ASEN 5519 – Special Topics: Introduction to Phononics (Fall 2018)
(Formally, Special Topics: Vibrations in Mechanics and Physics)

Instructor: Prof. Mahmoud Hussein, Aerospace Eng. Sciences, ECAE 194, 492-3177, mih@colorado.edu

Schedule: TTh 5:00-6:15 pm, Engineering Classroom Wing 1B08 **Office Hours:** By Appointment

Objective and Scope:

This course will provide an advanced exposure, coupled with hands-on development, of concepts and techniques in the theory of phonons with a focus on vibrations, wave propagation, and transport in periodic materials. Motivated by the growing interest in interdisciplinary research, the course will take a unique perspective of approaching the topic from both the mechanics and physics points of view, hence multiple system size scales will be considered ranging from the continuum to the atomistic. This approach promises to broaden the potential for cross-flow of ideas and the development of novel insights, techniques and applications, particularly in the emerging areas of *nanomaterials* and *metamaterials*.

Topics (tentative):

- Intro to course; intro to phononics at macro and nanoscales; motivation and applications

Macroscale Phononics (Vibrations in Mechanics)

Discrete models: Vibration/dispersion analysis of finite/infinite systems

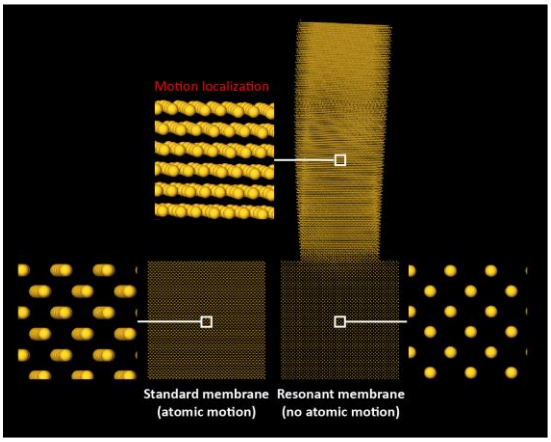
- Single-DOF and multi-DOF systems
- Modal analysis (mode superposition and selection):
- Treatment of damping (non-proportional and general)
- Vibration absorber and locally resonant elastic metamaterials

Continuous models: Vibration/dispersion analysis of finite/infinite systems

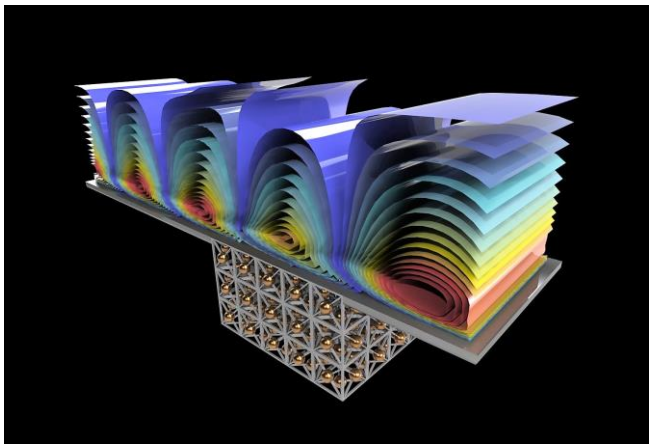
- Transfer matrix method (undamped and damped)
- Finite element method (undamped and damped; steady-state vibrations, wave simulation, and dispersion)
- Introduction to multi-dimensional lattices: Symmetry, Brillouin zone, and Bloch's theorem
- Applications of macroscale phononic crystals and elastic metamaterials

Nanoscale Phononics (Vibrations in Physics)

- Basic crystallography and interatomic potentials
- Lattice dynamics: dispersion, mode shapes, and density of states
- Thermal transport: thermal conductivity prediction; physical phenomena
- Research and development outlook: discussion, references



Thermal conductivity reduction by vibrons (nanoscale phononics) [1]



Flow stabilization by phonons (macroscale phononics) [2]

Course Themes:

- Discrete vs. continuous models
- Macroscale vs. nanoscale models
- Steady-state vibration vs. wave simulation vs. dispersion descriptions of the dynamics
- Analytical (e.g., transfer-matrix) vs. numerical (e.g., finite-element) methods
- Mathematics and physics of vibrations and wave propagation with a focus on the phenomena of dispersion, resonance, dissipation, and nonlinearity
- Intersection of disciplines between mechanics (elastodynamics) and physics (condensed matter physics)
- Applications of phononic crystals and elastic metamaterials (at macro or nano scales)

Course Philosophy:

- Physics- and mathematics-driven coverage of topics
- Research-oriented learning
- Students play an active role in learning and course progress
- Interdisciplinary treatment of course material

Course Visionary Outlook:

Could phononics impact the world as electronics and photonics did?

Course Textbook (available online at CU library):

Phani, A.S. and Hussein, M.I., (Eds.), "Dynamics of Lattice Materials," Wiley, New Jersey, 2017.

References:

Vibrations-Mechanics:
Rao, Singiresu S., *Mechanical Vibrations*, 5th Edition, Addison-Wesley, 2010

Vibrations-Physics:
Kittel, Charles, *Introduction to Solid State Physics*, 8th Edition, John Wiley & Sons, 2004

Phononics-Macroscale:
Deymier, Pierre A., *Acoustic Metamaterials and Phononic Crystals*, John Wiley & Sons, 2013

Phononics-Nanoscale:
Dove, Martin. T., *Introduction to Lattice Dynamics*, Cambridge University Press, 1993

Grading:

Homework assignments:	30%	(approximately 4-5 assignments)
Exam:	30%	(tentative date: October 25, 2018)
Project:	40%	(target: conference or journal publication)

[1] Honarvar, H. and Hussein, M.I., "Two orders of magnitude thermal conductivity reduction in silicon membranes by resonance hybridizations," *Physical Review B*, **97**, 195413, 2018.

[2] Hussein, M.I., Biringen, S., Bilal, O.R., and Kucala, A. "Flow stabilization by subsurface phonons," *Proceedings of the Royal Society A*, **471**, 20140928, 2015.

Course Project:

The course project will provide an opportunity to pick a wave propagation problem at the interface of mechanics and physics, carry a literature search on it, develop a mathematical model for it, solve it numerically, and present the results to the rest of the class. Students interested in doing an experimental project could potentially be permitted to do so if the time and resources are available. It should be possible, and will be encouraged, to produce a conference/journal paper out of this project. (Results from student projects in this course has made it to journal publications in the past.) Emphasis will be on using the project to develop an appreciation and an aptitude for conducting research in the emerging field of phononics and more generally in the area of dynamics of materials and structures.

More information on the project:

- Work will be done in groups of 2-3 students.
- Students choose a topic with guidance from instructor. Formal discussion on the project will take place in class around the middle of the semester, but students are encouraged to start thinking about possible topics and discuss these with the instructor as early as possible in the semester.
- Computational studies should be done using Matlab.
- A mini-research proposal will be prepared and presented to the class at an early stage.
- A literature search will be conducted by each group and presented to the class.
- A final conference-style research presentation will be given by each group at the end of the semester.
- A final conference-style paper will be submitted by each group at the end of the semester. High quality papers could potentially be submitted to a national conference and/or to a journal with the assistance and support of the instructor (even if this takes place after the course is over).

Prerequisite: Undergraduate dynamics and vibrations or consent of instructor

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If you have a temporary medical condition or injury, see Temporary Injuries under Quick Links at Disability Services website (http://disabilityservices.colorado.edu/) and discuss your needs with your professor.

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  See full details at

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and at

http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code

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