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Course ID MASC534 Materials Characterization

Units: 4

Fall 2021 Tu & Th 2PM to 3:50PM [With 10 minute break]

Location: VHE217.

Instructor: Anupam Madhukar
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Course Description

This is an introductory *graduate-level* course that introduces (a) the basic conceptual foundation of what and why is a solid, (b) what is "characterization", and (c) the dominant techniques for determining the structure and composition of solid state materials. Part (a) covers formation of chemical bonds and their basic characteristics that set the energy and length scales that govern and allow different solid structures. Part (b) covers what is a measurement and the fundamental notions of signal, noise, reliability, precision, and accuracy. Part (c) covers techniques and instrumentation for determining crystal structure and morphology of solids [X-ray diffraction, transmission and scanning electron microscopy (EM), atomic resolution imaging using transmission EM (TEM), scanning tunneling microscopy (STM), and atomic force microscopy (AFM)] and their chemical composition [X-ray photoemission and Auger spectroscopies, Energy loss spectroscopy and secondary ion mass spectroscopy].

The course is for students of Graduate standing in materials science, physics, chemistry, earth sciences, aerospace engineering, biomedical engineering, chemical engineering, civil engineering, electrical engineering, environmental engineering, and mechanical engineering. Students pursuing master's degree in any of these disciplines can benefit provided they satisfy the recommended preparation.

Learning Objectives

The course is aimed at teaching the application of photon and electron beams to reliably determine (measure) the arrangement and chemical nature of atoms constituting different classes of solid materials. To this end the students will learn: The concept of probe-system force as the fundamental basis for extracting information by matching length, energy, and time scales i.e. deciding what measurement to make for a given objective; How to decide on which techniques and tools to use to determine the structure and chemical composition of solids; They will learn the construction and operating principles of tools exploiting X-ray and electron diffraction to determine crystal structure and electron microscope to image structure and chemical composition with resolution down to the atomic scale; As most functional devices and structures involve

multiple materials and thus interfaces, the students will learn techniques sensitive to behavior near surfaces and interfaces such as X-ray core-level photoemission spectroscopy and and scanning tunneling microscopy.

Recommended Preparation

Undergraduate physics (mechanics and electricity & magnetism), chemistry (inorganic, analytical, and physical), mathematics (vector algebra, trigonometry, series expansion and convergence, Fourier and Laplace transforms, linear algebra, differential and integral calculus, ordinary and partial differential equations). Graduate level preparation in quantum mechanics or solid-state physics. Students can request waiver for the graduate level prerequisites if they have the necessary background.

Books: Lecture Notes containing necessary references will be provided; D. B. Williams & C. Barry Carter, "Transmission Electron Microscopy" (Springer).

Description and Assessment of Assignments

Three home assignments (before midterm exam) comprising assigned readings and solution of problems;
Two weeks after the midterm exam, outline of a term paper on a topic of student's choice related to the course and approved by the instructor is due.
Full term-paper written on the approved topic is due at the last lecture (will constitute written part of the final exam).
Presentation of the synopsis of the Term-paper during specified exam hour will complete the final exam.

Grading Breakdown

Attendance 10%
Homework 15%
Mid-Term Exam 25%
Final Exam [Written Term-Paper 35% + Synopsis Presentation 15%] 50%

Assignment Submission Policy

Hardcopy of answers to the assigned problems are to be turned in at the specified class

Grading Timeline

Graded homework will be returned typically within a week of the submission date.

Additional Policies

No late assignments accepted.
Expect 100% attendance.
If a class is to be missed, inform the instructor a week in advance so arrangement can be made (such as providing reading instructions and / or lecture handout, if any).
No electronic gadgets are allowed to be used in the class without the explicit permission of the instructor.

Course Schedule: Topics and Weekly Breakdown

	Topics/Daily Activities	Readings and Homework	Deliverable/ Due Dates
Week 1	**Fundamental Concepts:** "Characterization"-- Probe / System / Detection Concept & Information Transfer; Nature of the Probe— Wave & Particle; Fundamental Scales-- Length, Time, Energy; Detection-- What is it? Noise and Signal	Lecture notes	
Week 2	Atoms- Core & Valence electrons; Molecular/ Chemical Bonding & Stability- Charge Sharing & Transfer: Triatomic Molecules & Structure; Orbital hybridization & Coordination: Core level shifts & ESCA; X-Ray Photoemission	Lecture notes	HW 1 Assigned
Week 3	Waves: Longitudinal & Transverse; Interference; Reflection, Refraction, & Diffraction (vs Particle Blocking) Young's single & double slit interference; Concept of Resolution— Rayleigh Limit	Lecture notes	HW 1 Due
Week 4	Material Structure: Crystalline, polycrystalline, amorphous; Crystal structure-- space lattice & basis; primitive cell & translation vectors; Bravais lattices; types of crystal structures; Miller indices; directions & planes;	Lecture notes.	HW 2 Assigned

