EMA6518: Transmission Electron Microscopy
Fall 2015
3 Credits
Prerequisites: EMA 3513C or equivalent
Classroom location: CSE E107
Meeting times: MWF period 2 (8:30 a.m. – 9:20 a.m.)

I. Instructor information

Dr. Nicholas G. Rudawski
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Office hours: by appointment only (please do not come to my office unannounced)
Class website: run through e-learning in canvas at https://lss.at.ufl.edu/

II. Course description and objectives

This course provides an introduction and overview of transmission electron microscopy (TEM) as emphasized for materials scientists and those studying the physical sciences with emphasis placed mainly on analysis of inorganic materials (metals, semiconductors, and ceramics). This course also will provide students with a theoretical background required prior to training on the TEMs at the Major Analytical Instrumentation Center (MAIC); successful completion of this course completes the basic prerequisite necessary to start training on the TEMs at MAIC. By the end of the course, students will be able to understand the following:

Basics of microscopy and lenses
Basic construction and modes of operation of a TEM
Typical TEM sample preparation methods
Basics of electron scattering
Electron diffraction patterns
Amplitude contrast in TEM images
Fault analysis using TEM
Phase contrast in images
High-resolution imaging
Scanning TEM
Use of TEM for chemical analysis

III. Recommended textbooks

1. “Transmission electron microscopy: a textbook for materials science” by Williams and Carter; second edition (ISBN: 978-0-387-76500-6)

   http://link.springer.com/book/10.1007/978-0-387-76501-3/page/1

2. “Transmission electron microscopy and diffractometry of materials” by Fultz and Howe; third edition (ISBN: 978-3-540-73885-5)

   http://link.springer.com/book/10.1007/978-3-540-73886-2/page/1

Both of these textbooks are available online, fully downloadable, and completely free of charge at the above respective links when accessed through the UF network. Additionally, print black and white hardcopies may be ordered for $25 through the same links when accessed through the UF network; if you are planning on doing a lot of TEM work, I strongly recommend you invest in hardcopies of these books as both are excellent TEM reference texts, particularly for materials scientists or those studying the physical sciences.

IV. Course outline

A. Tentative course schedule and suggested reading (subject to change)

Date	Topic(s)	Suggested reading
08/24/15	Introduction; microscopy basics; electrons for microscopy; TEM history, advantages/disadvantages, basic electron-sample interactions	WC: 1 (entire)
08/26/15	Ray diagrams; lens basics (resolution, focusing, angles, depth of field/focus)	WC: 6.1, 6.2, 6.7; FH: 2.2
08/28/15	Magnetic lenses; lens defects; spherical/chromatic aberration, astigmatism; objective lens; TEM resolution, knock-on damage, C_s correction	WC: 4.6.E, 6.3 – 6.6; FH: 2.7.1. – 2.7.4
08/31/15	TEM environment; basic TEM construction; TEM illumination system (gun, C1/C2 lenses), gun types, illumination modes	WC: 5.1 – 5.4, 8.1, 9.1 – 9.1C; FH: 2.4.1, 2.4.2
09/02/15	TEM image forming system; imaging/diffraction modes; non-lens TEM components; cameras and screens; holders	WC: 9.1D, 9.2 – 9.3A, 7.2, 7.3C
09/04/15	TEM sample preparation; TEM grids; polishing; etching; ion milling; FIB; XTEM versus PTEM	WC: 10 (entire)
09/09/15	Electron scattering basics; wavefunctions; scattering from a single atom; cross-sections; atomic scattering factor	WC: 2.1 – 2.6, 3.1 – 3.8; FH: 3.1
09/11/15	Scattering from many atoms; light diffraction patterns; Bragg’s law; TEM diffraction patterns; camera equation	WC: 2.8 – 2.12, 3.10B, 9.6.B, 11.3 – 11.6; FH: 5.1
09/14/15	TEM imaging modes for single-crystal, polycrystalline, and amorphous specimens	WC: 9.3A – 9.3C; FH: 2.3
09/16/15	Open Q&A for exam 1; crystallography basics (planes, directions, lattice/basis); hexagonal crystal system	None
09/18/15	**EXAM 1**	N/A
09/21/15	d-spacing; reciprocal lattice; structure factor	WC: 3.9, 12.1 –

