Massachusetts Institute of Technology

EECS 6.012

Microelectronic Devices and Circuits

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I. Coverage of Course

A. Goal: Basic Knowledge of Microelectronic Devices and Circuits

- Interelationship

B. Major Topics

- Semicondutor Physics
- Metal-Oxide-Semiconductor (MOS) Transistors
- Digital Logic Circuits--Design Project 1
- Bipolar Transistors
- Amplifiers-BiCMOS--Design Project 2

C. Follow-on Courses

- 6.152J-Microelectronic Process Technology
- 6.720-Device Physics
- 6.301-Analog Circuit Design
- 6.374-Digital Integrated Circuit Design

II. Applications for Semiconductors

- **Amplifiers: Hi-Fi, μWave Communication, Telephony**
- **Logic Circuits: Computers, Digital Signal Processors**
- **Memories: DRAM, SRAM, EEPROM**
- **Lasers: CD Players, Optical Fiber Transmission**
- **Light Emitting Diodes (LED): Displays**
- **Photodiodes: Receivers for Optical Transmission**
- **Charge-Coupled Device (CCD): Cameras**
- **Many Others**

III. IC Fabrication Technology

A. History:

- 1958-59: J. Kilby, Texas Instruments and R. Noyce, Fairchild
- 1959-70: Explosive growth-SSI & MSI (Digital Gates, Analog Functions)-Discrete Functions
- 1970-80: MOS ICs introduced-LSI (RAMs, microprocessors) Watches; Calculators
- 1980-97: CMOS integrated systems-VLSI (X86 μP, nMBIT DRAM) - PC, Workstations
- 1997-200x $>10^8$ devices/chip-ULSI, RLSI (1000 MBIT DRAM)
- **Applications**-More powerful PC's, Integrated Computation and Communication Devices
- **Spin-offs** from IC technology in biotechnology/MEMS

B. Key Idea: *batch fabrication* of electronic circuits

- An entire circuit, say 10^6 transistors and associated wiring -- can be made in and on top of a single silicon crystal by a series of process steps similar to printing.

- The silicon crystal is a thin disk about the size of a small dinner plate (200mm) called a *wafer*. More than 100 copies of the circuit are made at the same time.

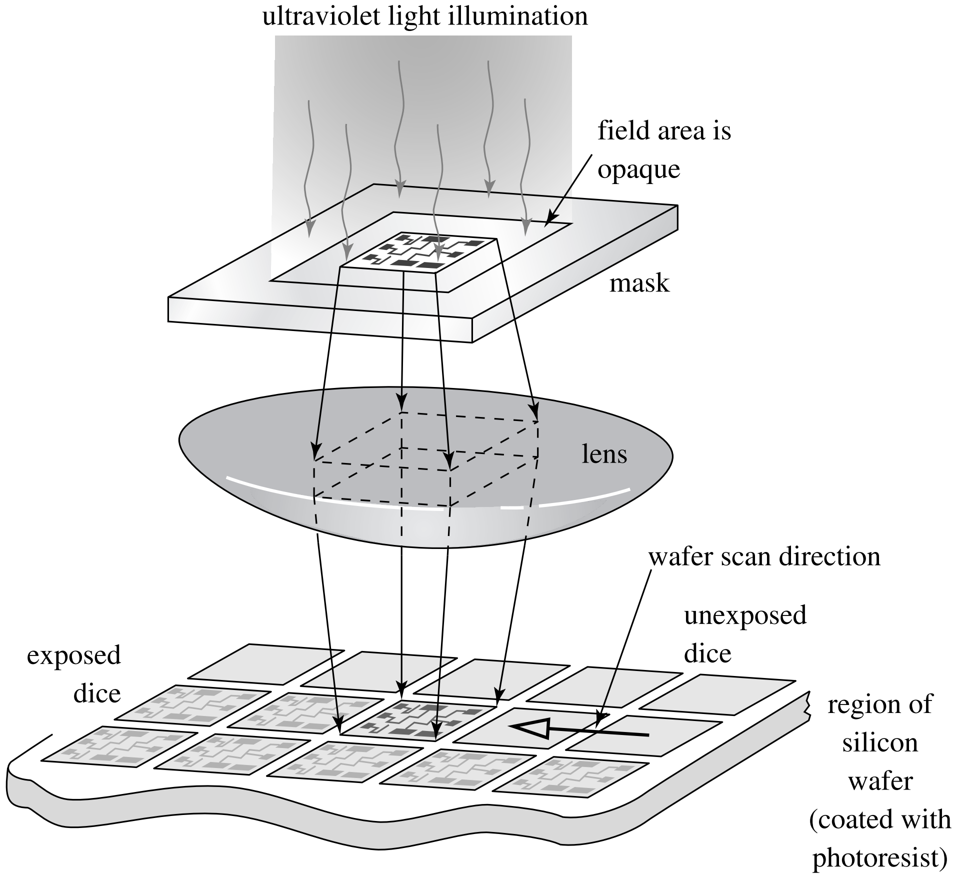
C. Results:

