab



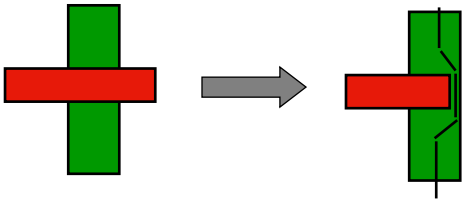
Intra-Layer Design Rules



Inter-Layer Design Rule Origins

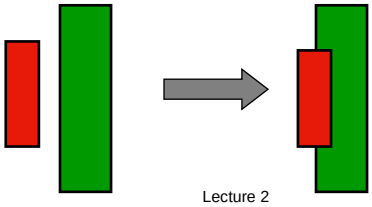
Transistor rules – transistor formed by overlap of diffusion (also called active) and poly layers

Transistors



Catastrophic error, source and drain are shorted

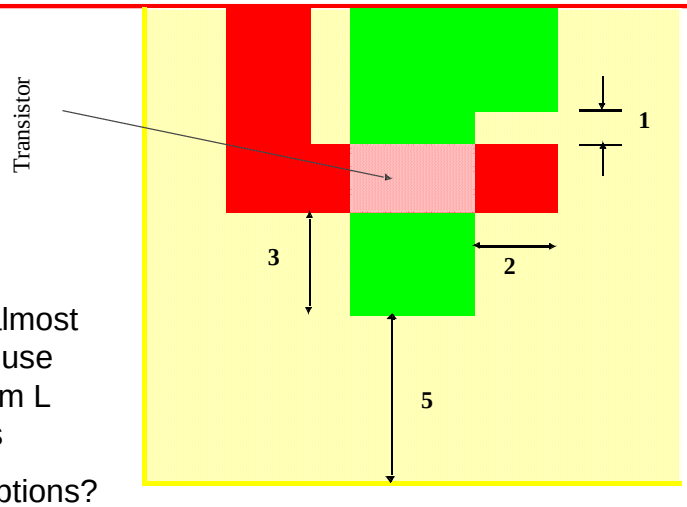
Unrelated Poly & Diffusion



Diffusion region is more resistive (narrower), but still working

But never use diffusion for routing!

Transistor Layout



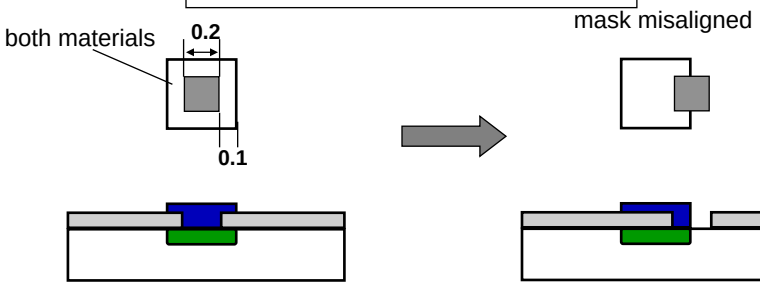
- We'll almost always use minimum L devices
- Exceptions?

Inter-Layer Design Rule Origins, Cont.

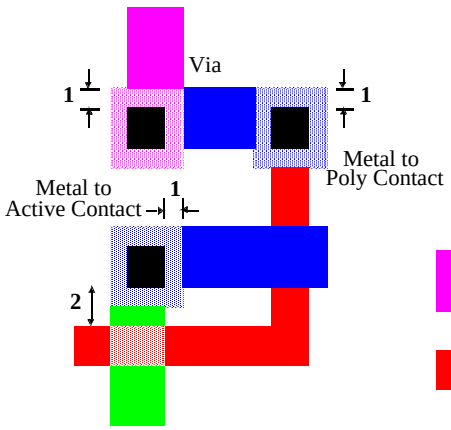
Contact and via rules

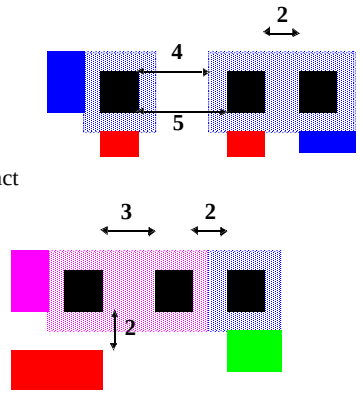
M1 contact to p-diffusion
M1 contact to n-diffusion
M1 contact to poly
→ Contact Mask

