Welcome

MICRO-331
Microfabrication technologies

2024 edition

Today's program

- 1st hour:
  - Teaching staff presentation
  - Cleanroom (CMI) presentation
  - Micro-331 course organization
- 2nd hour:
  - Some application examples with microfabricated microsystems success stories (computer chips, USB stick, drone navigation, smart phone and watches, environmental monitoring, biomedical & health care

Teaching team (1)

- Prof. Juergen Brugger
- Prof. em. Martin Gijs (MOOC)
- Prof. Stephanie Lacour

Guest lectures:

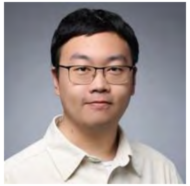
- Prof. A. Radenovic
- Prof. G. Villanueva
- Prof. A. Ionescu
- Prof. M. Gijs
- Dr. J. Arcamone (LETI) on MOOC

Teaching team (2)








- **Teaching assistants TA (PhD students):**
  - Minzonie Camilla
  - Laurine Kolly
  - Berke Erbas
  - Pol Torres
  - Tugçe Delipinar
  - Soenke Menke
  - Emilio Fernández Lavado
  - Chenxiang Zhang
  - Tao Zhang
- **+ 8 Student assistants AE (former course students)**
  - During MOOC sessions in the classroom
  - Q&A on the forum

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Class polling

ttpoll.eu
cleanfab

WEBPAGE **TTPOLL.EU**

ID: **CLEANFAB**

Schedule on MOODLE (part 1)

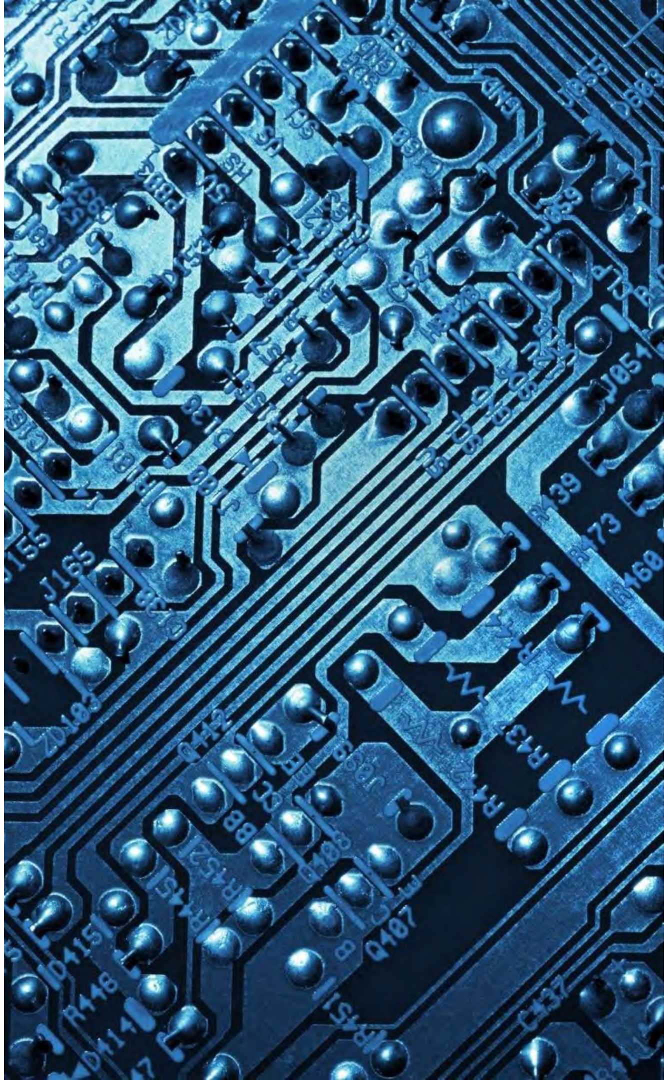
Week	Day / Date	Room	Lecture	MOOC	SLT
1	Wed / 11 Sep	CE 12	X		
	Thu / 12 Sep	CM 14		X	
2	Wed / 18 Sep	CE 12		X	
	Thu / 19 Sep	CM 14		X	
3	Wed / 25 Sep	CE 12	X		
	Thu / 26 Sep	Multiple*			X
4	Wed / 2 Oct	CE 12		X	
	Thu / 3 Oct	CM 14	X		
5	Wed / 9 Oct	CE 12	X		
	Thu / 10 Oct	CM 14		X	
6	Wed / 16 Oct	Multiple*			X
	Thu / 17 Oct	CM 14		X	
7	Autumn break	no teaching			

Schedule on MOODLE (part 2)

Week	Day / Date	Room	Lecture	MOOC	SLT
7	Autumn break	no teaching			
8	Thu / 30 Oct	CE 12	X		
	Thu / 1 Nov	CM 14		X	
9	Wed / 6 Nov	CE 12	X		
	Thu / 7 Nov	CM 14		X	
10	Wed / 13 Nov	CE 12		X	
	Thu / 14 Nov	Multiple*			X
11	Wed / 20 Nov	CE 12	X		
	Thu / 21 Nov	CM 14		X	
12	Wed / 27 Nov	CE 12	X		
	Thu / 28 Nov	CM 14		X	
13	Wed / 4 Dec	CE 12		X	
	Thu / 5 Dec	CM 14	X		
14	Wed / 11 Dec	Multiple*			X
	Thu / 12 Dec	CM 14	X		
15	Wed / 18 Dec	CE 12		X	
	Thu / 19 Dec	CM 14	X		

Learning objectives

- Basics of microfabrication
- How are computer chips made
- How are sensors made
- How does a modern cleanroom work
- Manufacturing equipment
- Create your own fabrication process flow



Teaching methods

- MOOC (self-studying)
- Online quizzes (ungraded) for self-assessment
- Ex-cathedra lectures by Professors with application examples
- Student-led-tutorials (SLT) where students present solutions to exercises in groups of ~20.

Expected student activities

The students follow the MOOC and prepare related questions before the lectures. They can also use the forum to contact other students, TA's, AE's and the Professors.

