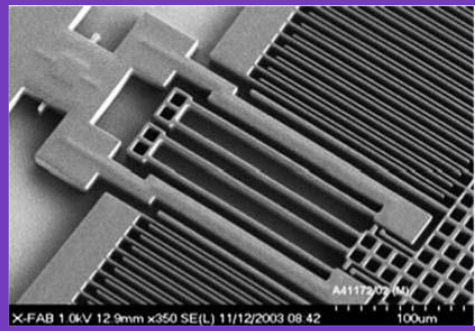
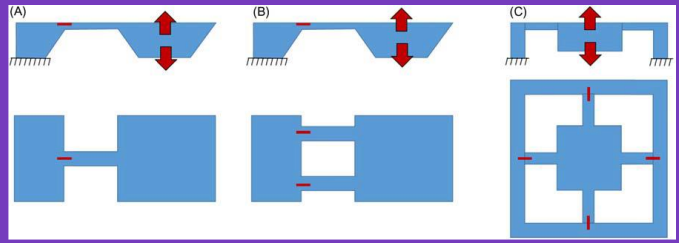
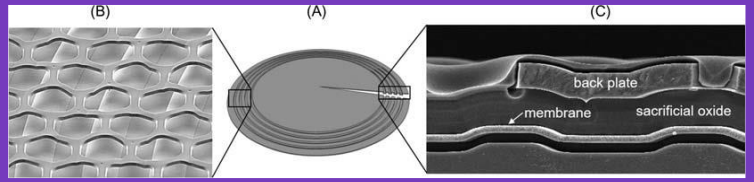
ELEC-E8715 Design and Analysis of MEMS

- **Lecture 1 - 5.9.2022**
  - Introduction to the course content and requirements

Prof. Mervi Paulasto-Kröckel
Dr. Nikhilendu Tiwary







Ref. Till, Paulasto-Kröckel et al, Handbook of Silicon Based MEMS Materials and Technologies, 2020

ELEC-E8715 Design and Analysis of MEMS

- **5 credits master level course, I-II period**
- **Assessment 0 – 5:**
  - Max 300 points total, 180 points from assignments, 120 points from exam
  - Both assignments and exam need to be passed
- **Methods: 14 lectures, 6 assignments, final exam**
  - Organized f2f at R030, T6 A136
  - Lectures Mondays 14:15 – 15:45
  - Assignment support Fridays 14:00 – 16:00 (note! not organized every Friday – follow the detailed schedule)
  - Exam 12.12. 14:00 – 16:00
- **Teachers from Aalto, VTT, Murata and Vaisala**
  - Course organization by Prof. Mervi Paulasto-Kröckel (mervi.paulasto@aalto.fi) and Dr. Nikhilendu Tiwary (nikhilendu.tiwary@aalto.fi)
  - Course assistants: Artem Gabrelian (artem.gabrelian@aalto.fi), Kristina Bespalova (kristina.bespalova@aalto.fi), Tarmo Nieminen (tarmo.nieminen@aalto.fi)
- **Materials:**
  - Lecture notes, other material provided by the lecturers
  - Recommended reference material:
    - Handbook of Silicon Based MEMS Materials and Technologies, 3rd Edition, 2020 http://libproxy.aalto.fi/login?url=http://www.sciencedirect.com/science/book/978-0-12-817786-0
    - Practical MEMS, Ville Kaajakari, 2009: copies available in the learning center

Learning outcomes

After the course the student will

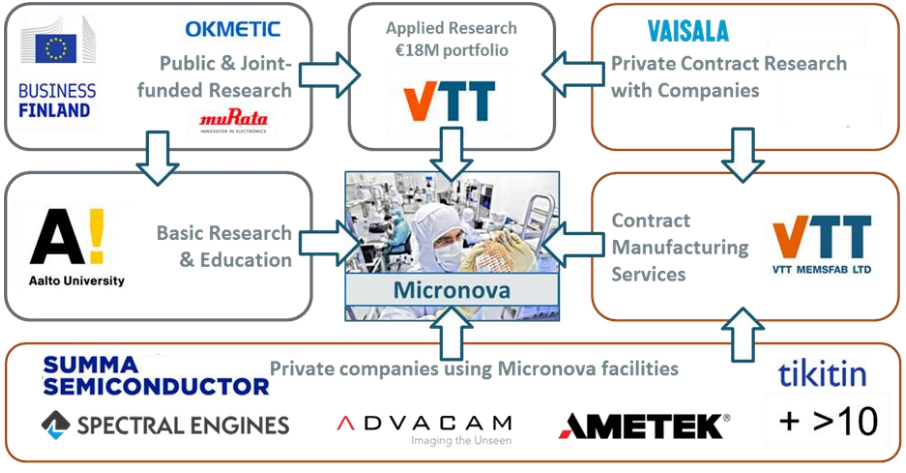
- **understand the physical operating principals of MEMS**
- **understand fundamentally important aspects of MEMS, impact of scaling, mechanical and thermal behavior of miniaturized structures and materials**
- **understand the design principals for inertial sensors, piezoactuated ultrasonic transducers and optical MEMS**
- **be familiar with main tools to characterize MEMS devices**
- **be able to utilize finite element analysis for simplified structures**
- **be able to identify and analyse key impact factors from manufacturing and design on device performance**
- **gain insight into future sensor and actuator development needs on accuracy, security, new materials and integration for high performance applications**

