MSE 460: Electronic Materials, Devices, and Processing

Lecture 1: Introduction and Orientation

Qing Cao-University of Illinois at Urbana-Champaign

Department of Materials Science and Engineering

Department of Chemistry

Department of Electrical and Computer Engineering

Frederick Seitz Materials Research Laboratory

Self-Introduction

2004-2009

2009-2018

Research Interest:

- Electronic Materials
- Unconventional Electronic Devices

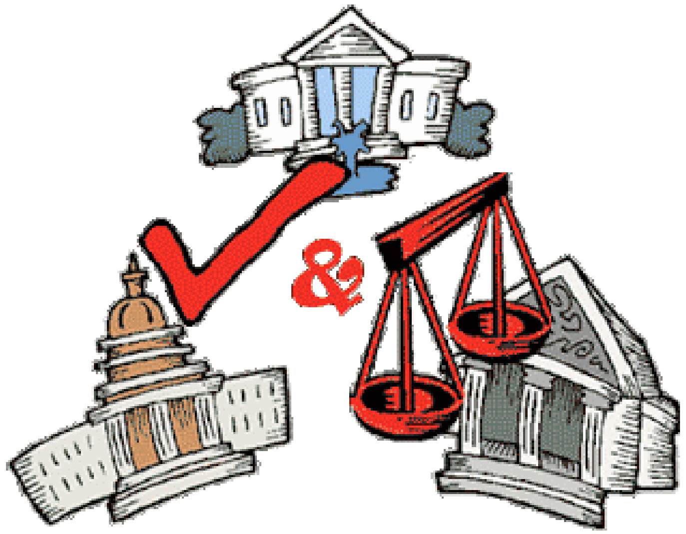
Email: qingcao2@Illinois.edu

Office: MRL 1008

Office hour: Friday 2-3 pm

Targets of MSE 460

1) Understand the processing technologies for electronic materials.
2) Understand the operational mechanism of various devices,
3) Understand the correlation between material properties and device performances,
4) Develop the technical insight into the choice of the most appropriate materials and processing techniques for different applications, and obtain of grasp of the most important challenges.



Engineering is the art of intelligent compromise.

About MSE 460 What will be covered in this class?

Overview and fundamentals of electronic materials

Lecture 1: Introduction and Orientation

Lecture 2: Overview of Electronic Materials

Lecture 3: Free electron Fermi gas

Lecture 4: Energy bands

Lecture 5: Carrier Concentration in Semiconductors

Lecture 6: Shallow dopants and Deep-level traps

Lecture 7: Silicon Materials

Lecture 8: Oxidation

Lecture 9: Doping

Lecture 10: Drift and diffusion

Lecture 11: Generation and recombination

About MSE 460

p-n junctions: Physics and fabrication

Lecture 12: Electrostatics of p-n junctions (I)

Lecture 13: Electrostatics of p-n junctions (II)

Lecture 14: Current Voltage Characteristics of p-n Junctions

Lecture 15: Metal Semiconductor interface and Schottky Diode

Lecture 16: Lithography I: Basics and Photoresist Chemistry

Lecture 17: Lithography II: EUV and Novel Patterning Techniques

Lecture 18: Etching Overview

Lecture 19: Wet Etching

Lecture 20: Dry Etching

About MSE 460

p-n junctions: LEDs and solar cells

Lecture 22: Light Emitting Diodes

Lecture 23: LED Materials

Lecture 24: Physics of Solar Cells

Homework 4

Lecture 25: Mid-term Exam

Lecture 26: Solar cell-Materials (I)

Lecture 27: Solar cell-Materials (II)

Lecture 28: Materials Deposition: PVD

Lecture 29: Materials Deposition: CVD (I)

Lecture 30: Materials Deposition: CVD (II)

Lecture 31: Transparent Conductive Oxide

About MSE 460

MOSFETs

Lecture 32: Electrostatics of MOS Capacitor

Lecture 33: C-V Characteristics of MOS Capacitor

Lecture 34: Operation of MOSFET

Lecture 35: Subthreshold Region of MOSFET And Device Scaling

Lecture 36: Velocity Saturation

Lecture 37: Short channel effects

Lecture 38: Non-ideal semiconductor-gate dielectric interface

Lecture 39: High-k/metal gate

Lecture 40: 3D Channel and New Channel Materials for MOSFETs

Lecture 41: Fabrication Flow of Si MOSFETs

Lecture 42: Electrodeposition

Grading

Grading will be composed of three elements

1) Homework (6x3%=18%)
   - 6 homework in total.
   - Collaboration policy: Limited homework collaboration
   - Homework will be due after the end of the next week, late homework will not be accepted.
2) Exams (2 exams for 82%)
   - Mid-term exam: 36%
   - Final exam: 46%
   - Exams will be open note (1 page, single-sided letter sheet)
   - Topics covered in mid-term will not be specifically tested in final

Course Webpage

Website: MSE460.matse.Illinois.edu

ILLINOIS ENGINEERING

MSE 460: Electronic Materials, Devices, and Processing

Materials Science & Engineering

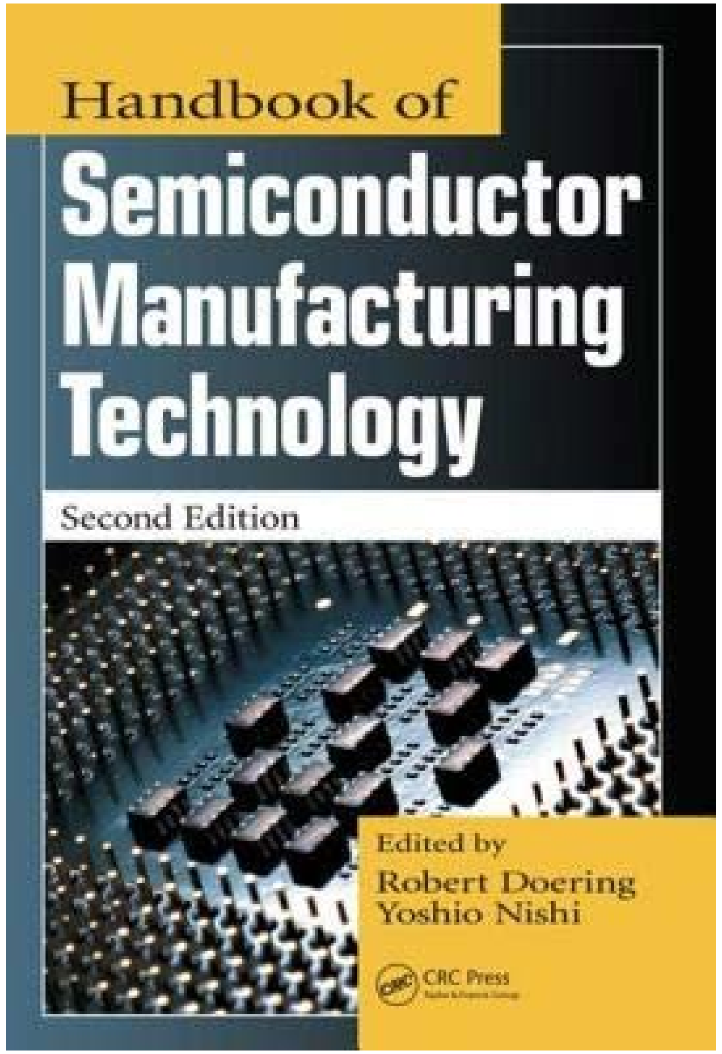
Home | Syllabus | Lecture Notes | Homework | Exams