The students prepare the answers to the SLT (student led tutorials) sessions and present the answer in the group when randomly selected.

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Assessment methods

SLT participation and quality of answer/discussion (15% of total grade).

Written exam in January (85% of total grade)

Electronic circuits are everywhere…

- Smart phone, watch
- Cars, airplanes, drones
- Medical systems
- Electronic functions, including wifi/BT

Portable data storage
(from floppy disc (magnetic) to Flash (semiconductor))

Wikipedia: 8-inch, 5,25-inch, and 3,5-inch floppy disks

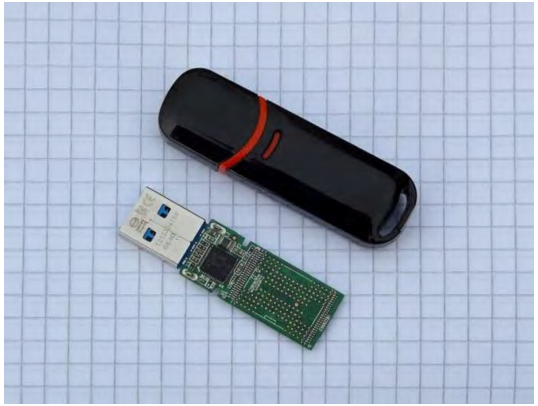
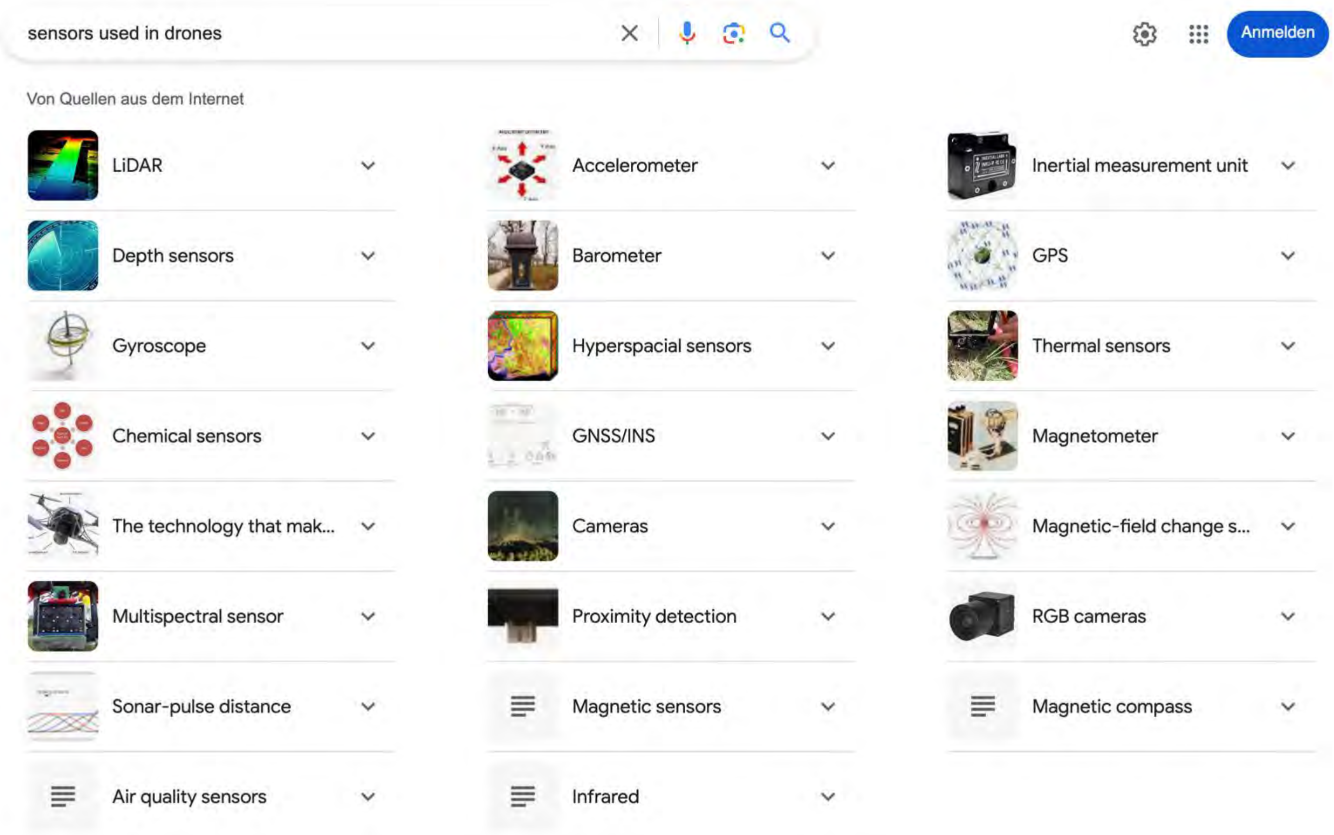


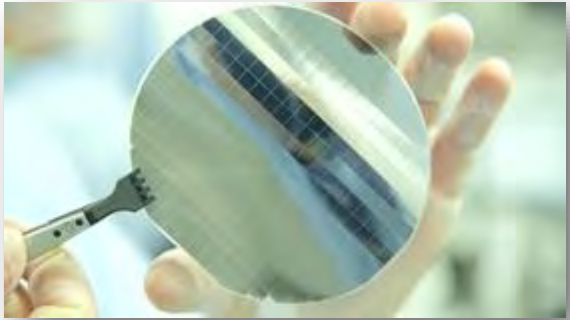
Image by Eugen Visan from Pixabay

Sensors used in drones



Learning objectives

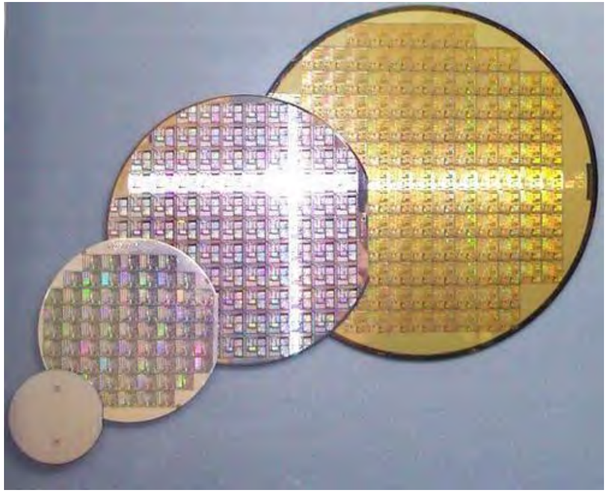
- Preparation for the TP MICRO-332
- Hands-on training how to handle a (fragile) silicon wafer or substrate



