EMA6518: Transmission Electron Microscopy
Fall 2018
3 Credits
Prerequisite: undergraduate degree in engineering or the physical sciences
Classroom location: CSE E122
Meeting times: MWF period 4 (10:40 a.m. – 11:30 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 at elearning.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 the theoretical background required for operation of the TEMs at the Research Service Centers (RSC). 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
TEM instrumentation
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 S/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)

   https://link.springer.com/book/10.1007%2F978-0-387-76501-3

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

   https://link.springer.com/book/10.1007%2F978-3-642-29761-8

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. Chronological order of topics and suggested reading

As a general guideline, we will cover one set of topics per lecture; however, there will be some topics requiring several lectures and some not requiring a full lecture to complete.

#	Topic(s)	Recommended reading
1	Introduction; microscopy basics; electrons for microscopy; TEM history, advantages/disadvantages, basic electron-sample interactions	WC: 1 (entire)
2	Ray diagrams; lens basics (resolution, focusing, angles, depth of field/focus)	WC: 6.1, 6.2, 6.7; FH: 2.2
3	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
4	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
5	TEM image forming system; imaging/diffraction modes; non-lens TEM components; cameras and screens; camera dynamic range; holders	WC: 9.1D, 9.2 – 9.3A, 7.2, 7.3C

6	TEM sample preparation; TEM grids; polishing; etching; ion milling; FIB; XTEM versus PTEM	WC: 10 (entire)
7	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
8	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
9	TEM imaging modes for single-crystal, polycrystalline, and amorphous specimens	WC: 9.3A – 9.3C; FH: 2.3
10	Crystallography; common crystal structures; planes and directions; the hexagonal lattice system	N/A
11	Reciprocal lattice; metric tensors; dot products; Weiss zone axis law; d-spacing; (hkl) absences	WC: 12.1 – 12.3,, 18.4; FH: 5.2
12	Kinematical scattering; role of specimen shape; structure factor; structure factor calculations for different structures	WC: 3.9, 16.1 – 16.7, 16.9, 17.1, 17.2; FH: 5.1, 5,3, 5.4
13	Higher order reflections; role of specimen shape; the Ewald sphere; reciprocal lattice-DP relationship; deviation parameter	WC: 11.5, 12.4 – 12.7; FH: 5.4 – 5.8
14	Indexing cubic single-crystal DPs with 4mm or 6mm symmetry	WC: 18.1- 18.4, 18.10; FH: 6.1
15	Indexing cubic single-crystal DPs with 2mm symmetry	WC: 18.1- 18.4, 18.10; FH: 6.1
16	Indexing hexagonal single-crystal DPs	N/A
17	Single-crystal DPs with 2 symmetry; indexing polycrystalline DPs; grain size effect on polycrystalline DPs; low-symmetry crystal DPs; tilt influence on DPs; CBED; double diffraction	WC: 16.9, 18.5, 18.9, 20.1 – 20.3, FH: 6.4, 6.5 (intro only)
18	Kikuchi diffraction; quantifying deviation parameter; DP simulation; DP applications; CBED applications	WC: 19 (entire); FH: 6.3
19	Concept of contrast; contrast mechanisms; mass-thickness contrast; quantifying contrast	WC: 22.1 – 22.3.B, 22.3.D, 22.3.E;
20	Diffraction contrast in perfect single crystals; 2-beam condition; thickness fringes; bend contours; diffraction contrast in polycrystalline samples; hollow-cone DF	WC: 9.3.D, 22.5, 24.1 – 24.4, 26.1 – 26.6; FH: 7.1 –