		12.3; FH: 5.2
09/23/15	Reciprocal lattice; structure factor calculations for different crystals	WC: 12.1 – 12.3, 16.1 – 16.7, 16.9; FH: 5.3.2
09/25/15	Reciprocal lattice; structure factor calculations for different crystals	WC: 12.1 – 12.3, 16.1 – 16.7, 16.9; FH: 5.3.2
09/28/15	Shape factor; Weiss zone axis law; Ewald sphere	WC: 12.5 – 12.7, 17.1, 17.2; FH: 5.4
09/30/15	Ewald sphere; reciprocal lattice-DP relationship; deviation parameter	WC: 12.5 – 12.7; FH: 5.6 – 5.8
10/02/15	Indexing of DPs from cubic crystals	WC: 18.1- 18.4, 18.10; FH: 6.1
10/05/15	Indexing of DPs from cubic and hexagonal crystals	WC: 18.1- 18.4, 18.10; FH: 6.1
10/07/15	Indexing of DPs from hexagonal crystal	WC: 18.1- 18.4, 18.10; FH: 6.1
10/09/15	Indexing polycrystalline DPs; DPs from low-symmetry crystals; tilt influence on DPs; double diffraction; Kikuchi diffraction; SingleCrystal DP simulation software	WC: 18.9, 19 (entire); FH: 6.3, 6.4
10/12/15	Open Q&A for Exam 2; image-DP relationship; orientation relationships; calculating deviation parameter; convergent beam electron diffraction	WC: 18.11, 19 (entire); FH: 6.3
10/14/15	**EXAM 2**	N/A
10/16/15	Concept of contrast; contrast mechanisms; amplitude contrast; mass-thickness contrast; 2-beam condition; diffraction contrast in perfect single crystals	WC: 22.1 – 22.3.B, 22.3.D, 22.3.E, 22.5, 24.1 – 24.4; FH: 7.1 – 7.2.4, 7.5, 7.6
10/19/15	Diffraction contrast in polycrystalline samples; defective single crystals; dislocations; stacking faults; Burgers vector determination	WC: 25.5, 26.1 – 26.6; FH: 7.7, 7.8
10/21/15	Contrast sharpness; weak-beam dark-field; fault vector determination; contrast from two-dimensional defects (stacking faults)	WC: 22.5, 26.1 – 26.6; FH: 7.10 – 7.12
10/23/15	Bragg beam approach to dynamical scattering; crystal potential; extinction distance; Howie-Whelan equations	WC: 13 (entire)
10/26/15	Dynamical scattering and Bloch wave formalism; Bethe equations; thickness fringes revisited	WC: 14 (entire)
10/28/15	High-resolution TEM; phase contrast; origins of lattice fringes; objective aperture size;	WC: 23.1 – 23.4
10/30/15	Interpreting HR-TEM images; extraneous lattice fringes; role of TEM; convolutions and Fourier transforms	WC: 23.4, 28.1 – 28.8, 28.10; FH: 10.4 – 10.5
11/02/15	Role of defocus, spherical aberration, phase shift error; contrast transfer function; intensity transfer function	WC: 28.1 – 28.8; FH: 10.3.1 –

		10.3.3
11/04/15	Optimizing the intensity transfer function; Scherzer conditions; role of specimen quality; orientation, thickness, and defocus effects	WC: 28.1 – 28.8; FH: 10.3.1 – 10.3.3, 10.5.3
11/09/15	Open Q&A for Exam 3; image filtering; measuring C_s and defocus; Moire fringes; STEM basics	WC: 9.4, 23.5, 23.6, 31.1 – 31.5B
11/13/15	**EXAM 3**	N/A
11/16/15	STEM modes; STEM detectors; HAADF-STEM; spot size and semi-angle of convergence	WC: 7.3.A, 7.3.B, 9.4.B; FH: 11.1 – 11.5
11/18/15	Exam 3 recap; STEM probe optimization; orientation and thickness effects in HAADF-STEM images;	TBD
11/20/15	HAADF-STEM applications; comparing HAADF-STEM to HR-TEM; C_s-corrected STEM; intro to analytical TEM	TBD
11/23/15	Analytical TEM; generation of characteristic X-rays; Fluorescence yield; EDS systems; TEM settings; EDS artifacts	WC: 4.2, 32 (entire), 36.1, 36.2, 36.4 (intro only); FH: 4.6
11/30/15	Mode of performing EDS; qualitative and quantitative EDS	WC: 34 (entire), 35 (entire); FH: 4.6.4
12/02/15	EELS basics; band theory of solids; EELS instrumentation; features of EELS spectra	WC: 37.1 – 37.4, 39.1 – 39.3, 40.1 – 40.4; FH: 4.2, 4.3
12/04/15	Modes of performing EELS; STEM SI and EFTEM SI; qualitative and quantitative EELS	WC: 37.6, 37.8, 38.2, 39.4; FH: 4.4, 4.5
12/07/15	Open Q&A for Exam 4; time allotted to cover any remaining material	TBD
12/09/15	**EXAM 4**	N/A

B. Putting theory into practice: live TEM demos

The laboratory counterpart course (EMA 6518L) will be offered next term. That being said, I do feel it is important for all of you to at least observe some live demonstrations of TEM principles discussed in class so as to start to put theory into practice and gain some basic practical familiarity with TEM. Tentatively, I have planned 3 live demos spaced regularly throughout the term. The demos will be recorded and available to watch on the course website, so attendance when the demos are conducted will not be necessary.