Learning objectives

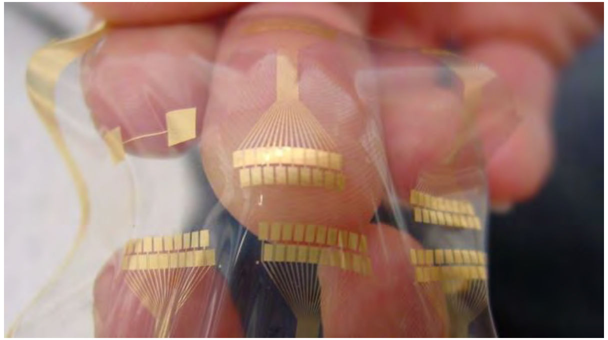
‘classical technologies’

- Silicon wafers
- Basis for CMOS electronics



‘advanced technologies’

- Flexible, stretchable, polymer
- Biomedial applications
- Nanotechnology



Why a MOOC for this course?

- Not only ‘dry’ theory
- Not only static images

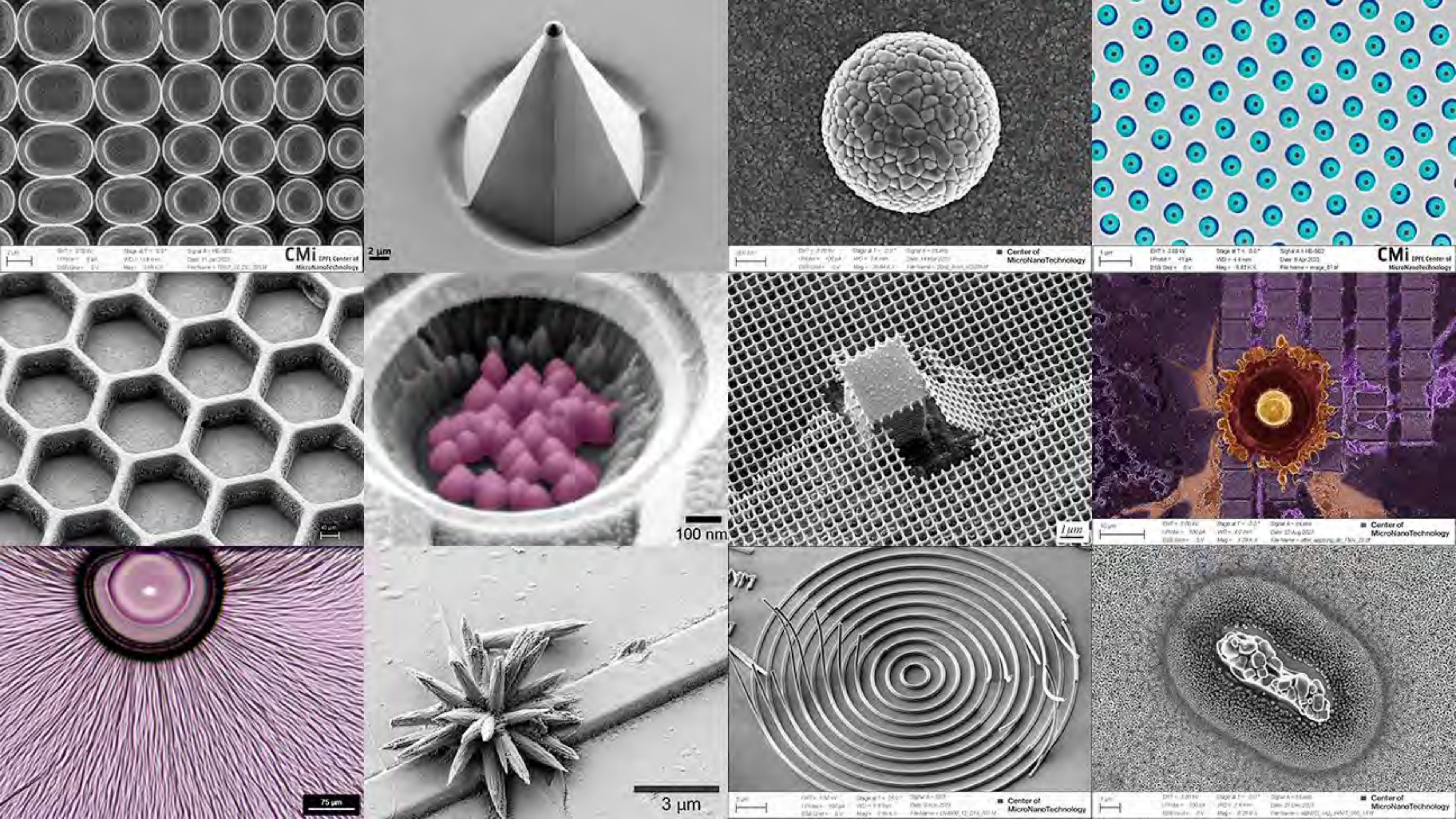
- Videos and animations
- Show how the microfabrication is done in the cleanroom