Why this course?

ELEC-E8715 is part of curricula in:

- ELEC: AEE/Electronic and Digital Systems https://into.aalto.fi/display/enaee/Electronic+and+Digital++Systems+2020-2022
- CHEM: Functional Materials https://into.aalto.fi/display/encbme/Functional+Materials+2020-2022
- Erasmus Mundus Joint International Master in Smart Systems Integrated Solutions (2021 – 2026)

Micronova facilities and ecosystem strong on MEMS



Schedule

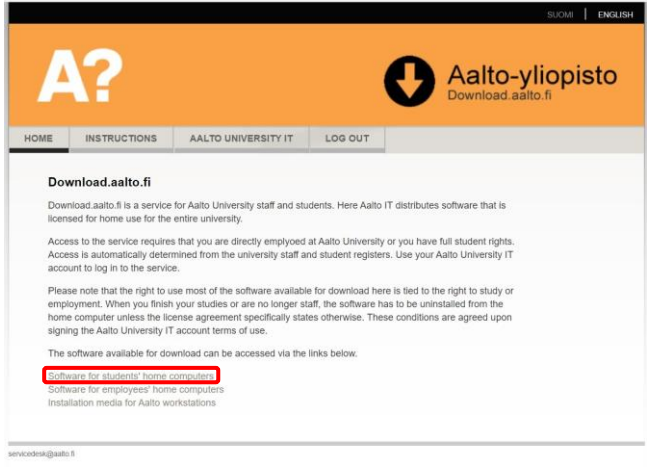
Date	Lecture	Responsible	Main content	Date	Related exercise / HW helpdesk	Assessment / points	Deadline
5.9.	Introduction lecture, Introduction to MEMS, Si for MEMS, SOI/C-SOI (L1)	Aalto	Course structure, introduction to MEMS and its applications, main principles, Si properties, SOI/C-SOI manufacturing, critical parameters for MEMS	9.9.	FE simulation basics, MEMS electrical domain modeling examples, COMSOL introduction, microcantilever case study (L2)		
12.9.	Scaling and mechanics of materials (L3)	Aalto	Mechanics of materials for isotropic materials, beam bending, Q factor, stiction	16.9.	Calculations on Q value and spring constants (A1)	0 - 10	25.9.
19.9.	Mechanics of materials: thin films, Residual stresses: thin films and bonded structures (L4)	Aalto	Mechanics of materials, anisotropic materials and thin films, grain size, Stresses in thin films and elements, characterization methods	23.9.	FEM analysis of a multilayer structure, Comsol (L5+A2)	0-40	9.10.
26.9.	Thermal effects in microscale (recorded lecture) (L6)	Aalto	Thermal properties MEMS materials, phase change actuators, nebulizers	30.9.	FEM analysis of multilayer structure, Comsol assignment support (A2)		
3.10.	Inertial sensors – accelerometers (L7)	Murata	Operation principals, capacitive sensing, resonance frequency, electrical and mechanical noise	7.10.	Introduction to accelerometer design & analysis by calculations (A3-I)	0 - 20	16.10.
10.10.	Inertial sensors continued (L8)	Murata	Electronics, system analysis	14.10.	Lab measurement on video and results, CV curve of moving mass and related analysis (A3-II)	0 - 30	23.10.
17.10.	Inertial sensors – gyroscopes (L9)	Murata	Operation principle, actuation, detection	21.10.	Reverse engineering analysis and Comsol simulation of Murata accelerometer (A3–III)	0 - 30	30.10
24.10.	PiezoMEMS (L10)	VTT	Introduction to piezoelectric transduction and its applications (BAW, FBAR)	28.10.	Constitutive relations of piezoelectricity, piezoelectric force generation and sensing (A4)	0-20	13.11.
31.10.	Piezoactuated ultrasound transducers (L11)	VTT	Piezoelectric thin film ultrasound transducer (PMUT) - principle and structure	4.11.	N/A		
7.11.	MEMS characterization (L12)	Aalto	Challenges in MEMS characterization, sidewall cantilever motion detection, electrical, SEM characterization	11.11.	N/A		
14.11.	RF-MEMS (L13)	Aalto	RF-MEMS and casimir effect in NEMS	18.11.	Design aspects of oscillator, Measurement of a mechanical resonator (A5)	0 - 15	27.11.
21.11.	Optical MEMS (L14)	Vaisala	Fabry-Perot interferometer/spectroscopic measurements	25.11.	FPI opto-electro mechanics (A6)	0 - 15	4.12.
12.12.	Exam					0-120	
						Max 300	