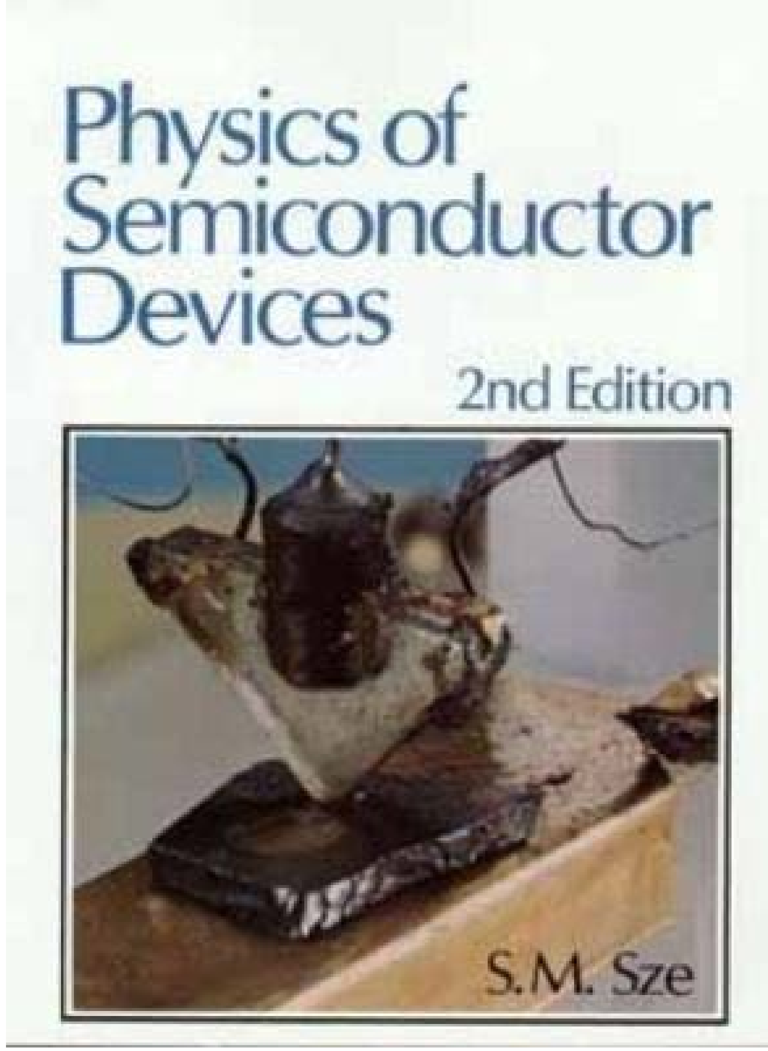
Home

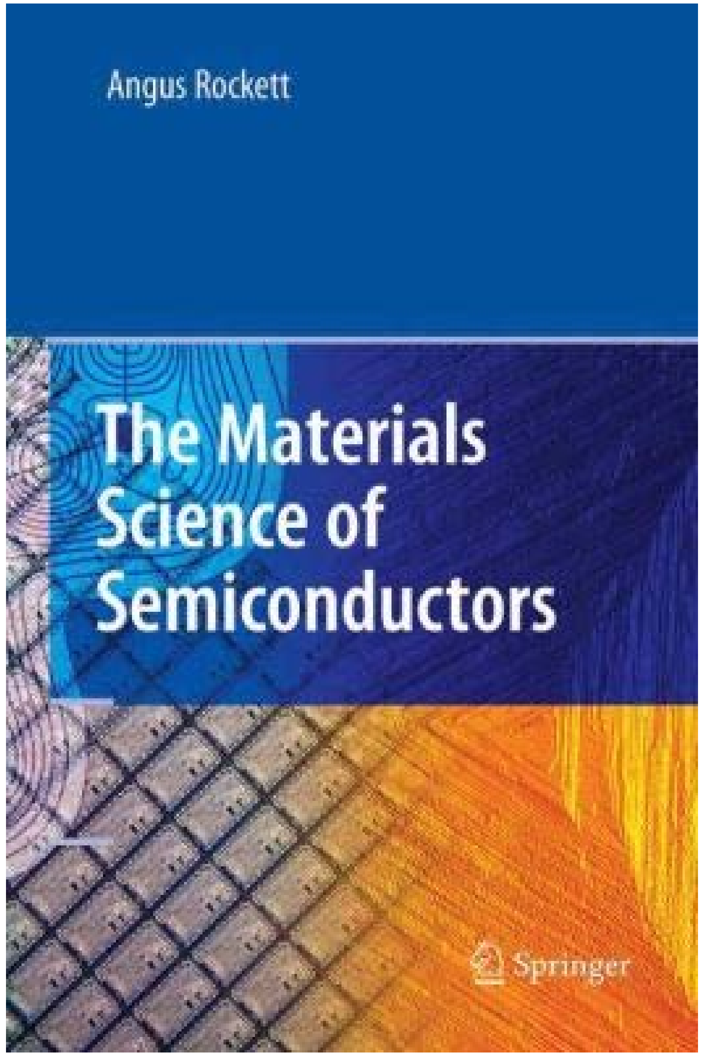
Welcome to the homepage of Class MSE 460.

Course Description: This class introduces students to materials used in modern electronic and optoelectronic devices. The progress of microelectronic industry is largely driven by the development and introduction of new materials. The structure, chemistry, and processing of materials are closely related to their electronic and optical properties and therefore the device characteristics. This course will cover the processing of electronic materials, the materials science and engineering of semiconductors, the physics behind the operations of various electronic and optoelectronic devices, and the adoption of different materials as well as bulk and nanoscale semiconductor processing techniques to deliver the desired device performances.