- Learn at your personal pace
- Prepare for TPs

Hands-on in microfab

- TP Micro-332 with Jalil Sayah

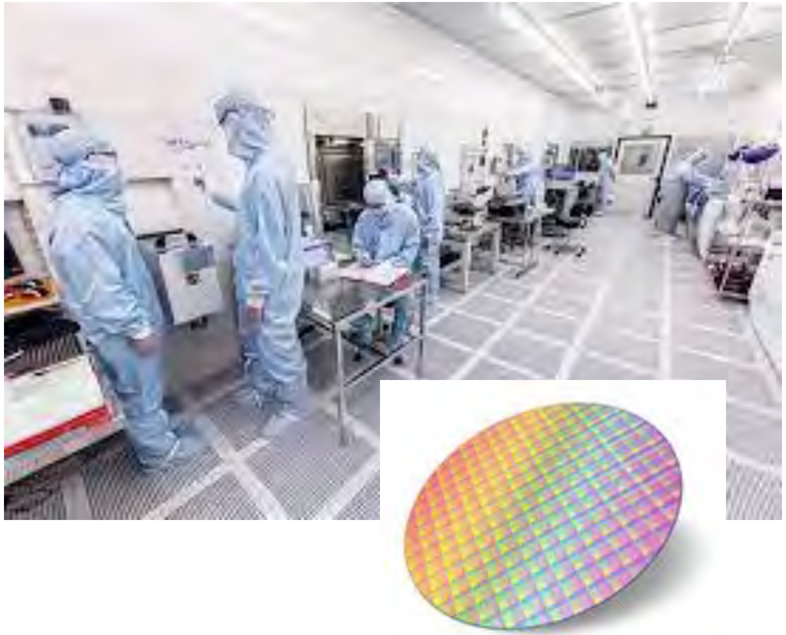
- EPFL cleanroom (CMI) with Joffrey Pernollet



CMi EPFL Center of MicroNanoTechnology
2 µm
Center of MicroNanoTechnology
CMi EPFL Center of MicroNanoTechnology
100 nm
1 µm
Center of MicroNanoTechnology
75 µm
3 µm
Center of MicroNanoTechnology
Center of MicroNanoTechnology

A cleanroom is like a kitchen

It is all about the tools and the recipes



Silicon wafer with chips

MOOC information (con't)

- MOOC is self-pacing, interactive, team-work recommended, discuss with others, check progress, practice quiz.
- You are ~150 EPFL students this year (>20k students worldwide have already taken this MOOC)
- You as EPFL students will have additional regular classroom lessons with teachers and TA's/AE's during the MOOC period
- The remaining weeks will be given by normal classroom lectures and interactive exercises in groups

MOODLE page

https://moodle.epfl.ch/course/view.php?id=14711

For all course relevant information and updates

EDstem forum

Class forum for Q&A

https://edstem.org/eu/courses/646/discussion/

TA’s and AE will moderate

Student led tutorials (SLT) Exercises

- We will form 7 groups of ~20 students (random).
- Final group list 20th September (deadline for course registrations)
- We will have 4 SLT sessions with 6 questions each.
- You will prepare for at least 3 of them to be ready to present & discuss the questions (partial grade)

Jupyter Notebooks

- 2nd time in MICRO-331
- Open on Moodle
- You can train micro fabrication processes by playing with parameters
- It will help you to better understand
- TA/AE support

Rehearsal quizzes

- On MOOC
- On Moodle
- Not graded, but HIGHLY recommended as they help you self-assessing your knowledge

Grading Information

- Writen exam in January (85%)
- SLT exercises during semester (15%)
- Material from both the MOOC and the classroom teaching is content for the final oral exam

- The best way to prepare for the exam is to:
  - Follow the MOOC in sync with the class
  - Come to the classroom session and bring in your questions
  - Do the SLT exercises in groups
  - Talk to the TA’s, teaching staff, and Professors
  - Use the discussion forum

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Questions for the course organization?

Today's program

- 1st hour:
  - Teaching staff presentation
  - Micro-331 course organization
- 2nd hour:
  - Microsystems examples and success stories
  - From electronic chips to sensors, MEMS
  - Flexible microsystems

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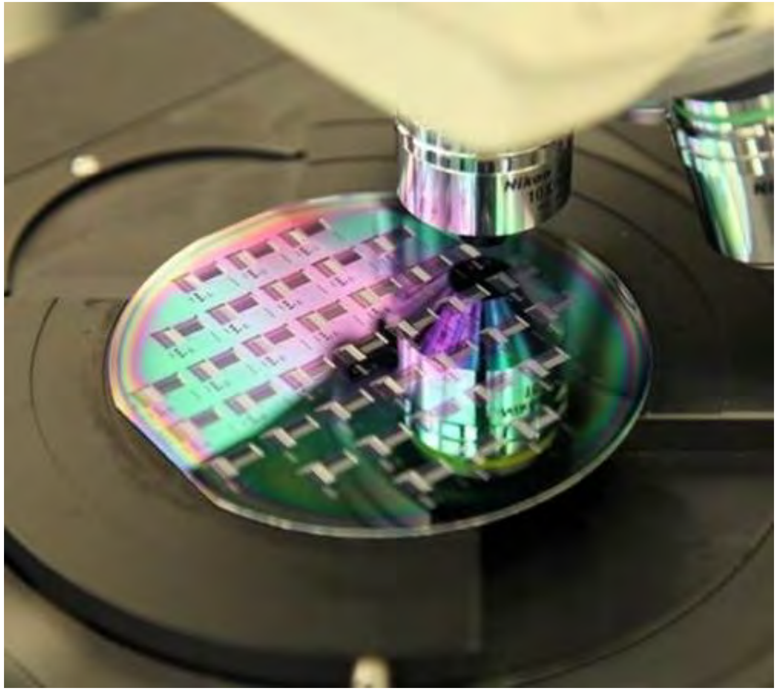
Integrated circuit (IC)



