



Lecture 0 Introduction 2025-2026

ME-426 – Micro/Nanomechanical Devices

Prof. Guillermo Villanueva

EPFL Welcome!!!

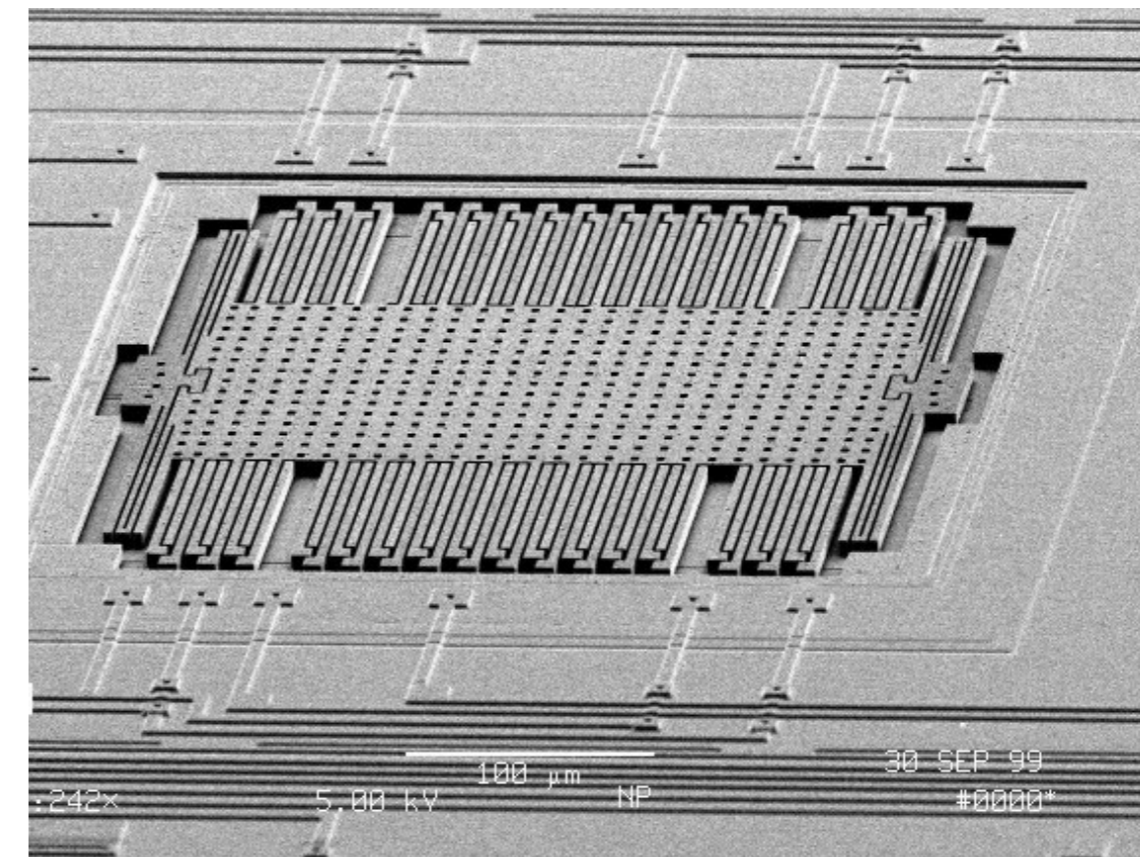
- Overall objectives of the course
- Organizational/Pragmatic matters
- “Schedule” for the semester

EPFL Who am I?

