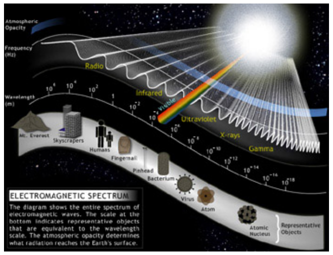
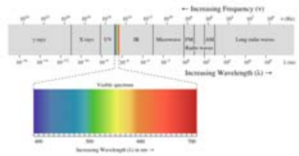
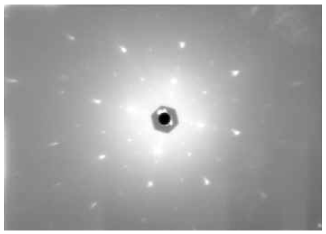


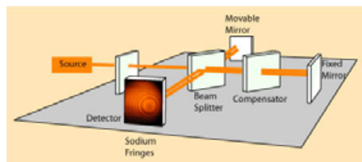
Welcome to



Phys 774: Principles of Spectroscopy



Fall 2007



Instructor:

Andrei Sirenko
Associate Professor at the Dept. of Physics, NJIT

http://web.njit.edu/~sirenko

476 Tiernan

Office hours: After the classes on We.'s or by appointment
973-596-5342

Class Schedule:

Wednesday	11:30am - 12:55pm	FMH 106
Friday	1:00pm - 2:25pm	FMH 203

Lucent Technologies / agere systems / TriQuint SEMICONDUCTOR 2000 – 2003

Plan for today:

- Introduction to the Course
- Introduction to Spectroscopy
- Your PhD projects / motivations
- Lab tour

Course Elements:

Textbooks:

- J. Michael Hollas, Modern Spectroscopy, 4th edition, Willey, ISBN 0-470-84416-7
- P. Yu and M. Cardona, "Fundamentals of semiconductors" (supplemental textbook)

Lecture Slides

Demonstrations in the Experimental Lab at NJIT

– Raman Scattering in Diamond
– High-Resolution X-ray Diffraction in Silicon wafer
– Transmission in InP-based multilayer device structure
– Micro-beam Photoluminescence in InGaAsP-based waveguide device structure

Grade Components:

– Homework: 10 %
– Research project: 10 %
– Two in-class exams: 15% each;
– Final exam: 50%

Course Goals:

The major objectives of this course are to integrate theory and practice and to bring together different branches of both Academic studies and Industrial Research through the presentation of critical aspects of modern Spectroscopy. The course will provide a valuable theoretical introduction and an overview of modern topics in spectroscopy, which are of current interest and importance in Semiconductor Industry and Biomedicine. A wide range of techniques is considered, including optical spectroscopy, synchrotron radiation spectroscopy, high-resolution x-ray diffraction, reciprocal space mapping analysis, and FTIR spectroscopy.

To help you with your PhD Project and future jobs

Outline of the course:

1a. Theory of radiation and Electromagnetic spectrum.
- Classification of different parts of Electromagnetic spectrum from radio-frequency waves to hard x-rays and beyond.

- **1b. Radiation sources.**
  - Single wavelength sources. Broadband sources. Lasers, Globars, Synchrotron Radiation Sources.
  - Characteristics of Radiation: Intensity, Polarization, Coherence Length. CW and pulsed radiation sources.
- **2a. Interaction of Electromagnetic Radiation with Matter.**
  - Dielectric Function Theory. Simple Harmonic Oscillator model. Kramers-Kronig transformation
- **2b. Linear absorption, Transmission, and Reflection Spectroscopy.**
- Applications for Solid State and Semiconductors.
- **2c. Spectrometers and Detectors for Near-IR and Visible range of Electromagnetic spectrum.**
- Diffraction grating, Single Grating spectrometers, High Resolution Spectrometers, CCD and array detectors. Characteristics of modern JY-Horiba spectrometers and Detectors.
- **2d. Optical Spectroscopy in Industrial Characterization Lab.**
- Photoluminescence characterization of Semiconductor Device wavers. Applications of Near-field optical Microscopy (NSOM).
- **3a. Phonons and Free Electron contribution to the Dielectric Function**
- IR-active phonons, Electron Plasma Frequency. Magnetic excitations
- **3.b Far-Infrared spectroscopy.**
- Michelson interferometers and bolometers. Examples of FT-IR Spectroscopy of High-Tc superconductors and Ferroelectrics.
- **3c. FT-IR in Industrial characterization Lab for the Process Control analysis.**
- Thin-films thickness measurements, Interface Quality, Multilayer device structures.
- **3d. Ellipsometry**
- **3e. Examples of Biomedical Applications of FT-IR spectroscopy**
  - FTIR Spectroscopy in the Clinical Sciences. Probing Drugs distribution in Living Tissue
- **4a. Nonlinear Spectroscopy**
- Second harmonic generation, Frequency converters
- **4b. Raman Scattering Spectroscopy**
- Raman scattering by electrons and Phonons, Resonant spectroscopy.
- **4c. Micro-Raman Spectroscopy in Industrial Lab.**
- Strain and composition measurements in Nitride-based semiconductor wafers
- **4d. Bio-medical applications of Raman Scattering Spectroscopy.**
- Whole Cell Studies and Tissue Characterization by Raman Spectroscopy

Outline of the course (continued):

5a. X-ray Spectroscopy.