- Micro processor
- Memory
- Sensors
- System-on-chip

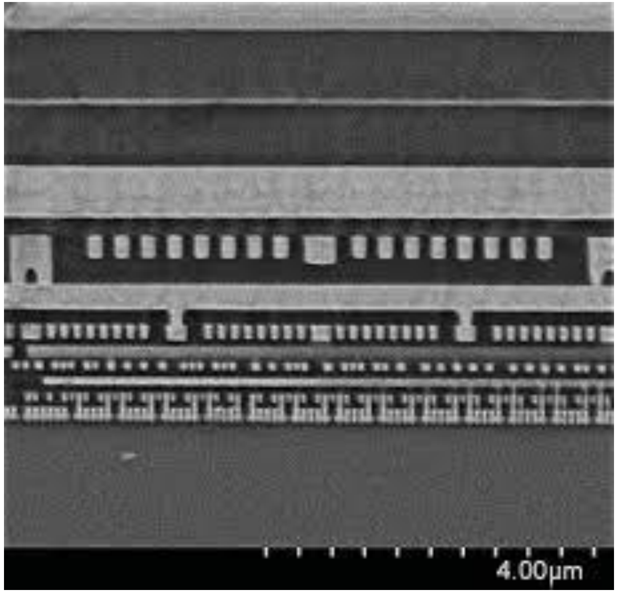
- Materials:
  - Silicon, or other semiconducting material
  - Dielectrics
  - Metal

IC fabrication steps

- IC
  - Silicon doping
  - Silicon oxidation
  - Thin film deposition (CVD/PVD)
  - Photolithography
  - Thin film etching (dry/wet)
  - …

Nothing moves !!

Cross-section of an IC



Hitachi Hi-tec (from internet)

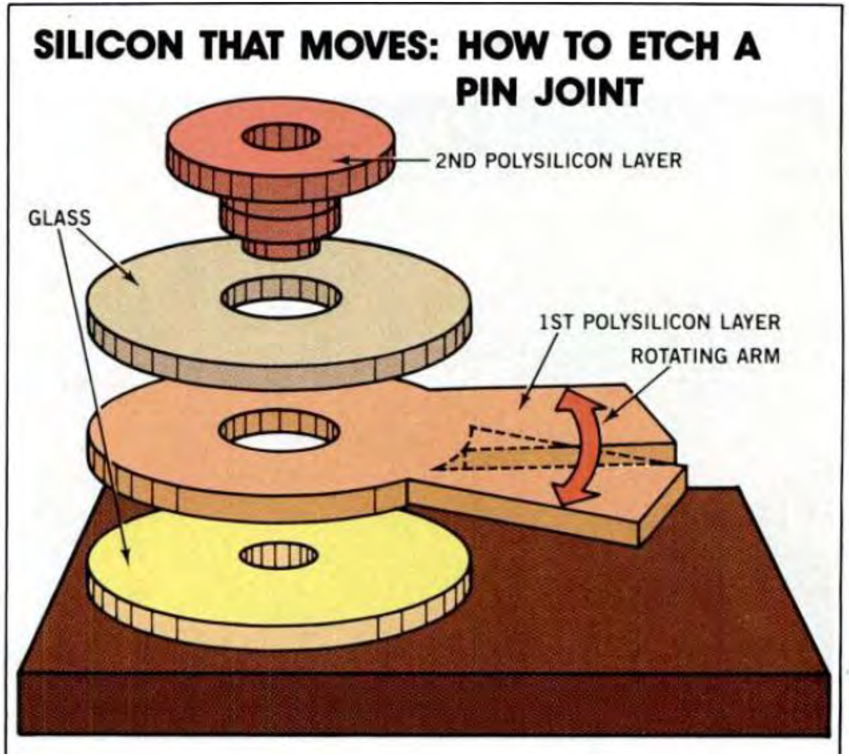
IC fabrication steps

- IC
  - Silicon doping
  - Silicon oxidation
  - Thin film deposition (CVD/PVD)
  - Photolithography
  - Thin film etching (dry/wet)
  - …

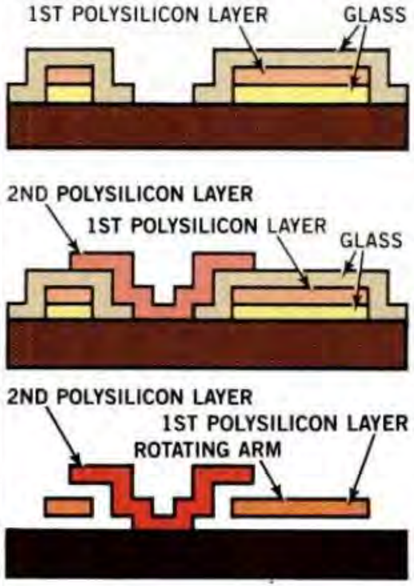
Nothing moves !!

- MEMS
  - All of the steps for IC's
  - + sacrificial layer etching
  - + bulk etching
- Create mechanically freestanding and movable elements for physical sensing or actuation
  - Cantilevers, membranes

