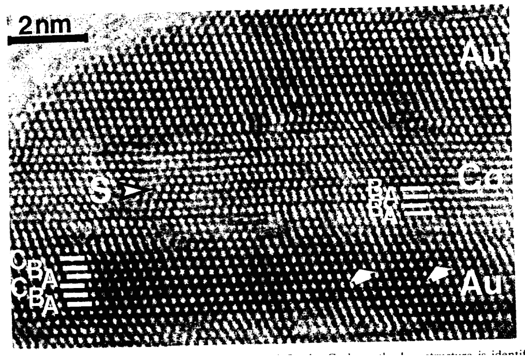
MSAE E4206x
Electronic and magnetic
properties of solids
Fall Semester 2008-9
Tu-Th 10:35 – 11:50
545 Mudd



(right: Co/Au superlattice used in magneto-optical recording)

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Texts:

Required:

Lecture notes distributed in class or on web.

D.J. Griffiths, Introduction to Electrodynamics, 3rd edition, Prentice-Hall, ISBN 0-13-805326-X (available at Labyrinth Books)

H. Ibach and H.J. Luth, Solid State Physics, 2nd edition (softcover), Springer-Verlag, ISBN 0-387-58573-7 (available at Labyrinth Books)

Course Reserves: (Engineering library)
above references, plus:

General solid state, ascending difficulty:

1. L. Solymar and D. Walsh, Electrical Properties of Materials, 6th ed., Oxford
2. H.P. Meyers, Introductory Solid State Physics, Taylor & Francis
3. C. Kittel, Introduction to Solid State Physics, <6th edition, Wiley

4. N.W. Ashcroft and N.D. Mermin, Solid State Physics, Harcourt-Brace

Computer simulations of solid state:
R.H. Silsbee and J. Drager, Simulations for Solid State Physics, Cambridge

Statistical Mechanics
C. Kittel and H. Kroemer, Thermal Physics 2nd edition, Freeman

Semiconductors
1. R.F. Pierret, Semconductor Fundamentals, *Modular Series on Solid State Devices* (1), G.W. Neudeck, eds, Addison-Wesley
2. R.F. Pierret, Advanced Semconductor Fundamentals, *Modular Series on Solid State Devices* (6), G.W. Neudeck, eds, Addison-Wesley
3. B.J. Streetman, Solid State Electronic Devices, Prentice-Hall

Magnetism
R.C. O'Handley, Modern Magnetic Materials, Wiley

Grading:
10% homeworks (weekly, assigned Thursdays, turn in Fridays to APAM box)
20% midterm #1: **Tues, 10/9**
20% midterm #2 **Thurs, 11/11**
50% final exam

Course Website: http://magnet.ap.columbia.edu/msae4206/4206.html

Course introduction

The intent of the course is to give one-semester, self-contained introduction to most types of materials used in electronic devices, especially nanoscale electronics. Emphasis is placed on understanding the materials properties which are most relevant for improved electronic, optical, or magnetic devices. A general undergraduate modern physics course (PHYS C1401-3 or equivalent) is required as background. However, there will be sufficient tutorial review provided that highly motivated, interested students of all backgrounds can participate.

The course is grouped into two parts. The first section covers "phenomenology:" electrical conductivity, dielectric properties (high and low - K dielectrics, ferroelectrics), and magnetic properties (paramagnets, ferromagnets, antiferromagnets) and superconductors. These properties of materials, and many of their device applications were known around 1900, although only at an empirical level. Electromagnetic theory is introduced for understanding these materials systems. Modern device applications which may be described, time permitting, include cellular telephone components, optical fibers, ferroelectric random access memory (FE-RAM), LCD's (liquid crystal displays), and magnetic recording media.

