Catalog Description

601 Micro- and Nanoscale Mechanics. I, II; 3 cr. Selected topics in such areas as structural mechanics, dynamics, experimental mechanics, vibrations, engineering materials, soil mechanics, engineering analysis, rheology, etc. P: Cons inst.

Course Prerequisite(s)

- See catalog description above.

Prerequisite knowledge and/or skills

Students should have a general understanding of mechanics and materials, and a deep curiosity in extending their knowledge beyond traditional bounds. This course is designed for students willing and able to work at least at the level of a first year graduate student. Literature reviews, critical peer discussion, and student presentations will be an integral part of the course.

Textbook(s) and/or other required material

No textbook will be used for this course. Course notes and technical papers will be utilized.

Course objectives

- To enhance students’ appreciation of the current state and potential future impact of nanotechnology
- To demonstrate how specific physical behavior and engineering design requirements change with scale
- To show how engineering mechanics concepts can be used or appropriately adapted to describe essential behavior at the nanoscale, and to demonstrate the critical role that mechanics plays in the design and implementation of nanotechnology concepts
- To expose students to the cross-disciplinary intersections that occur between mechanics and materials science, chemistry, physics, and biology when working at the nano-scale.

Topics covered

- Introduction to nanotechnology, overview of new opportunities, connections to mechanics
- Brief overview of synthesis techniques
• Overview of relevant mechanics concepts including mechanics of materials, fracture mechanics, contact mechanics, elasticity
• Atomic structure of materials, phase transformations, defects, dislocations
• Mechanical testing and material property determination at small scales including size-scale strength effects
• Surface characterization including scanning probe techniques, surface forces, and diffusion
• Using mechanics in micromachines (MEMS): application, design, performance, and testing
• Theory, modeling, and computational techniques for mechanics modeling of nano-systems including MD of fracture mechanics, mixed atomistic /continuum modeling of sliding friction
• Mechanics aspects in nano-biomaterials, molecular machines

Person(s) who prepared this description
• Kenneth Lux
EMAS - Spring 2005
Micro- and Nanoscale Mechanics

Prof. Wendy Crone
Department of Engineering Physics
Engineering Mechanics Program
529 Engineering Research Building
crone@engr.wisc.edu
262-8384

Prof. Robert Carpick
Department of Engineering Physics
Engineering Mechanics Program
543 Engineering Research Building
carpick@engr.wisc.edu
263-4891

Joint Office Hours: W 1:20-3:00 pm, R 1:20-2:30 pm, location TBD
Other office hours available by appointment

Course Goals:
- to enhance students’ appreciation of the current state and potential future impact of nanotechnology
- to demonstrate how specific physical behavior and engineering design requirements change with scale
- to show how engineering mechanics concepts can be used or appropriately adapted to describe behavior at the nanoscale, and to demonstrate the critical role that mechanics plays in the design and implementation of nanotechnology concepts
- to expose students to the cross-disciplinary intersections that occur between mechanics and materials science, chemistry, physics, and biology when working at the nano-scale.

Course Description:
This course will provide an introduction to nanoscale engineering with a direct focus on the critical role that mechanics needs to play in this developing area. Engineering is progressing to ever smaller scales, enabling new technologies, materials, devices, and applications. Mechanics enters a new regime where the role of surfaces, interfaces, defects, material property variations, and quantum effects play more dominant roles. We will discuss how mechanics becomes integrated with the fields of materials science, chemistry, physics, and biology at this scale. We will cover a variety of concepts and applications listed below, drawing connections to both established and new mechanics approaches. We will discuss the limits of continuum mechanics and present newly developed mechanics theories and experiments tailored to describe micro- and nano-scale phenomena. We will emphasize specific applications throughout the course.

Prerequisites:
Students should have a general understanding of mechanics and materials, and a deep curiosity in extending their knowledge beyond traditional bounds. This course is designed for students willing and able to work at least at the level of a first year graduate student. Literature reviews, critical peer discussion, individual and team problem assignments, a laboratory project, and student presentations will be an integral part of the course.
General Topic Areas Covered:
The topic areas listed are not necessarily a chronological list and may be interspersed amongst each other where connections between topics exist or logically complement each other.

- introduction to nanotechnology, overview of new opportunities, connections to mechanics
- brief overview of synthesis techniques
- overview of relevant mechanics concepts including mechanics of materials, fracture mechanics, contact mechanics, elasticity
- atomic structure of materials, phase transformations, defects, dislocations
- mechanical testing and material property determination at small scales including size-scale strength effects
- surface characterization including scanning probe techniques, surface forces, and diffusion
- using mechanics in micromachine (MEMS): application, design, performance, and testing
- theory, modeling, and computational techniques for mechanics modeling of nano-systems
- mechanics aspects in nano-biomaterials, molecular machines – possibly dropped for time constraints

Evaluation:
This course will incorporate the following types of assignments:

- **reflective writing assignments** asking students to evaluate information, draw inferences, identify cause and effect, and draw comparisons with examples from the literature *(reflective writing assignments will be posed as weekly email questions about the current lecture topics, students will respond with 1-2 paragraphs by Sunday evening using the forum on the course website)*

- **manuscript** presenting an in-depth critical review of a nano-science research topic that incorporates interdisciplinary issues; written as a technical article submission to a peer-reviewed journal; incorporates reviews and appropriate revisions; graded by the instructors and by peers *(due dates indicated in the syllabus)*

- **homework** sets based on individual effort and group work *(due dates indicated in the syllabus)*

- **laboratory** experiments on synthesis and characterization of nanoscale components, and construction of a microfluidic device that will filter nanoparticles from solution*(each student will keep a lab notebook for the course; a copy of the recent lab notebook pages are due on the lab due dates indicated in the syllabus; a final lab report is due at the completion of the lab series with the last lab assignment)*

Laboratory work will be conducted in teams although each student will construct a final device using the components and solutions created by the lab team. Each student will take on the leadership role for the lab group for at least one laboratory.
Laboratory experiments will include the following modules:

**Lab 1:** Functionalization of a silver coated substrate with a decanethiol monolayer followed by contact angle characterization

**Lab 2:** Atomic Force Microscopy characterization of the silver substrate and the functionalized silver created in Lab 1

**Lab 3:** Construction of a microfluidic device on the functionalized substrate created in Lab 1 followed by creation of a nylon filter within the device

**Lab 4:** Synthesis of colloidal gold nanoparticles in an aqueous solution

**Lab 5:** Testing of nanofilter device using the nanoparticle solution created in Lab 4

**Lab 6:** Atomic Force Microscopy imaging of filtered nanoparticles from Lab 5

An on-line video-based lab manual is available at:
http://www.mrsec.wisc.edu/edetc/nanolab/Fluidics/index.html

Grades in the course will be decided with the following weighting:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Class Participation/Weekly Emails</td>
<td>10%</td>
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<tr>
<td>Homework Sets</td>
<td>30%</td>
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<tr>
<td>Laboratory Reports</td>
<td>30%</td>
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<tr>
<td>Manuscript</td>
<td>30%</td>
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**Required Text:**
A.N. Cleland (2003) Foundations of Nanomechanics
Note: we will follow this text directly for certain sections of the class, but other sections will rely on other supplementary sources including texts, journal articles, and notes.

**References on Reserve:**
See the course webpage http://courses.engr.wisc.edu/ecow/get/ema/601/crone/ for a complete listing of reserve items and on-line references.

Books on reserve at Wendt:
G. Timp (1999) Nanotechnology T174.7 N373 1999
<table>
<thead>
<tr>
<th>Date</th>
<th>Week</th>
<th>Lecture #</th>
<th>Instructor</th>
<th>Topic</th>
<th>Due Dates</th>
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<td>1/18</td>
<td>1</td>
<td>1</td>
<td>WCC</td>
<td>Introduction to nanotechnology</td>
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<td>1/20</td>
<td>2</td>
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<td>Overview of new opportunities and connections to mechanics</td>
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<td>WCC</td>
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<td>WCC</td>
<td>Overview of synthesis techniques</td>
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<td>2/1</td>
<td>3</td>
<td>5</td>
<td>RWC</td>
<td>- Bottom up</td>
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<td>- Top down</td>
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<td>2/3</td>
<td>6</td>
<td>RWC</td>
<td>Atomic structure of materials</td>
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<td>WCC</td>
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<td>Underpinnings of mechanics, elasticity relations</td>
<td>HW #1 due</td>
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<td>2/15</td>
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<td>9</td>
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<td>Manuscript topic choice due</td>
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<td>2/22</td>
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<td>11</td>
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<td>Defects and dislocations</td>
<td>Lab #1 due. Notes for Lab #2 handed out.</td>
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<td>RWC</td>
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<td>- applying load on small scale structures</td>
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<td>- measuring strain on small scale structures</td>
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<td>- cantilever deflection as a detection technique</td>
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<td>- size-scale strength effects</td>
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<td>- impact of size on thin film ductility and fracture</td>
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<td>- capillary forces and tall walls</td>
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<td>4/21</td>
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<td>RWC</td>
<td>- hard MEMS: applications, design, performance, and testing</td>
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<td>RWC</td>
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<td>4/28</td>
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<td>RWC</td>
<td>Nanotubes and nanocomposites</td>
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<td>nonsystems including MD of fracture mechanics, mixed atomistic/continuum</td>
<td>Manuscript final draft due</td>
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<td>modeling of sliding friction</td>
<td>Lab #6 due</td>
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Version 2/16/05
Homework Assignment #1

Instructions: Students are encouraged to discuss homework and course material with the instructor and classmates. However, the submitted homework solutions for HW #1 must involve only the individual student’s effort.

Due in class on Tue. Feb. 15th. No late homework will be accepted.

Problem 1

What exactly is meant by the term “peer-reviewed archival journal”?