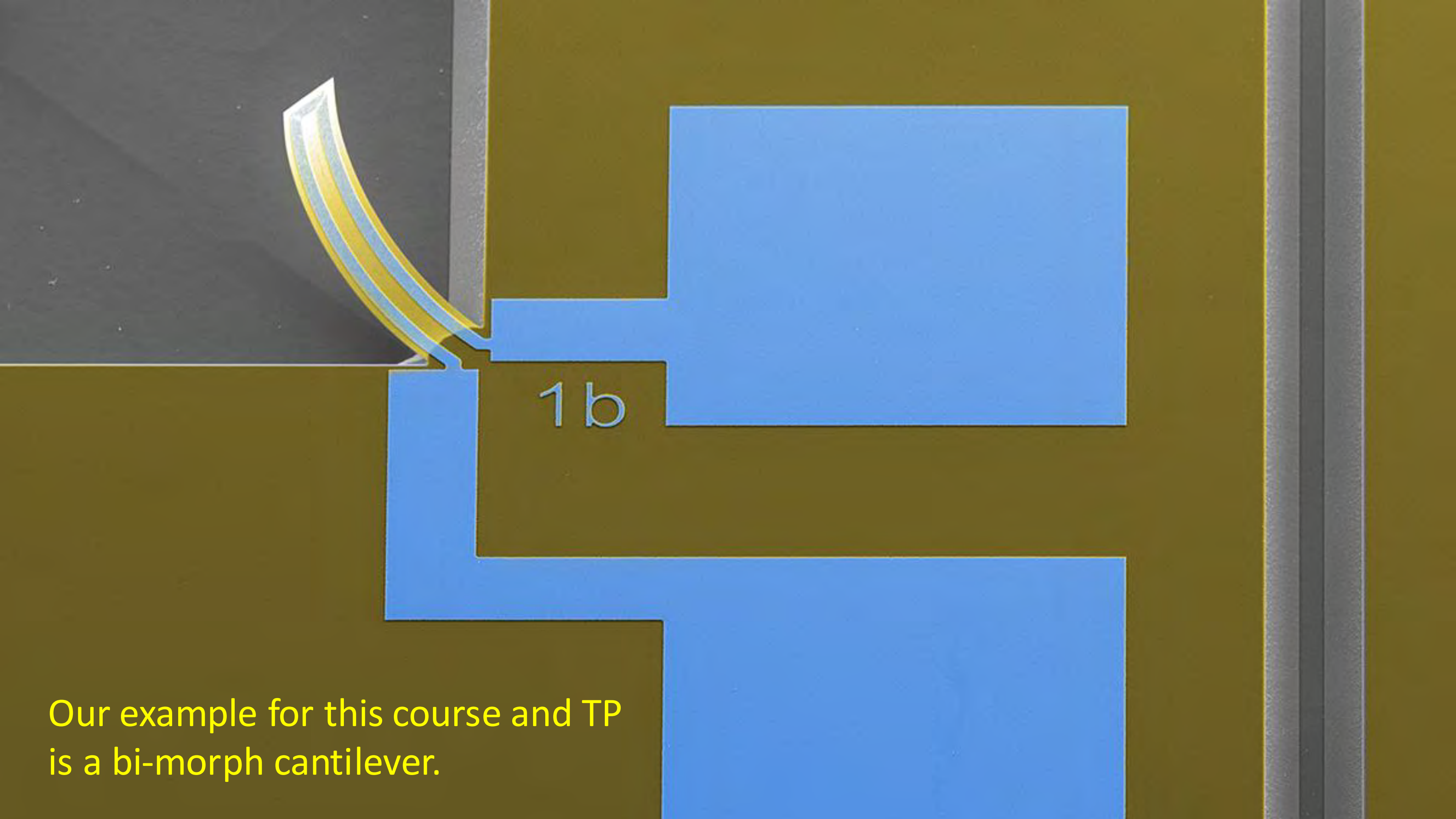
First IC made micromotor (1988)



Creating a pin joint with a fixed hub and a rotating component involves several etching and deposition steps. A layer of glass is first sandwiched between a polysilicon layer and a silicon base. Acid is used to etch a hole through the two upper layers (top). Next, glass is deposited to seal the edges of the hole. An opening is etched through this glass layer at the bottom of the hole, exposing the silicon base. A second layer of polysilicon—the pin—is deposited and fixed to the base (middle). When the glass layers are etched away, the arm formed by the first polysilicon layer is free to rotate (bottom). Multiple arms would form the rotor of a micromotor. This pin-joint fabrication sequence may take place simultaneously at thousands of sites on a silicon wafer as patterns are exposed through a template, etched, and then recoated.



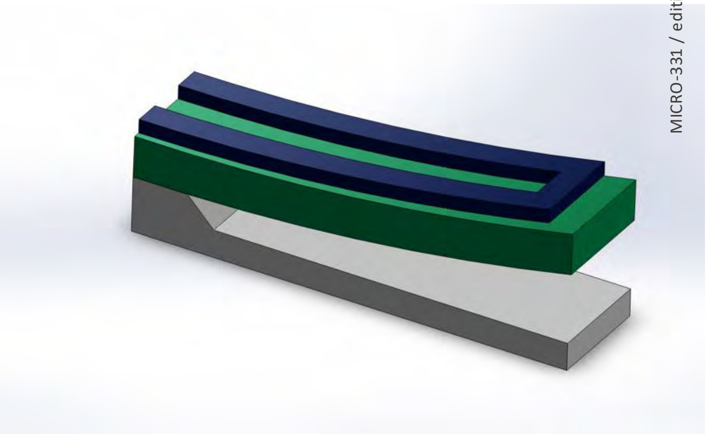
DRAWINGS BY MITCHELL J. ALBALA



Our example for this course and TP
is a bi-morph cantilever.

What is the bi-morph micro-actuator?

- Bi = 2; morph = shape
- Thermo-mechanical actuation
- Sandwich of two thin films
- Different thermal expansion coefficient α
- ΔT induces bending



$$\frac{1}{r} = \beta \cdot \Delta\alpha \cdot \Delta T$$

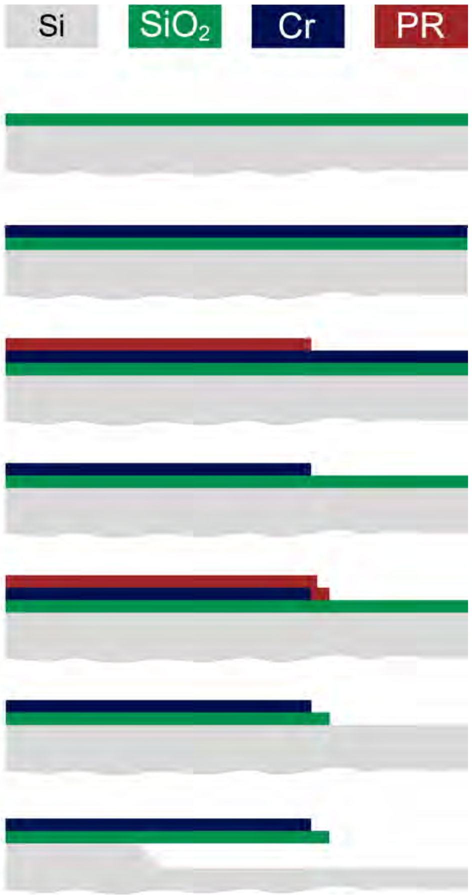
r: radius of curvature
β: constant, f(t, E)
α: thermal expansion coefficient [K $^{-1}$]
ΔT: temperature difference [K]

$$k = \frac{3EI}{L^3} \qquad \omega_{res} = \sqrt{\frac{k}{m_{eff}}}$$

I: area moment of inertia [m^4]
L: length of the beam [m]
t: thickness [m]
W: width [m]
m_{eff}: beam effective mass [kg]

k: spring constant [N/m]
E: Young's modulus [N/m^2]
σ: strain [Pa]
ω_{res}: resonant angular frequency [s-1]

