MSE 422 – Electrical Ceramics
Spring 2022

Instructor: Prof. Nicola H. Perry
Class Time: MWF 9:00-9:50AM
Class Location: CIF 2036 (except for week 1: Jan 19, 21 on Zoom)

Email:	nhperry@illinois.edu (*Canvas* discussion board preferred when possible)
Office Hours:	By *Zoom* – time TBD
Course Website:	*Canvas* (note: *Zoom* link for first week and office hours is listed on *Canvas*)
Assignments:	*Gradescope*
Quizzes, Exams:	*In Class (or on Gradescope, as needed)*

Text:
Electroceramics: Materials, Properties, Applications
By A. J. Moulson, J. M. Herbert, 2nd Edition, Published by Wiley: New York (2003) – available online free through library on campus internet or by VPN

Additional Reference Text:
Fundamentals of Electroceramics: Materials, Devices, and Applications
By R.K. Pandey, Published by Wiley (2018) – available online free through library on campus or by VPN

Texts on hold at Grainger Library (for Reference):
1. A. J. Moulson, J. M. Herbert, *Electroceramics*, Wiley: New York (2003).
2. W. D. Kingery, H. K. Bowen, D. R. Uhlman, *Introduction to Ceramics*, Wiley: New York (1976).
3. Y.-M. Chiang, D. Birnie, III, W. D. Kingery, *Physical Ceramics*, Wiley: New York (1997).
4. R. C. Buchanan, Ed., *Ceramic Materials for Electronics*, Marcel Dekker: New York (2004)
5. L. L. Hench, J. K, West, *Principles of Electronic Ceramics*, Wiley: New York (1990).
6. L. M. Levinson, Ed., *Electronic Ceramics*, Marcel Dekker: New York (1990).
7. L. Edwards-Shea, *Solid-State Electronics*, Prentice-Hall: New York (1996).

Prerequisites:
According to the UIUC course catalog, MSE 420 is a prerequisite for this course. However, this course will assume only basic levels of knowledge from MSE 420 and will cover additional materials as needed. A basic understanding of chemistry and physics will also be assumed. MSE 420 may be taken concurrently.

Class Description and Objectives:

<u>Objectives:</u>
Students will be able to:
1) describe mechanisms, i.e., structure-property relationships and physical processes, of functional insulating, ionic, electronic, dielectric, magnetic, and optical behavior underlying performance of electroceramics in devices
2) classify electroceramics according to crystal/electronic/magnetic/micro - structure and associated properties
3) apply the above knowledge to a) select appropriate materials for given applications, b) predict behavior on the basis of structure, c) interpret measured experimental data to describe properties, and d) understand and analyze recent academic/industrial developments in the field of electroceramics
4) identify electroceramics and their applications in daily life as well as cutting-edge research needs/trends

5) select material-specific methods for tailoring structure (e.g., valence states, spin states, electronic structure, point defect concentrations, carrier mobilities) across many length scales to modify electroceramic behavior
6) select appropriate resources for finding further information on electroceramics

Course readings, in-class activities, and assignments are designed to help students make progress toward these objectives. Assessment (grading) will be based on demonstrated student learning gains towards these objectives.

Course catalog description of content:
Electrical ceramics, from insulators to conductors, and magnetic and optical materials; the role of the processing cycle and microstructure development on the design and performance of electrical components; capacitors, resistors, and inductors; structure-property relations for pyro-, piezo-, and ferroelectric materials; perovskite and spinel based structures; varistors, thermistors, transducers, actuators, memory elements, multilayered components, and their applications. Design project.

Class Outline & Topics:

Note: Owing to limited time, we may not be able to cover all the topics listed.