- Complex systems can be fabricated reliably
- Cost per function drops as the process improves (e.g., finer printing),

D. Photolithography

• The essential process step: makes possible the transfer of a series of patterns onto the wafer -- all aligned to within 0.1 μm

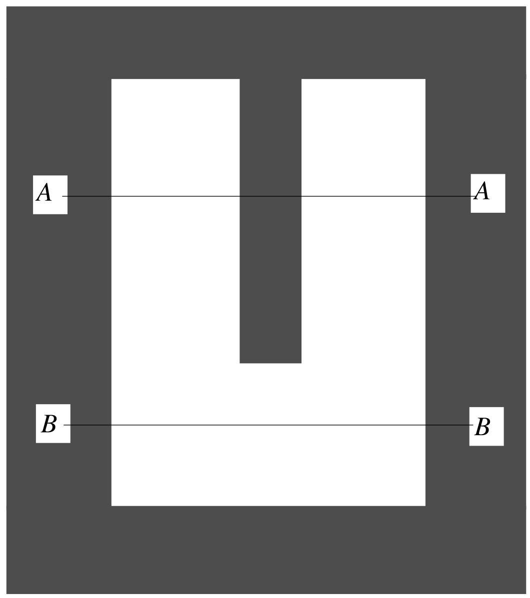
• Process "Tool" -- *wafer stepper*



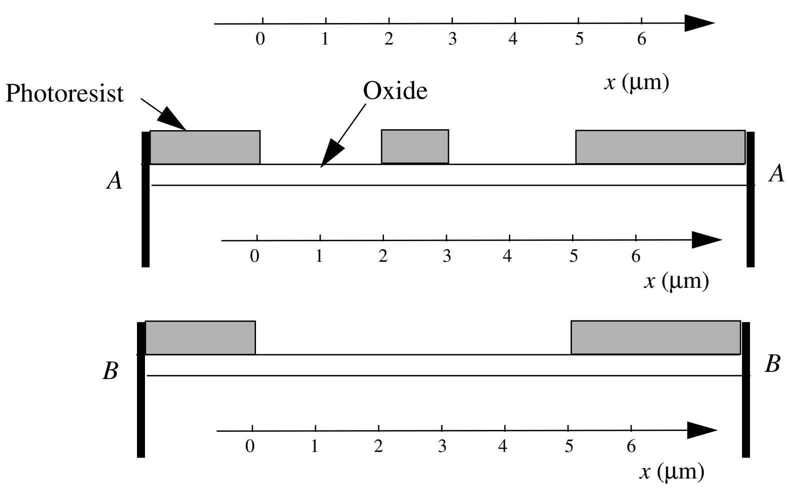
• UV-sensitive film is called *photoresist.* Regions exposed to UV dissolve in developer (for positive photoresist)

E. Pattern Transfer Example - Etch Pattern in Oxide

- Simple example of a *layout* and a *process* (or *recipe*)
- Layout is the set of mask patterns for particular layer (top view)
- Process is the sequence of fabrication steps (crossection)