Overview of multi-step microfabrication sequence



1. Oxidation
2. Cr layer deposition
3. Lithography 1 (heater)
4. Cr etch
5. Lithography 2 (cantilever)
6. SiO2 etch in BHF
7. Silicon etch in KOH

- 7 steps for thermo-mechanical cantilever
- Color code for each material
- Process flow in cross section

You will learn how to make your own process flow.

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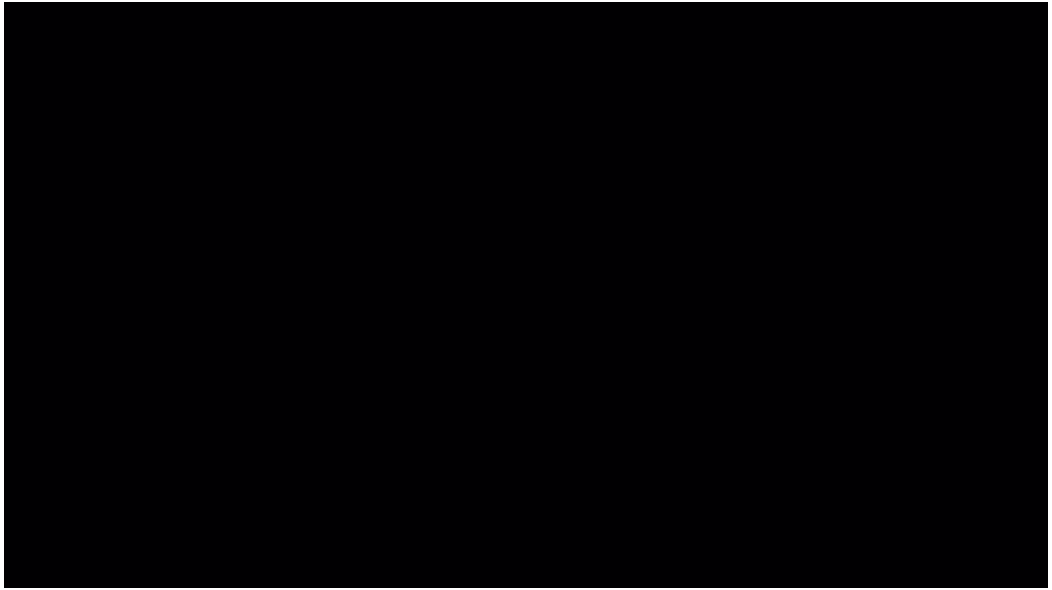
Foldable display