Textbooks

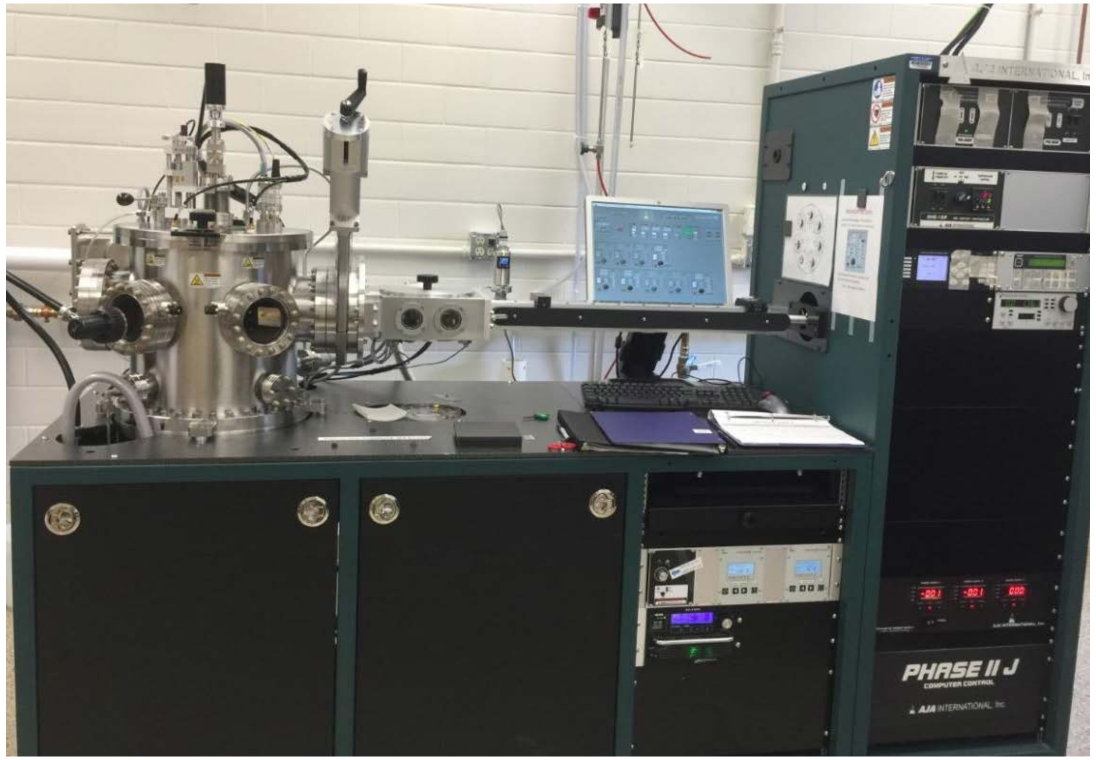

Handbook of
Semiconductor
Manufacturing
Technology
Second Edition
Edited by
Robert Doering
Yoshio Nishi
CRC Press

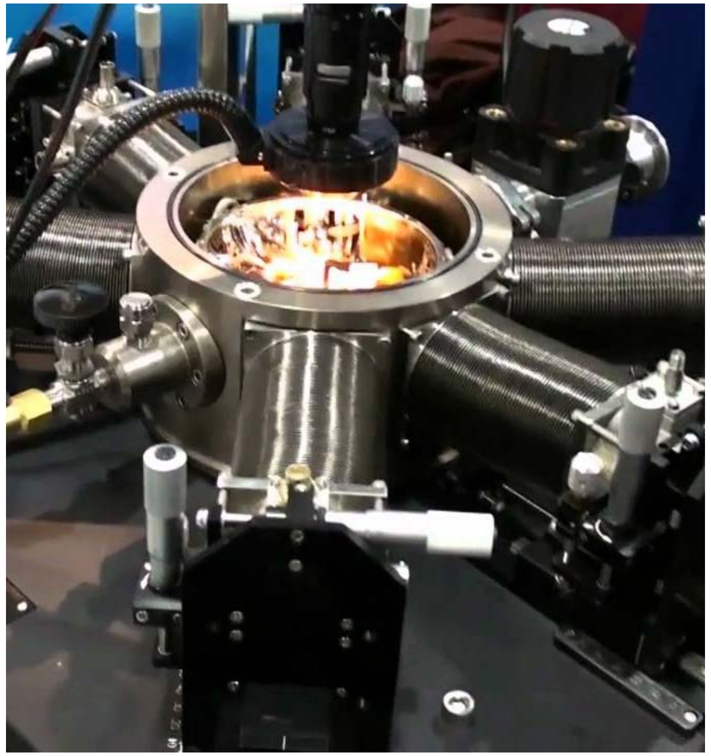

Physics of
Semiconductor
Devices
2nd Edition
S.M. Sze


Angus Rockett
The Materials
Science of
Semiconductors
Springer

Advertisement

If you are interested in obtaining hands-on experiences in electronic materials research, you are welcome to discuss with me about the opportunities of research assistants in my group!





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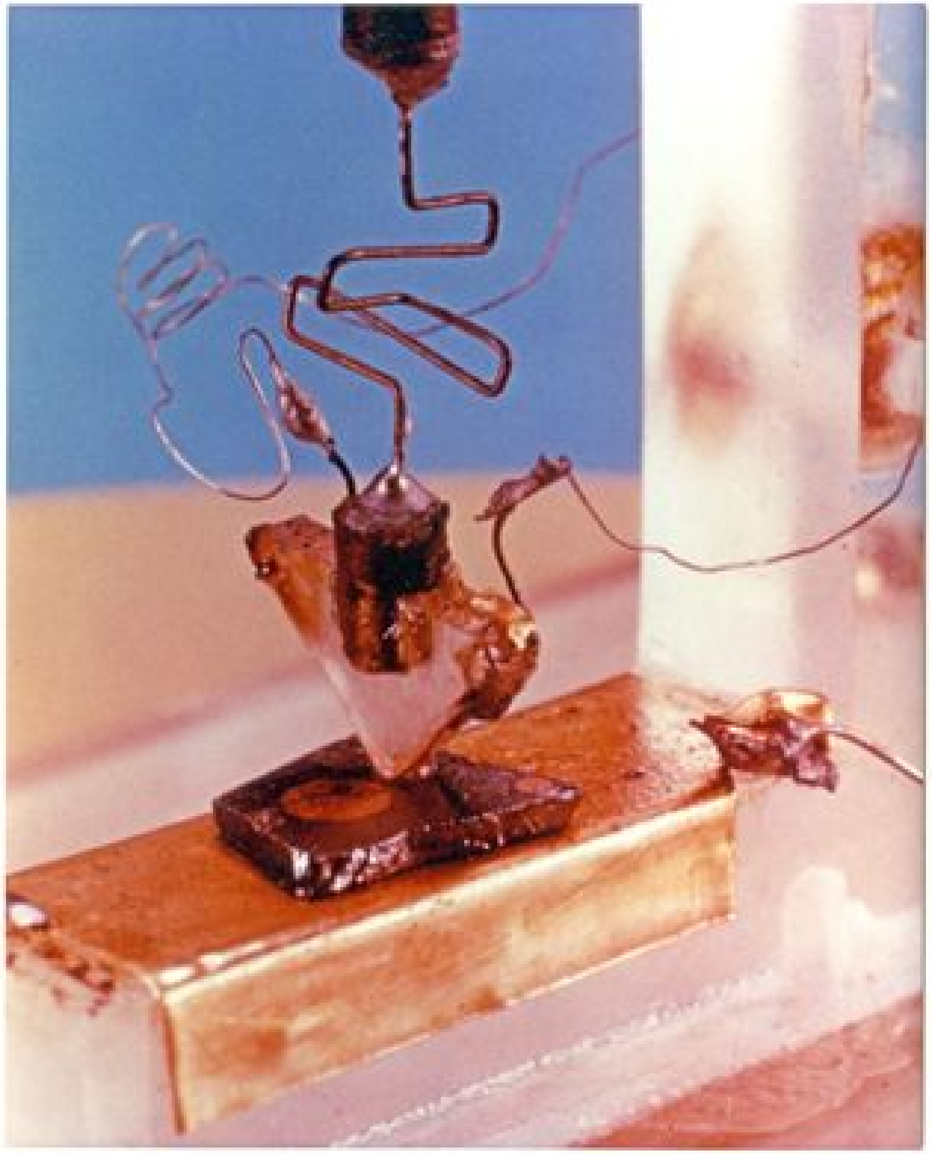
First Transistor