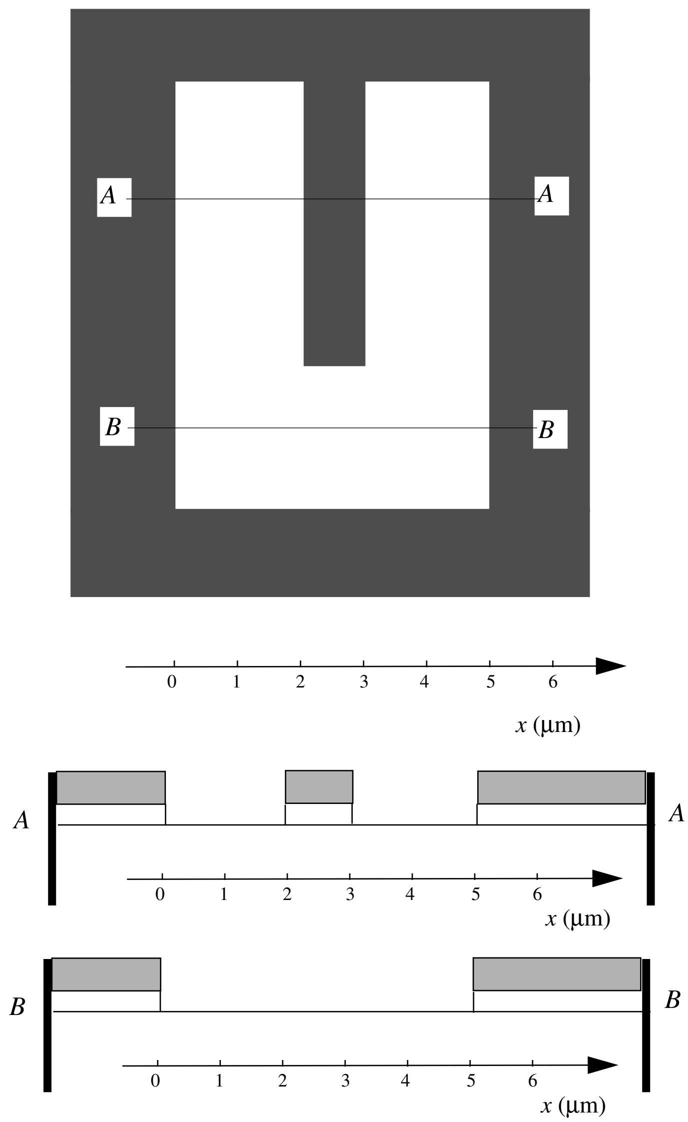
Mask Pattern



- Photoresist has been developed from clear areas of the mask

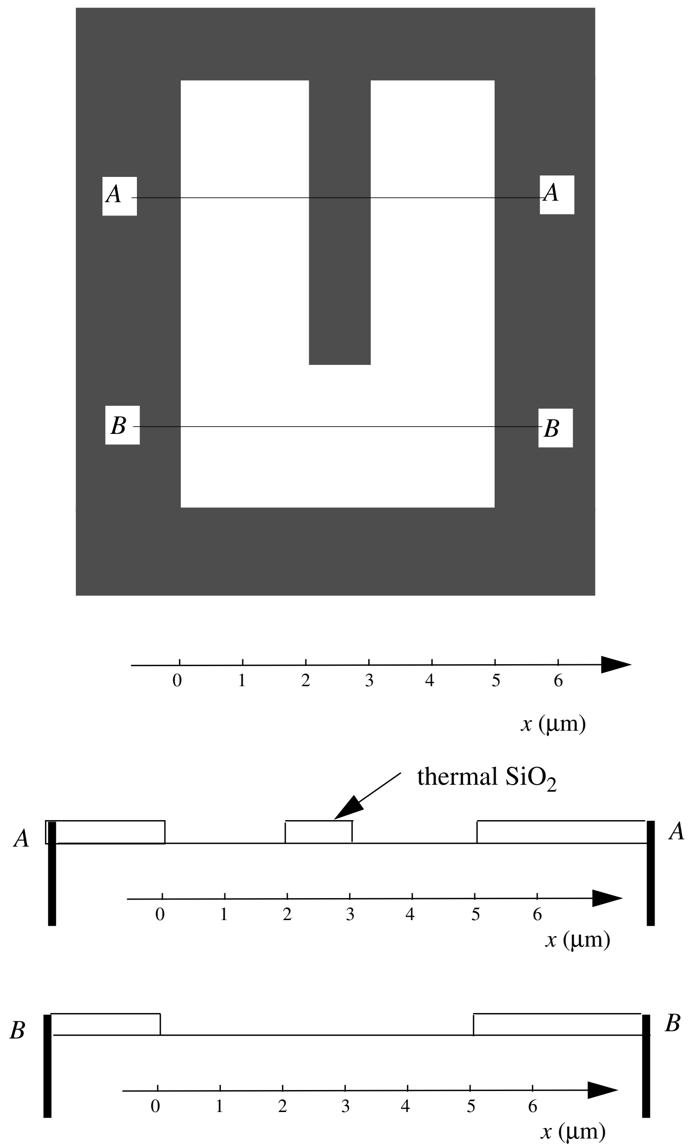
Pattern Transfer Example (cont.)