Thin-film display on plastic support

Materials
Polymers
Metals
Organic semiconductors

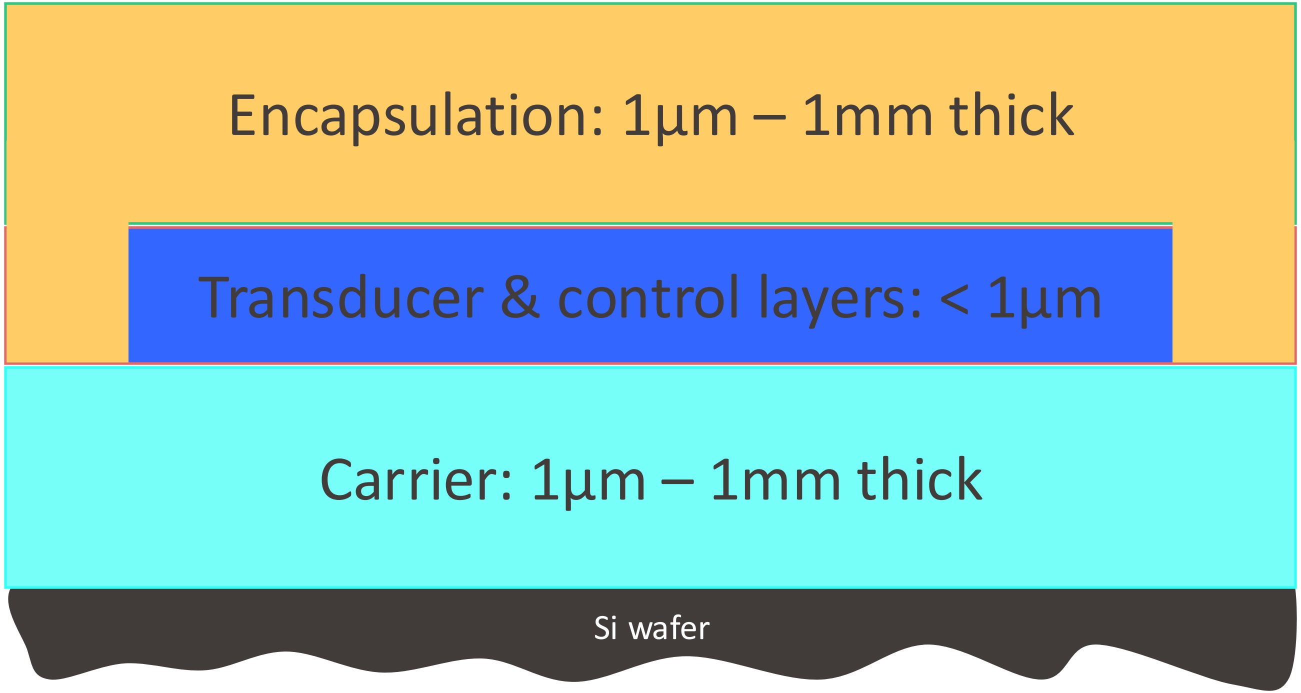
Devices
OLED and TFT
interconnects

Process
Thin-film technology

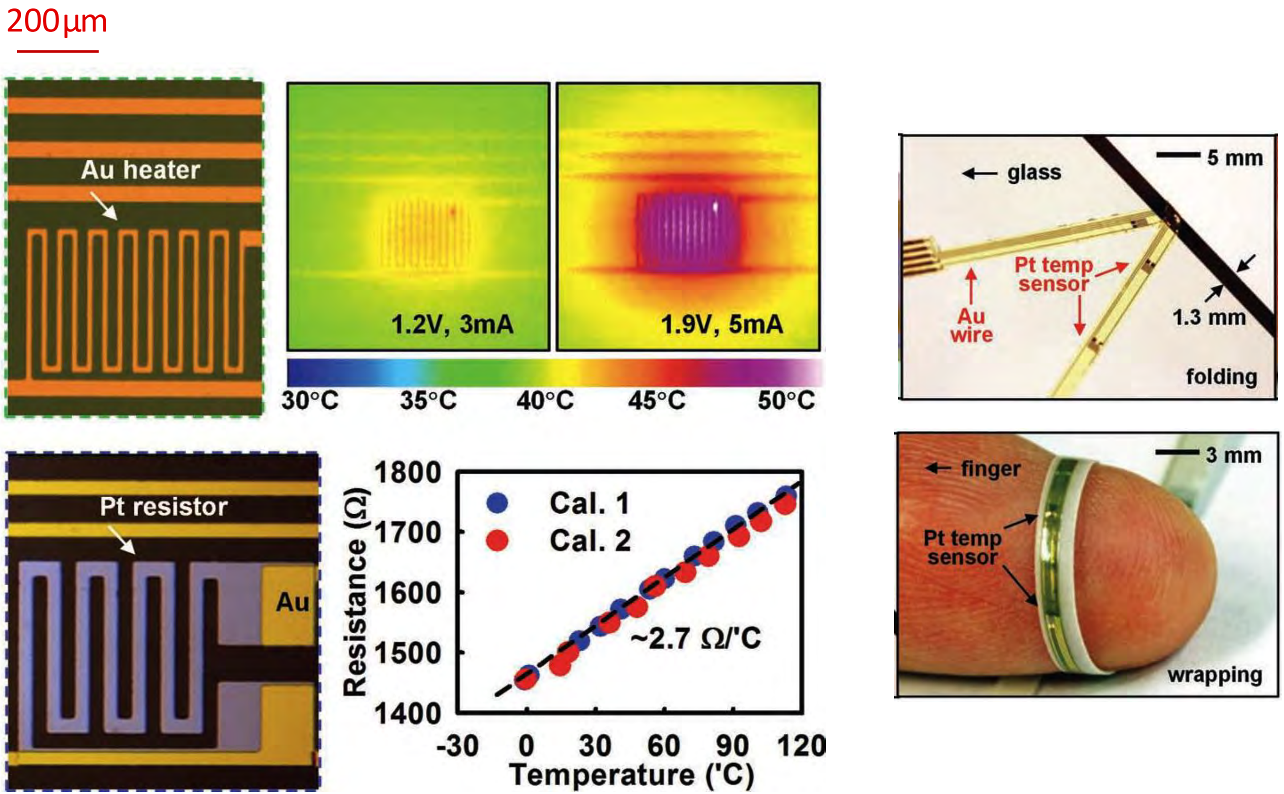
Substrate: not a semiconductor wafer
Devices: built-on using successive thin films and patterning
Encapsulation: thin polymer (usually)

Flexible electronic devices – general architecture

THIN = FLEXIBLE



Ex. 1 Microfabricated thin metal film temperature sensors



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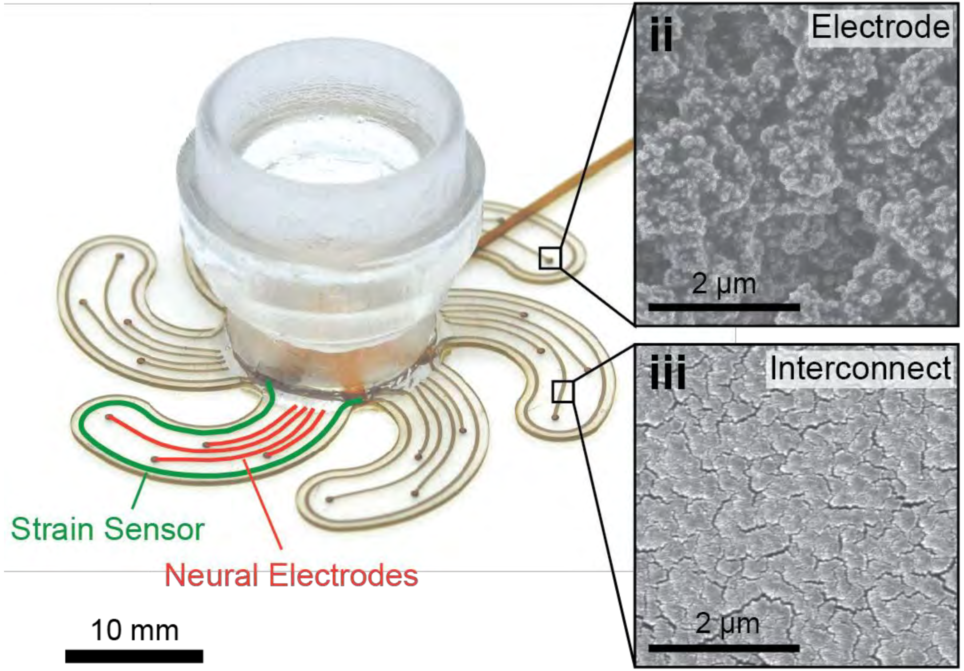
Deployable electrodes



S. Song et al., Science Robotics 2023

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