Chapter 2

- The Well
  - Cross Sections
  - Patterning
  - Design Rules
  - Resistance
  - PN Junction
  - Diffusion Capacitance
Cross Sections

Figures from CMOS Circuit Design, Layout, and Simulation, Second Edition
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DESCRIPTION

– **Substrate**
  - Epi → epitaxial layer (p-), expensive
  - p+ Boron doping substrate
  - Body of NMOS

– **PWell**
  - No PWell, unless expensive process
  - Twin tub/moat
    - Old nomenclature, do not use

– **NWell**
  - n- Phosphoros doping
  - Isolation by parasitic diode
  - Can be used as a resistor
    - Current flows where?
    - What potential problem?

*Figure 2.1* The top (layout) and side (cross-sectional) view of a die.

*Figure 2.2* The n-well can be used as a resistor.
### Generic Patterning

Figures from CMOS Circuit Design, Layout, and Simulation, Second Edition

- **A,B) Starting material**
  - P-type Si, ~500µm thick

- **C) Grow oxide**
  - Thermal process, SiO2 result
  - Dry Oxide, less defects, longer
  - Wet Oxide, more defects, shorter
  - Consumes Si

- **D) Deposit photoresist (PR)**
  - Spin on viscous liquid ~1µm
  - Soft bake to harden

- **E,F) Align mask**
  - Mask was made from layout tool

- **G) Expose PR**
  - Light will make PR more acidic/basic
  - Over/Under expose feature size
  - Hard bake

- **H) Develop PR**
  - Neutralize expose PR

- **I) Etch underlying layer**
  - Acid etch, H2SO4 or similar

- **J) Remove PR**
  - Clean up, do not leave residue

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**Nwell Patterning**

- Deposit PR
- Expose PR
  - Nwell layout from tool → mask
- Develop PR
- Implant Nwell
  - N- Phosphoros
  - Depth of implant set by energy
- Diffuse dopant material
  - Diffusion coefficient
  - Gaussian profile → rectangular
- Remove PR
- Nwell formed
Design Rules

- **DESCRIPTION**
  - DESIGN RULE CHECK
    - DRC
  - NWELL-NWELL SPACING
    - INTERLAYER
    - ISOLATION DRIVEN
  - NWELL WIDTH, LENGTH
    - INTERLAYER
    - PR, IMPLANT DRIVEN
  - Bipolar parasitics formed
    - NPN, weak beta
    - Depends on what node for activity?

**Figure 2.7** Sample design rules for the n-well.
**Resistance**

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Mathematical Description:

- \[ R = \frac{\rho \cdot L}{A} = \frac{\rho \cdot L}{W \cdot t} = \frac{\rho}{S} \cdot \frac{L}{W} \]

- **SHEET RESISTANCE**
  - LUMP THICKNESS INTO VALUE
  - NEED SEPARATE MONITOR

- **NUMBER OF SQUARES**
  - CURRENT DIRECTION
  - SQUARES = \( \frac{L}{W} \)

- **TAP**
  - N+ to Nwell
  - P+ to Psub

- **DIFFUSION**
  - N+ in Psub
  - P+ in NWell

- **Contact to Nwell**
  - Not as shown, but close
  - Nwell must enclose tap
  - Metal is really contact / LI layer
**PN Junction**

**DESCRIPTION**

- **USES**
  - ISOLATION
  - ACTIVE DIODE
- CONDUCTION, VALENCE BANDS
  - SEPARATED BY BANDGAP
- OFFSET IN BANDS PRODUCE $V_{bi}$
- FORWARD BIAS, OVERCOME $V_{bi}$

**Figure 2.11** An electron moving to the conduction band, leaving behind a hole in the valence band.

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(a) Intrinsic silicon  (b) p-type silicon  (c) n-type silicon

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(d) A pn-junction diode

**Figure 2.12** The Fermi energy levels in various structures.
Depl, Diffusion Capacitance

DESCRIPTION

- DEPLETION REGION ISOLATION
  - AKA JUNCTION ISOLATION
  - NO CURRENT CONDUCTION
  - WIDTH OF DEPL LAYER VS. BIAS
  - LOWER DOPING, LARGER Wdepl

- UNDERSTAND CAPACITANCE
  - FUNDAMENTAL
  - REPEATED IN ALL DEVICES

- SIDEWALL VS. BOTTOM WALL
  - DIFFERENT PHYSICS, MODEL
  - DOPING, ISOLATION DIFFERENT

- ZERO BIAS DEPL IN MODELS (CJ₀)
  - CAP EXISTS AT ZERO BIAS
  - CAP INCREASES W/INCR FB

- DIFFUSION CAP
  - PRESENT IN FORWARD BIAS (FB)
  - OP POINT FOR DIODE USUALLY RB
• When p-type and n-type materials are joined, diffusion occurs.

Excess holes in p-type region diffuse to n-type, and excess electrons in n-type diffuse to p-type region

• This diffusion is opposed by the resulting electric field of the uncovered ionic charges. The positive ion cores in the n-type region oppose the diffusion of the p-type carriers from the p-type region, and vice-versa.

• The exposed ionic cores in the p-type region (negative, Na) must be matched by the exposed ionic cores in the n-type region (positive, Nd), leaving a net charge-neutral device:
  \[ q_A x_p N_A = q_A x_n N_D \]

• If \( A \) is the same on both sides, then
  \[ x_p N_A = x_n N_D \]
meaning the depletion depth is greater for a more lightly doped region

• The ionic charge results in an E-field, which causes a built-in potential to form. This \( V_{bi} \) will oppose the diffusion and it will match the \( -qV_{bi} \) in the band diagrams.

\[ C = \frac{\varepsilon A}{t} \]