Welcome

MICRO-331
Microfabrication technologies

2025 edition

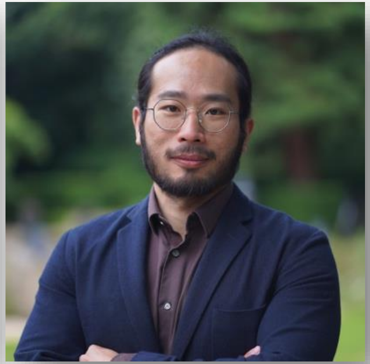
Today's program

- 1st hour:
  - Teaching staff presentation (10')
  - Course objectives: "Learn how to make a microchip" (10')
  - Cleanroom (CMI) presentation / you can join CMI as AE (10')
  - Micro-331 course organization & assessment (10')
- 2nd hour:
  - Student-led-tutorials (SLT) (10')
  - A.I. Tutor Bot (5')
  - Mixed Reality in TP-332 (10')
  - How to use the MOOC (10')
  - Q&A (10')

Teaching staff

Teaching team

- Prof. Juergen Brugger
- Prof. Yujia Zhang
- Prof. em. Martin Gijs (MOOC)



Guest lectures:

- Prof. Minshen Zhu (TU Chemnitz, flex battery)
- Prof. Giuseppe Schiavone (EPFL, soft MEMS)

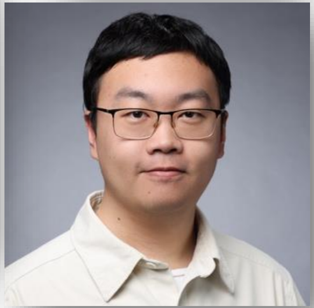
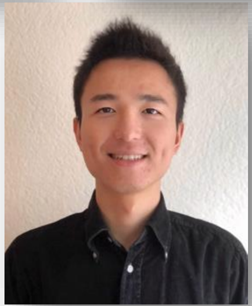
Teaching team (2)

- **Teaching assistants TA (PhD students):**
  - Yide Harris Jiao
  - Zhang, Chenxiang
  - Delipinar, Tugce
  - Shen, Shulang
  - Pol Torres Vila
  - Jansen, Hendrik
  - Alatas, Yagmur Ceren
  - Angela Braccia
  - Erbas, Berke
  - Kolly, Laurine
  - Minzoni, Camilla







- **+ 8 Student assistants AE**
  - During MOOC sessions in the classroom
  - Q&A on the forum

More ...

Class quiz #1

Course objectives

Microfabricated electronic chips are everywhere…

- Smart phone
- Smart watch
- Cars
- Airplanes
- Drones
- Medical systems
- Pacemaker
- Glucose sensor/pump
- Wifi/BT

Microfabricated sensors used in drones

sensors used in drones

Anmelden

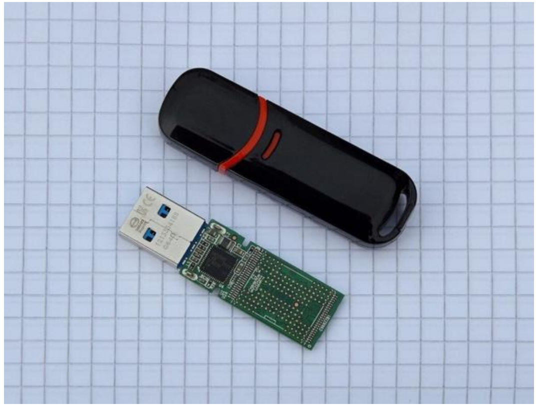
Von Quellen aus dem Internet

- LiDAR
- Depth sensors
- Gyroscope
- Chemical sensors
- The technology that mak...
- Multispectral sensor
- Sonar-pulse distance
- Air quality sensors
- Accelerometer
- Barometer
- Hyperspacial sensors
- GNSS/INS
- Cameras
- Proximity detection
- Magnetic sensors
- Infrared
- Inertial measurement unit
- GPS
- Thermal sensors
- Magnetometer
- Magnetic-field change s...
- RGB cameras
- Magnetic compass

Portable data storage

from floppy disc (magnetic) to SSD (microfabricated semiconductor)

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



SD drives (microfabricated chips)

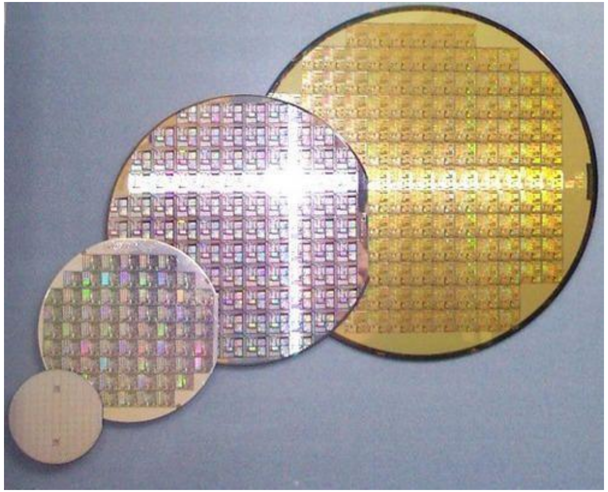
Learning objectives

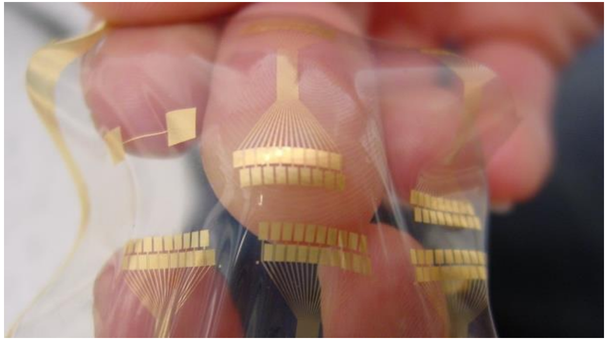
‘classical technologies’

- Silicon wafers
- Basis for CMOS electronics

‘advanced technologies’

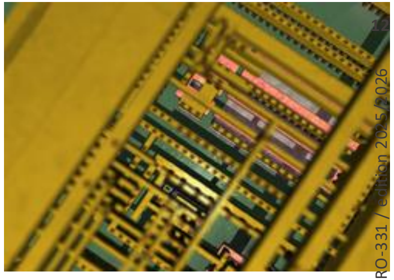
- Flexible, stretchable, polymer
- Biomedial applications
- Nanotechnology





EPFL

If you google «Microfabrication»



Wikipedia:

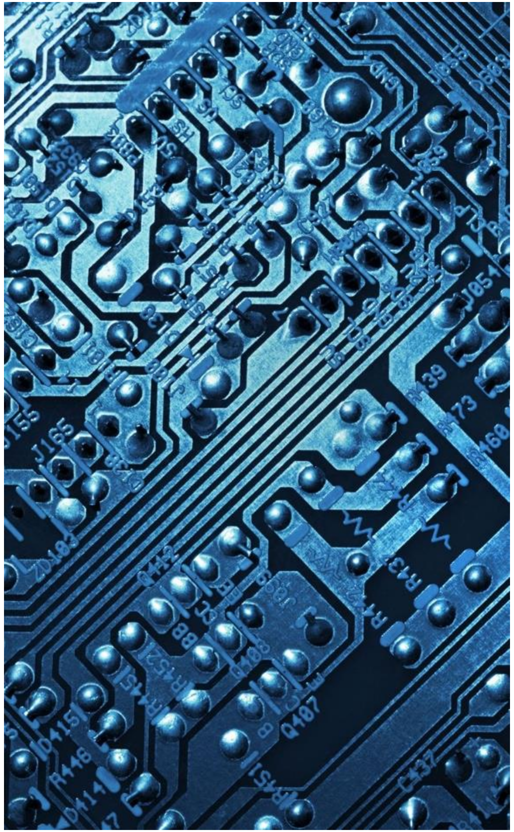
- **Microfabrication** is the process of fabricating miniature structures of micrometre scales and smaller. Historically, the earliest microfabrication processes were used for integrated circuit fabrication, also known as "semiconductor manufacturing" or "semiconductor device fabrication". In the last two decades, microelectromechanical systems (MEMS), microsystems (European usage), micromachines (Japanese terminology) and their subfields have re-used, adapted or extended microfabrication methods.