John Bardeen Walter Brattain

William Shockley

Your Motivations

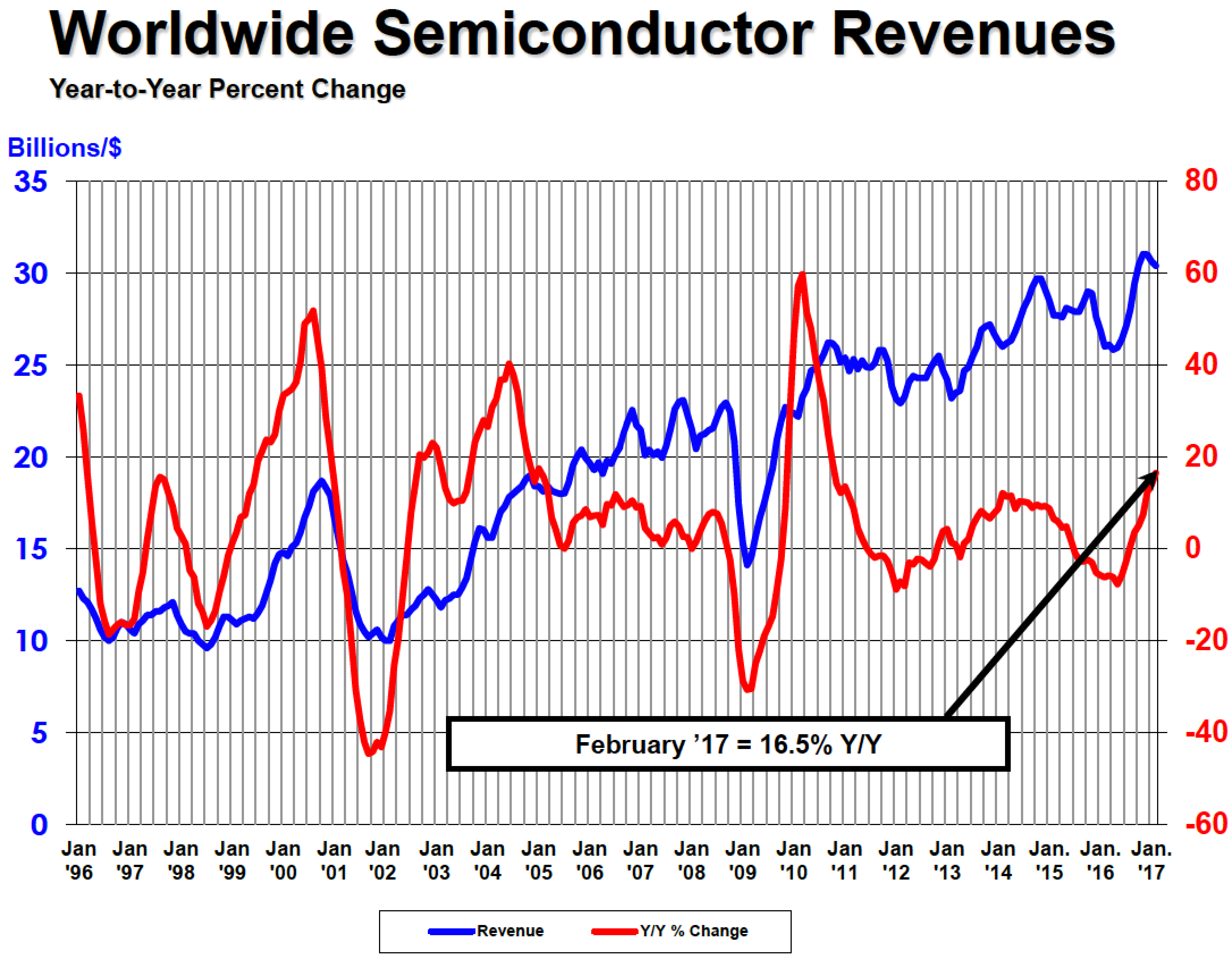
For undergraduate students:

1) Overall understanding of the field of electronic materials and electronic devices, and make informed choices if you would like to go to graduate school.
2) Scientific knowledge of cutting edge electronics, which will make you distinct if you would like to find a job in either consulting firms or work in the public policy.

For graduate students:

1) Pass the qualify exam on electronic materials
2) Help you to kick start your research: know the concepts, appreciate the problems, understand literatures, be able to communicate with you colleagues including your advisor.

Overview of Semiconductor Industry



Attributes of the semiconductor industry:

1) High capital investment:
Intel fab 42 at Arizona: 7B
GF fab 8 at Malta: 8.5B

2) High R&D investment:
Around 20% of total revenue

3) High profit margin:
Industry average gross margin about 60%

Players/Job Opportunities in Semiconductor Industry

Integrated Design and Manufacture (IDM)