Week 5	**Structure Determination: Phenomenon--** Diffraction & Bragg law; Reciprocal lattice; Brillouin zones; Scattering & Ewald Construction; Fourier analysis; Structure factor & Atomic form factor; Illustrative examples.	Lecture notes	HW 2 Due HW 3 Assigned
Week 6	**Structure determination Probe**: X-Rays—Interaction and Instrumentation; Methods & Analyses; Electrons; Need for higher energy & thin specimens; Nearly Grazing incidence	Lecture notes.	HW 3 Due
Week 7	Review **Mid-Term Exam**		
Week 8	Electron Microscope—analogy with Optical microscope; Electron Gun; Electromagnetic lenses**;** Aberrations; diffraction vs Imaging; Resolution	Lecture notes. TEM, by D. B. Williams & C. Barry Carter, (Springer) Ch.5 & Ch 6	
Week 9	TEM Imaging: Intensity-based--Thickness vs Z-Contrast; Bright & Dark field conditions; Lattice Resolution; Phase based—Interference between diffracted beams	Lecture Notes TEM, by D. B. Williams & C. Barry Carter, (Springer) Ch.7 & Ch 9	**Term Paper Outline Due**

Week 10	SEM: Solid Morphology- Backscattered & Secondary electrons; Instrumentation; Depth of Field;	Lecture notes	Term Paper Outline Finalized
Week 11	Analytical Electron Microscopy: Chemical Composition— Electron Energy Loss Spectroscopy (EELS); X-Ray Dispersive Spectroscopy; Auger electron spectroscopy.	Lecture notes	
Week 12	XPS: The Si / a-SiO_2 system— Characterizing Glass— Structure Induced Charge Transfer & Continuous Random Network model; Atomically sharp interfaces; Heterojunctions	Lecture notes	
Week 13	Morphology at atomic resolution—AFM: Inter-atomic and Inter-Body Forces; Instrumentation; Cantilever deflection; Non-Contact and Contact mode imaging protocols;	Lecture notes	
Week 14	Scanning Tunneling Microscopy: Tip – Solid Fermi level alignment; Tunneling Phenomenon & Current; Instrumentation & Atomically- resolved imaging modes	Lecture notes	
Week 15	Review of the course.		**Term Paper Due**
FINAL			Dec 2021 2PM to 4PM VHE 217 For the date and time of the final for this class, consult the USC

			Schedule of Classes at www.usc.edu/soc.

Statement on Academic Conduct and Support Systems

Academic Conduct:
Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Part B, Section 11, "Behavior Violating University Standards" https://policy.usc.edu/scampus-part-b/. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Support Systems:
Student Counseling Services (SCS) - (213) 740-7711 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention. https://engemannshc.usc.edu/counseling/

National Suicide Prevention Lifeline - 1-800-273-8255
Provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week. http://www.suicidepreventionlifeline.org

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-4900 - 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender-based harm. https://engemannshc.usc.edu/rsvp/

Sexual Assault Resource Center
For more information about how to get help or help a survivor, rights, reporting options, and additional resources, visit the website: http://sarc.usc.edu/

Office of Equity and Diversity (OED)/Title IX Compliance – (213) 740-5086
Works with faculty, staff, visitors, applicants, and students around issues of protected class. https://equity.usc.edu/

Bias Assessment Response and Support
Incidents of bias, hate crimes and microaggressions need to be reported allowing for appropriate investigation and response. https://studentaffairs.usc.edu/bias-assessment-response-support/

The Office of Disability Services and Programs
Provides certification for students with disabilities and helps arrange relevant accommodations. http://dsp.usc.edu

Student Support and Advocacy – (213) 821-4710
Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. https://studentaffairs.usc.edu/ssa/

Diversity at USC
Information on events, programs and training, the Diversity Task Force (including representatives for each school), chronology, participation, and various resources for students. https://diversity.usc.edu/

USC Emergency Information
Provides safety and other updates, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible, http://emergency.usc.edu

USC Department of Public Safety – 213-740-4321 (UPC) and 323-442-1000 (HSC) for 24-hour emergency assistance or to report a crime.
Provides overall safety to USC community. http://dps.usc.edu