MSE 460: Electronic Materials, Devices, and Processing

Lecture 1: Introduction and Orientation

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Self-Introduction

2004-2009

Research Interest:
Electronic Materials
Unconventional Electronic Devices
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2009-2018
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 a 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
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

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

  - Edited by Robert Doerring and Yoshio Nishi

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

- The Materials Science of Semiconductors
  - Angus Rockett
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!

Email: qingcao2@illinois.edu
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
$11 trillion
Estimated additional value added to GDP in the last 20 years, due to the pace of innovation by Moore’s Law
Greatest Evolutionary Technological Progress

"If the auto industry advanced as rapidly as the semiconductor industry, a Rolls Royce would get a half a million miles per gallon, and it would be cheaper to throw it away than to park it.”

-Gordon Moore
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 patterning 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?