Course description

EK2360 Hands-on Microelectromechanical Systems Engineering

7.5 ECTS credits, given in KTH period 2 (Oct-Dec)

Course responsible, organizer and examiner:
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latest update: 2010-01-12

Course overview:

Microsystems or Micro-electromechanical systems (MEMS) are ubiquitous in our society. MEMS sensors and actuators are used for intelligent embedded systems interacting with their environment in various application fields, including automobiles, consumer electronics, telecommunication devices, medical technology, aeronautics and space. This course is designed as a “hands-on” project course for students who would like to deepen their basic understanding of micro-electromechanical systems by actively designing, fabricating and evaluating different MEMS micro-actuator concepts.
The course is based on a few initial lectures for providing basic knowledge (20% of course) and on supervised project work as the main task (80%). The students are working in small teams (preferred size is 3 people), and the different teams are competing against each other in creating best-performance devices fulfilling the requirements of different application problems.
The students will have access to state-of-the-art tools in the design phase (professional FEM and layout software on CAD workstations), will actively fabricate their own devices in the KTH class-100 clean-room facilities, and will utilize semiconductor and MEMS measurement tools during device characterization and failure analysis.

Course goals:

During the course, the student will gain in-depth knowledge and understanding on microsystems, with emphasis on different micro-

electromechanical actuator types, on their working principles, concept and design, process technology, clean-room fabrication, device characterization, and failure analysis. Upon successfully completing the course, the student will be able to:

- develop different concepts of microsystem actuators for real-world applications
- design microsystem devices and adapt them to different application requirements
- predict the behaviour of microsystem devices by (1) qualified guessing based on general understanding of the microsystem and the application; (2) rough estimation by using/adapting text book formulas; (3) accurate modelling and simulating by modelling using state-of-the-art multi-physics finite-element based design tools (FEM)
- work out design concepts under consideration of fabrication-technology limitations
- develop a fabrication process flow
- carry out basic microsystem fabrication steps in a class-100 clean-room environment under the safety requirements of such an environment
- characterize the devices for their electrical, mechanical, and thermal behaviour
- identify failure mechanisms, conclude on device limitations and reflect on device improvements based on the characterization results of the prototype devices
- write a project report summarizing design, fabrication, characterization, failure analysis, and potential future device improvements
- present and defend the results to a critical audience
- work in a small microsystem development team, including taking management responsibility from project plan writing to work distribution and task assignment to the team members

Course format:

EK2360 is a project course worth 7.5 ECTS credits, which is equivalent to 200 work hours of full-time study. As the course runs about 8 weeks, this implies that about 25 hours a week must be devoted to various course activities, including introductory lectures and reading of course material, together comprising about 20% of the course activities, and carrying out the project work, which comprises 80% of the course work.

The introductory lectures on basic MEMS design and fabrication, with special focus on the following project work, will be taught by the course responsible. Attendance of the introductory lectures is compulsory.

After the introductory lectures, a brief written intermediate examination will be carried out, assessing whether the knowledge and understanding of the student is sufficient for continuing with the actual project work.

The project work is supervised by senior PhD students and the course responsible.
The report writing and the final presentation and a brief post-discussion are supervised by the course responsible.

Course level and prerequisites:
The course level is adapted to students enrolled in an engineering master programme at KTH, but may also be taken by PhD students.
The students must have basic knowledge in electrical engineering, engineering physics, or an equivalent basic education. It is highly recommended that the students already some basic knowledge in micro-electromechanical systems (MEMS). The student should have successfully completed the "EK2350:Microsystem Technology" basic course given at KTH, or any equivalent basic microsystem technology or semiconductor fabrication course. Practical experience with general engineering design tools, such a FEM and CAD software, is useful.
All students without MEMS background which are interested in course participation must contact the course responsible in advance, in order to assess their qualification for participation.

