# EEC 118 Lecture #17: Future Directions Alternatives to CMOS Final Review

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# Digital Circuits Beyond CMOS

- **Past digital technologies**
  - Electromagnetic Relay: mechanical switch controlled by a current; ideal switch but high power and slow
  - Vacuum Tube: three (usually) terminal device, similar to a MOSFET but very high power
  - Bipolar Transistor: high transconductance, but high power, finite input impedance limits fanout
- **State-of-the-art digital technology is bulk silicon CMOS**
  - Low power, little static power (compared to other technologies)
  - Infinite input impedance allows large fanouts
  - Vast development investment has led to extremely high reliability, high yields, and high performance

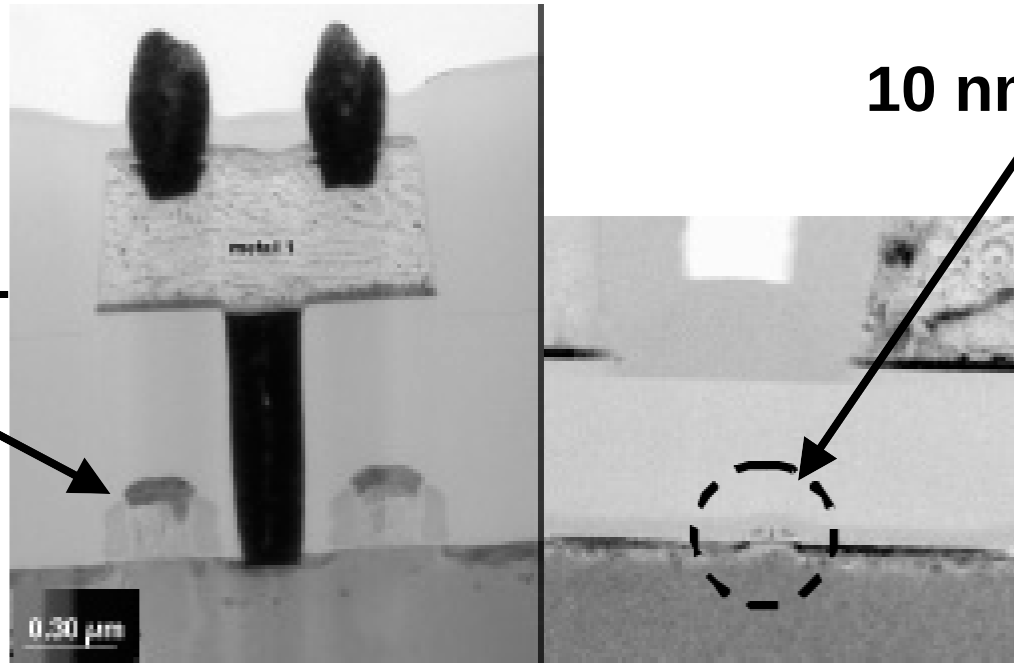
# Digital Circuits Beyond CMOS

- **Modifications on CMOS can extend Moore's Law**
  - Strained silicon: mechanical stress on bulk crystal improves mobility
  - Silicon-on-Insulator: insulating bulk decreases parasitic capacitors, allows tighter integration
  - New materials: low-k interconnect dielectrics, high-k gate dielectrics, metal gates
  - New structures: 3D gates (finFET)
- **But what happens when scaling stops?**
  - International Technology Roadmap for Semiconductors extends to about 20 nm gate lengths in 2015-2020 time frame
  - Research devices demonstrated down to 5 nm gate lengths

