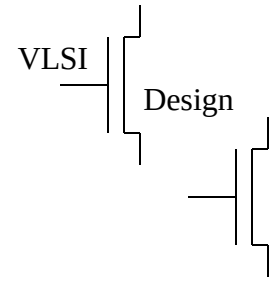

VLSI Design

Why VLSI?

- Integration improves the design
  - Lower parasitics = higher speed
  - Lower power consumption
  - Physically smaller
- Integration reduces manufacturing cost - (almost) no manual assembly

VLSI Applications

- VLSI is an implementation technology for electronic circuitry - analogue or digital
- It is concerned with forming a pattern of interconnected switches and gates on the surface of a crystal of semiconductor
- Microprocessors
  - personal computers
  - microcontrollers
- Memory - DRAM / SRAM
- Special Purpose Processors - ASICS (CD players, DSP applications)
- Optical Switches
- Has made highly sophisticated control systems mass-producable and therefore cheap

Moore's Law

- Gordon Moore: co-founder of Intel
- Predicted that the number of transistors per chip would grow exponentially (double every 18 months)
- Exponential improvement in technology is a natural trend:
  - e.g. Steam Engines - Dynamo - Automobile

The Cost of Fabrication

- Current cost $2 - 3 billion
- Typical fab line occupies 1 city block, employees a few hundred employees
- Most profitable period is first 18 months to 2 years
- For large volume IC's packaging and testing is largest cost
- For low volume IC's, design costs may swamp manufacturing costs

What is a Silicon Chip?

- A pattern of interconnected switches and gates on the surface of a crystal of semiconductor (typically Si)
- These switches and gates are made of
  - areas of n-type silicon
  - areas of p-type silicon
  - areas of insulator
  - lines of conductor (interconnects) joining areas together
    - Aluminium, Copper, Titanium, Molybdenum, polysilicon, tungsten
- The geometryof these areas is known as the layout of the chip
- Connections from the chip to the outside world are made around the edge of the chip to facilitate connections to other devices

Switches

- Digital equipment is largely composed of switches
- Switches can be built from many technologies
  - relays (from which the earliest computers were built)
  - thermionic valves
  - transistors
- The perfect digital switch would have the following:
  - switch instantly
  - use no power
  - have an infinite resistance when off and zero resistance when on
- Real switches are not like this!

Semiconductors and Doping

- Adding trace amounts of certain materials to semiconductors alters the crystal structure and can change their electrical properties
  - in particular it can change the number of free electrons or holes
- N-Type
  - semiconductor has free electrons
  - dopant is (typically) phosphorus, arsenic, antimony
- P-Type
  - semiconductor has free holes
  - dopant is (typically) boron, indium, gallium
- Dopants are usually implanted into the semiconductor using Implant Technology, followed by thermal process to diffuse the dopants

IC Technology

- Speed / Power performance of available technologies
- The microelectronics evolution
- SIA Roadmap
- Semiconductor Manufacturers 2001 Ranking

Metal-oxide-semiconductor (MOS) and related VLSI technology

- pMOS
- nMOS
- CMOS
- BiCMOS
- GaAs

Basic MOS Transistors

- Minimum line width
- Transistor cross section
- Charge inversion channel
- Source connected to substrate
- Enhancement vs Depletion mode devices
- pMOS are 2.5 time slower than nMOS due to electron and hole mobilities

Fabrication Technology

- Silicon of extremely high purity
  - chemically purified then grown into large crystals
- Wafers
  - crystals are sliced into wafers
  - wafer diameter is currently 150mm, 200mm, 300mm
  - wafer thickness <1mm
  - surface is polished to optical smoothness
- Wafer is then ready for processing
- Each wafer will yield many chips
  - chip die size varies from about 5mmx5mm to 15mmx15mm
  - A whole wafer is processed at a time

Fabrication Technology

- Different parts of each die will be made P-type or N-type (small amount of other atoms intentionally introduced - doping - implant)
- Interconnections are made with metal
- Insulation used is typically SiO2. SiN is also used. New materials being investigated (low-k dielectrics)

Fabrication Technology

- nMOS Fabrication
- CMOS Fabrication
  - p-well process
  - n-well process
  - twin-tub process

Fabrication Technology

- All the devices on the wafer are made at the same time
- After the circuitry has been placed on the chip
  - the chip is overglassed (with a passivation layer) to protect it
  - only those areas which connect to the outside world will be left uncovered (the pads)
- The wafer finally passes to a test station
  - test probes send test signal patterns to the chip and monitor the output of the chip
- The *yield* of a process is the percentage of die which pass this testing
- The wafer is then scribed and separated up into the individual chips. These are then packaged
- Chips are ‘binned’ according to their performance

CMOS Technology

- First proposed in the 1960s. Was not seriously considered until the severe limitations in power density and dissipation occurred in NMOS circuits
- Now the dominant technology in IC manufacturing
- Employs both pMOS and nMOS transistors to form logic elements
- The advantage of CMOS is that its logic elements draw significant current only during the transition from one state to another and very little current between transitions - hence power is conserved.
- In the case of an inverter, in either logic state one of the transistors is off. Since the transistors are in series, (~ no) current flows.
- See twin-well cross sections

BiCMOS

- A known deficiency of MOS technology is its limited load driving capabilities (due to limited current sourcing and sinking abilities of pMOS and nMOS transistors.
- Bipolar transistors have
  - higher gain
  - better noise characteristics
  - better high frequency characteristics
- BiCMOS gates can be an efficient way of speeding up VLSI circuits
- See table for comparison between CMOS and BiCMOS
- CMOS fabrication process can be extended for BiCMOS
- Example Applications
  - CMOS - Logic
  - BiCMOS - I/O and driver circuits
  - ECL - critical high speed parts of the system