21	Diffraction contrast in defective single crystals; imaging dislocations and stacking faults; weak-beam DF; fault analysis	7.2.4, 7.5, 7.6 WC: 22.5, 25.5, 26.1 – 26.6, 27.1 – 27.5; FH: 7.7, 7.8, 7.10 – 7.12
22	Bragg beam approach to dynamical scattering; crystal potential; extinction distance; Howie-Whelan equations	WC: 13 (entire)
23	Dynamical scattering and Bloch wave formalism; Bethe equations; thickness fringes revisited	WC: 14 (entire)
24	High-resolution TEM; phase contrast; origins of lattice fringes; objective aperture size;	WC: 23.1 – 23.4
25	The role of the TEM in high-resolution TEM	WC: 28.1 – 28.8; FH: 10.3.1 – 10.3.3
26	Specimen effects in high-resolution TEM	WC: 23.5, 23.6; FH: 10.5.3, 12.2.3
27	FFT analysis of HR-TEM images; applications of HR-TEM imaging; fault analysis; measuring TEM parameters; image-structure relationship	WC: 31.1 – 31.5.B; FH: 10.4 – 10.5
28	STEM basics and modes	WC: 7.3.A, 7.3.B, 9.4
29	Contrast in STEM images; applications of STEM; SEM in a STEM	9.4.C; FH: 11.1 – 11.5
30	Analytical TEM; generation of characteristic X-rays; Fluorescence yield; EDS spatial resolution	WC: 4.2, 36.1, 36.2, 36.4 (intro only); FH: 4.6
31	EDS instrumentation; STEM configuration for performing EDS	WC: 32
32	Qualitative EDS; EDS mapping; artifacts; system and spurious signals; atomic-resolution EDS mapping	WC: 34 (entire
33	Quantitative EDS	WC: 35 (entire) FH: 4.6.4

34	Electron energy loss spectroscopy; EELS instrumentation; band theory of solids; features of EELS spectra; EELS mapping; energy-filtered TEM; quantitative EELS	WC: 37.1 – 37.4, 39.1 – 39.3, 40.1 – 40.4; FH: 4.2 – 4.4.6
35	EELS mapping; energy-filtered TEM; quantitative EELS	WC: 39.4; FH: 4.4.7, 4.5

B. Putting theory into practice: live TEM demos

It is beneficial for all of you to 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. The demos will be prerecorded and uploaded to the course website, allowing you to watch said demos at your convenience. Watching of the demos is completely optional and is not intended as a means to enhance your ability to succeed in this course but rather as an enhancement to the course in general.

C. Recommended reading

Recommended reading from both textbooks for each class is specified in the above tentative schedule (subject to change). All the information you will need to complete this course will be covered in the lectures and thus performing the recommended reading is optional. It remains unclear if there is any correlation/causation between performing the recommended reading and performance in this course, but performing the recommended reading certainly will not hinder your ability to succeed in this course (and there isn't any financial barrier since you can access the books for free, too).

D. List of assessments

1. Four (4) in-class exams (15% of final score for each exam)

   The exams will consist of extended answer and essay format questions; this will be the first time that this formatting will be used for the exams; you will be allowed the use of the following items for each exam:

   1. Writing utensil
   2. Ruler
   3. Calculator (memory must be cleared if it is graphical)
   4. 3" x 5" notecard (front and back) containing any information you wish

   Tentative exam dates and coverage: 09/21 (topics 1 – 9), 10/19 (topics 10 – 18), 11/09 (topics 19 – 27), and 12/05 (topics 28 – 35)

   Due to the systematic way we will cover the material in this course, you should have the expectation that the exams will be implicitly cumulative in nature.

2. Homework assignments (30% of final score for on-campus students, 40% of final score for EDGE students)

   Homework will be assigned on an approximately weekly basis and will be essay/extended answer in nature. 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 (including justifying your answers and/or showing your work where relevant), you will receive a grade of "pass" for it. The weight of a particular homework assignment towards your final homework grade will be reflective of the amount of work required for that assignment; assignments requiring more work will thus be weighted more heavily. You may work together in groups on the homework assignments, but each student must turn in his or her own homework. Your homework assignments may be typed and/or handwritten, either is acceptable. However, each homework assignment must be turned in through the course website as a single document 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 (e.g. emailed directly to me) and/or not in PDF format and/or not completed will be graded as "fail"; no partial credit will be given for homework assignments. To remain fair to all students, I cannot make exceptions for computer malfunctions, Internet outages, 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. Participation (10% of final score for on-campus students only)

   A participation grade will be assessed based on the accumulation of 20 "participation points" over the course of the class. Participation points will only be given for answering questions I ask during class or for thoughtful comments/questions made by you during class. Participation points will not be awarded for comments/questions asked before class, after class, or via email. You may accumulate up to 2 participation points during any given class period. Your final participation grade will be assessed on an "all or nothing" basis; in other words, if your final number of accumulated participation points at the end of the course is 19 or less, your final participation grade will be zero.