- **Absorption, Diffraction and Fluorescence**
- Braggs law; Laue Diffraction
- **5b. Synchrotron Radiation Facilities, High-resolution X-ray Diffractometers, X-ray Detectors.**
- **5c. HRXRD in Industrial Characterization Labs.**
- Strain, thickness, and composition measurements in semiconductor device wafers.
- Microbeam X-ray spectroscopy, Zone plates, and capillaries. Parameters of Philips Diffractometer.
- **5d. Macromolecular Diffraction. DNA structural analysis. Biomedical applications of X-ray spectroscopy**
- **6a. Neutron Diffraction Spectroscopy**
- Sources, detectors, diffractometers. Resolution.
- Comparison between Neutron and X-ray diffraction spectroscopes
- **6b. Application of Neutron Diffraction for Solid State Research.**
- Dispersion of phonons and magnons in Oxide crystals
- **7 Principles of Modulation Spectroscopy**
- Spectroscopy of Solids in Electric and Magnetic Field and under Uniaxial and Hydrostatic pressure. Pump-probe Experiments.
- **8. Overview of NMR and EPR spectroscopy and mass spectrometry for biomedical applications**

Lectures:

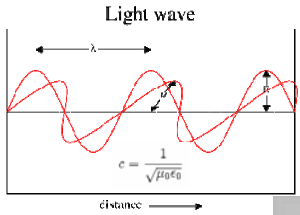
- Presentation of the concepts and techniques of Spectroscopy.
- Demonstrations of Spectroscopy in action.
- Lecture quiz (periodically)
- Lectures are not a substitute for reading the textbook and independent literature search

  Read ahead; you'll get more from lecture.
- Slides will be posted on the course web.

  Use these as a study guide/note taking aid

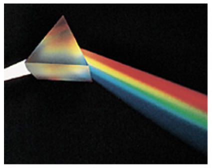
Scope and Requirements

$$\nabla \cdot \mathbf{E} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial}{\partial t}\mathbf{B}$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial}{\partial t}\mathbf{E}$$

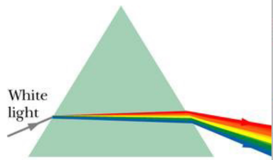


Required for Phys-774

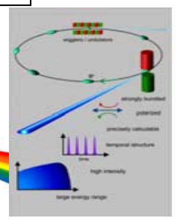
$c = 299792458$ m / s,



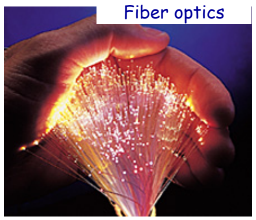
(a)



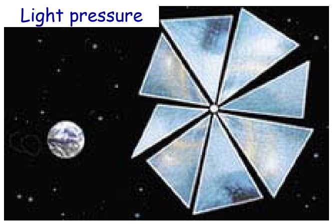
(b)



Covered in Phys-774



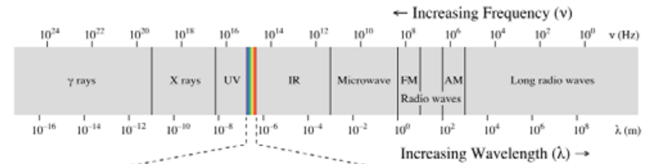
Fiber optics

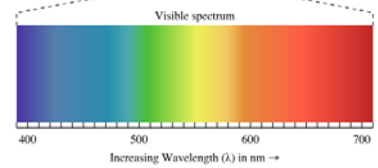


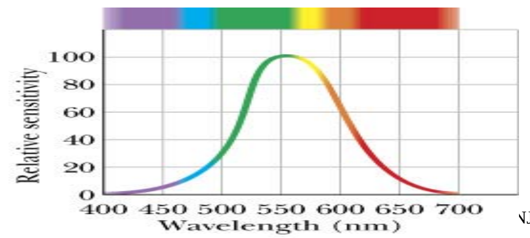
Light pressure

Not covered in Phys-774

Spectrum of Electromagnetic Radiation and Light







CLASS	FREQUENCY	WAVELENGTH	ENERGY
γ	300 EHz	1 pm	1.24 MeV
HX	30 EHz	10 pm	124 keV
SX	3 EHz	100 pm	12.4 keV
	300 PHz	1 nm	1.24 keV
EUV	30 PHz	10 nm	124 eV
NUV	3 PHz	100 nm	12.4 eV
NIR	300 THz	1 μm	1.24 eV
MIR	30 THz	10 μm	124 meV
FIR	3 THz	100 μm	12.4 meV
EHF	300 GHz	1 mm	1.24 meV
SHF	30 GHz	1 cm	124 μeV
UHF	3 GHz	1 dm	12.4 μeV
VHF	300 MHz	1 m	1.24 μeV
HF	30 MHz	1 dam	124 neV
MF	3 MHz	1 hm	12.4 neV
LF	300 kHz	1 km	1.24 neV
VLF	30 kHz	10 km	124 peV
VF	3 kHz	100 km	12.4 peV
ELF	300 Hz	1 Mm	1.24 peV
	30 Hz	10 Mm	124 feV

Intensity of light

$$I = S_{avg} = \left(\frac{\text{energy / time}}{\text{area}}\right)_{avg} = \left(\frac{\text{power}}{\text{area}}\right)_{avg}.$$

$$I = S_{avg} = \frac{1}{c\mu_0}\left[E^2\right]_{avg} = \frac{1}{c\mu_0}\left[E_m^2 \sin^2(kx - \omega t)\right]_{avg}$$

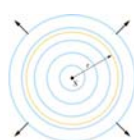
$$I = \frac{1}{c\mu_0}E_{rms}^2.$$

$$c = 299792458 \text{ m / s},$$

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \quad \text{(wave speed)}$$

Point source of light (atom)

Variation of Intensity with Distance



$$I = \frac{P_s}{4\pi r^2}$$

How can we produce EM waves ?