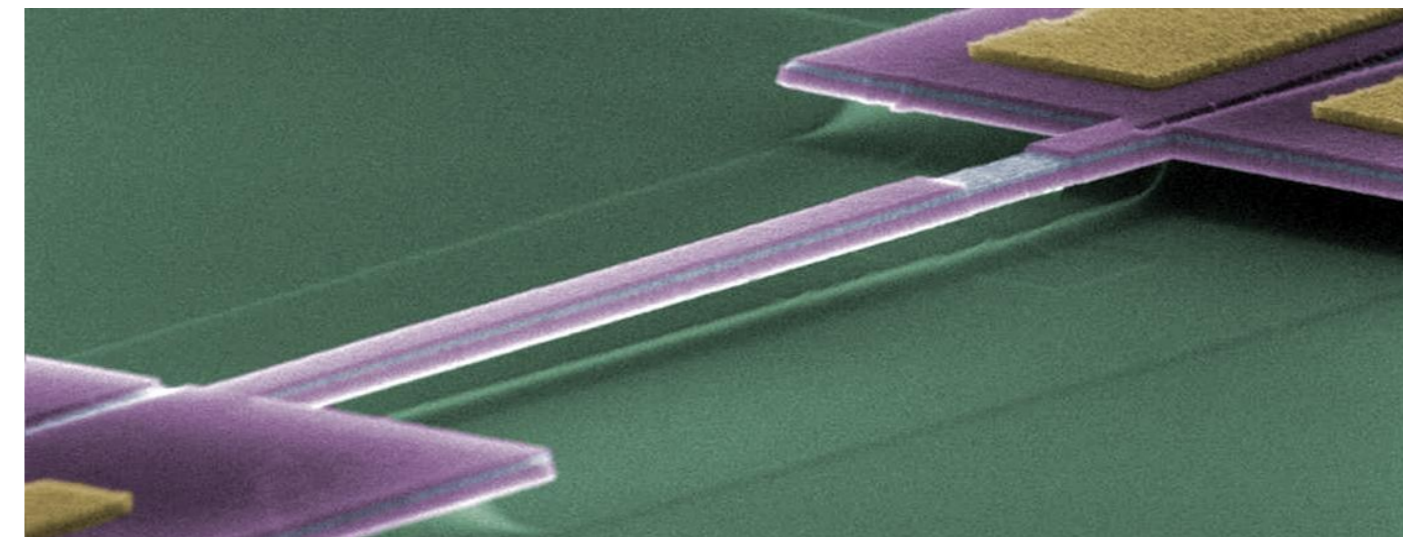
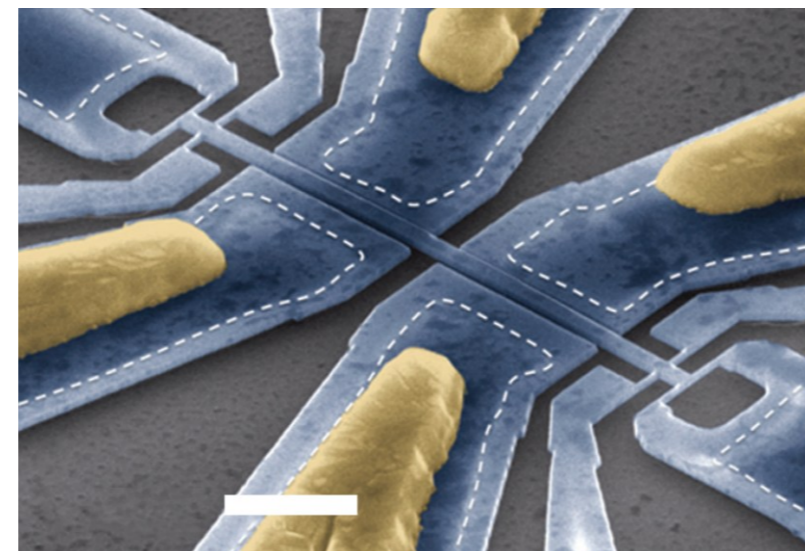
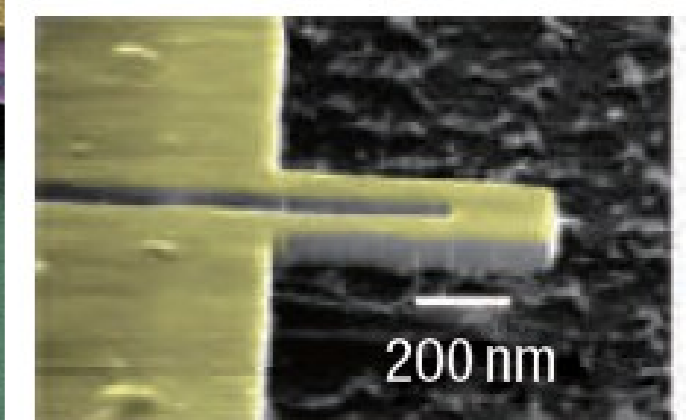
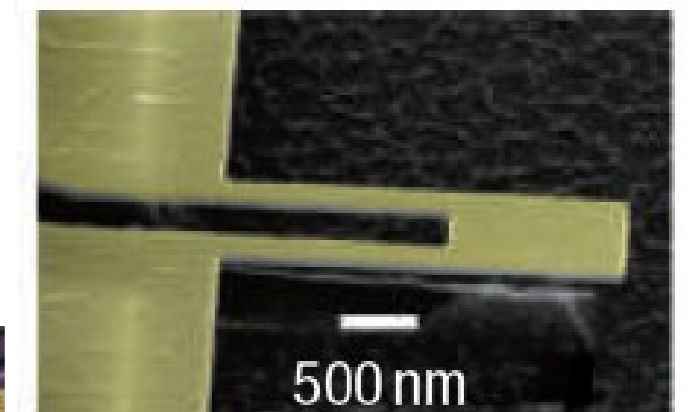
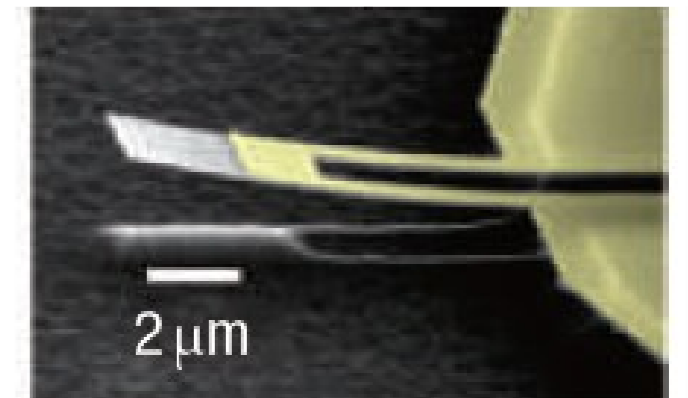
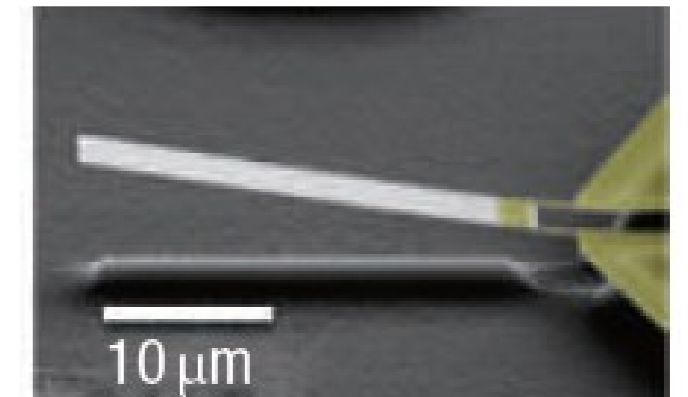
- 2002-2006 – PhD in CNM (Barcelona, Spain)
 - Static NEMS cantilevers for biomolecular detection
- 2007-2009 – PostDoc @ EPFL (LMIS1)
 - Novel Nanofabrication tools for NEMS
- 2009-2012 – Marie Curie PostDoc @ Caltech – Pasadena, California
 - Resonant NEMS – Nonlinear and coupled dynamics
- 2012-2013 – Marie Curie PostDoc @ DTU – Copenhagen, Denmark
 - Resonant M/NEMS – Dissipation and back-action mechanisms
- 2013-2022 - Assistant Professor @ EPFL – IMT-IGM
- 2022-... - Associate Professor @ EPFL – IGM
 - Advanced NEMS
 - Novel sensing schemes
 - Novel communication devices
- Check out our [student projects](#)!!!

