

EPFL

Scaling Laws in Micro & Nanosystems
Micro-606

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v. 2025

Course MICRO 606: Scaling in MEMS

August 25-27, and Sept 18 2025

| Day | Time | Location | Topic |
|---------------------------------------|------------------|---|--|
| 25.08.2025 Monday | 09:15 –12:30 | Room MC B1 273 Microcity, Neuchatel | <ul style="list-style-type: none">• Intro• Mechanical +LEM• Electrostatics 1/2 |
| 26.08.2025 Tuesday | 09:15 – 12:30 | Room MC B1 273 Microcity, Neuchatel | <ul style="list-style-type: none">• Electrostatics 2/2• Thermal |
| 27.08.2025 Wednesday | 09:15 - 12:30 | Room MC B1 273 Microcity, Neuchatel | <ul style="list-style-type: none">• Fluidic• Piezo |
| 18.09.2025 | 13h00 – 17h30 | Room AAC 1 06 Lausanne | <ul style="list-style-type: none">• Student presentations |

Attendance for all four half-days is mandatory

Scaling in MEMS

Chapters

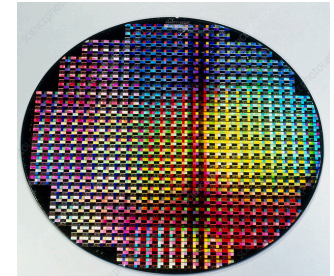
- I Mechanics
- II Electrostatics
- III Thermal
- IV Fluidics
- V Piezoelectric

Student Presentations on 18 September 2025

- See [detailed info](#) on class Moodle
- Sign up by 28.08.2025 [here](#)
- Groups of 2, 16 minute presentations.
- Your task: Analyze how scaling laws influence the design, performance, and limitations of one specific MEMS device (e.g., a resonator, accelerometer, micropump, RF switch, micromirror, etc)

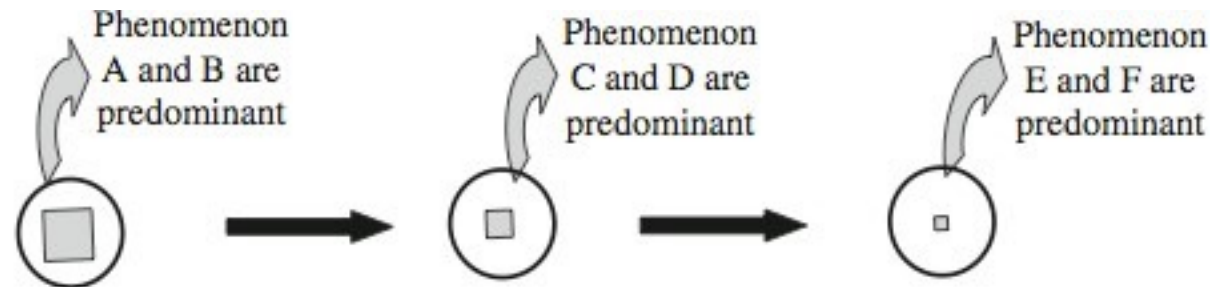
Motivation for miniaturization and MEMS

- Smaller size (or more components, large arrays, ...)
- Less material, better materials (ex: single crystal Si)
- Lower energy consumption
- Better performance (when well-fabricated)
- Cheaper (when mass produced)
- Different physical phenomena dominate



What happens at smaller size scales ?

- Competing physical effects do not follow the same scaling
- Simple scaling ?
- Continuum breakdown ?
- Quantum-like breakdown ?