Introduction to Functional Ceramics (Chap. 1)
- What are ceramic materials?
- Historical development, methods of ceramic development in general
- Selected applications

Solid State Science and Crystal Structures Review (Chap. 2: Sections 2.1 and 2.2 Only, Chap. 3 - briefly)
- Models of atoms & ions
- Arrangement of ions: crystal structures, amorphous structures
- Ceramic processing (briefly)

Conductors (Chap. 2: Sections 2.5 and 2.6 Only, Chap. 4, & Supplementary Reading)
- Point defects
- Electrical conduction
- Electronic conduction (band diagrams; intrinsic/extrinsic; semiconducting/metallic/superconducting; polarons; temperature dependence)
- Ionic conduction (hopping mechanism, origins of temperature dependence)
- Mixed ionic/electronic conductors
- Composite conductivity models
- Electronic conductor applications: heating elements, resistors, varistors, thermistors, temperature-sensitive resistors
- Ionic & mixed conductor applications: fuel/electrolysis cells, batteries, sensors, gas separation membranes, thermochemical reactors
- High transition temperature superconductors & applications
- Possible special topics: conductivity along and across interfaces & related devices (grain boundaries, hetero-interfaces, semiconductor junctions, etc.); conductivity & strain; heterogeneous doping; transparent conductors; metal-insulator transitions; memristors/resistive RAM; conduction in amorphous ceramics/glasses

Dielectrics and Insulators (Chap. 2: Section 2.7 Only, Chap. 5)
- Polarization mechanisms in electric field
- Complex permittivity (power dissipation, frequency dependence, temperature dependence, loss factor, loss tangent, quality factor)
- AC impedance spectroscopy

- Permittivity of composites & barrier layer dielectrics
- Ferroelectricity
- Capacitive applications
- Dielectric strength, breakdown
- Capacitor characteristics (efficiency, resonant frequency, resistance)
- Non-ceramic vs. ceramic capacitors (incl. multilayer capacitors, high voltage/power capacitors)
- Classes of dielectrics
- Low-permittivity dielectrics and insulators (materials, electronic packaging, low temp co-fired ceramics)
- Medium-permittivity ceramics (materials, high power capacitors, low loss capacitors, microwave resonators)
- High-permittivity ceramics (materials, applications)
- Ferroelectrics & ferroelectric memory

Piezoelectric Materials (Chap. 2: Sections 2.3, 2.4 Only; Chap. 6)
- Crystal symmetry, polarity, phase transformations
- Direct and converse (indirect) effects, electrostriction
- Piezoelectric coefficients & their measurement
- Role of microstructure/domains & defect chemistry
- Commercial piezoelectric ceramics & composites
- Applications: voltage generation, actuation, frequency control, generation/detection of acoustic energy

Pyroelectric Materials (Chap. 7)
- Symmetry, thermodynamics, electrical and thermal considerations, and phenomena
- Measurement of pyroelectric effects
- Design of a pyroelectric detector, energy conversion, figures of merit, materials selection

Electro-Optic Ceramics (Chap. 8)
- Light descriptors, polarized light, refractive indices
- Electro-optic effects
- Non-linear optics
- Transparent ceramics
- Optical absorption & relationship to point defects, electronic structure
- Measurement of electro-optic effects
- Materials systems (crystalline, non-crystalline) and applications

Magnetic Ceramics (Chap. 9)
- Origins of magnetism in materials – special focus on oxides
- Classification of magnetic materials: dia-/ para-/ ferro-/ antiferro-/ ferri-magnetic
- Magnetic phenomena: spontaneous magnetization, anisotropy, magnetostriction, hysteresis, hard vs. soft magnets, magneto-optical effects, domains
- Soft magnet key parameters: initial permeability, loss factor, electrical resistivity, permittivity, resonance effects & microstructure
- Hard magnet key parameters: remanence, coercivity, maximum energy product
- Influence of composition, microstructure, field, temperature
- Fabrication & materials (ferrites, etc.)
- Applications (inductors, transformers, antennas, information storage, optical signal processing, microwave applications)

Grading Policies:
Student learning gains will be assessed based on the following assignments:

- Homework (10% of total grade)
  - There will be approximately 4 +/- 1 assignments throughout the semester.
  - Assignments will be posted and turned in on *Gradescope*.
- Quizzes (30% of total grade)
  - There will be approximately 5 +/- 1 in-class quizzes throughout the semester.
  - Quizzes will cover materials presented in class, in readings, and on homework.
- Participation (5% of total grade)
  - Classes such as this are greatly improved by active discussion and participation.
  - You could participate by, for example: 1) asking questions after student presentations or during zoom class time (office hours), 2) finding and describing to the class relevant research literature, news, or applications of electroceramics, 3) contributing to class discussions and discussion boards.
- Exams (20% midterm exam and 20% final exam, together 40% of total grade)
  - There will be no makeup exams. If you have a valid reason for missing an exam (e.g., documented health emergency, death in the family, etc.) I will work with you to reach an acceptable time to take the exam. Such rescheduling will be dealt with on a case-by-case basis.
- Presentation (15% of total grade)
  - Students will prepare and deliver a presentation on a special topic related to the course, incorporating recent scientific literature.
  - Prior to the presentation, students will prepare an abstract.
  - Topics will be assigned based on ranking of topic preferences; every effort will be made to provide students with one of their top 3 choices but this might not be possible.
  - Additional details concerning the subject matter, grading, and expectations will be provided separately.

Homework & Quiz Policy:
I recognize that we are continuing to teach and learn under extremely challenging circumstances. Therefore the following policies are in place to provide some flexibility this semester:

- Homework: Students can turn in assignments up to 5 days after the deadline, with a penalty of *10% off the maximum attainable grade per day late* unless prior arrangements are made with the instructor for valid, documented reasons. Valid reasons for alternative arrangements include, but are not limited to, deaths in the family, jury duty, hospitalization for illness, etc.
- Quizzes: no re-arrangement of the schedule is possible, but the *lowest quiz score will be dropped* automatically.

Academic Integrity:
The University of Illinois at Urbana-Champaign Student Code should also be considered as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: http://studentcode.illinois.edu/.
Academic dishonesty *may result in a failing grade*.
Every student is expected to review and abide by the Academic Integrity Policy: https://studentcode.illinois.edu/article1/part4/1-401/. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

Disability-Related Accommodations:
To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to https://www.disability.illinois.edu. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments

available that can help diagnosis a previously undiagnosed disability. You may access these by visiting the DRES website and selecting "Request an Academic Screening" at the bottom of the page.

Diversity:
I greatly value the diversity that students bring to the (virtual) classroom, particularly in a discussion/presentation-heavy class such as MSE 422. I learn a lot from your questions, ideas, interests, and comments. Together as a class, our perspective on the science and applications is greatly broadened when everyone participates. More generally, it's clear that diverse participation in engineering is needed to ensure that technology is designed to serve and be accessible to the whole population rather than a narrow subset. In science, diverse perspectives and lenses benefit the whole community through increasing creativity and innovation. Further, in the context of increasing globalization, students need to be well prepared for teamwork and communication in a diverse and international setting to address challenges where electrical ceramics knowledge can assist (e.g., climate change, disease epidemics, water accessibility, sustainable energy, etc.). My goal is to create an inclusive classroom environment where all students can take risks to fully participate and thereby grow and learn. If you have suggestions for the instructor on improving the course environment and culture from a diversity perspective, please do reach out.

Inclusivity Statement from the College:
The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community. The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART) (https://bart.illinois.edu/). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

Sexual Misconduct Reporting Obligation:
The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.
A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential.
Other information about resources and reporting is available here: wecare.illinois.edu.

Religious Observances:
Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. You should examine this syllabus at the beginning of the semester for potential conflicts between course deadlines and any of your religious observances. If a conflict exists, you should notify your instructor of the conflict and follow the procedure at https://odos.illinois.edu/community-of-

care/resources/students/religious-observances/ to request appropriate accommodations. This should be done in the first two weeks of classes.

Family Educational Rights and Privacy Act (FERPA):
Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.