EPFL What's this course about?

- Why reducing size???



MICRO/NANO



EPFL Overall objectives of the course

- Understand what is different in mechanical devices when you reduce dimensions down to the micro/nano-scale
- Introduce how these devices are designed and fabricated
- Understand the principle of transduction of the motion and introduce several techniques to perform it
- Introduce concepts like
 - Energy loss mechanisms
 - Nonlinear dynamic behavior
 - Thermomechanical noise
- Soft skills:
 - Reading papers and analyzing them
 - Discussing in group the contents of the papers

EPFL Key concepts

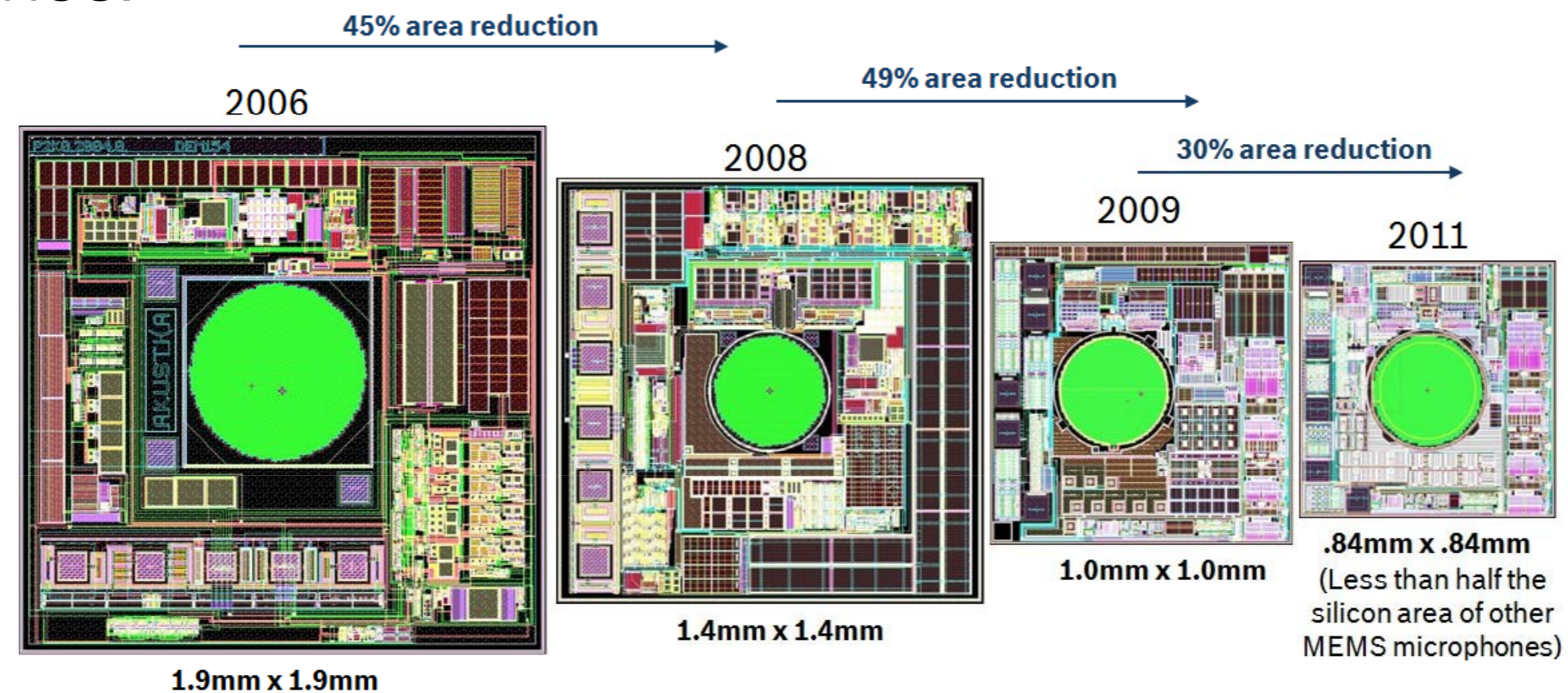
- Benefits of reducing size
- How to analyze composite structures
- Onset of nonlinearity (static, dynamic)
- Intrinsic stress
- Quality factor
- Thermomechanical noise
- Responsivity and Resolution