In the second part, the band theory is introduced.   This theory is essential to understand materials which have been engineered on the atomic scale to yield "designer" properties, representing a millenial promise for materials science. Semiconductors, semiconductor doping, p-n junctions, optoelectronics, and "spintronic" ultrathin ferromagnets are covered here.   Furthermore, the theory is used to enrich *microscopic* understanding of some topics developed in the first part, particularly superconductivity and ferromagnetism. Some topics from elementary quantum mechanics and statistical mechanics are introduced in this section. Devices described include semiconductor LED's, LASERs, MOS-FETs, spin valves, and magnetic random access memory (m-RAM).

Syllabus; covered time permitting:

Part 1—Electronic materials before 1920

Electrons as a "free particle swarm"

Electrical conductivity (Drude). Hall effect. Influence of Lorenz force.

Review of electricity and magnetism

Exposition of Maxwell's equations and relevant math; simple electrostatic and magnetostatic problems. Electromagnetic (EM) waves. Units: SI and cgs.

Optical properties:

Example of free-carrier reflectivity. General properties: index of refraction, Snell's law, dispersion, brewster's angle. Graded optical fibers.

Response of "bound" electrons:

Dielectric materials: the Clausius-Mossoti equation, high-K gate dielectrics. Ferroelectricity. FE-RAM

Linear magnetic materials: diamagnetism, paramagnetism, high m materials

Superconductivity—phenomenology

Meissner effect, London equations, penetration depth, critical currents and critical temperatures, high-Tc materials.

Ferromagnetism—phenomenology & applications

Magnetic recording heads: inductive write; recording media: hard alloys.

High-frequency properties—complex permeability/ permittivity, anomalous dispersion, ferromagnetic resonance.

Applied optical properties

Liquid crystal displays (LCD’s), filters in RF telecommunications: superconducting and magnetic, electrooptics and holographic recording.

Part 2—The band theory; its materials and devices

Review of basic physics
- Quantum mechanics: electrons as waves
- Statistical mechanics; the fermi-dirac distribution

The reciprocal lattice and Brillouin zones

Energy bands
- Nearly free electron model; Bloch theorem
- Tight binding model
- Classification of solids: metals, insulators, and semiconductors

Lattice vibrations: phonons, heat capacity, *microscopic metallic conductivity*

Semiconductors and semiconductor devices
- Carrier statistics and doping
- Microscopic semiconductor conductivity
- Semiconductor types and engineered materials:
  - Si, SiGe, GaAs, AlGaAs, GaN, ZnSe, etc.
- The p-n junction
- The CMOS transistor (MOS-FET)
- Optoelectronic processes; photoconductivity and radiative recombination
- The light-emitting diode (LED)
- Semiconductor lasers (application: DVD’s; CD-RW)

Band ferromagnetism and “spintronics”
- Band structure of transition metal ferromagnets
- Spin-valve giant magnetoresistance--GMR recording heads
- Spin-dependent tunneling and M-RAM

Microscopic treatment of superconductivity
- The BCS theory
- High-Tc-superconductors

Atoms as building blocks: designer materials
- Band-structure calculations; a*b-initio* treatment of physical properties (qualitative treatment)

Class meetings:

1. Tu 2 Sep
2. Th 4 Sep
3. Tu 9 Sep
4. Th 11 Sep
5. Tu 16 Sep
6. Th 18 Sep
7. Tu 23 Sep
8. Th 25 Sep
9. Tu 30 Sep
10. Th 2 Oct
11. Tu 7 Oct
12. Th 9 Oct **midterm exam #1**
13. Tu 14 Oct
14. Th 16 Oct
15. Tu 21 Oct
16. Th 23 Oct
17. Tu 28 Oct
18. Th 30 Oct ; [4 Nov: Election Day Holiday]
19. Th 6 Nov
20. Tu 11 Nov. **midterm exam #2**
21. Th 13 Nov.
22. Tu 18 Nov
23. Th 20 Nov
24. Tu 25 Nov. [27 Nov: Thanksgiving Holiday]
25. Tu 2 Dec:
26. **Tu 4 Dec. Last class meeting**

Final examination: Not yet announced, but *probably* Dec 18.