ChatGPT:

- **Microfabrication** is the set of processes used to create very small structures, typically on the scale of micrometers or nanometers. It combines techniques from physics, chemistry, and engineering — such as photolithography, etching, and thin-film deposition. These methods are essential for making microchips, sensors, microelectromechanical systems (MEMS), and other miniature devices.

You will learn …

- The basics of microfabrication
- How computer chips are made
- How sensors are made
- How a modern cleanroom works
- What manufacturing equipment is used
- How to create your own fabrication process flow



What is currently the most valuable company selling micro-chips?

NVIDIA chips (new leader in advanced chip design… fab is outsourced to foundry TSMC)

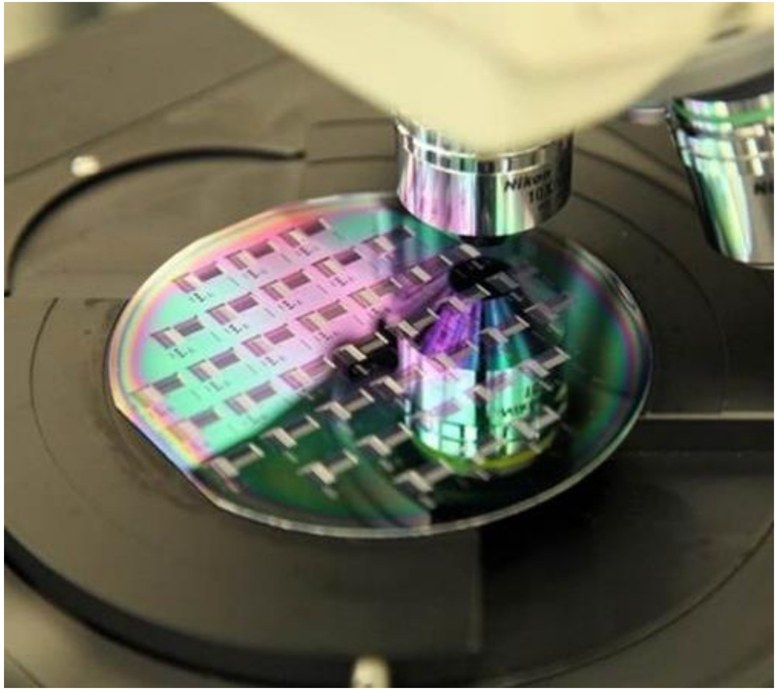
Low power electronics and time frequency – a Swiss speciality

em microelectronic
A COMPANY OF THE SWATCH GROUP

32.768 kHz Quartz Crystals

MICRO CRYSTAL
A COMPANY OF THE SWATCH GROUP

Integrated circuit (IC)



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

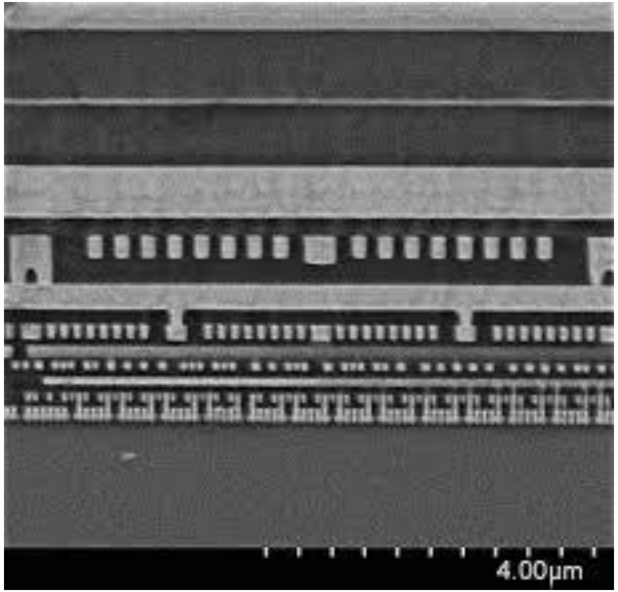
- Materials:
  - Silicon, or other semiconducting material
  - Dielectrics
  - Metal

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)

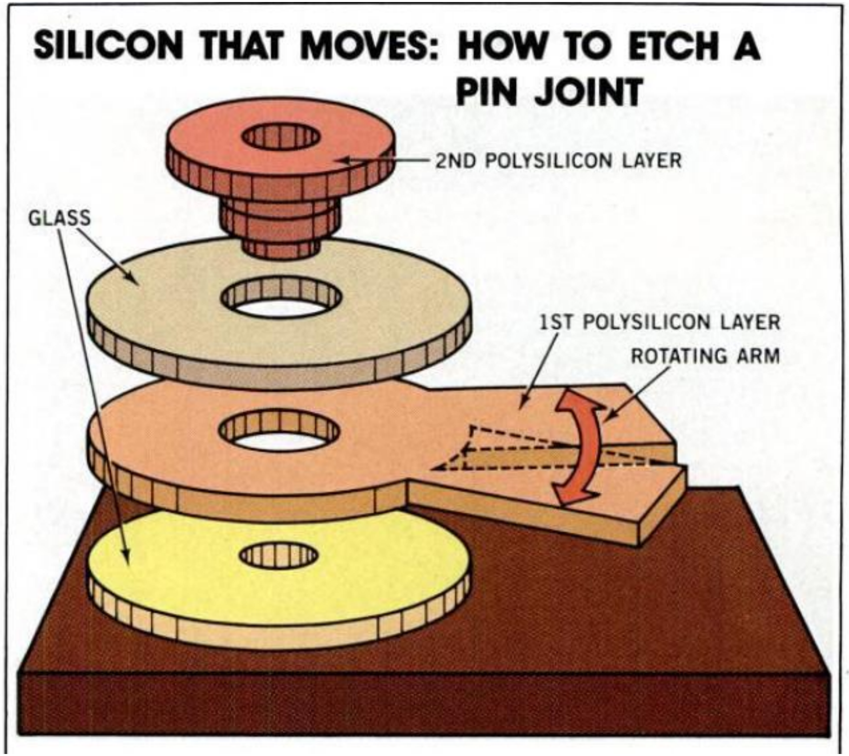
IC fabrication steps

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

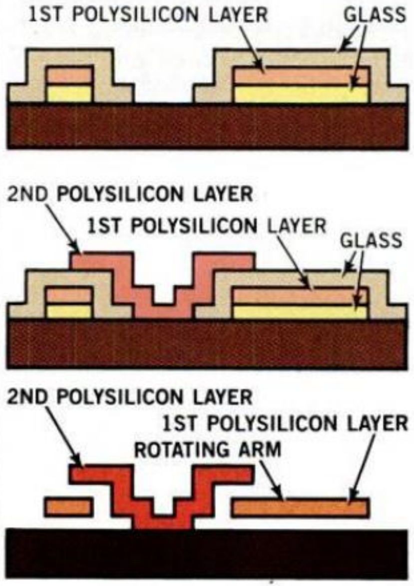
Nothing moves !!