EPFL What this course is about

- Course for both SGM (most of you) and SMT
- At first it will be tougher for SGM students
 - Many concepts that SMT students have already seen
- Then it will get easier for SGM students

EPFL What this course is **NOT** about

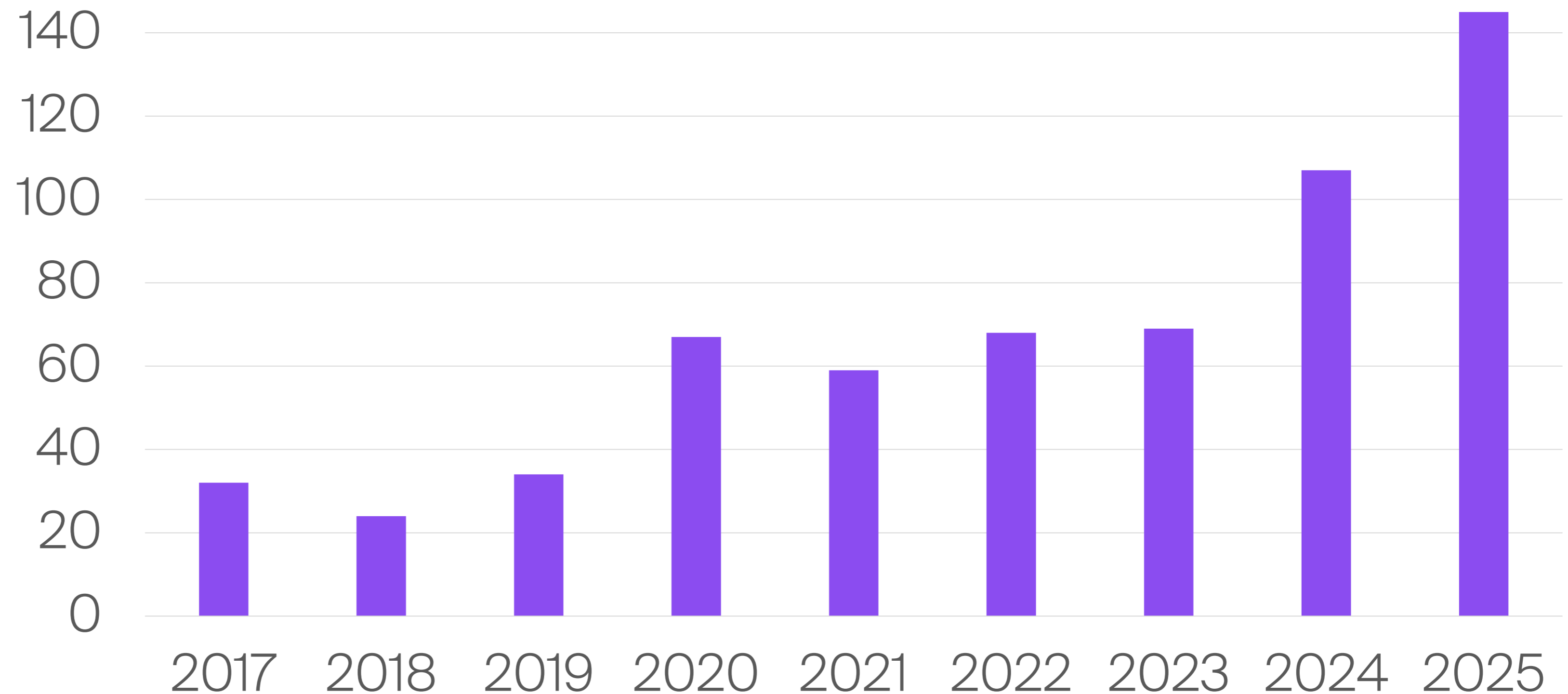
- We will remain at the “device” level
- In reality, commercial MEMS and NEMS are part of much more complex systems
 - E.g. Microphones:



- If interested in systems, you should check out the course
 - MICRO534 – Advanced MEMS (3 credits, Spring semester)

EPFL Practical matters

- Disclaimer:
 - We are not sure what will happen during the semester, so let's try to have fun and learn!
 - You are **145**, so I will have to adapt



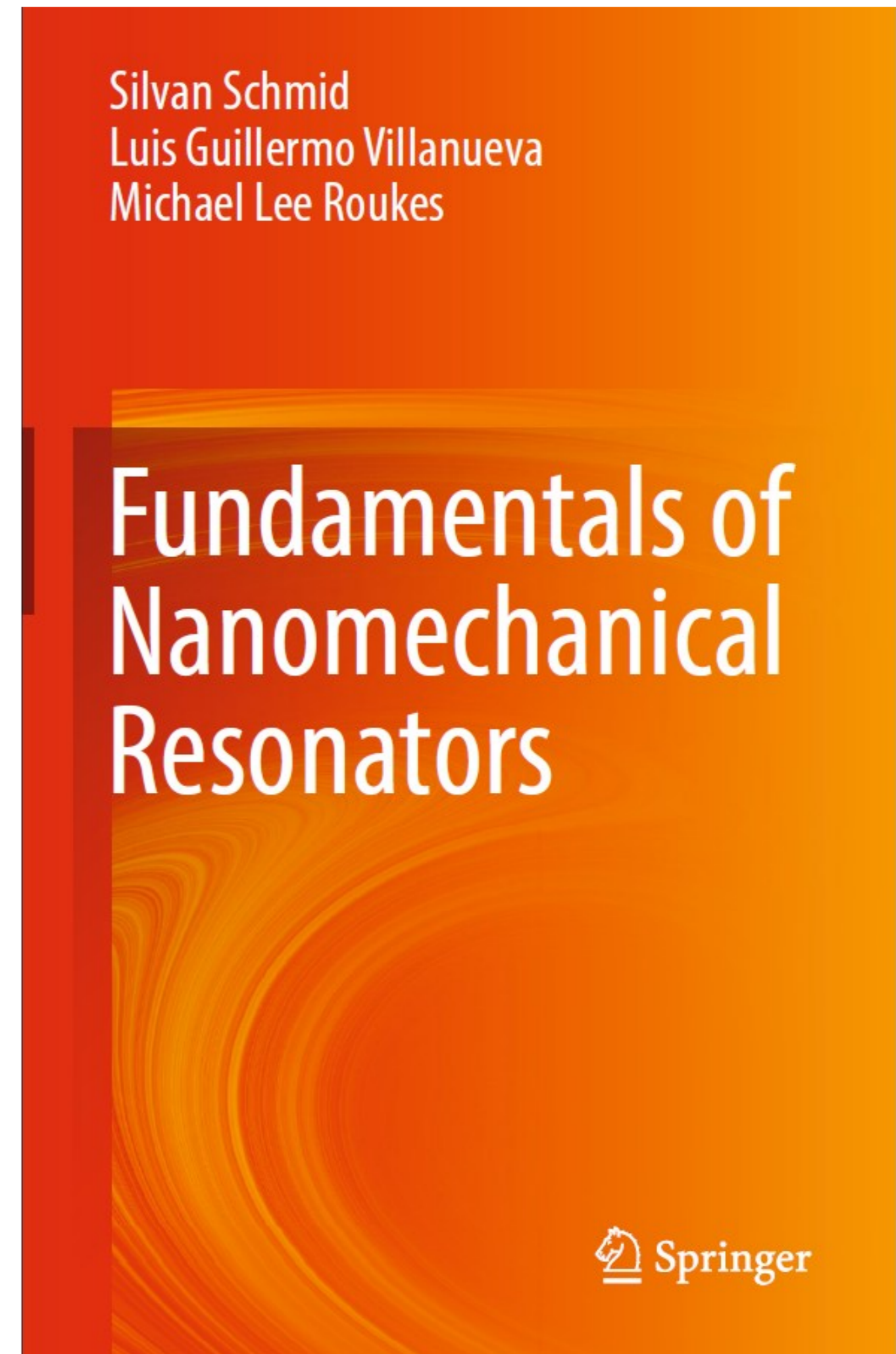
EPFL Practical matters

- Disclaimer:
 - We are not sure what will happen during the semester, so let's try to have fun and learn!
 - You are **145**, so I will have to adapt
- Classes:
 - Splitting: 10h15-11h45 – 45 mins break – 12h30-14h00 (approx)
 - Lecture videos from last year already in MediaSpace
 - For paper discussions, I will record and upload the videos for this year
 - Exercises are these “paper discussions” and not every week – Better to be there
- Evaluation:
 - Discussions in class (10 interventions) – 20%
 - Exam (see later “Take home messages”) – 80%

EPFL Practical matters – Course materials

- Lecture Videos:
 - [ME-426 Micro/Nanomechanical devices](#)
- Moodle:
 - <https://moodle.epfl.ch/course/view.php?id=15503>
 - Lecture slides WITH annotations
 - Papers to read
 - Paper discussions WITH annotations
 - Book as support material

- Fundamentals of Nanomechanical Resonators
- Do NOT buy it, just get it online – it's for free from EPFL
- I already put it in moodle



EPFL Practical matters – Workload for you

- Come to class // Watch the lectures videos
 - Read parts of the book when needed