Content of introductory lectures:
- Lecture 1 (2h): (1) general course information; (2) refreshing of knowledge on microsystem technology with (3) emphasis on basic MEMS actuation principles
- Lecture 2 (2h): essential MEMS design tools: (1) device performance estimation with textbook formulas; (2) introduction to finite element modelling and simulation with examples shown for some actuator concepts to be investigated
- Lecture 3 (2h): (1) introduction to fabrication process flows available within this course; (2) introduction to MEMS design CAD software
- Meeting 4 (1.5h): (1) intermediate examination (written test, about 30 minutes); (2) summary of evaluation criteria for project work, report and presentation; (3) organization of project work; (4) forming of student teams

Content of project work:
It is compulsory for every student team to design microsystem devices based on two given actuator principles, for instance electrostatic and electrothermal. The students must implement different device strategies for these two principles, in order to meet given specifications of real-world applications. Some specifications might be the same for all teams, other specifications will be different to force the students to implement different parameter optimization strategies. The teams are competing against each other in an effort to develop the best optimized devices for the given applications. Prices will be given to the winning team. Beside the compulsory content, students are encouraged to implement additional

device principles, such as Lorentz-force actuators, or combine any suitable device principles in order to create winning devices.
The project work is divided in different phases:

(1) project plan writing and task assignment within the teams
(2) work out device concepts and operation principles
(3) device design: modelling and simulation
(4) device implementation: layout, design of process flow
(5) handing in of informal summary on expected device performance
(6) device fabrication in the KTH clean-room facilities (supervised)
(7) device characterization: physical characterization, performance evaluation, failure analysis
(8) writing of project report and presentation
(9) presentation to critical audience, and individual team de-briefing

The end of phase (4) has a common deadline for all teams.
The summary obtained after phase (5) is used to compare the final device results to the expected performance after the design phase.
Phase (6) is carried out in a joint effort. All other phases are individual to each team.

Examination and grading:
The student's final grade in the course will be based on

- attendance of the introductory lectures (pass/fail criteria)
- performance on an intermediate assessment inform of a written examination test after the introductory lecture. The examination will test the student's overall comprehension of the various topics covered in the lectures. It will mainly be used as a pass/fail criteria for the student being allowed to carry on with the practical course part, but will also be used to influence the of final mark (10%)
- project work: overall evaluation of the project work of the project team as a whole, including the project report and the final project presentation to a critical audience, adding up to 90% of the final mark. Individual adjustments might be done. Criteria for the evaluation of project work, report, and presentation will be communicated before the start of the actual project work. The grading of the project work is given independent on the outcome of the student competition. The summary of the expected device performance after the design phase (see previous section) will not be used for determining the grade.
- after the presentation, the course responsible will have a short discussion with the individual student teams, which might be used for adjusting the final mark of the teams and of the individuals

As mentioned above, the course is worth 7.5 ECTS points; grading will be on a scale from A to F, with A being the highest mark and E being the lowest mark for passing the course, and F being a failing mark.

Course literature:
Essential reading material will be distributed during the course.

PDF versions of the introductory lecture slides will be made available before the lectures through the BILDA online resource, and it is required to read this material before the respective lectures.
For additional literature to the course, especially for students with limited pre-knowledge on MEMS, the following books are recommended (copies dedicated to the course participants are available in limited numbers at the Microsystem Laboratory, and may additionally be found in the KTH library):

- Marc J. Madou, *Fundamentals of Microfabrication: The Science of Miniaturization,* CRC, 2 edition (March 13, 2002), ISBN-10: 0849308267, ISBN-13: 978-0849308260
- Gregory T. Kovacs, *Micromachined Transducers Sourcebook*, McGraw-Hill, 1st edition (February 1, 1998), ISBN-10: 0072907223, ISBN-13: 978-0072907223
- Sami Franssila, *Introduction to Microfabrication*, Wiley, 1st edition (June 14, 2004), ISBN-10: 0470851066, ISBN-13: 978-0470851067

Language:
General teaching language is English, used for lectures, the intermediate assessment, project work documentation, the report, the presentation. Undocumented project work supervision might be handled in a language agreed upon by the team supervisor and the team members.

Online resources:
The course homepage maintained by Doc. Joachim Oberhammer may be found at the following URL: http://www.ee.kth.se/mst/courses/EK2360/

Please feel free to contact the course responsible for any comments or questions.