EPFL

MICRO-470

Scaling laws & simulations in micro & nanosystems

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Cursus	Sem.	Type
Electrical and Electronical Engineering	MA1, MA3	Opt.
Microtechnics	MA1, MA3	Obl.

Language of teaching	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Courses	3 weekly
Exercises	1 weekly
Number of positions	

Summary

This class combines an analytical and finite elements modeling (FEM) simulations approach to scaling laws in MEMS/NEMS. The dominant physical effects and scaling effects when downsizing sensors and actuators in microsystems are discussed, across a broad range of actuation principles.

Content

The following topics are introduced and **analytical modeling** and **scaling laws** are discussed.

- **Introduction to scaling laws**
  Scaling of classical mechanical systems, scaling of classical electrical systems, breakdown in scaling, quantum breakdown
- **Thermal effects**
  Conduction, convection, dynamics, breakdown, thermal micro-actuators.
- **Mechanical devices**
  Mass-spring model, mechanical noise, squeeze film effects.
- **Electrical devices**
  Electrostatic micro-actuators, electrostatic breakdown, tunnel sensors, coils and inductors, electromagnetic micro-actuators, magnetic beads.
- **Microfluidics & Nanofluidics**
  Liquid flow, gas flow, mixing, surface tension, chromatography.
- **Electrokinetics**
  Dielectrophresis, EHD and MHD pumps, electrowetting.

The following topics are introduced and **hands-on finite modeling** is performed using COMSOL Multiphysics for typical microsystems. For a selected set of problems, **lumped element modeling** is introduced and discussed.

- **Introduction to Finite Element Modeling**
  Meshing, convergence, material models.
- **Structural Mechanics FEM**
  Boundary conditions, loads, nonlinear geometry, modal analysis.
- **Thermal FEM**
  Electro-thermo-mechanical coupling.
- **Electro-Static FEM**
  Fields, boundary conditions, parallel-plate actuator, voltage-displacement, comb drive actuator.
- **FEM and Failure Modes at the Microscale**
  Pull-in, buckling, stress concentration.

Keywords

Micro-Electro-Mechanical Systems (MEMS)
Nano-Electro-Mechanical Systems (NEMS)
Scaling
Finite Element Method (FEM)
Lumped Element Model (LEM)
Electrostatics
Electromagnetic
Fluidic
Cantilever
COMSOL

Learning Prerequisites

Required courses

Capteurs

Important concepts to start the course

solid grasp of electromagnetics, electrostatics, fluid dynamics
knowledge of analysis of electrical circuits
mastery of Matlab

Learning Outcomes

By the end of the course, the student must be able to:

- Analyze MEMS designs
- Exploit scaling laws in MEMS
- Predict performance of MEMS devices analytically and by simulation
- Take into consideration how different actuation principles scale with size
- Compare different MEMS physical principles

Transversal skills

- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Use a work methodology appropriate to the task.
- Communicate effectively, being understood, including across different languages and cultures.
- Negotiate effectively within the group.

Teaching methods

ex-cathedra
problem sets
simulations tutorials
simulation projects

Expected student activities

attend all lectures
attend all FEM tutorial sessions
read assigned papers
do the problem sets

Assessment methods

project
oral exam