EMA6518: Transmission Electron Microscopy
Fall 2014
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: TBD and by appointment
Class website: run through e-learning support services 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 heavily electron scattering, diffraction, and analysis of inorganic materials (metals, semiconductors, ceramics, etc.). 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
08/25/14	Introduction; microscopy basics; electrons for microscopy; TEM history, advantages, disadvantages	WC: 1 (entire)
08/27/14	Electron-sample interactions; ray diagrams; lens basics (resolution, focusing, depth of field/focus, angles)	WC: 6.1, 6.2, 6.7; FH: 2.2
08/29/14	Magnetic lenses; lens defects; spherical/chromatic aberration, astigmatism; objective lens; TEM resolution	WC: 6.3 – 6.6; FH: 2.7.1. – 2.7.4, 2.8
09/03/14	TEM environment; basic TEM construction; TEM illumination system (gun, C1/C2 lenses)	WC: 5.1 – 5.4, 8 (entire), 9.1 – 9.1C; FH: 2.4.1, 2.4.2
09/05/14	TEM image forming system; imaging/diffraction modes; non-lens TEM components; cameras and screens	WC: 9.1D, 9.2 – 9.3A, 7.2, 7.3C
09/08/14	TEM sample preparation; TEM grids; polishing; etching; ion milling; FIB; XTEM versus PTEM	WC: 10 (entire)
09/10/14	Electron scattering basics; wavefunctions; scattering from a single atom; atomic scattering factor	WC: 2.4, 3 (entire) FH: 3.1
09/12/14	Scattering from many atoms; light diffraction patterns; Bragg’s law; TEM diffraction patterns; camera equation	WC: 2.8, 2.9, 3.10B, 11.3 – 11.6; FH: 5.1
09/15/14	TEM imaging modes; crystallography basics (lattice/basis, planes, directions)	WC: 9.3A – 9.3C; FH: 2.3
09/17/14	The hexagonal crystal system; lattice/basis examples; the reciprocal lattice	WC: 12.1 – 12.3; FH: 5.2
09/19/14	Calculating d spacing; scattering from a whole crystal; structure factor; complex exponentials	WC: 16 (entire); FH: 5.3
09/22/14	Open Q&A for MT 1; structure factor for different crystals; crystal structure-reciprocal lattice relationship; shape factor; zone axes	WC: 16 (entire); FH: 5.4

09/24/14	**MID-TERM EXAM 1**	N/A
09/26/14	Ewald sphere; Laue zones; reciprocal lattice-DP relationship; deviation parameter	WC: 12.5 – 12.7
09/29/14	Indexing diffraction patterns for cubic system; low-index zone axes; manual DP indexing	WC: 18.1 – 18.4, 18.10; FH: 6.1
10/01/14	Indexing diffraction patterns; diffraction patterns from non-cubic crystal systems; hexagonal notation	WC: 18.1 – 18.4, 18.10; FH: 6.1
10/03/14	Diffraction pattern calibration; indexing spots in HOLZ; double diffraction	WC: 18.9; FH: 6.4
10/06/14	Applications of diffraction patterns; orientation relationships; double diffraction	WC: 18.9, 18.11; FH: 6.4
10/08/14	Simulating diffraction patterns (SingleCrystal); Kikuchi diffraction; deviation parameter; 2-beam condition	WC: 19 (entire) FH: 6.3
10/10/14	Contrast in TEM; amplitude (mass-thickness and diffraction) contrast; Kinematical scattering (2-beam)	WC: 22.1 – 22.3B, 22.3D; FH: 7.1 – 7.2.4
10/13/14	BF and CDF imaging; thickness fringes; bend contours; contrast from defects (invisibility criterion)	WC: 9.3C, 22.5, 24 (entire); FH: 7.5.2, 7.7
10/15/14	Dislocations (line direction and Burgers vector); g dot b analysis; dislocation contrast	WC: 26.1 – 26.6; FH: 7.8
10/20/14	Open Q&A for MT 2; dislocation contrast (effect of deviation parameter); determining dislocation type; weak-beam dark-field	WC: 22.5, 26.1 – 26.6; FH: 7.10 – 7.12
10/22/14	**MID-TERM EXAM 2**	N/A
10/24/14	Weak-beam dark-field; contrast from two-dimensional defects (stacking faults)	WC: 27.1 – 27.5; FH: 7.10 – 7.12
10/27/14	Dynamical scattering; crystal potential; Bragg beam treatment; Schrodinger's equation	WC: 13 (entire)
10/29/14	Dynamical scattering; extinction distance; Howie-Whelan equations; dynamical versus kinematical	WC: 13 (entire)
10/31/14	Thickness fringes revisited; "absorption"; Bloch wave approach; Bethe equations	WC: 13 (entire), 14 (entire)
11/03/14	Bloch wave approach; beats of Bloch waves; Bloch wave locations	WC: 14 (entire)
11/05/14	High-resolution TEM; phase contrast; objective aperture size; lattice fringes (origin and examples)	WC: 23.1 – 23.6; FH: 10.3.2 – 10.3.3
11/07/14	Influence of TEM on HRTEM image; Fourier transforms; convolutions; spherical aberration; defocus	WC: 28.1 – 28.8; FH: 10.3.1 – 10.3.3
11/10/14	Path length difference; phase shift; role of specimen; transfer function; spatial frequencies	WC: 28.1 – 28.8 FH: 10.3.1 – 10.3.3
11/12/14	Spatial Frequencies; transfer function optimization and other factors; Scherzer conditions; specimen quality	WC: 28.1 – 28.8 FH: 10.3.1 –