- Read EVERY PAPER (9 papers)
- Actively participate in the discussions around each paper (so better if you come)
 - You need 10 interventions during the discussions to get 20% of the grade
 - You can have 10 interventions on 1 paper, or around 1 per paper
- Exam – Please see Take Home messages

EPFL Practical matters – Schedule (version 09.2025)

Week	Day	Theory		
1	09.09	Introduction; Scaling laws, Fabrication*		
2	16.09	Transduction of the motion – Techniques		
3	23.09	Transduction of the motion – Techniques		Paper (1)
4	30.09			Paper (1)
5	07.10	Static deflection – Force, Linear behavior, Intro noise		
6	14.10			Paper (2)
7	28.10	Station deflection – Stress		Paper (3)
8	04.11	Dynamic behavior – Linear Analysis Dynamic behavior – Stress influence on frequency		
9	11.11	Dynamic behavior – Mode coupling Dynamic behavior – Nonlinearities, Parametric drive		
10	18.11			Paper (4)
11	25.11	Material properties – Size effects		Paper (5)
12	02.12	Quality factor – Energy losses		Paper (6)
13	09.12	Thermomechanical noise, Detection schemes		Paper (7)
14	16.12			Paper (8, 9)

- Paper 1 – Downmixing – Transduction
- Paper 2 – Cellular Force – Force sensing
- Paper 3 – Biomolecular recognition – Surface stress sensing
- Paper 4 – Absorption of light – Stress dependence of frequency
- Paper 5 – Mode Coupling
- Paper 6 – Nonlinearities in cantilevers
- Paper 7 – Stress dilution – Q in SiN
- Paper 8 – Hollow resonators
- Paper 9 – Single protein detection

EPFL For questions...