Mx contact to My → Via Masks

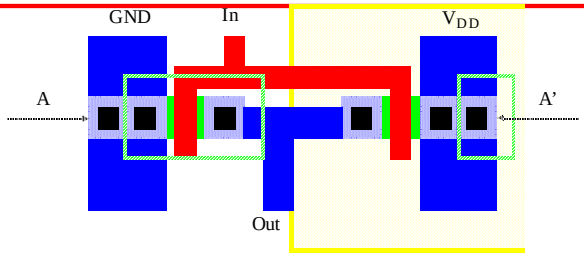


Vias and Contacts

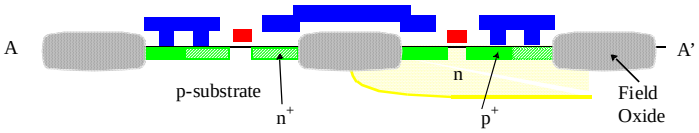




CMOS Inverter Layout

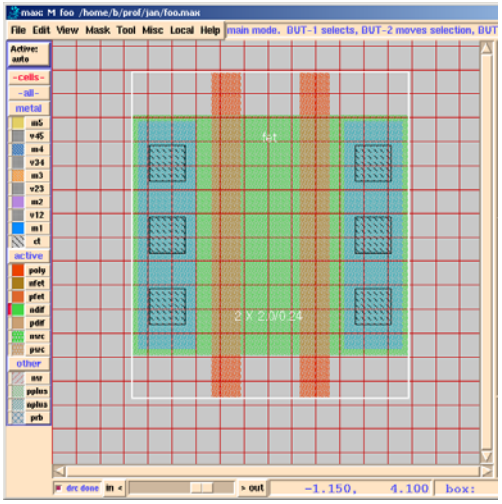


(a) Layout



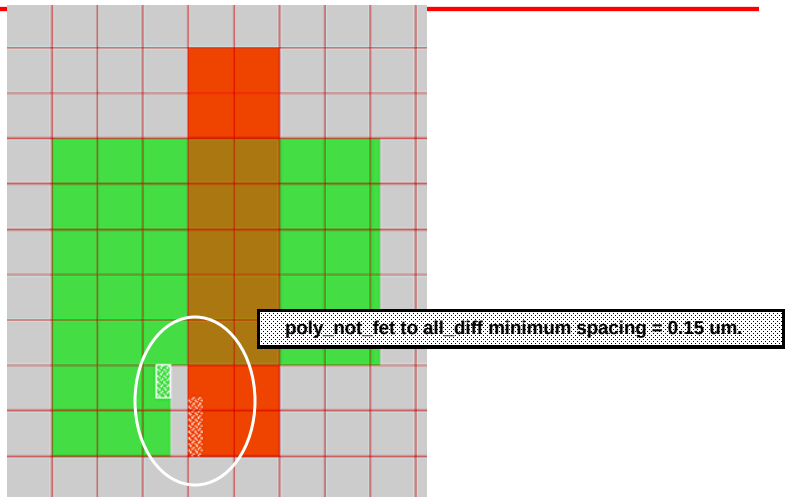
(b) Cross-Section along A-A'

Example of Layout Editor

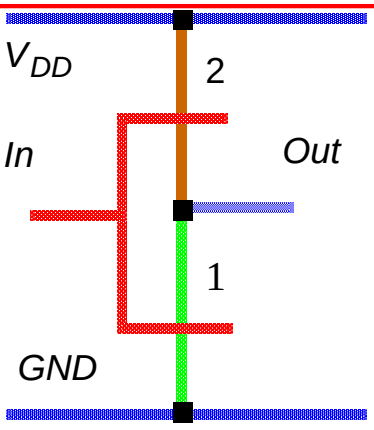


2 series connected devices

Design Rule Check (DRC)