- 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)

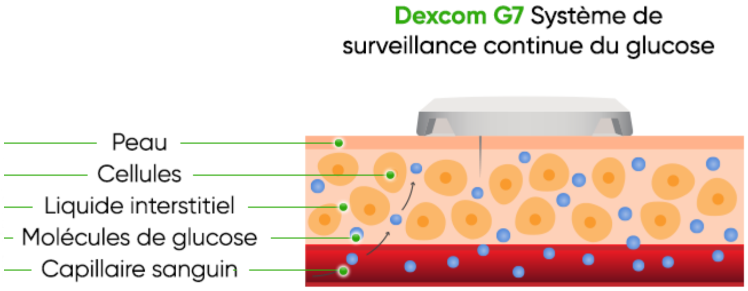


Creating a pin joint with a fixed hub and a rotating component involves several etching and deposition steps. A layer of glass is first sandwiched between a polysilicon layer and a silicon base. Acid is used to etch a hole through the two upper layers (top). Next, glass is deposited to seal the edges 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.

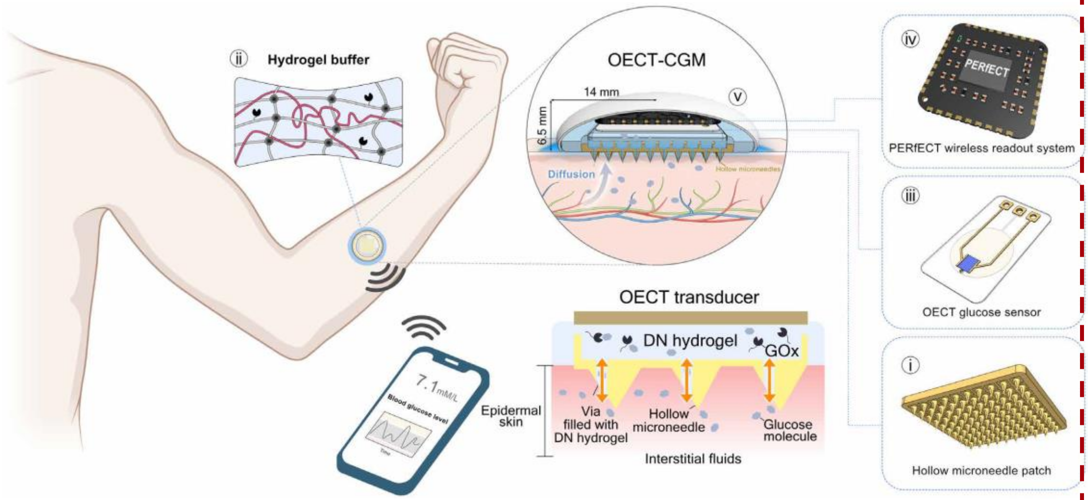


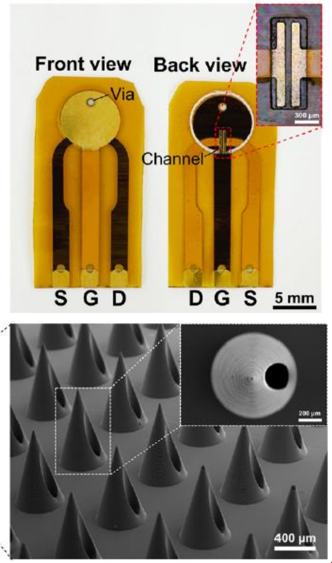
DRAWINGS BY MITCHELL J. ALBALA

Wearable continuous glucose monitor (CGM)



Advanced version: **Flexible electrodes + fluidic microneedles**





Laboratory for Bio-Iontronics (BION)
PI: Prof. Yujia Zhang

Images from Dexcom; Bai *et al.*, *Sci. Adv.* **10**, eadl1856 (2024)

What is a process flow?

- A process flow is like following a recipe: you combine the right ingredients in the right order and under the right conditions, building step by step—just like making a pizza.
- We will prepare you to be able to understand process flows, and how to create new ones.
- If you can design process flows in micro- and nanofab, you'll be in high demand in both research and industry.

A cleanroom is like a kitchen

It is all about the tools and the recipes

Silicon wafer with chips

'Advanced technologies' in 'kitchen'

RESEARCH

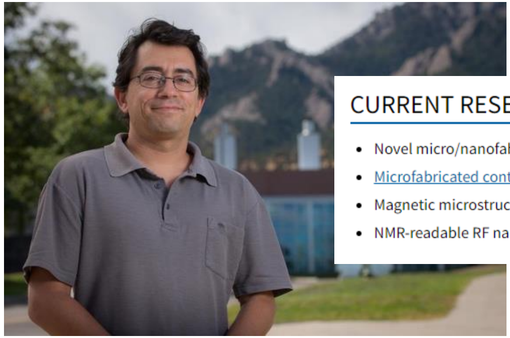
MICROFABRICATION

Reflow transfer for conformal three-dimensional microprinting

G. Zabow*

Applied Physics Division, National Institute of Standards and Technology; Boulder, CO 80305, USA.
*Corresponding author. Email: gary.zabow@nist.gov

Zabow, *Science* **378**, 894–898 (2022)   25 November 2022

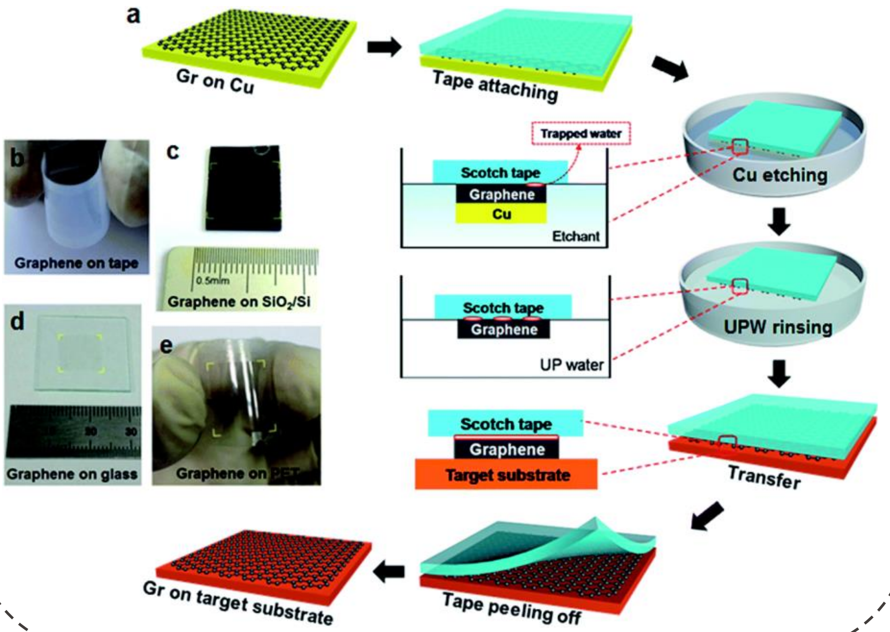


CURRENT RESEARCH PROJECTS

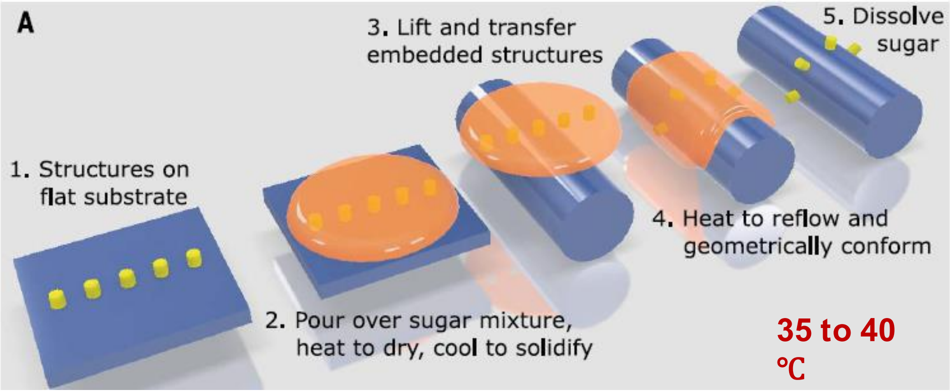
- Novel micro/nanofabrication techniques
- Microfabricated contrast agents for cell labeling and tracking
- Magnetic microstructures for multiplexed MRI
- NMR-readable RF nanosensors for embedded sensing

How to manufacture micropatterns or structures on soft or nonplanar substrates?