- Class time
 - Tuesdays 10h15-14h
- By email:
 - Guillermo.Villanueva@epfl.ch



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Questions for the Exam

EPFL Exam (January)

- 5 questions, graded 0 – 0.5 – 1
- Random choice for everyone within the pool of questions (1 question per slide)
- Answers should be well known
 - Short time to answer (30 mins if written, 10 mins if oral)
- We can do it in English ou bien en Français o en Español o en Català (as you wish)

EPFL Take home messages

- Scaling laws
 - How does the mass, stiffness, frequency scale in the microscale? What does this mean for applications?
 - Is gravity important in the microscale? How are reaction times in the microscale? What does this mean for applications?
 - Can you give 3 examples for applications where MEMS/NEMS are useful? Why?
- Fabrication (also from papers)
 - What is the major challenge when fabricating a mechanical device? What are the 2 main points to pay attention to solve this challenge? How can you solve them?
 - Do we need several materials for our devices? Why? What can this cause in the structure?
 - What is an SOI wafer? What advantages does it provide for MEMS/NEMS? How are they made?
 - What are the pros/cons of using polymers to make your MEMS/NEMS?
 - Choose one paper (1-9) and succinctly describe the fabrication process

EPFL Take home messages

- Transduction of the motion
 - What are the two most used actuation (of the motion) principles for NEMS/MEMS? Explain how one of them works (with equations)
 - What are the two most used detection (of the motion) principles for NEMS/MEMS? Explain how one of them works (with equations)
 - What is background? What is signal to background ratio? How can we improve this SBR?
 - What is the difference between noise and background? How can we reduce them?
 - What different types of nonlinearity can we have in the transduction of the motion? Why is this relevant for practical applications?
 - What does it mean to perform a "balanced measurement" and why is it important/useful to do so? (give also an example)
 - What is down-mixing? What advantages does it provide? (write formulas)
 - What is measurement bandwidth? Why can this be an issue for smaller devices?

EPFL Take home messages

- Force/Stress
 - What do we want in a structure to have a great force responsivity? Discuss dimensions, material properties, boundary conditions, etc. Provide formulas.
 - What is dynamic range of a sensor? What limits our dynamic range in static mode?
 - What do we want in a structure to make a great surface stress sensor? Discuss dimensions, material properties, etc. Provide formulas
 - How important is it to have a reference device for sensing? How would you design it? Illustrate with an example.
 - In paper 2
 - Which forces are going to be detected?
 - How important is the geometry of the metallic line?
 - Why in polymer?
 - In paper 3
 - Why in Silicon?
 - Why the metal on top? And on the bottom?

EPFL Take home messages

- Dynamical behavior (single)
 - What are eigenmodes and eigenvalues of a structure? Are they orthogonal? What do they depend on?
 - What happens to the eigenmodes and eigenvalues with stress? Write formulas.
 - What changes when we change the normalization constant of the modes? Give examples of different normalization choices. Write formulas.
 - What are the effective mass and effective stiffness (write formulas)? What do they depend on?
 - What is dynamic nonlinearity? Which are the different possible origins?
 - How does Temperature affect a resonator and its resonance frequency? (different effects depending on the type of resonator)
 - When a single (punctual) mass lands on a resonator - What changes? Does it depend on the landing position? Can we detect the mass? Write formulas
 - When mass arrives to a resonator distributed over its surface - What changes? How is it different than single (punctual) mass landing? How much does the effect depend on the width? Write formulas
 - When a mass flows through a hollow resonator - What changes? What types of sensing can we have? What is different in each case? Write formulas

EPFL Take home messages

- Dynamical behavior (coupled)
 - What happens when we connect two resonators via a mechanical clamp? How does the effect depend on the resonators and clamp properties?
 - Why can we have coupling within a single beam? What is the origin of that coupling? What does it imply for the modes?
- Size effects
 - What happens to the Young's modulus when thickness reduces? What did the papers shown in classed report?
- Quality factor
 - What is the quality factor? How does stress affect the quality factor? Write formulas
 - Describe the typical energy loss mechanisms we find, and ways to minimize/reduce them
 - What are the two regimes for viscous losses on resonators? How can we reduce this effect?
- Noise
 - What types of noise are important for mechanical devices?
 - Where does thermomechanical noise come from?
 - What is the Allan Deviation? How can we reduce it?