Logic:
Intel, Samsung

Analog:
TI, Analog Devices, ST
NXP-Freescale

Memory:
Micron, Hynix

Fabless

IBM, AMD
Qualcomm, Broadcom
Nvidia
MediaTek

Foundry

TSMC
UMC
Global Foundry

Tool

Applied Materials
ASML
Lam Research
Novellus
Varian

Progress in Electronics

Computation

1956 IBM SAGE computer:
1MW
13,000 transistors, vacuum tubes, and diodes.

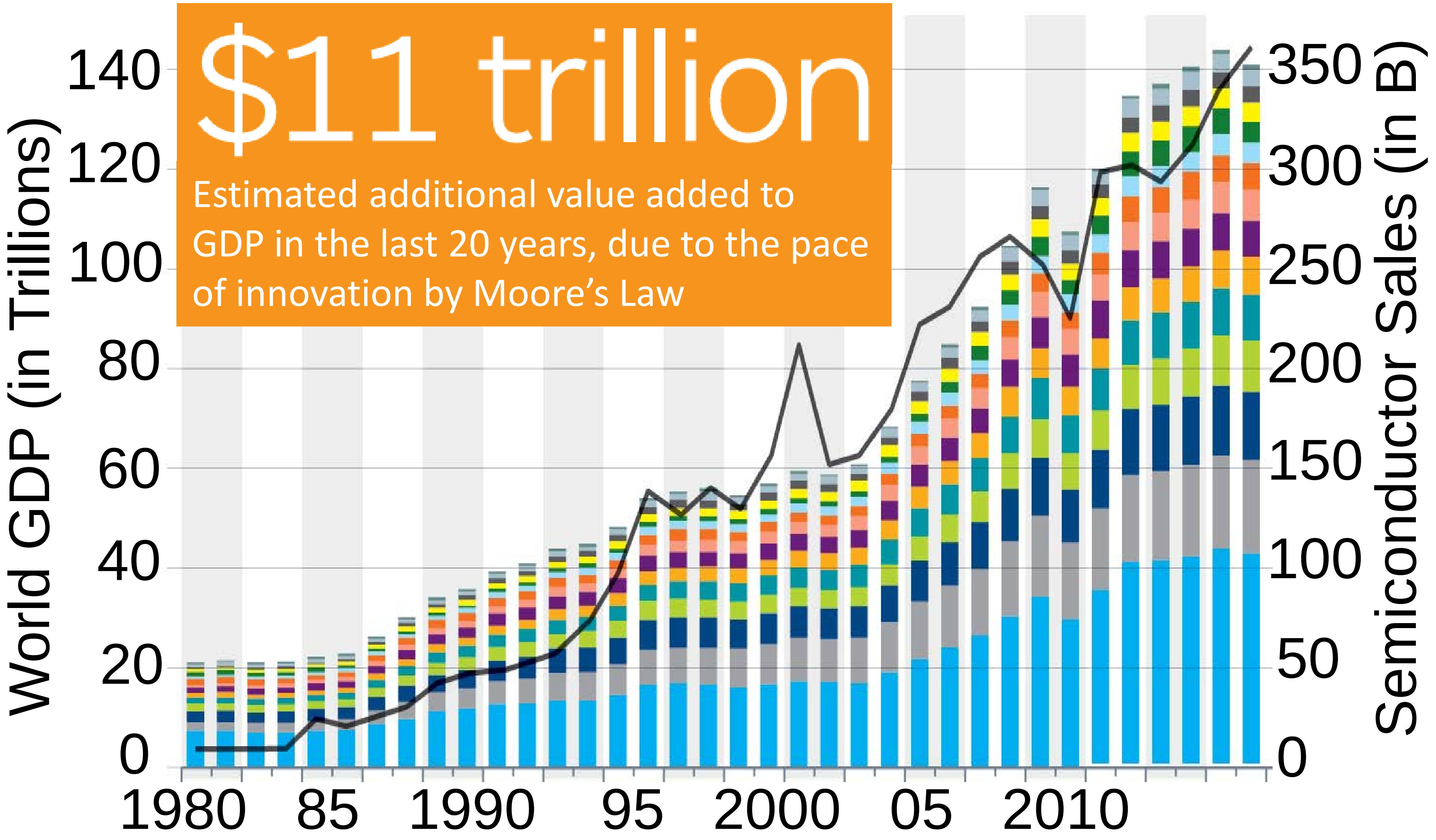
2016 Qualcomm Snapdragon 835:
~1W
3B transistors.