- Oxide is etched in the fluorine plasma, without (much) etching of the underlying silicon



Completed Structure

- Oxygen plasma strips (i.e., etches) the photoresist



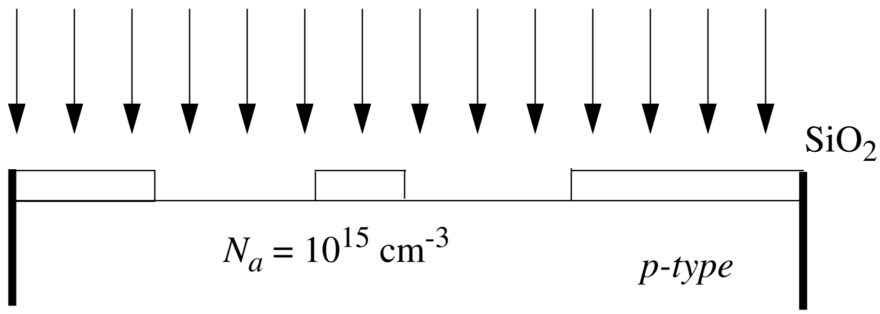
- Pattern Transfer = Photolithography + Etching

F. Doping by Ion Implantation

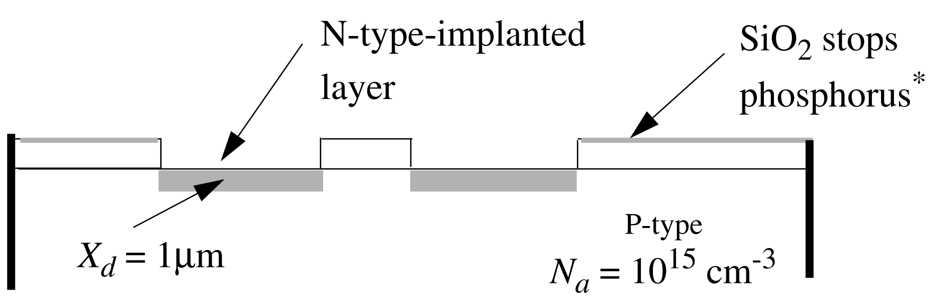
- *Dose* = ion beam flux (# cm^{-2} s^{-1}) x time for implant ... units # cm^{-2}

Example:

phosphorus ions, dose $Q_d = 10^{14}$ cm^{-2}



- SiO_2 film masks the implant by preventing ions from reaching the underlying silicon (assuming it's thick enough)
- After implantation, the phosphorus ions are confined to a damaged region near the silicon surface
- Anneal damaged silicon and diffuse phosphorus atoms deeper into the silicon with a high temperature (900-1000 C) anneal



- N-type concentration $N_d = Q_d / X_d = 10^{14}$ cm^{-2}/10^{-4}cm = 10^{18} cm^{-3}

G. IC Materials and Processes

• *Polycrystalline silicon (polysilicon)*: silicon deposited from a gas at temperatures around 600 ^{o}C, made up of small crystallites (grains), so-so conductor when heavily doped with phosphorus, but can survive very high temperatures.

• *Deposited oxides*: silicon dioxide deposited from a gas at temperatures from 425 ^{o}C to 600 ^{o}C, boron and phosphorus are sometimes added to allow it to flow. These oxides are known as "CVD" oxides for "chemical vapor deposition."

• *Metals*: aluminum is the standard "wire" for ICs and is usually deposited by "sputtering." Tungsten (grown from a gas reaction) is sometimes used, with increasing interest in copper.

Summary

In order to make an IC, we need

1. The mask patterns (the *layout*) - Top View

2. The sequence of fabrication steps (the *process*) - Crossection

MOSFET Fabrication

- This MOS transistor has made possible the revolution in digital electronics. It can be made in only 4 masking steps.