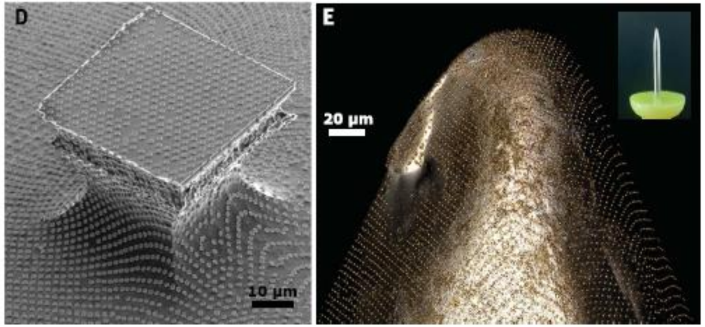
Classic *tape method* for pattern transfer



Reflow-driven flexible transfer (REFLEX)

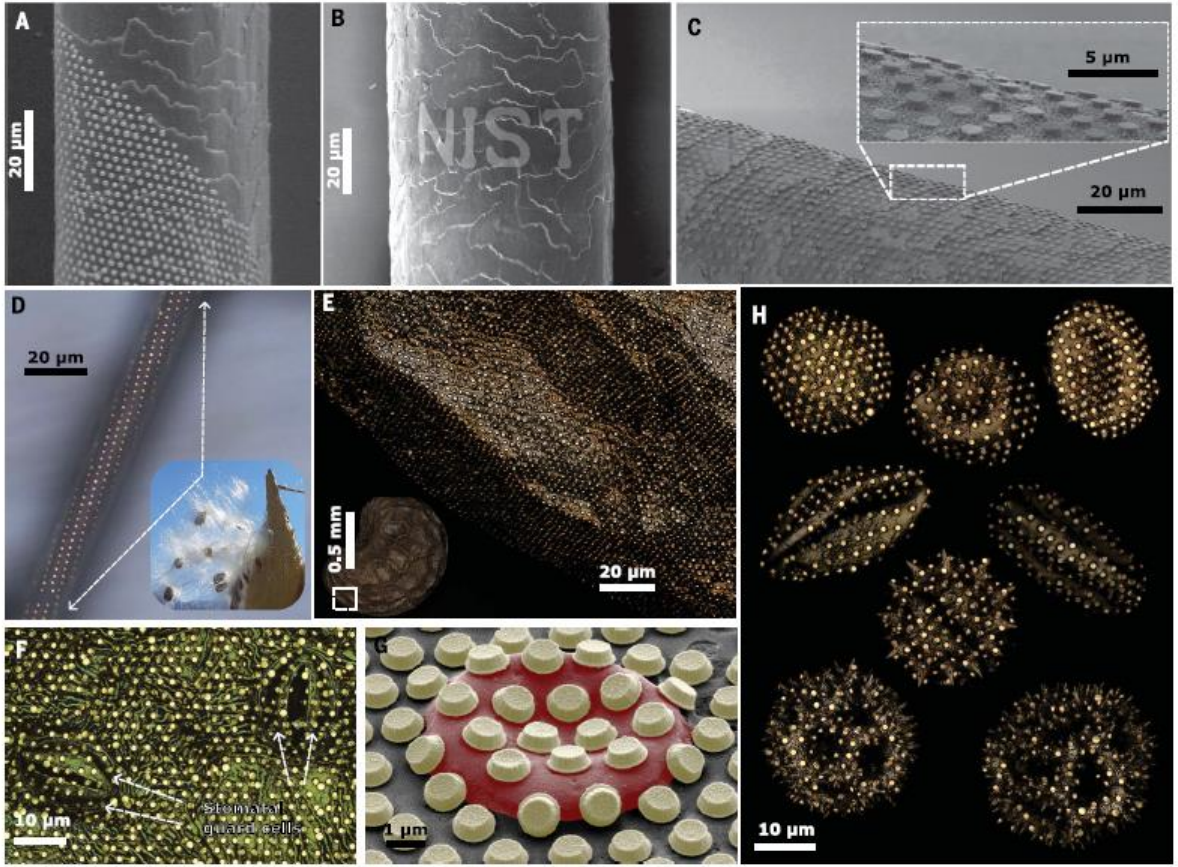


35 to 40 ℃



At small size-scales, prints can adhere directly through **van der Waals forces** without substrate modification

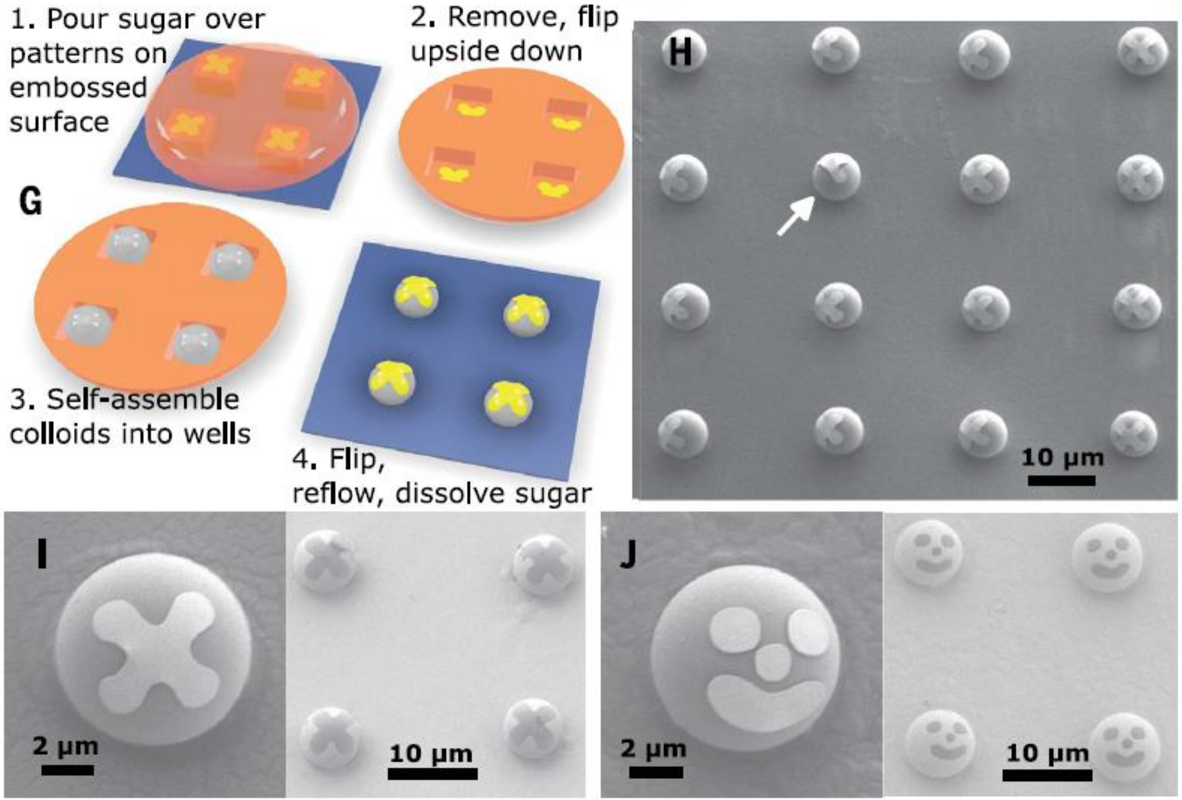
Conformal transfer of extended structures



Multilevel functionalization

- **Material**
  e.g., magnetic iron disks
- **Microstructure**
  e.g., optical metasurface
- **Substrate**
  e.g., milkweed seed pod and fibers (microrobots), red blood cells

Micropatterning colloids



Take-home messages:

1. A clean room is like a kitchen:
It's all about the tools and the receipts!

2. **Microfabrication technologies are fun and evolving!**

CMI

EPFL
CMi

EPFL
CMi - Center of MicroNanoTechnology

Joffrey Pernollet

École
polytechnique
fédérale
de Lausanne

Historical Milestones

Historical Milestones

Microelectronics & MEMS 1998	• CMi created in 1998 & Cleanroom opened in March 1999 • Basic Microelectronics processes • MEMS processes like **Deep silicon etching**, **SU-8**
Nano 2005	• **Electron Beam Lithography** ordered in december in 2005 • Focused Ion Beam ordered in september 2003 • Atomic Layer Deposition in 2011
Cleanroom extension 24/7 2010	• Cleanroom extension opened in 2010 for **more flexibility** and cheaper access • **Operated now in 24/7 mode** since 2012 • **PDMS**, SU-8, Chemistry, Metrology, Non-conventional processes
Materials Diversity 2013	• **Ion Beam Etching**, PVD, ALD, PLD, Dry Etching • Chemistry • Photolithography: Mask Fabrication, Coater & Developer, Mask Aligner
DUV Stepper lithography 2019	• **DUV stepper** • Renewal of aging tools & Adding new capabilities • Envision the acquisition of a second EBEAM at the horizon of 2022
Renewal & Broadening 2019-2022	• Deep Si etcher - XeF2 etcher - CMP - Post CMP Cleaner - Super Critical Dryer - Metal etcher • **PVD Cluster** - LPCVD furnaces - PECVD - Flash Lamp Annealing - Direct Writer • **Wafer bonding** - CVD diamond - Optical Profiler - SEM - Ellipsometer
Quantum Science & Engineering 2022…	• UHV evaporator for **Josephson Junctions** - HD PECVD • Second electron beam lithography system

EPFL

Users in 2024

Engineering Sc.		Basic Sc.	EPFL various	Ext. Acad.		Companies		
STI-IBI-BIOS	STI-IGM-INSTANT-L	SB-IPHYS-CRP	Life Sciences	AMI_FR_BioPhysics	UNIGE_GAP	ABC_Lab	GB_Microfab	Rolex
STI-IBI-CLSE	STI-IGM-LMTS	SB-IPHYS-GR-GA	SV-GHI-UPKIN	CERN_BE_dept	UNIGE_Physique	ActLight	Gersteltec	Rolex_Bienne
STI-IBI-LBEN	STI-IGM-LNET	SB-IPHYS-HQC	SV-IBI-UPDEPLA	CERN_EP_dept	UNIL_GTF	Advanced_Fiber_Re	Hexisense	Safran_Sensing
STI-IBI-LBMM	STI-IGM-LRESE	SB-IPHYS-LASPE	SV-IBI-UPLUT	CSEM_T1	UNIZH_IBT	Alpes_Lasers	Icoflex	SEED
STI-IBI-LBNC	STI-IGM-MICROBS	SB-IPHYS-LBEM	SV-IBI-UPNAE	CSEM_T4	UNIZH_Physik	AMO	ID_Quantique	SICPA
STI-IBI-LBNI	STI-IGM-NEMS	SB-IPHYS-LEB	SV-ISREC-UPBRI	CSEM_T5	Eidikos_Logariasm	AMS_Intl_AG	Infrascreen	Sigatec
STI-IEM-ALCHEMY	STI-IMX-FIMAP	SB-IPHYS-LPBS	SV-ISREC-UPKARTHAUS	CSEM-Allschwil	Kyoto_Uni	Annaida	Ligentec	SM-ABDAD
STI-IEM-AQUA	STI-IMX-INE	SB-IPHYS-LPQM1	SV-PTECH-PTBET	ETHZ_D-BSSE_QDB	UGent-CMST	ArcoScreen	LSPR	Spryngs
STI-IEM-GALATEA	STI-IMX-LMGN	SB-IPHYS-LQP	SV_SSV-TP1	ETHZ_D-CHAB	UNI_Tokyo	Axetris	Lunaphore	Sunbioscience
STI-IEM-HYLAB	STI-IMX-LMSC	SB-IPHYS-LUMES		ETHZ_D-ITET_IIS	Uni-Amsterdam	Bloesch	Luxtelligence	SwissflexMicro
STI-IEM-LAFT	STI-IMX-LP	SB-IPHYS-SQIL	Computer & Communication	ETHZ_D-MAVT_IEPE_	UNI-SUSSEX-PH-IQT	Bruker	Mackinac	Swistor
STI-IEM-LAI	STI-IMX-SMAL	SB-ISIC-LAS	Sciences	ETHZ_D-MAVT_MNS		CH-SCNAT-FemtOprint	MCH-processing	SYANDSE
STI-IEM-LANES	STI-INX-LSBI	SB-ISIC-LIMNO	IC-IINFCOM-LSI1	ETHZ_D-PHYS_LFKP		CH-SCNAT-Hexisense	Melexis	TAG_Heuer
STI-IEM-LAPD	STI-SCI-JVH	SB-ISIC-LNCE	IC-IINFCOM-SENS	HE_Arc_le_Locle		CH-SCNAT-Miraex	Metromol	XeedQ
STI-IEM-LEAP	STI_SEL	SB-ISIC-LNQ		HES-SO-GE_inSTI		Corintis	Microcrystal	XRnanotech
STI-IEM-LMIS1	STI_SMT-TP1	SB-ISIC-LPDC	Architecture, Civil and	HES-SO-NE_HEARC		Creal	Miraex	Xsensio
STI-IEM-LPMAT	STI_SMT-TP2	SB-ISIC-LPI	Environmental Engineering	Metas		Deeplight	Morphotonix	
STI-IEM-LPQM2		SB-SCGC-GE	ENAC-GE	PSI_LNQ		Diamond_Light	Nanoga	
STI-IEM-LWE		SB-SCI-RH	ENAC-IIE-GR-LUD	PSI_LSB		Doppl	Nanoworld	
STI-IEM-NAM		SB-SPC-II		PSI_TOMAC		Edwatec	Novagan	
STI-IEM-NANOLAB				UNIBAS		El_Richemont_Intl	Oxford_Ionics	
STI-IEM-PHOSL			Centers and Platforms	UNIBAS_2		Enlightra	Pi_Imaging	
STI-IEM-POWERLAB			AVP-CP_EPIX	UNIBE-Eco-Evol		EXALOS	Piemacs	
STI-IEM-PV-LAB			AVP-CP-ECO	UNIFR_Chemistry		FEMTOprint	Q_Ant	
STI-IEM-SCI-SC				UNIGE_CHIAM		Festo_Microtech	QBP	
STI-IGM-EMSI				UNIGE_DPNC		Foxmat	Richemont	
STI-IGM-ETA-LAB				UNIGE_DQMP		Freshape	Richemont_Intl	
44 (344)		20 (119)	14 (27)	38 (66)		70 (153)		

# of laboratories

# of users

- Total: 116 labs & 70companies (total of 709 users)