Memory

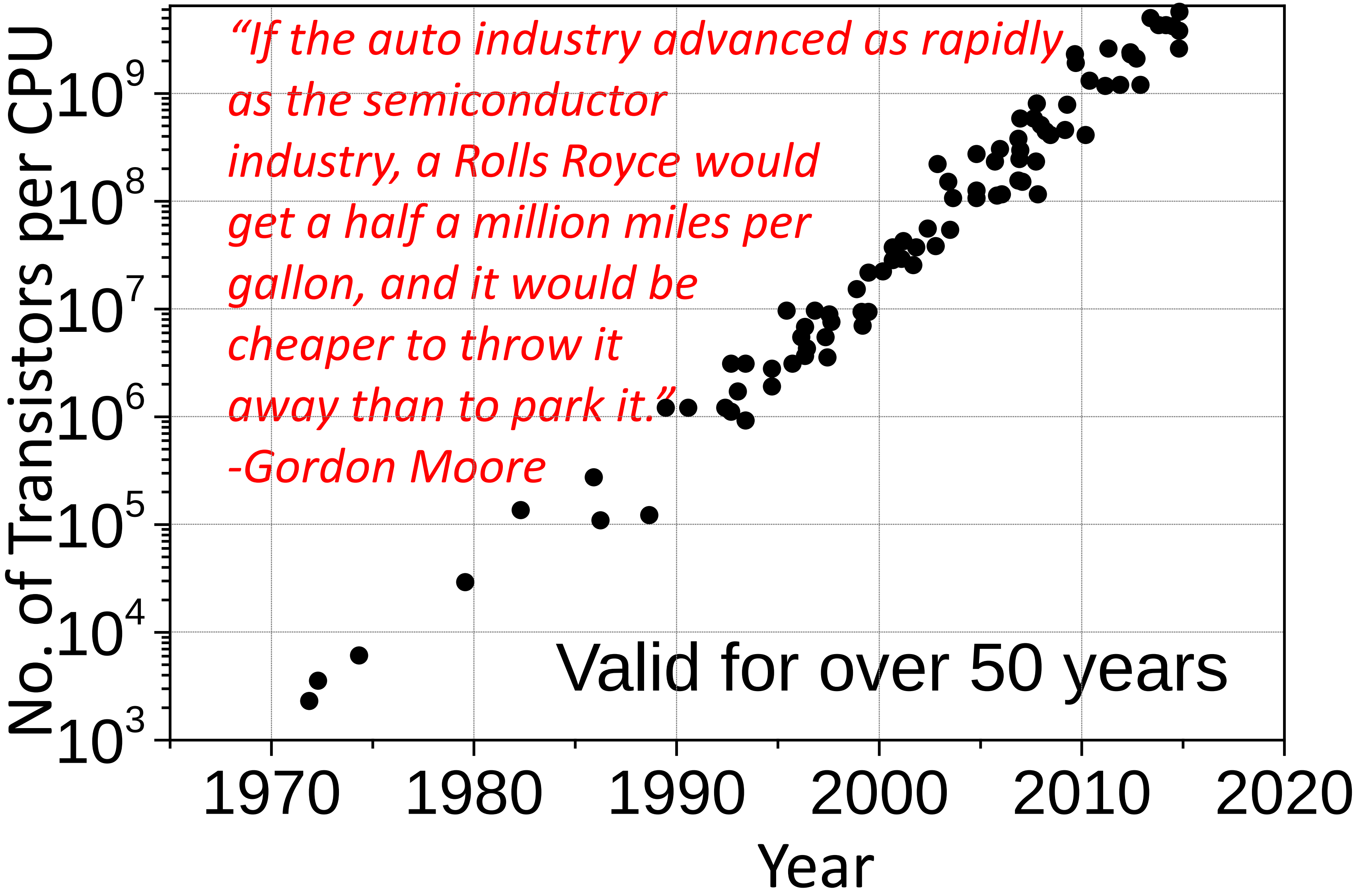
1980
IBM 3380
20GB
4400lbs
Cost: ~$0.8M

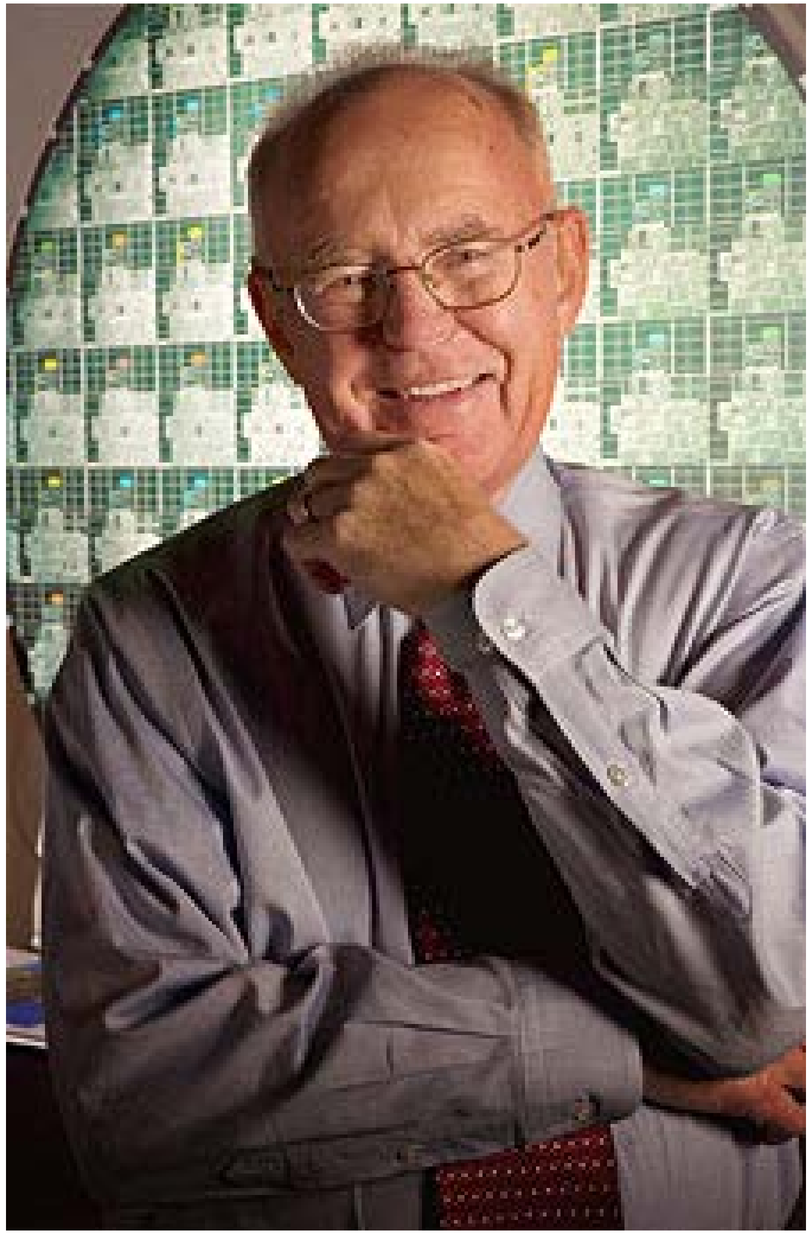
2014
Sandisk
512 GB
0.001lbs
Cost: ~$200

Economic Impact



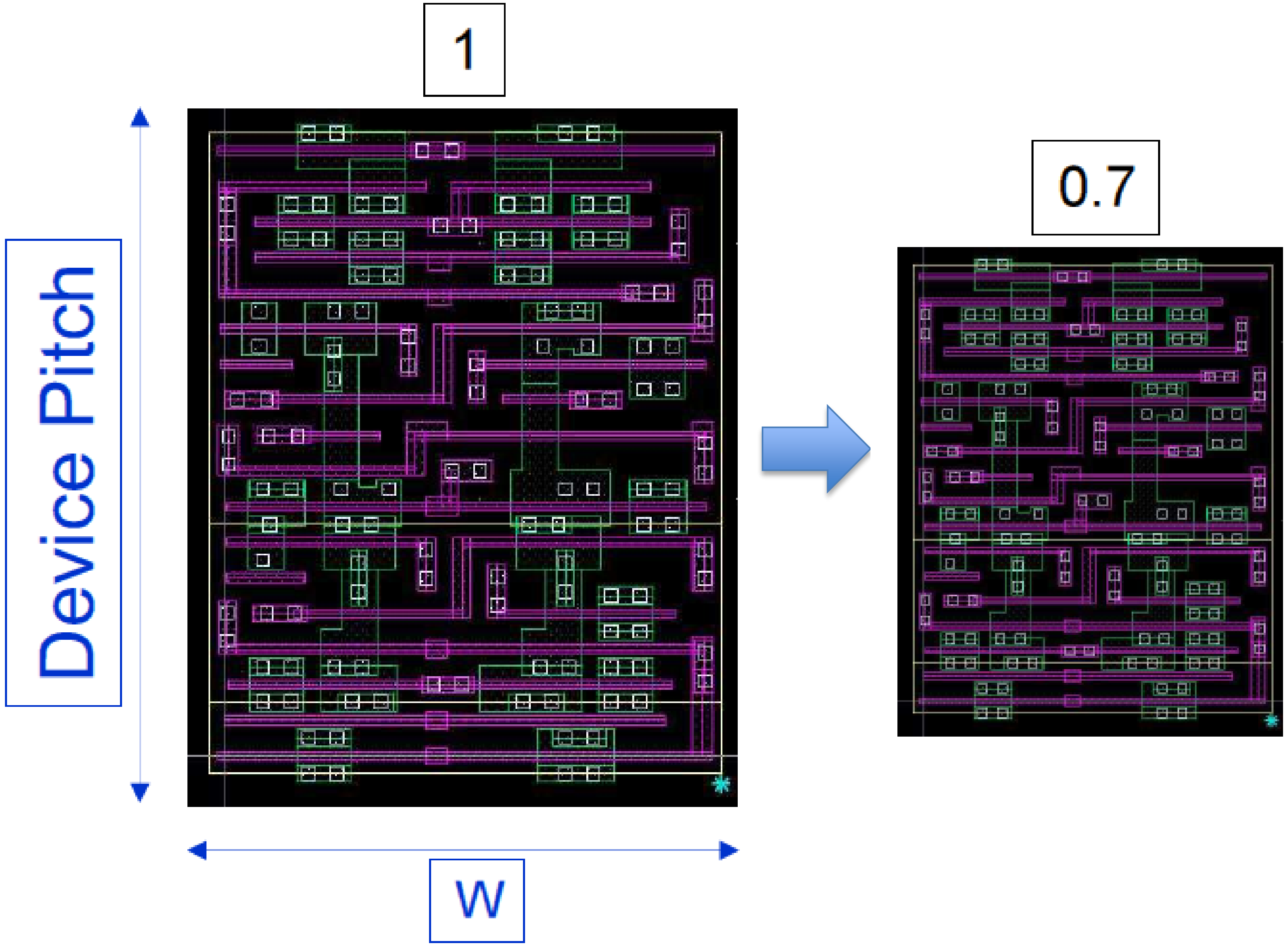
Greatest Evolutionary Technological Progress





