MSE 598/PHY 598/PHY 494 (22137/24109/21368/21367/31770)

Advanced Scanning Electron Microscopy and X-ray Microanalysis

Spring 2025 (In-Person and Online)

Course Description

This course is designed for students with background in Materials Science & Engineering, Physics, Geosciences, Chemistry, Life Sciences, or related fields. The course is specifically designed for students who want to a) learn the fundamental principles of SEM imaging, diffraction, and spectroscopy; b) understand electron-specimen interactions, signal generation and detection; c) **correctly interpret** various types of images and associated X-ray spectra and diffraction patterns; and d) master appropriate skills to solve various types of image and microanalysis problems of practical materials. The learning outcomes of this course include i) understanding the key concepts and fundamental principles, ii) correctly selecting appropriate electron beam parameters (e.g. voltage, current, probe size, and depth of focus) for studying different types of materials (e.g. conductors, semiconductors, insulators, or polymers), and iii) understanding how to eliminate artefacts in images, spectra and diffraction patterns. It is expected that students focus on **problem-solving skills** and skillfully utilize the modern SEM to solve challenging materials research problems and product development issues.

Course Content

This course first introduces electron beam-specimen interactions and how such interactions produce different types of useful signals that carry specimen specific information (morphology, structure, elemental distribution, etc.). Then extensive discussions on the parameters that affect the formation of various types of electron probes (e.g. for high resolution imaging vs for microanalysis) will be given. Discussions of different types of electron and X-ray detectors and how these detectors are used to form interpretable images and/or spectra will follow. During the first part of the semester, emphasis is on understanding the fundamental principles of probe formation and image interpretation with a focus on how to choose appropriate electron optical parameters for specific types of samples. During the second part of the semester, we will discuss qualitative and quantitative compositional analyses of heterogeneous samples by X-rays, structural information of crystalline materials by electron backscatter diffraction (EBSD) patterns, and how to use low voltage (down to tens of volts) or variable pressure SEM to image non-conducting or wet samples. Dual beam FIB-SEM (electron and focused ion beams) microscopes and atomic resolution imaging in the modern SEMs will be discussed.

Lecture Time: Mon/Wed 12:00-1:15 pm; **Location**: HLMK 333 (and ASU Online); **Instructor**: Dr. Jingyue (Jimmy) Liu (https://isearch.asu.edu/profile/1816322); Office: PSF 432A; E-mail: jliu152@asu.edu.

Virtual Office Hours (https://asu.zoom.us/j/4464996909): Mon/Wed 2:30-4:00 PM or by appointment.

Main Reference Textbook: *Scanning Electron Microscopy and X-Ray Microanalysis.* 4th Edition (2018) by Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W. M. Ritchie, John Henry J. Scott, David C. Joy. **Extensive lecture notes (700-800 slides) will be distributed**.

Grading: Two Midterm exams will be given; each midterm accounts for 20% of the course grade. The final exam will account for 30% of the course grade. All exams are take-home exams. Three homework assignments will be given; each assignment accounts for 10% of the course grade.

Course Timetable and Format: 01/13/25 - 05/02/25. The lecture contents are flexible, depending on the students' backgrounds and feedback comments/suggestions; extensive lecture notes will be available prior to each lecture. Classes are excused on January 20th (MLK Day) and March 9th - 16th (Spring Break).

Proposed Exam Schedule:

Midterm exam 1: February 17th; *Midterm exam 2*: March 24th; *Final exam*: May 5th.

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Proposed Schedule for Spring 2025 Advanced SEM and X-ray Microanalysis

Date	Lecture	Discussion Topic	Comments
1/13/2025	Lecture 1	Learning objectives; brief history of SEM development; & capabilities of modern SEMs	
1/15/2025	Lecture 2	Electron-specimen interactions I: Signal generation, interaction volume, backscattered electrons & channeling from crystalline materials	
1/22/2025	Lecture 3	Electron-specimen interactions II: Secondary electron emission (introduction)	
1/27/2025	Lecture 4	Electron-specimen interactions III: Secondary electron emission (key processes)	
1/29/2025	Lecture 5	Electron-specimen interactions IV: X-ray emission	
2/03/2025	Lecture 6	Electron-specimen interactions V: Generation of other types of signals	
2/05/2025	Lecture 7	Electron probe formation I: Electron guns & vacuum system	
2/10/2025	Lecture 8	Electron probe formation II: Introduction to lens systems	
2/12/2025	Lecture 9	Electron probe formation III: Lens aberrations & their effects on probe size/current	
2/17/2025	Lecture 10	SEM detectors & detection of various signals	Midterm 1
2/19/2025	Lecture 11	Image formation & interpretation I: Imaging with different types of secondary electrons	
2/24/2025	Lecture 12	Image formation & interpretation II: Image quality & imaging with backscattered electrons	
2/26/2025	Lecture 13	Image formation & interpretation III: Image artefacts & how to choose the appropriate electron beam parameters	
3/03/2025	Lecture 14	High-resolution imaging: Imaging with type I secondary electrons	
3/05/2025	Lecture 15	Low voltage and ultralow voltage SEM: Fundamentals, pros & cons	
3/17/2025	Lecture 16	Variable pressure SEM: Fundamentals, pros & cons	
3/19/2025	Lecture 17	SEM imaging: Practical considerations	
3/24/2025	Mid-term	No lecture	Midterm 2
3/26/2025	Lecture 18	Energy dispersive X-ray spectrometry I: introduction	
3/31/2025	Lecture 19	Energy dispersive X-ray spectrometry II: Qualitative analysis	
4/02/2025	Lecture 20	Energy dispersive X-ray spectrometry III: Quantitative analysis	
4/07/2025	Lecture 21	Energy dispersive X-ray spectrometry IV: Practical considerations	
4/09/2025	Lecture 22	Low voltage X-ray microanalysis: Pros and cons	
4/14/2025	Lecture 23	Wave dispersive spectroscopy & compositional mapping in SEM	
4/16/2025	Lecture 24	Electron channeling pattern, electron backscattered diffraction pattern, & Kossel diffraction in SEM	
4/21/2025	Lecture 25	Pole figures, inverse pole figures & orientation imaging of bulk crystals	
4/23/2025	Lecture 26	Focused ion Beam-SEM I: Instrumentation, principles and nanofabrication	
4/28/2025	Lecture 27	Focused ion Beam-SEM II: Preparation of TEM/STEM samples	
4/30/2025	Lecture 28	Atomic resolution STEM in modern SEMs and SE imaging in STEMs	
5/05/2025	Final Exam	No lecture	Final