Users in 2024

Engineering Sc.		Basic Sc.	EPFL various	Ext. Acad.		Companies		
ST	STANT-L	SB-IPHYS-CRP	Life Sciences	AMI_FR_BioPhysics	UNIGE_GAP	ABC_Lab	GB_Microfab	Rolex
ST	S	SB-IPHYS-GR-GA	SV-G	CERN_BE_dept	UNIGE_Physique	ActLight	Gersteltec	Rolex_Bienne
ST	S	SB-IPHYS-HQC	SV-I	CERN_EP_dept	UNIL_GTF	Advanced_Fiber_Re	Hexisense	Safran_Sensing
ST	S	S PE	SV-I	CSEM_T1	UNIZH_IBT	Alpes_Lasers	Icoflex	SEED
ST	S	S	SV-I	CSEM_T4	UNIZH_Physik	AMO	ID_Quantique	SICPA
STI-IBI-LBNI	STI-IGM-NEM	S	SV-I	CSEM_T5	Eidikos_Logariasm	AMS_Intl_AG	Infrascreen	Sigatec
STI-IEM-ALCHEMY	STI IMAP	S	SV-ISREC-UPKA	CSEM-Allschwil	Kyoto_Uni	Annaida	Ligentec	SM-ABDAD
STI-IEM-AQUA	S	S	SV-PT BET	ETHZ_D-BSSE_QDB	UGent-CMST	ArcoScreen	LSPR	Spryngs
STI-IEM-GALATEA	S	SB-IPHYS-LQP	SV_S	ETHZ_D-CHAB	UNI_Tokyo	Axetris	Lunaphore	Sunbioscience
STI-IEM-HYLAB	S	SB-IPHYS-LUMES		ETHZ_D-ITET_I	Uni-Amsterdam	Bloesch	L e	SwissflexMicro
STI-IEM-LAFT	S	SB-IPHYS-SQIL	Com	ETHZ_D-MAVT	X-PH-IQT	Bruker	M	Swistor
STI-IEM-LAI	S IMX-SM	SP	Scie	ETHZ_D-MAVT		CH-SCNAT-FemtOprint	M	SYANDSE
STI-IEM-LANES	STI-INX-LSBI	S	IC-II FCOM-L	ETHZ_D-PHYS_		CH-SCNAT-Hexisense	M	TAG_Heuer
ST D	STI-SCI-JVH	S	IC-IIN SENS	HE_Arc_le_Loc		CH-SCNAT-Miraex	M	XeedQ
S	STI_SEL	S		HES-SO-GE_inSTI		Corintis	Microcrystal	XRnanotech
S	STI_SMT-TP1	S	Arc	HES-SO-NE_HEARC		Creal	Miraex	Xsensio
S	STI_SMT-TP2	SB-ISIC-LPI	Env	Metas		Deeplight	Morphotonix	
S IEM-L		SB-SCGC-GE	ENA	PSI_LNQ		Diamond_Light	Nanoga	
STI-IEM-LWE		SB-SCI-RH	ENAC-IIE-GR-	PSI_LSB		Doppl	Nanoworld	
STI-IEM-NAM		SB-SPC-II		PSI_TOMAC		Edwatec	Novagan	
STI-IEM-NANOLAB				UNIBAS		EI_Richemont_Intl	Oxford_Ionics	
STI-IEM-PHOSL			Cen	UNIBAS_2		Enlightra	Pi_Imaging	
STI-IEM-POWERLAB			AVP	UNIBE-Eco-Evol		EXALOS	Piemacs	
STI-IEM-PV-LAB			AVP	UNIFR_Chemistry		FEMTOprint	Q_Ant	
STI-IEM-SCI-SC				UNIGE_CHIAM		Festo_Microtech	QBP	
STI-IGM-EMSI				UNIGE_DPNC		Foxmat	Richemont	
STI-IGM-ETA-LAB				UNIGE_DQMP		Freshape	Richemont_Intl	
44 (344)		20 (119)	14 (27)	38 (66)		70 (153)		

- Bio Engineering
- Mechanical Engineering
- Physics
- Global Health
- Materials
- Swiss Inst. for experimental cancer research
- CERN CSEM PSI EMPA ETHZ Universities
- Startups SMEs Large enterprises
- Electrical and Micro Engineering
- Chemical Sciences and Engineering
- Computer & Commn. Sciences
- Civil & Environmental Engineering

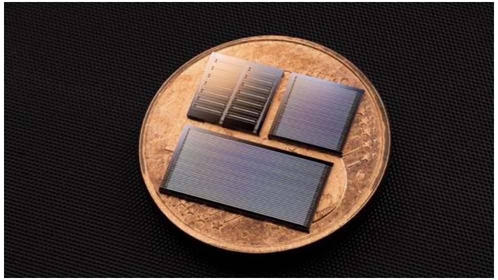
# of laboratories

# of users

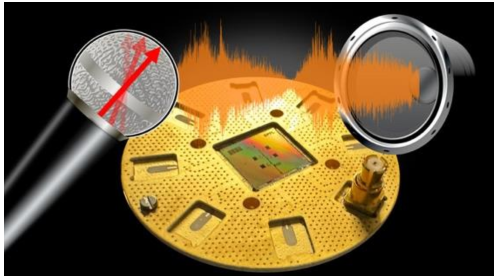
- Total: 116 labs & 70companies (total of 709 users)

CMi inside

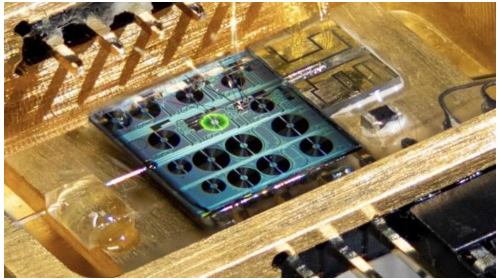
Kippenberg (PHOTONIC INTEGRATED CIRCUITS)
Nature
https://doi.org/10.1038/s41586-024-07369-1
May 2024



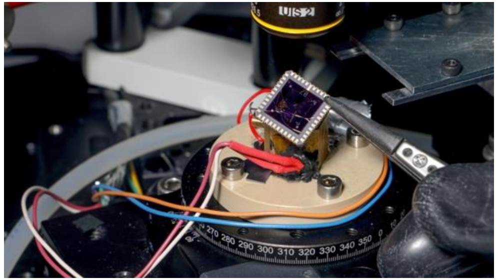
Kippenberg (QUANTUM COMPUTING)
Nature Communications
https://doi.org/10.1038/s41467-024-48230-3
May 2024



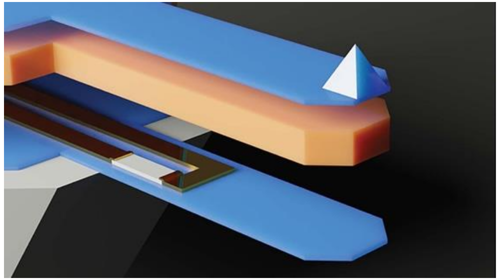
Kippenberg (Photonics)
Nature Photonics
https://doi.org/10.1038/s41566-024-01454-7
June 2024



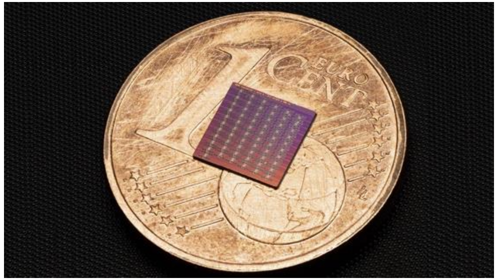
Kis (ELECTRONICS)
Nature Nanotechnology
https://doi.org/10.1038/s41565-024-01717-y
July 2024



Fantner (MEMS)
Nature Electronics
https://doi.org/10.1038/s41928-024-01195-z
July 2024