Fundamental Driving Forces for Semiconductor Industry

Scaling (Moore's Law)



About every two years:

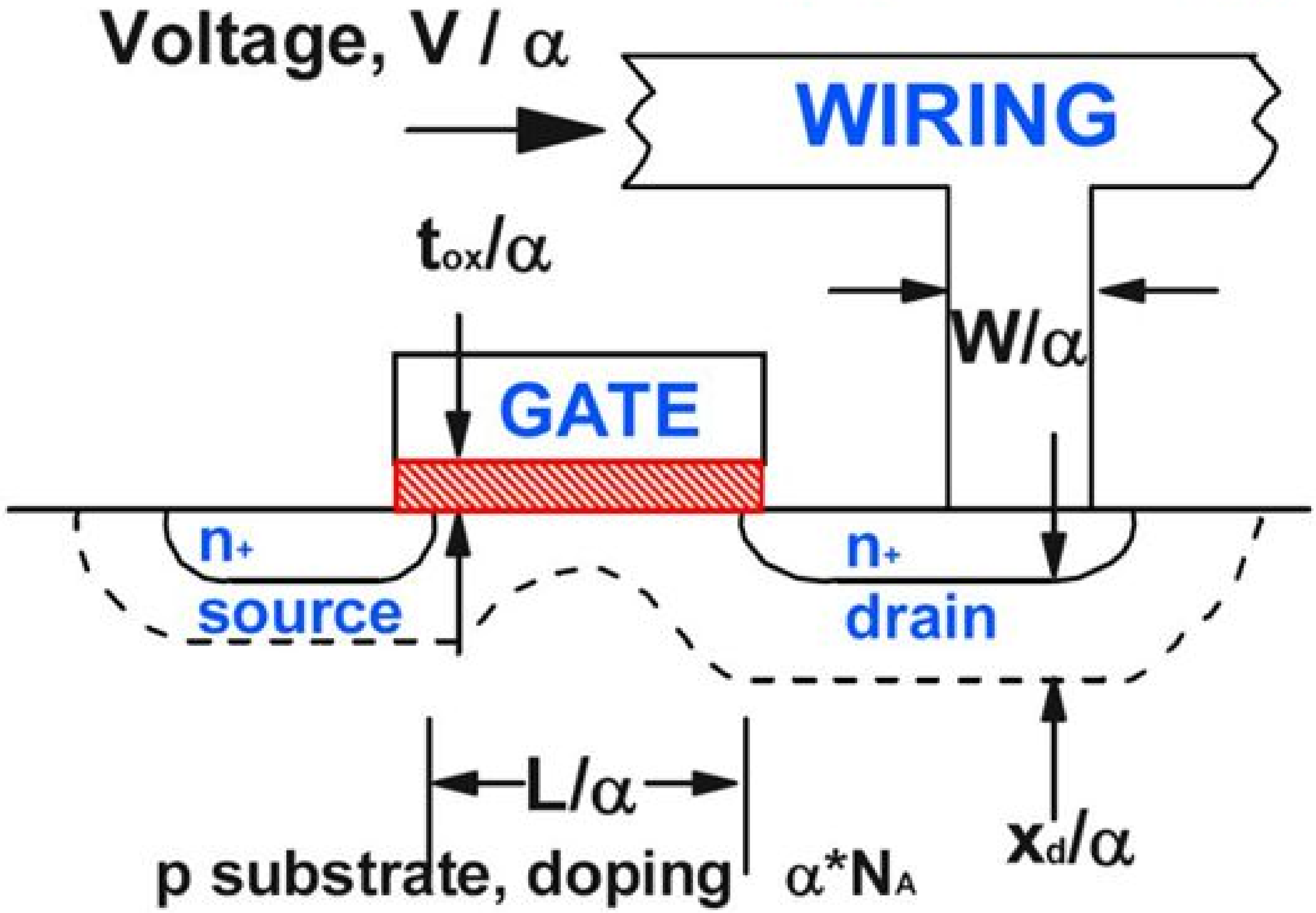
30% Reduction in W and device pitch

– 50% area reduction (**Cost**)