Change in predominance of phenomena with varying scale

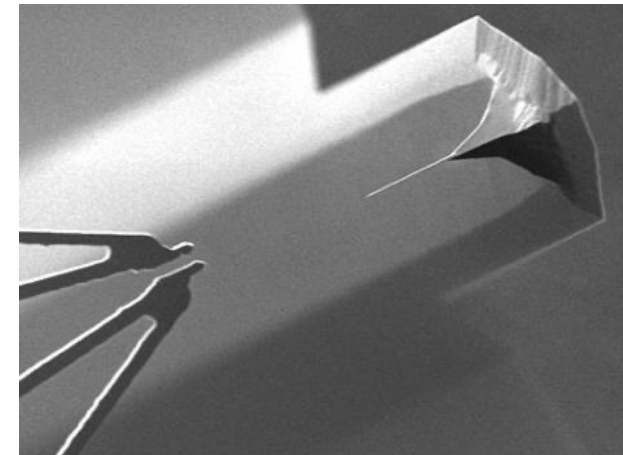
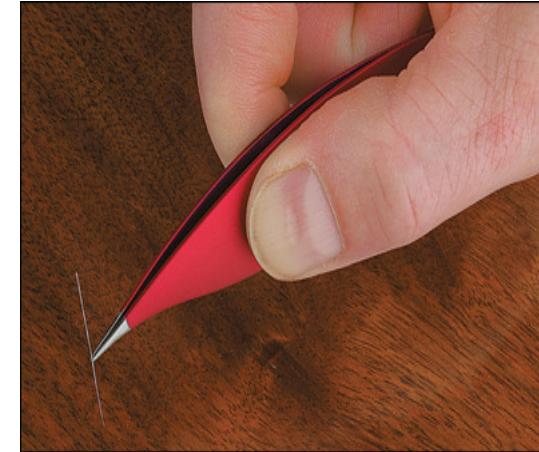