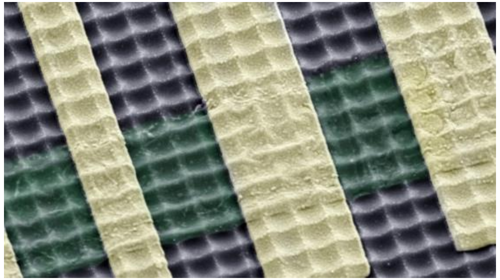
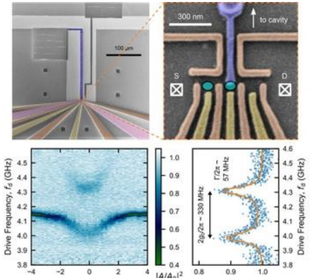
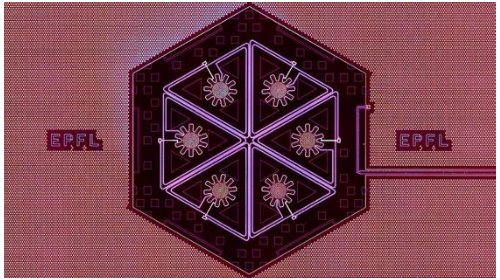
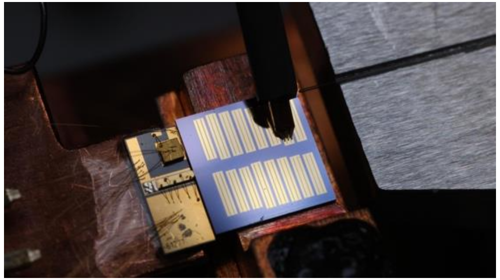
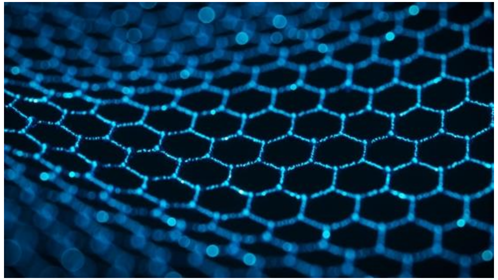
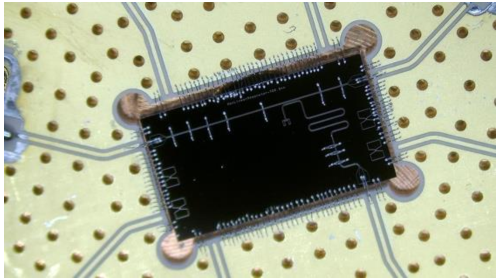


Kippenberg (QUANTUM COMPUTING)
Nature Communications
https://doi.org/10.1038/s41467-024-49467-8
July 2024



- A selection of publications which attracted special interest (last 12 months)
- Publications in high impact journals were relayed onto the EPFL home page

CMi inside

Brugger (NANOTECHNOLOGY) Nature Communications https://doi.org/10.1038/s41467-024-51165-4 August 2024	Scarlino (QUANTUM COMPUTING) Nature Communications https://doi.org/10.1038/s41467-024-54520-7 November 2024	Kippenberg (QUANTUM SCIENCES) Science https://doi.org/10.1126/science.adr8187 December 2024
		
Kippenberg (PHOTONICS) Nature https://doi.org/10.1038/s41586-024-08354-4 January 2025	Banerjee (QUANTUM ELECTRONICS) Nature Communications https://doi.org/10.1038/s41467-025-56141-0 February 2025	Scarlino (Quantum Physics) Nature Communications https://doi.org/10.1038/s41467-025-56830-w March 2025
		

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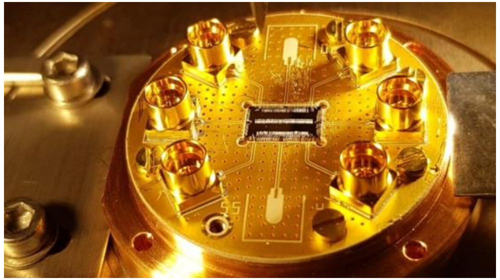
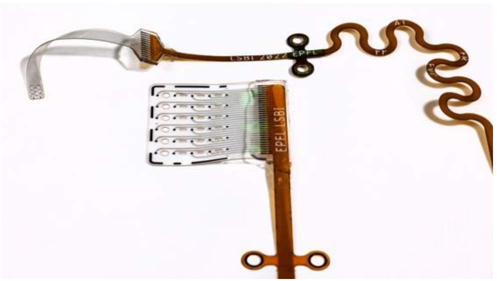
CMi inside

Kippenberg (PHOTONICS) Nature https://doi.org/10.1038/s41586-025-08666-z March 2025	Scarlino (QUANTUM PHYSICS) Nature Communications https://doi.org/10.1038/s41467-025-58595-8 April 2025	Lacour (BIOMEDICAL) Nature Biomedical Engineering https://doi.org/10.1038/s41551-025-01378-9 April 2025
		

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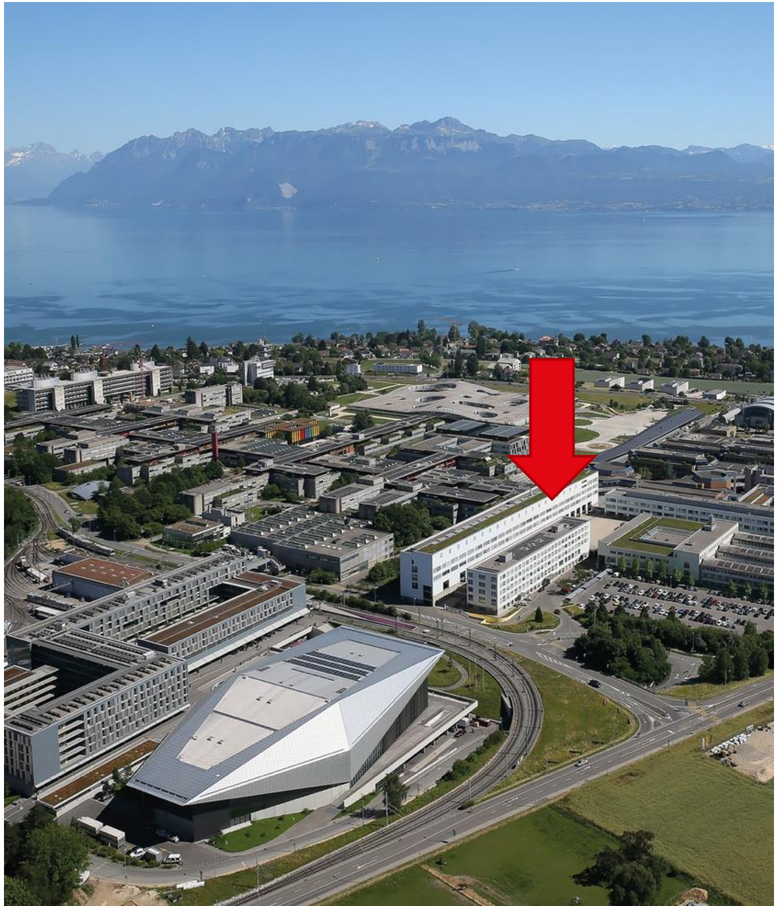
Cleanroom in BM Building

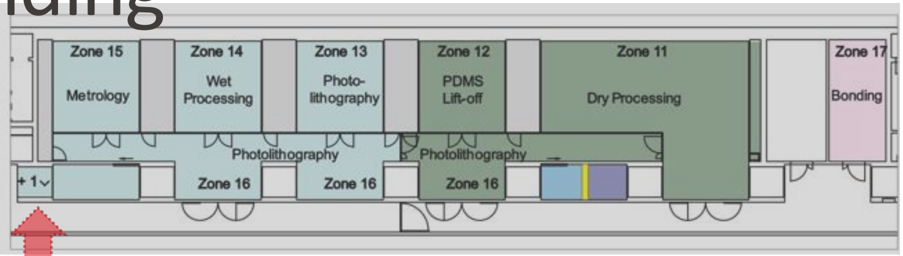


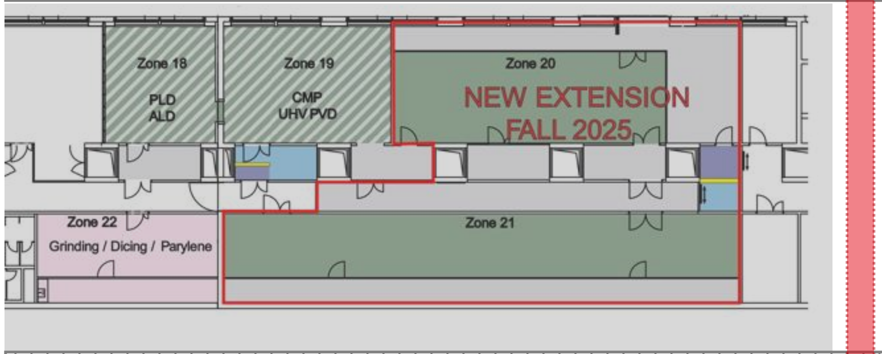
- Entrance
- Changing Room
- Clean Room ISO 5 / Class 100
- Clean Room ISO 6 / Class 1'000
- Clean Room ISO 7 / Class 10'000
- Technical Area ISO 7 / Class 10'000
- Non - Clean Room Working Area