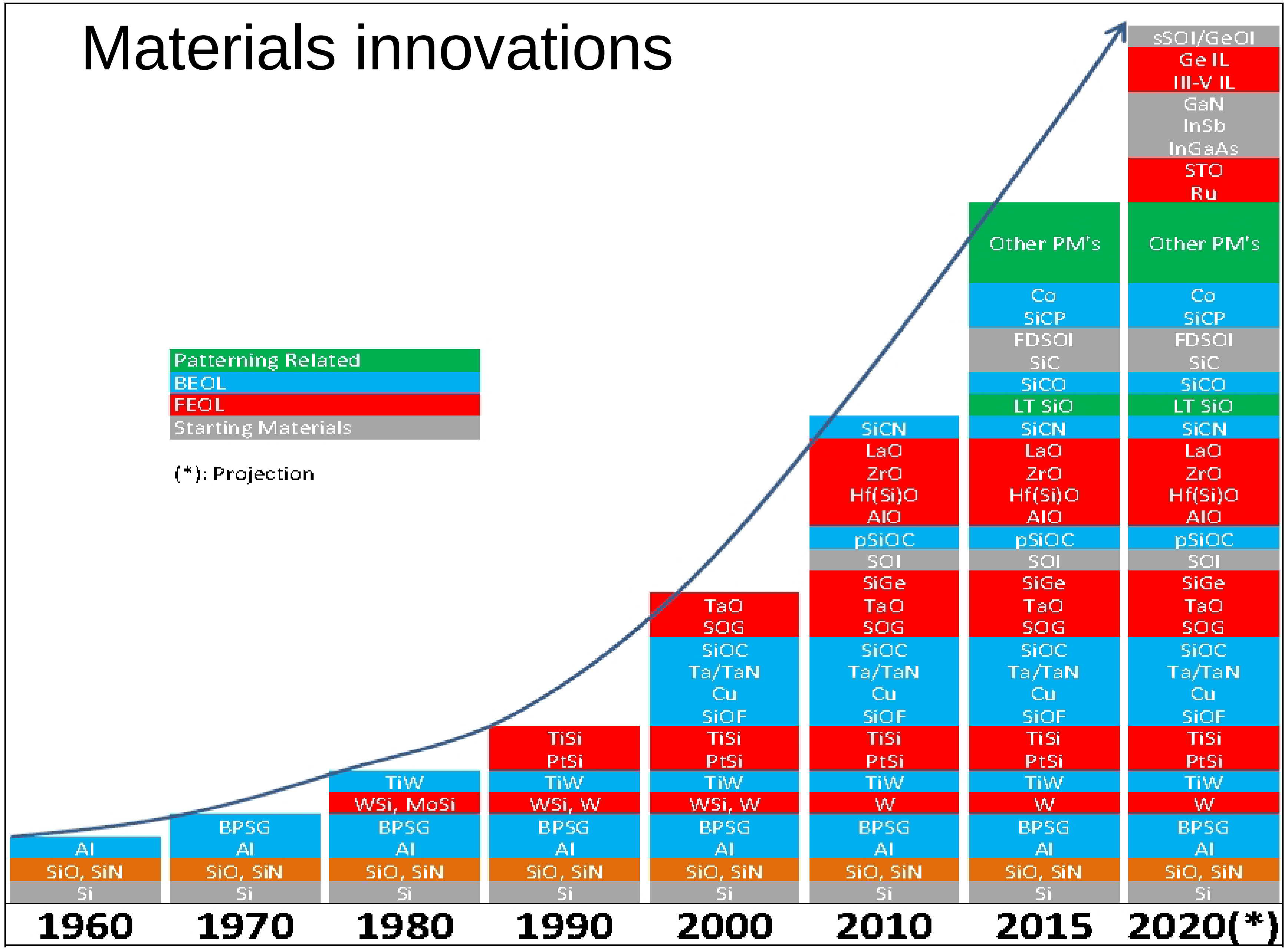
– 2X increase in device/area

30% drop in power/operation

Dennard Theory



Fundamental Driving Forces for Semiconductor Industry



From the 1960s through the 1990s, only a handful of materials were used, most notably silicon, silicon oxide, silicon nitride and aluminum. Soon, by 2020, more than 40 different materials will be in high-volume production, including more "exotic" materials such as hafnium, ruthenium, zirconium, strontium, et. al.

As A MatSE Class We Will Cover

New pattering materials: EUV resist, di-block copolymers

New materials processing: transfer printing, additive manufacturing

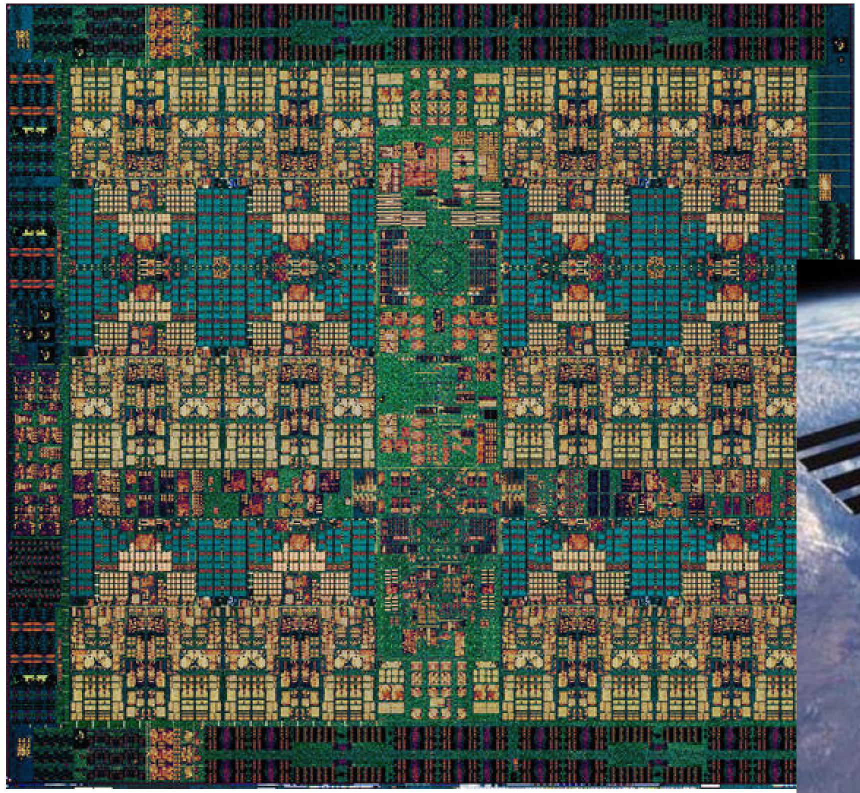
New materials for LEDs and solar cells:
organics, quantum dots, CdTe, CIGS, perovskite, et. al.

New materials for transistors:
III-Vs, high k/metal gates, nanotubes, graphenes, 2D TMDCs, et. al.

New materials for memory:
PCM, oxides/chalcogenides for memristors

Technology Today

IBM Power 9
24 cores with 8B transistors

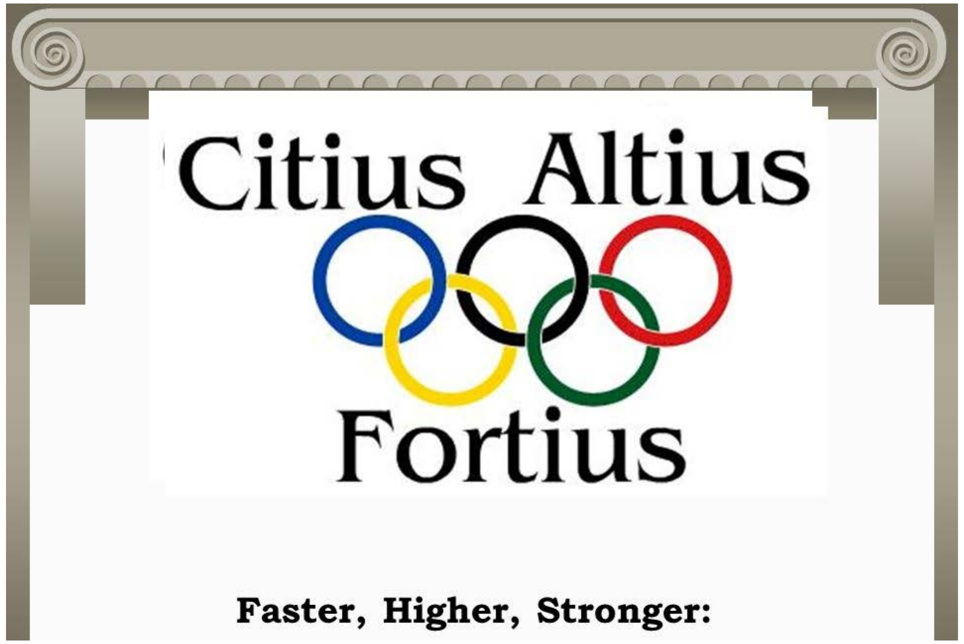


Multi-junction solar cell
Efficiency >50%

IBM Flash System
57TB per building block

Challenges Ahead for Our (Your) Generation

Devices for new paradigms of computing
More-Moore platform for mobile computing and IoT
Technologies for Datacenters
Heterogenous integration for low power and multifunctional system-on-chip
Better solar cells for renewable energy in TW regime
…….



Key enabler: New Electronic Materials

More functionality
Better performance
Lower cost

Summary

1. Logistics about MSE 460
2. Overview of semiconductor industry
3. Fundamental driving forces for semiconductor industry: Physical scaling and new materials
4. Current status and challenges for our (your) generation

Any Questions/Comments/Suggestions?