C. Suggested reading

Suggested reading from both textbooks for each class is specified in the above tentative schedule (subject to change). It is not necessary to complete the suggested reading to successfully complete this course, but I do feel that the suggested reading provides a valuable counterpart to the lectures and certainly cannot hurt.

D. List of assessments

1. Four (4) in-class exams (20% of final score for each exam)

   The exams will be entirely multiple-choice format; this is to remove the ambiguity and fairness issues that tend to accompany the grading of essay/extended answer questions.

   Tentative exam dates: 09/18, 10/14, 11/13, and 12/09

2. Weekly (approximately) homework assignments (20% of final score)

   Unlike exams, the weekly homework assignments will be essay/extended answer in nature. Also unlike the exams, the grading of the homework assignments will be pass/fail and on the basis of "effort", rather than correctness; in other words, if you make a reasonable effort on a homework assignment, you will receive a grade of "pass" for it. You may work together in groups on the homework assignments, but each student must turn in his or her own homework. All homework must be turned in through the course website in PDF format by the assigned deadlines and must be complete; a "complete" homework assignment is one that has **all** parts completed. Homework not turned in through the course website and/or not in PDF format and/or not completed will be graded as "fail". To remain fair to all students, I cannot make exceptions for computer malfunctions, incomplete/blank uploads, or any other mistakes (honest or otherwise). I strongly suggest you download and view your assignment after you upload it to make sure everything is in order; you will be allowed an unlimited number of resubmissions prior to each homework deadline to make sure everything is in order.

3. Four (4) in-class, unannounced extra credit quizzes

   These will be entirely true/false; again, this is for reasons similar to those outlined regarding the exams. The first quiz will be given between the drop/add deadline and the first exam, the second quiz between the first and second exams, the third quiz between the second and third exams, and the fourth quiz between the third and fourth exams. The unannounced quizzes will start promptly at the beginning of class; if you arrive more than 5 min late, you will not be allowed to take the quiz. The quizzes provide an opportunity to earn bonus credit on the exams and to give you an incentive to attend class.

E. Make-up assessments policy

In general, make-ups for missed exams or extensions for late homework will not be given except in cases of illness or planned attendance of academic-related functions (research conferences, etc.). If you claim you could not be present to take an exam due to illness, you may take the exam at a later date provided you produce a doctor's note

verifying your need to be absent. You have until 5:00 PM on the last day of the drop/add period (08/28/14) to inform me of any planned absences due to academic-related functions so that I may accommodate you accordingly. Absences for reasons not related to illness or planned attendance of academic-related functions (e.g., missing class to go on vacation), will not be accommodated. No make-ups will be given for missed extra credit quizzes for **any** reason.

V. Attendance and classroom conduct

Attendance is not required, and based on my experience over the past three years I am forced to begrudgingly conclude that regular attendance may not even be necessary to perform well in this course. However, you will have to attend class regularly if you want to take advantage of the extra credit opportunity via the unannounced quizzes and you must be present to take the exams. During class, please be respectful and pay attention; silence/put away your cell phones; please do not bring and read newspapers; you may bring in your laptop computers to take digital notes, but please do not use your computers for leisurely activities (aimlessly surfing the internet, accessing social networking sites, playing games, etc.). As the instructor, I reserve the right to have anyone removed from the classroom that is acting disrespectfully and/or disruptively.

VI. Grading procedure

An absolute grading scale will be used for this course as follows:

90% ≤ A
90% > A- ≥ 87%
87% > B+ ≥ 84%
84% > B ≥ 80%
80% > B- ≥ 77%
77% > C+ ≥ 74%
74% > C ≥ 70% (lowest possible passing grade)

This scale is based on grade data collected over the last three years of teaching this course. Greater information on current UF policies for assigning grade points can be found at: http://gradcatalog.ufl.edu/.

VII. Academic misconduct

Academic misconduct (cheating, plagiarism, etc.) is a very serious matter and will not be tolerated in any capacity; all students are required to abide by the Student Honor Code as described in detail at:

https://www.dso.ufl.edu/sccr/process/student-conduct-honor-code/

It is the responsibility of you, the students, to understand what does and does not constitute a violation of the student honor code. If I believe any student is violating

the student honor code, it will be reported immediately to academic services in the MSE department, fully investigated, and (if necessary) properly sanctioned.

VIII. Accommodations for students with disabilities

Students requesting classroom accommodation must first register with the Dean of Students Office. The Dean of Students Office will provide documentation to the student who must then provide this documentation to the instructor when requesting accommodation.