4. Four (4) out-of class extra credit mini-projects (optional)

   These will be essay/extended answer in nature and will usually be mathematical and/or computational in nature. These will also be graded on the basis of *correctness* as well as effort (i.e. justifying your answers and/or showing your work where relevant). Attempting of the mini-projects is completely optional. You may work together in groups on the mini-projects, but each student must turn in his or her own mini-project and you are expected to complete the mini-project without any assistance from me. The turning in of mini-projects follows the exact same stipulations and conditions outlined for the turning in of homework. Grading of the mini-projects will be "all or nothing" in nature. In other words, you will either receive full credit for the mini-project or you will receive no credit. To receive full credit on a mini-project, all parts must be completed correctly and you must show your work. Successful completion of a mini-project will result in a 10% bonus to be added on to the corresponding exam.

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

   The quizzes will be 10 questions and true/false format; 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 and keep up with the material. Scoring 6 or fewer, 7, 8, 9, and 10 correct questions will result in 0, 2.5, 5.0, 7.5, and 10% bonus, respectively, to be added on to each corresponding exam. If you are an EDGE student, you will also have the opportunity to take these quizzes, which will be proctored in the same manner as the exams (but obviously will not be subject to any attendance requirements).

E. Late homework policy

Attendance is not required to turn in homework and therefore late homework will generally not be accepted. Traveling for academic-related reasons and/or last-minute internet/computer problems are not sufficient justifications for late homework to be accepted.

F. Make-up assessments policy

In general, make-ups for missed exams will not be given except in cases of illness, planned attendance of academic-related functions (research conferences, etc.), family emergencies, or genuinely extenuating circumstances. If you claim you could not be present to take an exam due to an aforementioned reason, you may take the exam at a later date subject to verification of your need to be absent. You have until 5:00 PM on the last day of the drop/add period to inform me of any planned absences due to academic-related functions so that I may accommodate you accordingly. Absences for reasons not previously mentioned (e.g., missing class to go on vacation, oversleeping, etc.), will not be accommodated. No make-ups will be given for missed extra credit quizzes or mini-projects for **any** reason.

V. TEM training

Those of you who intend to use the FEI Tecnai F20 S/TEM as part of your research may start training a few weeks into the course (or anytime after the course is completed). You must apply for an RSC account (https://rsc.aux.eng.ufl.edu/), set up a funding source, take basic safety training, pass the radiation safety short course, and apply for a dosimeter badge before starting training. Only graduate research assistants who intend to use TEM regularly for research in the *physical* sciences may be trained on the RSC TEM. Students intending to use TEM for research in the *biological* sciences should use the electron microscopy core of the Interdisciplinary Center for Biotechnology Research: http://www.biotech.ufl.edu/cores/electron-microscopy/.

VI. Class emails

A group email list will be used to send out as-needed mass communications for purposes of sudden schedule changes (which hopefully will not happen), clarification of course material, and/or other important issues. You are expected to read all class-related emails.

VII. Attendance and classroom conduct

With the exception of exam days, attendance is not required; however, you will have to attend class regularly if you want to accumulate participation points and/or take advantage of the extra credit opportunity via the unannounced quizzes. If you choose to attend 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; failure to follow proper classroom conduct will result in the following consequences: first offense: public warning; second offense: reduction in possible participation grade from 10 to 5% (and you must still accumulate 20 points to get the 5%); third offense: participation grade of zero.

VIII. 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)

Greater information on current UF policies for assigning grade points can be found at: http://gradcatalog.ufl.edu/. Your final grade will be rounded to the nearest whole percent (e.g. 89.51% will get rounded up to 90% and 69.49% will get rounded down to 69%).