Give an example of a peer-reviewed archival journal that either partially or exclusively contains articles related to nanoscience/nanotechnology. Who is the publisher of the journal? How often is it published? If possible, determine how long it typically takes articles to be published in this journal.

Briefly describe the process for submitting and publishing an article in this journal.

Where did you find the journal? What campus libraries is the journal available in? Is it available on the internet? If so, what is the URL?

Go to any campus library and find an article from the journal you have chosen which addresses a nanomechanics research topic. Do not use the internet for this task. On your homework, write down the precise reference information for the article. The reference information should be written down using precisely the same format that is used for journal references within the article itself.

Bring a photocopy of the article to class with your homework.

Write a 1-paragraph original summary of the content of the article as best as you can interpret it. Do not just copy the abstract. Include in your summary what the importance of the article is: is there a relevant technological application in mind? Does this contribute to the basic understanding of a particular phenomenon? Be prepared to be called on at random in class on the day this assignment is due to share your summary with the class.
Problem 2

1. (a) The angles between the tetrahedral bonds of diamond are the same as the angles between the body diagonals of a cube. Use elementary vector analysis to find the value of this angle.

(b) Show that the c/a ratio for an ideal hcp structure is \( \left( \frac{8}{3} \right)^{1/2} \).

(c) What is the atomic packing factor for the simple cubic, bcc, fcc, and hcp crystal structures?

(d) Consider the (111), (110), and (100) surfaces of the fcc unit cell, assuming no reconstruction. Sketch both the 1st (i.e. topmost), 2nd, and 3rd planes starting from the surface (indicate the relative position of each plane as well). What is the coordination number (number of nearest neighbors) of the atoms for the 1st and 2nd planes?

(e) Considering the favorable nature of surface close packing, which of the three fcc low index planes do you expect to have the lowest surface energy and why?

Problem 3

A strip of SMA is constrained at constant length in a tensile testing machine, subjected to a small initial load, and heated electrically. The strip is initially at 20°C and the material transformation temperatures are \( A_s = 40°C \) and \( A_f = 80°C \). The load measured by the machine increases during the \( M \rightarrow A \) transformation, then falls off somewhat with further heating.

a) Explain the observed decrease in load.

b) What would be the optimum temperature at which to maintain the SMA to produce the maximum steady load?

Problem 4

For a perspective on surface-to-volume ratio, consider a sphere whose radius is 1 cm and determine its surface area and volume. If the sphere is now subdivided into identical spheres, whose radii are each 1 nm, how many spheres will there be if the total volume of the original large sphere is preserved in the collection of nanospheres? Determine the collective surface area of these nanospheres.
Problem 5

Create a table for face-centered cubic (FCC) unit cells that lists the numbers of surface and interior atoms as a function of cube size up to the size at which there are more interior than surface atoms. For the element Au with a unit cell edge length of about 4 Å, at about what size does the number of interior atoms exceed those on the surface?

Problem 6

Cleland, problem 2.4. Clarification - the problem should read:

Show that the fcc crystal lattice can be represented as a triangular lattice. In other words, using a triangular lattice in the plane with generating vectors $a_1$ and $a_2$, find a third generating vector such that the three together generate the fcc crystal.
Select a topic with a reasonable scope – not so small that only one or two journal articles have ever been written on the topic and not so large that there are thousands of relevant journal publications.

To help you out, two examples of a high-quality review articles have been posted on the course website. You are NOT expected to just copy the format; rather, read this articles and use them as a general guide, two examples of many good examples, of the type of writing, level of organization, and use of images that are appropriate for a review article.

The paper, including references and figures, should be 10-15 pages in length (types, single-spaced, 12 point font, 1” margins)

Remember that your paper will be reviewed and graded by TWO of your classmates and by one of us instructors, so you need to make sure your paper is understandable to a broad audience.

Therefore, it is important that you have an introduction that clearly describes the motivation behind the research. For example, if you are discussing nanotubes, you should describe why they are important, what are the key features that people are excited about, and what are the current or envisioned applications.

Your manuscript must also have a thesis statement that is clearly expressed up front. For some of you, this may be the most difficult part of the paper, but it is also the most important.

Be sure to highlight the role of mechanics in your discussion. Some description of, for example, how a material is synthesized, what its electrical properties are, etc., is acceptable, but only if it is relevant in the context of the mechanics of your topic.

You should be putting together a comprehensive set of references in your topic area, from which you need to select a few to discuss in detail. Your manuscript should not be a laundry list of other papers that have been written. Rather, you need to synthesize the information you have into a coherent and critical review that describes the progress made in the area of interest as well as the challenges that remain.

Finally, a word about originality. These days it is easy to download mounds of text from the web, and cut and paste it into a paper. In less blatant cases, a figure caption or a couple sentences might be used. Yet neither of these cases is acceptable, and in both cases it is considered plagiarism. Furthermore you are shortchanging your own learning experience by resorting to the use of others' text. Be aware that we are obligated to check for originality.