Stick Diagram



Stick diagram of inverter

- Useful to visualize the layout you intend to use for a gate

Antenna rules

- Charging in semiconductor processing
  - Many process steps use plasmas, charged particles
  - Charge collects on conducting poly, metal surfaces
  - Large amounts of charge on poly can create huge E-fields across the thin gate oxide and lead to breakdown
  - Amount of charge collected is proportional to area of conductors
- Important ratio: antenna ratio defined as:
  - $(A_{poly} + A_{M1} + \ldots) / A_{gate\_ox}$
  - A_{Mx} = metal x area electrically connected to node
    - This is very conservative as higher levels of metal can alleviate the problem
  - If a diode is attached along the line, antenna rules are relaxed
    - Provides a low impedance path for large amounts of charge to be removed from the conductor

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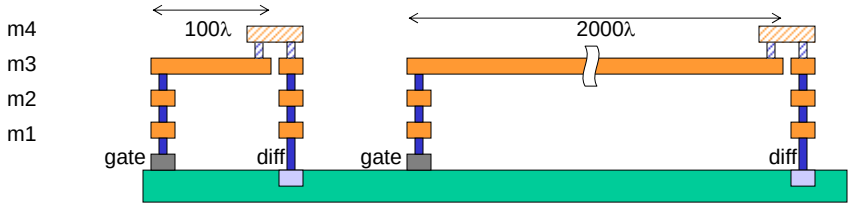
Problem: If a gate sees a **long** metal before a diffusion does



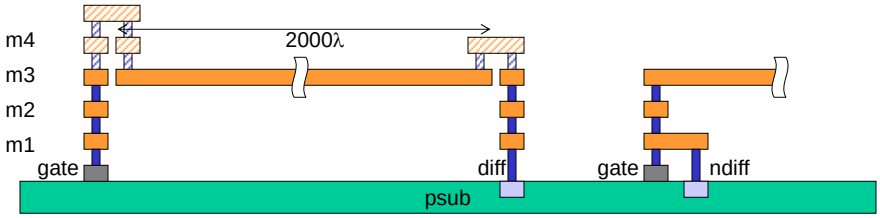
Safe: m3 is too short to accumulate very much charge; won't kill gate

Dangerous: lots of m3; will probably accumulate lots of charge and then blow oxide

From Ron Ho

Antenna Rules

- Two solutions: bridging and node diodes
  - Bridging attaches a higher layer intermediary
  - Diode is a piece of diffusion to leak away charge

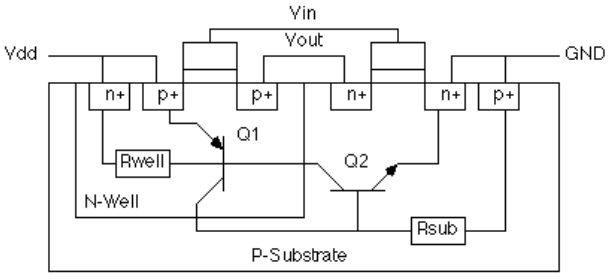


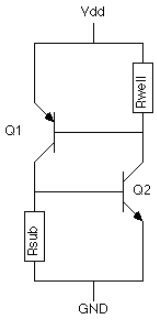
Bridging keeps gate away from long metals until they drain through the diffusion

Node diodes are inactive during chip operation (reverse-biased p/n); let charge leak away harmlessly

From Ron Ho

Latch-up



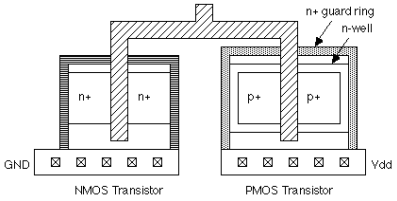


- Most commonly a problem for I/O pads with big drivers, large currents, possible voltage overshoots

How to avoid latch-up

- Reduce the gain product $\beta 1 \times \beta 2$
  - move n-well and n+ source/drain farther apart increases width of the base of Q2 and reduces gain $\beta 2$ → also reduces circuit density
  - buried n+ layer in well reduces gain of Q1
- Reduce the well and substrate resistances, producing lower voltage drops
  - higher substrate doping level reduces Rsub
  - reduce Rwell by making low resistance contact to GND
  - guard rings around p- and/or n-well, with frequent contacts to the rings, reduces the parasitic resistances

Aim for 1 well or substrate plug per gate



Summary

- Design rules = contract between process engineer and designer
  - Balance between yield and performance
- Next time: Integrated Circuit (IC) design flows (Ch. 8)
- Remember the CAD tutorial, which will really introduce you to layout
  - Hands-on: the only way to learn layout