TEXAS — WHAT STARTS HERE CHANGES THE WORLD

CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication

Lecture 2
Moore's Law

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Reading:
Chapter 1, *Fabrication Engineering at the Micro- and Nanoscale*, 4th edition, Campbell

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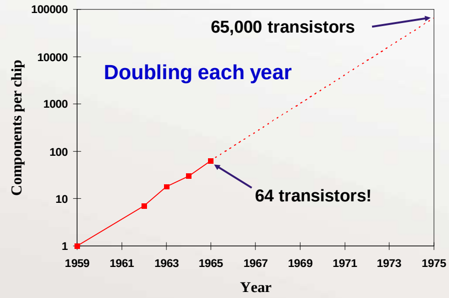
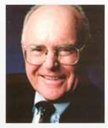
1965: Moore's Observation





G. E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics* Vol. 38, No. 8 (Apr. 19, 1965) pp. 114-117.

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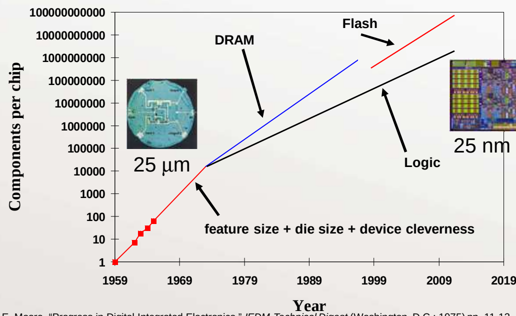
Moore's Law

"Doubling every 1 – 2 years"



G. E. Moore, "Progress in Digital Integrated Electronics," *IEDM Technical Digest* (Washington, D.C.: 1975) pp. 11-13.

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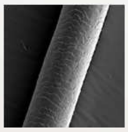
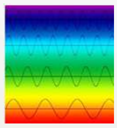
A Note on "Small"



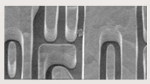
Human Hair
~70 micron

Red Blood Cell
~7 micron

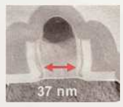


Red Light
Wavelength
~700 nanometer

Retrovirus
~70 nanometer



Patterns printed with lithography to make transistors are as small as 25 nm today, and still getting smaller!



(Note: 1 micron = 1000 nanometers)

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Dennard's MOSFET Scaling Rules

Robert Dennard

Device/Circuit Parameter	Scaling Factor*
Device dimension/thickness	$1/\lambda$
Doping Concentration	λ
Voltage	$1/\lambda$
Current	$1/\lambda$
Capacitance	$1/\lambda$
Delay time	$1/\lambda$
Transistor power	$1/\lambda^2$
Power density	1

* Constant electric field scaling

There are no trade-offs. Everything gets better when you shrink a transistor!

IEEE Journal of Solid-State Circuits, Vol. SC-9, October 1974, pp. 256-268.

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The Golden Age
1975 - 2000

- Dennard Scaling: as transistor shrinks it gets
  - Faster
  - Lower power (constant power density)
  - Smaller/lighter
- Moore's Law
  - Keep the cost/area about constant while shrinking
  - More transistors/chip & lower cost/transistor

Two Versions of Moore's Law

- Moore's Law 1.0: scaling up
  - Doubling the number of transistors every 1–2 years
  - More powerful chip for the same price
- Moore's Law 2.0: scaling down
  - Shrinking transistor area lowers the cost of a transistor by about 30%/year
  - Same chip for lower price
- Both versions enable many new applications
  - Results in a large increase in chip volumes

Problems with Dennard Scaling

- Voltage has always shrunk more slowly ($\sim 1/\sqrt{\lambda}$)
- Voltage essentially stopped shrinking 10 years ago
  - Thermal noise (kT/q = 25 mV at room temperature)
  - Subthreshhold leakage current
- Power is at a wall, dominates shrink issues
- Clock speed is stuck – we can't make our transistors faster
- Today, shrinking a transistor makes it worse

Dennard + Moore Today

- The only benefits of shrinking a transistor today are more functions/chip and/or lower cost/function
- Moore's Law cost: despite rising fab, equipment and material costs, and increasing process complexity, the cost/cm^2 of finished silicon has remained about constant (or risen only slowly) over the years.
  - Result: lower cost per transistor each year

Moore's Law 3.0

- Moore's Law 1.0: Scaling up
  - Only applies to Flash and supercomputers today
- Moore's Law 2.0: Scaling down
  - Higher costs are putting this version in danger
- Moore's Law 3.0: Scaling Out (Innovation through Integration)
  - New materials (e.g., HkMG)
  - 3D integration
  - Silicon photonics
  - Memory on microprocessor
  - Smart sensors and actuators, MEMS
  - More… (More than Moore)

Conclusions

- All three versions of Moore's Law have always been present
  - A shift in emphasis over time
- The Golden Days of Moore + Dennard are over
- Moore's Law is primarily an economic law
  - It is getting harder to keep costs down, putting the future of Moore's Law in danger
- Moore's Law 3.0 is the most exciting version yet

Lecture 2: What have we learned?

- What are the three versions of Moore's Law?
- What is Dennard scaling?
- Why does Dennard scaling no longer work?
- What are the consequences of the end of Dennard scaling?