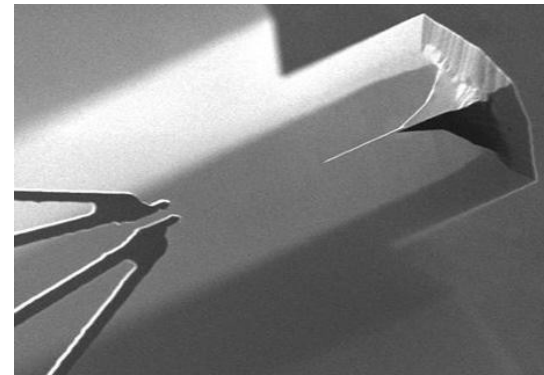
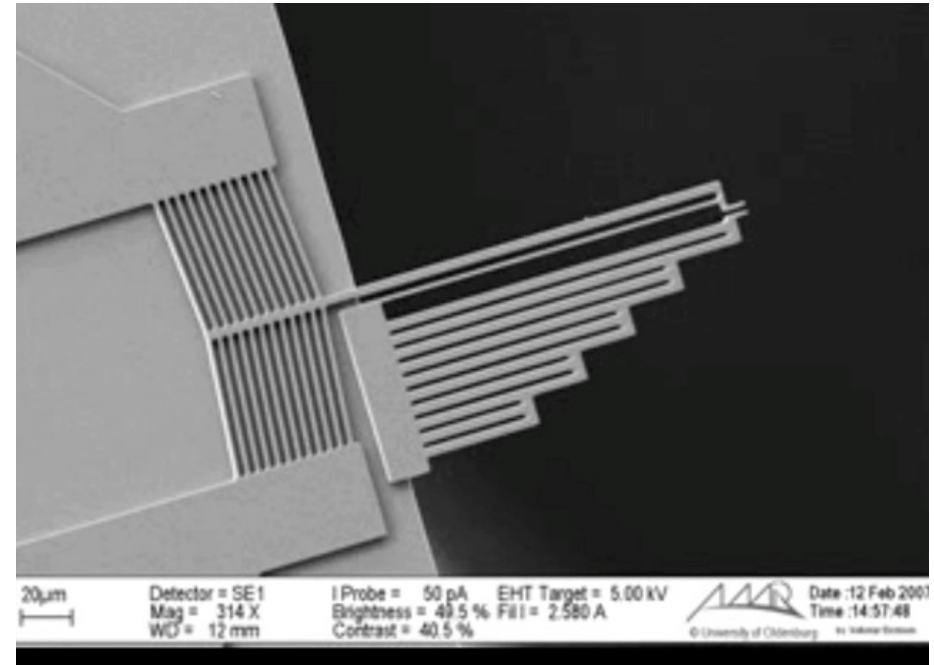
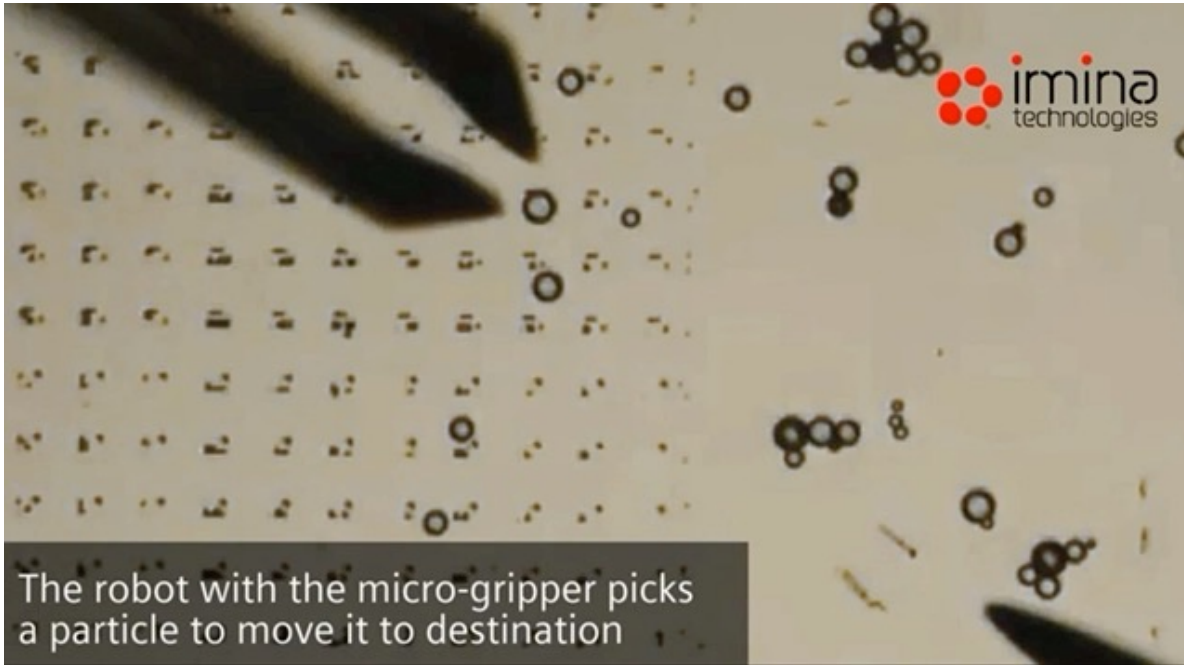
Real fly on a ceiling



Objectives of this course

- Study scaling-related effects in different physical domains
- Establish simple scaling rules
- Show examples where scaling effects are exploited
- Enable you to select an appropriate actuation/sensing principle adapted to your size scale and application





Continuum breakdown in down-scaling

Some examples:

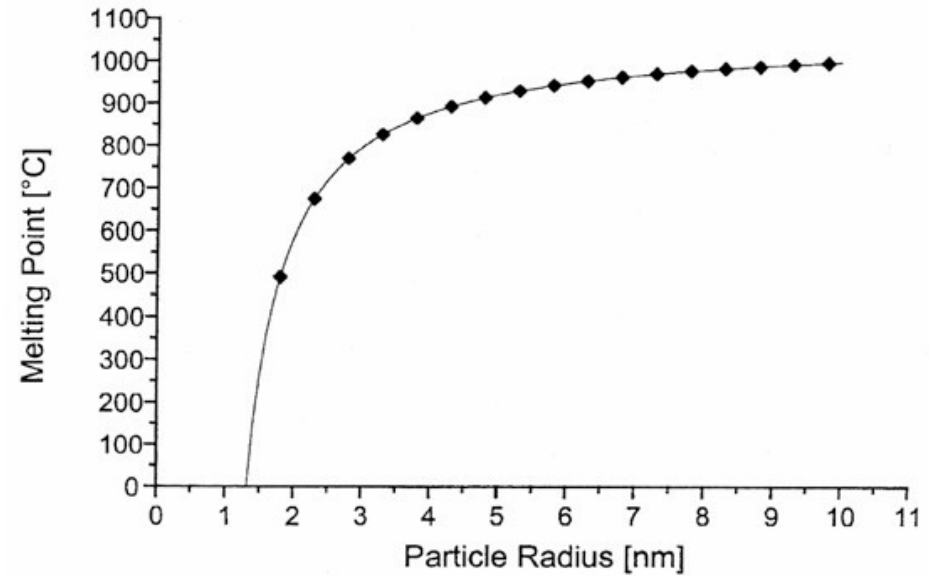
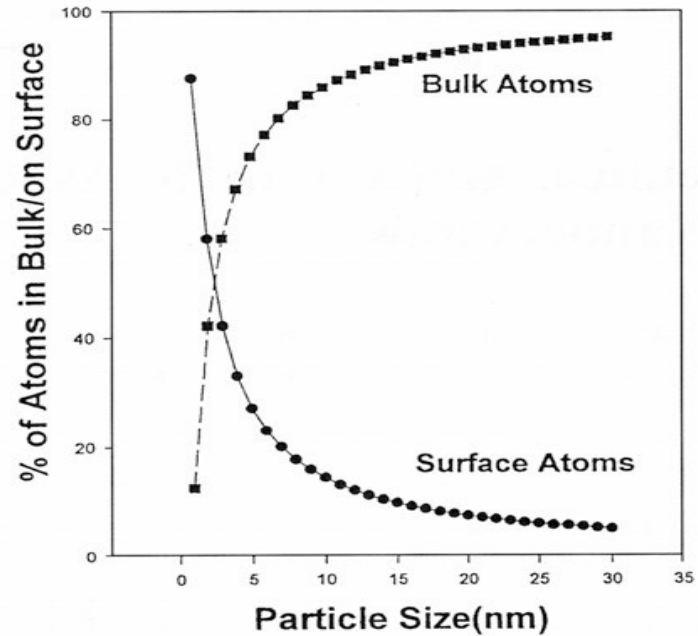
"Grain size" effects:

- Electrical conductivity (ex: Cr thin film)
- Strength and elastic modulus (ex. whiskers)
- Fatigue (ex. DMD)

Rarefied gas properties:

- Flow in capillaries ("slip flow")
- Fluid to molecular flow
- Mechanical damping
- Heat conduction
- Electrical breakdown (Paschen curve) - *important*

10 Downscaling particles



for spherical iron nanocrystals : J. Phys. Chem. 1996, 100, 12142

This leads to size dependent physical and chemical properties:

- Optical properties, magnetic properties
- Bandgap
- Melting point
- Specific heat
- Surface reactivity

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Quantum-like breakdown (we will ignore this in this class)

The non-classical effects start to dominate when the feature size of the devices are in the order of magnitude of the associated "wavelength" of the energy carriers (photons, phonons and electrons).

For visible photons, the wavelength is below 1 micron.

For electrons and phonons (at room temperature), this is below 1 nm.

| | Electrons in metals | Phonons in Insulators and Semiconductors |
|---------------------|---------------------|--|
| Wavelength [nm] | 0.1 -1 | 1-5 |
| Mean free path [nm] | 10 | 10-100 |

- When feature sizes are larger than 100 nm, quantum confinement is not effective for electrons and phonons. But for optics (photons) diffractive models must be used.
- Examples:
 - Surface roughness (atoms at the surface).
 - Super-paramagnetic limit in magnetic recording
 - Electrical conduction in nanowires
 - Quantum wells and quantum dots
 - Depletion in ultra-small MOS channels (no depl. <20 nm)
 - Heat conduction in nanostructures