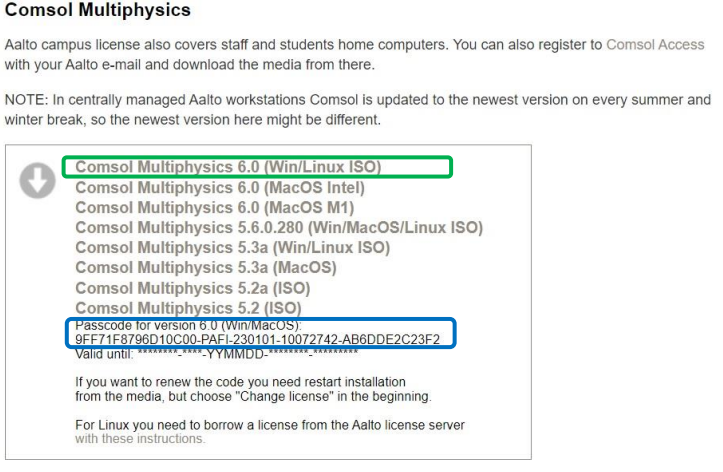
Requirements

- **Assessment:**
  - Assignments max. 180 points
  - Exam max. 120 points
  - Both assignments and exam need to be accepted (at least grade 1)
  - Extra 5 points available for returning Aalto Webropol course feedback
  - Total max. 300 points (305 with feedback)
- **Grades:**
  - 0 – 5
- **No attendance requirements**

COMSOL installation instructions

- Establishing a remote connection (VPN) to Aalto network: https://www.aalto.fi/en/services/establishing-a-remote-connection-vpn-to-an-aalto-network
  - Step 1: Installation of client software – **Cisco AnyConnect VPN Client**: https://download.aalto.fi/
  - Step 2: Connecting to Aalto network – After installing client software, enter the connection address: **vpn1.aalto.fi** or **vpn2.aalto.fi** (or **vpn.aalto.fi**). Then login with your Aalto credentials.
- Installing COMSOL on personal computers:
  - ➢ Go to: https://download.aalto.fi/index-en.html





  - ➢ Download the file and run the installer (marked in green).
  - ➢ Use the passcode provided for the version (marked in blue).
  - ➢ Stick to the default recommendations and complete the installation.

COMSOL installation instructions

- If you don't want to install COMSOL on your personal computer, you can use classroom computers: https://wiki.aalto.fi/pages/viewpage.action?spaceKey=AaltoWin&title=Aalto+IT+Windows+Classroom+Software+list

Comsol	Classrooms (all except ARTS and BIZ specific) - Windows ELE Classroom Laptops PHYS OppLab VDI Windows 10 3D

- Or, use servers brute.aalto.fi/force.aalto.fi: https://www.aalto.fi/en/services/servers-for-light-duty-calculation
  - For instructions: https://linux.aalto.fi/instructions/#using-your-own-computer
  - Install VcXsrv (Windows X server) and PuTTY (SSH Client)
  - After installation:
    1. Open XLaunch
       - Click 'Next' on all steps with default settings
    2. Open PuTTY SSH
       - Go to 'SSH' under category:
         - click on 'X11' and tick 'Enable X11 forwarding'
       - Go to 'Session':
         - Type 'brute.aalto.fi' or 'force.aalto.fi' in host name
         - Click 'open'
         - Login with Aalto credentials
         - In the command prompt, type 'comsol'