IX. Concerns about grades

I have made every effort to be as transparent as I possibly can be about grading so there are no surprises and you all know exactly how well you need to do to obtain certain grades. In previous years, I provided access to old exams, but as the exam format is being changed this year, I am not doing this (at least for this year) as I feel it would probably be more detrimental than beneficial given the different formatting (your homework assignments should be considered more indicative of what to expect in terms of your exams). However, as the format of the bonus quizzes will remain the same, I will provide access to old bonus quizzes. Furthermore, the optional extra credit opportunities also have the potential to improve each exam score by up to 20%. If you have specific concerns about course material, I am more than happy to discuss these with you. However, I am not willing to meet with you if you are simply unhappy about your grade and want to express your frustration with me, want me to provide you with special grading leniency, or want me to provide you with a special extra credit opportunity to improve your grade. The *only* provided extra credit opportunities will be those already outlined in this syllabus; I suggest that you take as much advantage of those opportunities as you possibly can.

X. Performing well in this course

The people who perform well in this course are those who are able to properly and correctly understand the material and (at minimum) also complete the homework assignments. As far as understanding the material is concerned, some students may be able to do this at a very high level with very little effort. Other students may put in a tremendous amount of effort and will still have difficultly understanding the material at a mediocre level. I cannot guarantee that you will receive a good grade simply by putting a lot of effort into this course; ultimately, it comes down to performance. That being said, my experience over several years of teaching is that the students who perform well tend to be those who put in more effort; however, I'm not necessarily sure that there is a causal relationship between effort and understanding of the material; it may be the case that students who have an easier time understanding the material become more interested in the material and therefore are more driven to put in effort (so it may be like a positive feedback loop).

XI. Academic misconduct

Academic misconduct (cheating, plagiarism, comparing exam answers after the conclusion of an exam, 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.

XII. 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. Only documentation that is signed by someone from the Dean of Students Office will be accepted.

XIII. Frequently asked questions (and answers)

Q: If I pass this course, may I claim that I am “proficient” or an “expert” in TEM?

A: You may claim whatever you want to claim, but that doesn’t necessarily mean your claim will be accurate. In general, to claim you are “proficient” or an “expert” in TEM you need not only a thorough theoretical understanding of TEM, but also hundreds of hours of hands on TEM operation and often an extensive publication record of TEM-related research.

Q: Are UF instructors required to use the same grading scale?

A: UF has a “standard” grading scale that is suggested for use by instructors. However, instructors are not required to use this scale and individual instructors may use whatever grading scales they wish; there is no requirement that UF instructors use the same grading scale.

Q: Are UF instructors required to use the same assessment methods?

A: UF instructors may use whatever assessment methods they wish; some may not use any exams, some may use exams, but prefer to have the questions all be extended answer/essay in nature while others may prefer to only use multiple choice questions; some instructors may assign homework and others may not; if different instructors assign homework, the weight of the homework toward the final grade may be different; there is no requirement that UF instructors use the same assessment methods.

Q: Are UF instructors allowed to change the grading scales and/or assessment methods from those outlined in the syllabuses provided at the beginning of their classes?

A: UF instructors may (at any time during the course) change their grading scales and/or assessment methods if circumstances arise which they deem justify such changes; they are required to notify you of any changes but are not required to obtain approval (from students or anyone else).

Q: May I take the last exam (12/05) early so that I may leave early to go on Winter break?

A: Requests to take the last exam early may only be granted in cases of extenuating circumstances for which proper, reasonable planning was not possible. Given that the last exam is over three months away from the start of classes, this provides all students with enough time to properly plan travel arrangements (including obtaining of visas). Simply wanting to go on Winter break early, wanting to save money on travel, etc. do not qualify as an extenuating circumstances.

Q: Will you write a letter of recommendation for me?

A: I generally only write recommendations for students whom I enthusiastically and wholeheartedly will endorse and whom I feel I know well. Please also keep in mind that any recommendation I provide will only be given on the basis upon which I know you. In other words, if a recommendation asks about your ability to perform research and I only know you as a student in my class, I will not be able to provide any evaluation in such a capacity.