

Some key themes for MEMS Scaling – oral exam micro-470 (exam 01-2025)

- When you enter the exam room, you will receive a page with two or three questions.
- You then have 20 minutes to prepare. You can write notes and answers directly on this page.
- You will **not** have access to your lecture notes or any other documentation.
- Then, you will have 20 minutes of oral exam to discuss the questions with the professor.
- You can answer in French or in English

The course is broad and covers many topics. You are not expected to memorize all formulas and graphs. However, it is important to understand “why” and key scaling concepts.

Here are some typical themes that could be addressed in the exam questions:

- Explain the origin of thermal mechanical fluctuations, and the implications for miniaturization of accelerometers
- Give the key scaling laws for mechanical systems for a cantilever (the formulas for stiffness and stress are given to you): spring constant, resonant frequency, resistance to shocks, deformation due to own weight.
- There are quality factor issues in micro-resonators. Why use doubly clamped and higher vibration modes ? What are advantages of bulk mode resonators ?
- Stress in MEMS structures: compare simply and doubly clamped cantilever. explain effect of stress gradient, of uniform stress
- Non-linear resonators: describe effect/origin of spring softening and of spring hardening. Explain how it can be associated to (1) electrostatic actuation (2) doubly clamped beam.
- Describe mechanism of collapse of microstructure in wet processing, how to avoid or decrease effect
- List some short-range forces that can affect behaviour or stability of MEMS. How do they scale with distance?
- micro-heaters: what are main losses mechanisms at small scale. Discuss the case of a cantilever suspended near a surface.
- Describe a thermo-mechanical bimorph: optimization of layer thicknesses, effect of scaling for time response, explain the frequency response of thermal bimorphs
- Explain a simple model for the energy density of electrothermal actuators
- Time constants in thermal MEMS: simple RC model. How does time constant scale for different heat transfer mechanisms.
- Explain the difference between paramagnetic, superparamagnetic and magnetic beads. Discuss the behavior of these beads in homogeneous and gradient magnetic field.
- Present Scaling laws for electromagnetic actuators, without and with a magnet in the magnetic path

- Scaling laws for electrostatic MEMS actuators, energy density, non-linear effects, spring stiffening and softening
- Description of electrostatic resonators: non-linear effects due to (a) structure stiffening (b) electrostatic force
- Explain pull-in in electrostatic actuator. Do comb drives have pull-in? what is the stability condition for lateral stiffness ?
- Liquid flows at small scale: flow profile in rectangular channels, liquid with particles: how to make a filter, focusing due to lift forces, H-filter principle
- Capillary effects: Washburn equ., capillary stop, concept of electrowetting
- Gas in small (thin) cavities: viscous damping behaviour, rarefied gas regimes, thermal conductivity in small gaps. Radiative heat transfer: what happens in small gaps ?
- Key failure modes for MEMS, and steps you can take to mitigate those failure modes.