CALIFORNIA INSTITUTE OF TECHNOLOGY
Applied Physics
APh 183 Physics of Semiconductors and Semiconductor Devices

Spring 2011

Description:
9 units (3-0-6); third term.

In APh 183, we will focus on fundamental device physics and performance aspects of basic and advanced semiconductor electronic and optoelectronic devices. Topics will include the Fermi energy, band-bending, carrier generation and recombination mechanisms, quasi-Fermi levels, carrier drift and diffusion transport, pn junctions, metal-semiconductor contacts, MOS field effect devices and quantum transport. Lectures will consist of two parts: i) exposition of device physics fundamentals and ii) "complements" to fundamental issues in the form of focused topically-oriented sketches of real-world semiconductor physics science issues, devices and technologies .

Prerequisites:
Although there are no formal prerequisites, familiarity with several subjects will be helpful. If there is a need for it, we may organize background tutorials in some of these topics. Solid state physics at the level of APh 114b will be helpful. In APh 114b, we focused on semiconductor electronic band structure, carrier transport properties, and optoelectronic properties relevant to semiconductor device physics, but didn't do any device physics, per se. Quantum mechanics at the level of Physics 125 or equivalent, and some statistical physics may also be helpful as background.

Lectures:
Tuesdays and Thursdays, 1-2:30 pm in 104 Watson (see calendar for details and exceptions)

Texts: First book is required and the others are recommended:

1. Physics of Semiconductor Devices, 3rd Edition, S.M. Sze and Kwok K. Ng, John Wiley and Sons, New York, ISBN: 13-978-0-471-14323-9, 2007.
2. Semiconductor Material and Device Characterization, D.K. Schroder (editor), Wiley, New York, ISBN: 13-978-0-471-73906-7, 2006.
3. Semiconductor Device Fundamentals, Robert F. Pierret, Addison-Wesley, ISBN: 0-201-54393-1, 1996.
4. Basic Semiconductor Physics, Chihiro Hamaguchi, Springer Verlag, ISBN: 3-540-41639-0, 2001.

Staff:
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Evaluations:

Homeworks (~1-2 problems/week)	50pts.
Mid-Term Exam	25 pts.
Final Design Problem	25 pts.
Total:	100 pts.

Evaluation Policies:

1. The Mid-Term Exam will be 2-3 hours in length and will be issued on April 29th at 9 am and is due by 5 pm on May 5th.
2. Homework problems will be issued frequently; homework problems issued on Tuesdays will be due on the following Fridays, and homework problems issued on Thursdays will be due on the following Mondays.
3. The Final Design Problem is in lieu of a final exam, and is focused on use of analytic and simulation device models to design a specific semiconductor device.
4. `Limited' collaboration for homeworks: you can share anything that can be communicated with spoken words, but cannot share written notes or solutions.
5. Late homeworks will be graded according to the following time dependence, in days, where $t = 0$ is the due date: $h(t) = h(0)\exp(-t/7)$.

Topics and Reading:

1. **Bands, Statistical Physics, Quantum States and the Fermi Energy**
   Sze and Ng: Chapter 1 (section 1.1-1.2)
   Photocopied reading: Semiconductor Statistics,J.S. Blakemore
   Complement 1: Gallium Nitride and III-Nitride Semiconductors

2. **Semiconductors and Junctions in Equilibrium**
   Sze and Ng: Chapter 1 (section 1.3-1.4)
   Schroder: Chapter 1 Resistivity Measurements
   Complement 2: Dopants and Impurities in Semiconductors

3. **Inhomogeneous Materials in Equilibrium**
   Sze and Ng: Chapter 2 (Section 2.1-2.2)
   Schroder: Chapter 3
   Complement 3: Contacts and Interconnects in Integrated Circuits

4. **Bandbending in Semiconductors**
   Sze and Ng: Chapter 3 (Section 3.1-3.2)
   Complement 4: Dislocations and Grain Boundaries in Semiconductors

5. **Carrier Dynamics in Steady-State:Quasi-Fermi Energy**
   Sze and Ng: Sze and Ng pp 62-63
   Complement 5: Where does Silicon Come From?

6. **Generation-Recombination Mechanisms**
   Sze and Ng
   Schroder
   Complement 6: ULSI Fabrication Processes

7. **Boltzmann Transport Equation: An Approach to Non-Equilibrium in Semiconductors**
   Sze and Ng
   Schroder
   Complement 7: ULSI Scaling and the ITRS Roadmap

8. **Transport in Quasi-Neutral Regions**
   Sze and Ng
   Schroder
   Complement 8: Magnetic Semiconductors

9. **pn Junction**
   Sze and Ng
   Schroder
   Complement 9: Silicon Solar Cell

10. **Transport at Metal-Semiconductor Contacts: Schottky Barrier and MESFET**
    Sze and Ng
    Schroder
    Complement 10: Flash Memory

11. **MOS Capacitor and MOSFET**
    Sze and Ng
    Schroder

Complement 11: Charge-Coupled Devices (CCDs) and CCD Arrays

12. **Bipolar Transistors** Bipolar Junction Transistor, Ebers-Moll Equations, Charge Control Model, Heterojunction Bipolar Transistor**.**
    Sze and Ng
    Schroder
    Complement 12: Thyristors and Power Devices

13. **Semiconductor Heterostructures**: Band structure in heterojunctions. Wide bandgap and narrow bandgap semiconductors, band lineup models, effects of alloy composition, misfit strain, interface states.
    Sze and Ng
    Pierret
    Schroder
    Complement 13: *Heterojunction Bipolar Transistor and Modulation-doped Heterostructures*

14. **Optoelectronic pn Junction Devices I** Solar Cell, Communications Photodetector, Light-Emitting Diode,
    Sze and Ng
    Pierret
    Schroder
    Complement 14: Vertical Cavity Surface Emitting Lasers (VCSELs) and GRINSCH Lasers

15. **Optoelectronic pn Junction Devices II** Solar Cells: performance characteristics; multijunction cells; 3rd generation photovoltaics concepts
    Sze and Ng
    Pierret
    Schroder

16. **Optoelectronic pn Junction Devices III** Solar Cells: Detailed Balance Limiting Efficiency
    Sze and Ng
    Pierret
    Schroder

17. **Amorphous Semiconductors** Amorphous semiconductors: localized state conduction, Mott theory of variable-range hopping, application to a-Si thin film transistors. Polycrystalline semiconductors: majority carrier transport, minority carrier trapping and passivation.
    Sze and Ng
    Pierret
    Schroder
    Complement 15: Flat Panel Displays

18. **Polycrystalline and Organic Semiconductors** Molecular orbital engineering in polymeric semiconductors, organic transistors
    Sze and Ng
    Pierret
    Schroder
    Complement 16: Light Emitting Diodes (LEDs): Inorganic and Organic