# Nanometer Gate Length Bulk FETs

10 nm FET

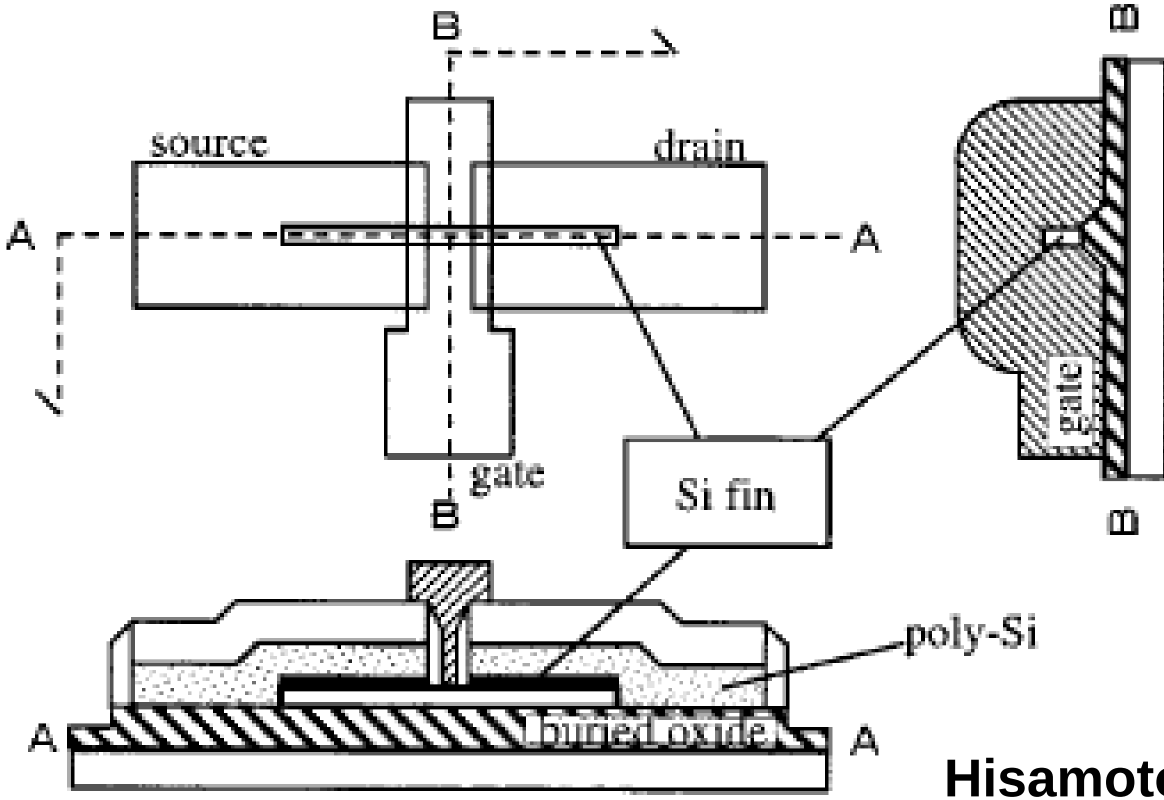
180 nm FET



Doyle, Intel 2002

- **Still more room at the bottom!**
- **In 10 nm CMOS, Intel 386 occupies 25 $\mu$m x 25 $\mu$m**
- **Fabricated using a combination of lithography and epitaxial growth to define feature sizes**

# Three Dimensional Transistors: FinFETs




**Hisamoto, JSSC 2000**

- **Channel forms in thin silicon fin**
- **Gate wraps around fin to control channel formation**
- **Allows very small channel lengths**

# Digital Circuits Beyond CMOS

- **New devices based on new materials or quantum effects**
  - Gallium Arsenide (GaAs) MESFET: high electron mobility but no complementary device and poor oxide isolation
  - Josephson Junctions: superconducting logic and interconnect promises very high speed (THz), but only two terminals inconvenient for circuit design
  - Carbon Nanotube Transistors: carbon nanotube devices demonstrate high carrier mobilities and promise high speed
  - Molecular Electronics: single organic molecules shown to switch states in the lab, but also only two terminals
  - Organic Electronics: semiconducting plastic substrate, enables flexible displays and low cost but offers poor performance

# Alternatives to Electronics

- **A number of completely different digital technologies**
  - Optical Computing: use photons to carry information instead of charge carriers, but no good three terminal nonlinear optical element and difficult integration
  - Quantum Computing: using various atomic-scale structures to store multiple bits simultaneously and operating on them using laws of quantum mechanics allows massive parallelism, but very sensitive to noise
  - Biological Computing: use DNA gene coding and promoter and repressor sites to control synthesis of proteins, which form the digital “signals”
- **But can anything replace CMOS?**
  - Maybe, but not for a long time
  - Some parts of a system (memory) before others (logic)

# Final Exam Review List

Closed Book, Closed Notes, 1 8.5 in. x 11 in. Formula Sheet allowed, both sides, (You may bring a calculator)

- **MOS Fabrication (very basics)**
- **MOS Structure**
- **Inverter Operation**
- **CMOS Inverter**
- **CMOS Inverter (AC)**
- **Complex Gates, Pseudo NMOS**
  - DC and Transient characteristics
- **Sequential Logic**

# Final Exam Review List

- Pass Transistor Logic, Pseudo NMOS
- Dynamic Logic
- Memory (DRAM, SRAM, Flash, ROM)
- Low Power Circuits
- Arithmetic Circuits
- Interconnect
- Study all homework and lecture materials
- Study labs

# Key Learnings

- **Should know what region of operation the transistor is in given the bias voltages at its terminals**
- **Should know what the PMOS and NMOS Id vs Vds curves look like**
- **Be able to identify major points of the VTC for a CMOS Device [Voh, Vol, Vih, Vil, Vth]**
- **Need to know how to calculate the total capacitance at the output node (including Miller effect)**
- **Know the relevant capacitances of a transistor used in transient analysis (i.e. Cgs, Cgd, …).**

# Key Learnings

- **Know how to calculate propagation delay using Req and capacitance load. Be able to derive Req and Cload.**
- **Know Pseudo NMOS and Pass Transistor Logic pros and cons**
- **Know Different Adders and Multipliers**
  - Know concepts of how they speed up these arithmetic units
- **Dynamic Logic concepts**
  - Pros and cons, techniques used to cascade, avoid noise, etc.
- **Memory (different types, SRAM operation)**
- **Low Power Design techniques (voltage scaling, pipelining, etc.)**
- **Interconnect basics (resistance, capacitance)**

# Key Learnings

- **Know how to find the Boolean function from a schematic**
- **Know how to properly size transistors to get the equivalent resistance of a basic inverter**

These are here to help focus your study but is not an exhaustive list of what you are responsible for