		10.3.3
11/14/14	Open Q&A for MT 3; Fourier analysis of HRTEM images; fast Fourier transforms; image filtering; FFT calibration	WC: 31.1 – 31.5B
11/17/14	**MID-TERM EXAM 3**	N/A
11/19/14	Interpreting HRTEM images; dislocations; twins; grain boundaries; interfaces; Moiré fringes	WC: 23.1 – 23.6, 28.16; FH: 10.5.1 – 10.5.4
11/21/14	Scanning TEM; STEM detectors; HAADF-STEM; atomic-level Z-contrast	WC: 9.4, 7.3A, 7.3B; FH: 11.1 – 11.5
11/24/14	HAADF-STEM model (incoherent imaging); STEM probe optimization	FH: 11.5
12/01/14	Atomic-resolution HAADF-STEM; analytical TEM; intro to EDS and EELS	WC: 32 (entire), 37 (entire)
12/03/14	STEM configurations for analytical work; typical EDS data; Fluorescence yield; X-ray nomenclature	WC: 4.2, 33 (entire); 36.1, 36.2, 36.4 (intro)
12/05/14	EELS instrumentation; relation to band structure; typical EELS data; spectrum terminology; spectrum imaging	WC: 37.1 – 37.5, 39.1 – 39.3, 40.1 – 40.4; FH: 4.2
12/08/14	TBD	TBD
12/10/14	Open Q&A for final exam	N/A
12/19/14	**FINAL EXAM: 7:30 a.m.**	N/A

B. Putting theory into practice: live TEM demos

The laboratory counterpart course (EMA 6518L) will be offered next term (so it is not run concurrently with this course). 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 am planning to 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. It is up to you whether you do or do not want to perform the suggested reading.

D. List of assessments

1. Three (3) in-class mid-term exams and one (1) out-of-class final exam (17% of final score for each mid-term, 34% of final score for the final 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 mid-term exam dates: 09/24; 10/22; 11/17
   Final exam date and time: 12/19/14 at 7:30 a.m. (room TBD)

2. Weekly (approximately) homework assignments (15% 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 "effort" based; in other words, if you make a reasonable effort on a homework assignment, you will receive full credit 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 group website in PDF format; homework not turned in through the group website and/or not in PDF format will be graded as "fail".

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 before the first mid-term, the second quiz between the first and second mid-term, the third quiz between the second and third mid-term, and the fourth quiz between the third-mid term and the final. 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 (08/29/14) 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 two 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 (obviously). During class, please be respectful and pay attention; silence your cell phones and put them away; please do not bring in newspapers and read them during class; 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

At the end of the term, students will be ranked in terms of final scores. Different letter grades will be assigned to distinct groupings of scores (i.e., the top group will receive A and A- grades, the next group will receive B+ through B- grades, etc.); thus, you are effectively been graded relative to the performance of the rest of the students in the case. There is no predetermined or preset scale for grading, but I will give a projected final grade for everyone after each mid-term exam. Greater information on current UF policies for assigning grade points may 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.