Syllabus
Course: ELEC 677 002 (CRN: 26231)
Abercrombie Labs AEL A116 – MW 4:30pm-5:45pm
Finite Element Method for multiphysics modeling
(Multiphysics Modeling)

Instructor Information
Alessandro Alabastri
E-mail: alabastri@rice.edu
Web: http://alabastri.rice.edu
Office: BRK 238, Brockman Hall
Tel: 713-348-4286

Course type: lecture
Credits: 3
Office hours: contact the instructor to schedule an appointment
Teaching assistants:
Jiang Yang (jy43@rice.edu)

Course description
This course will provide a hands-on experience on the modeling of micro and nano systems based on the mutual interaction among different physical phenomena. COMSOL Multiphysics, based on the Finite Element Method (FEM), will be utilized as flexible modeling tool to learn how to design a wide range of devices or describe coupled physical mechanisms including electromagnetic waves, heat transfer, fluid dynamics and mass transport. The course will focus in particular on the interaction between light and nanomaterials and how electromagnetic heat dissipation can play a major role in different applications.

Objectives
The aim is to introduce COMSOL as working tool which can be utilized in different contexts providing, at the same time, a method to approach a variety of physical problems and examples to show practical outcomes.

Learning Outcomes
After taking the course the students will know how to approach many physical problems in terms of Finite Element Method. In particular they will be able to design devices coupling them with the relevant physical mechanisms. The students will be also capable to perform predictions and optimize the modeled systems depending on the specifics of a given problem. More in general, the students will learn how to use the Finite Element Method as a comprehensive way to describe systems ruled by partial differential equations understanding advantages and limits of this approach in both theoretical and practical contexts.

Prerequisites
Basic electromagnetism and basic calculus

Topics
1. Introduction to modeling
   a. Why modeling
   b. Simplifying without oversimplifying
   c. Partial differential equations (PDEs) for physical phenomena
d. Computation solution of PDEs: variational problems and weak forms  
e. Testing: Method of manufactured solutions

2. **Introduction to COMSOL**  
   a. COMSOL tree  
   b. Global definitions and parameters  
   c. Model components  
   d. Local definitions, variables, functions, probes  
   e. Component couplings: concept of linear and general extrusions  
   f. Geometry, Materials, Physics, Mesh and Study  
   g. Results and Post processing  
   h. Solvers: direct and iterative

3. **Introduction to Equation Based Modeling**  
   a. Coefficient form  
   b. Weak form

4. **Introduction to AC/DC module**  
   a. Electrostatics  
   b. Electric currents  
   c. Magnetic Fields (in 2D)

5. **Introduction to Heat Transfer Module**  
   a. Heat transfer in solids

6. **Introduction to Fluid flow module**  
   a. Laminar flows

7. **Coupling between Fluid flow and Heat transfer modules**  
   a. Mono & bi-directional coupling  
   b. Periodic conditions  
   c. Convective mechanisms, Boussinesq approximation

8. **Introduction to Chemical Species Transport module**  
   a. Transport of diluted species

9. **Coupling between Transport and Fluid flow modules**

10. **Introduction to Wave optics module**  
    a. Frequency domain  
    b. Time domain  
    c. Beam envelopes  
    d. Perfectly matched layers  
    e. Perfect Electric and Perfectly Magnetic conductors

11. **Applications of Wave Optics modules**  
    a. Optical response of dielectric and conductors  
    b. Plasmonic structures: single particles and arrays  
    c. Approximated interaction between optical pulses and metallic structures

12. **Coupling between Wave Optics and Heat Transfer module**  
    a. Electromagnetic heating  
    b. Bi-directional coupling (influence of temperature on optical response)

**Textbooks**

The books mentioned in the following can serve as references. However they are not necessary for successful completion of the course or solving assignments/exams. The course material is expected to be sufficient.

- **Automated Solution of Differential Equations by the Finite Element Method** – Anders Logg, Kent-Andre Mardal, Garth N. Wells – Springer
- **Solving PDEs in Python**, The Fenics Tutorial – Hans Petter Langtangen, Anders Logg – Springer Open
- **COMSOL for engineers** – Mehrzad Tabatabaian – Mercury Learning and Information
- **Classical Electrodynamics** – John David Jackson – Wiley
- **Plasmonics: fundamental and applications** – Stefan A. Maier – Springer
- **Thermoplasmonics: heating metal nanoparticles using light** – Guillaume Baffou – Cambridge University Press

**Grading**

- Individual homework: ~30%
- Projects in team (in class or at home): ~30%
- Final exam: ~40%

Late submission of individual homework or projects in team can be subject to a penalty. Submissions after the solutions are posted are not valid and will not be graded.

**Honor Code Policy:**

*Homework assignments:*

You can use textbooks, course notes, and any other reference materials (such as scientific articles or online material). You can discuss problems and models with other students. However, you must deliver your own solutions or models. You should avoid using the completed work of other students, old homework or completed models found online. You should understand and, upon request, be able to recreate any part of the solutions or models on your own.

*Final Exam:*

Exam must be completed independently.

*In class projects:*

Some projects will be conducted during the class and the rules of each project subject to grade will be announced in the previous class.

**Absence policy**

Class attendance is required during in-class projects and final exam. Students are not required to attend the lectures, but they are strongly encouraged to do so. The slides presented during the class and the models will be available on the course website, and it is the responsibility of the student to make up for the missed lecture contents.

**Students with Disabilities**

Any student with a documented disability seeking accommodations in this course should contact the instructor after class or during office hours. Additionally, please contact the Disability Support Center located in the Allen Center.

**Updates to the course**

Information contained in this course syllabus, except the absence policies, may be subject to change with reasonable advance notice as appropriate.