Initial surface BM-1 (1998)	900m^2
Extension BM+1 (2010)	350m^2
Extension BM0 (2017)	150m^2
Extension BM0 (2025)	440m^2
Total Surface	1840m^2

Cleanroom in BM Building

Floor +1





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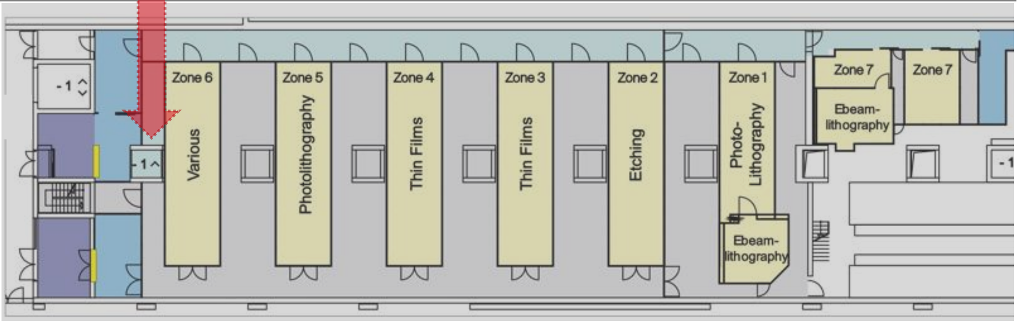
- Entrance
- Changing Room
- Clean Room ISO 5 / Class 100
- Clean Room ISO 6 / Class 1'000
- Clean Room ISO 7 / Class 10'000
- Technical Area ISO 7 / Class 10'000
- Non - Clean Room Working Area

Floor -1



Capital Investment

- Processing Equipment

Scientific Equipment Levels -1 / 0 / +1	50 MCHF
Total	**50 MCHF**

- Cleanroom Infrastructures

Cleanroom Infrastructures Level -1	12 MCHF
Cleanroom Infrastructures Level +1	7 MCHF
Cleanroom Infrastructures Level 0 (1)	2 MCHF (2017)
Cleanroom Infrastructures Level 0 (2)	4 MCHF (2025)
Total	**25 MCHF**

- Total 75MCHF

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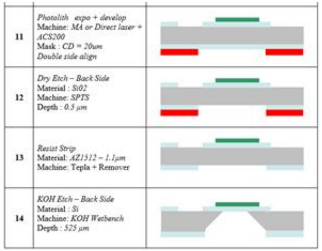
Cleanroom

1. **Safety and behaviour in the cleanroom**
   - Formal presentation of CMi facilities and CMi rules
   - Cleanroom visit
   - Email from CMi secretary with **process flow template + MCQ test link**

2. **Project approval by CMi process engineers**
   - You send a process flow or a draft to infocmi@epfl.ch
   - Process flow review by a technical committee
   - Email from CMi secretary (username, password)



11	Photolith expo + develop Machine: MA or Direct laser + ACS200 Mask : CD = 20um Double side align	
12	Dry Etch – Back Side Material : SiO2 Machine: SPTS Depth : 0.5 µm	
13	Resist Strip Material: AZ1512 – 1.1µm Machine: Tepla + Remover	
14	KOH Etch – Back Side Material : Si Machine: KOH Wetbench Depth : 525 µm	

3. **Start working in the cleanroom**
   - Trainings
   - Rights to book equipment
   - Work on your own according to process flow (reservation, login, processing, logout…)

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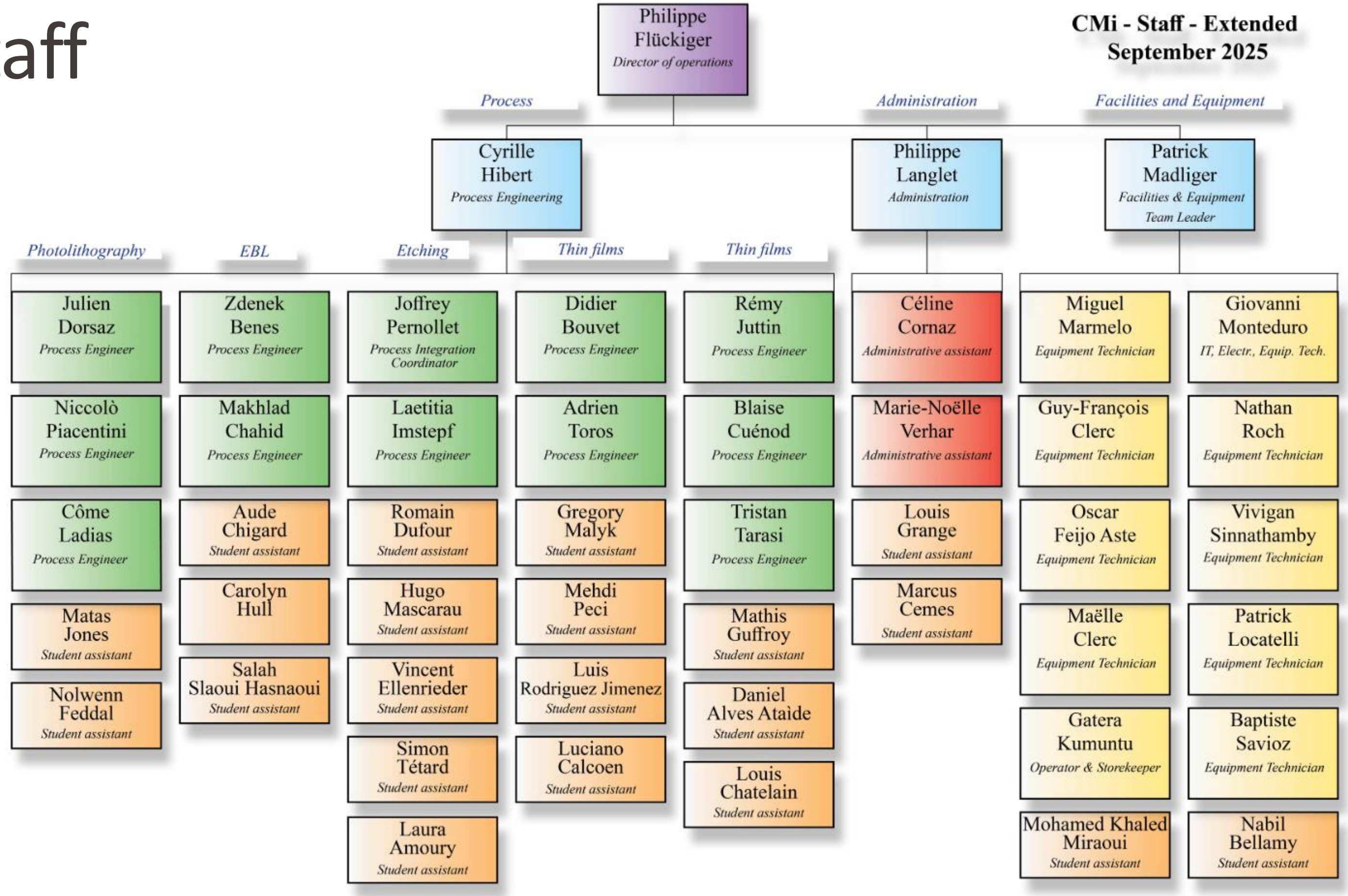
Staff



- The 21 student assistants play an important role in the daily operations
- They provide services and they perform training for the new users

5 open positions !!

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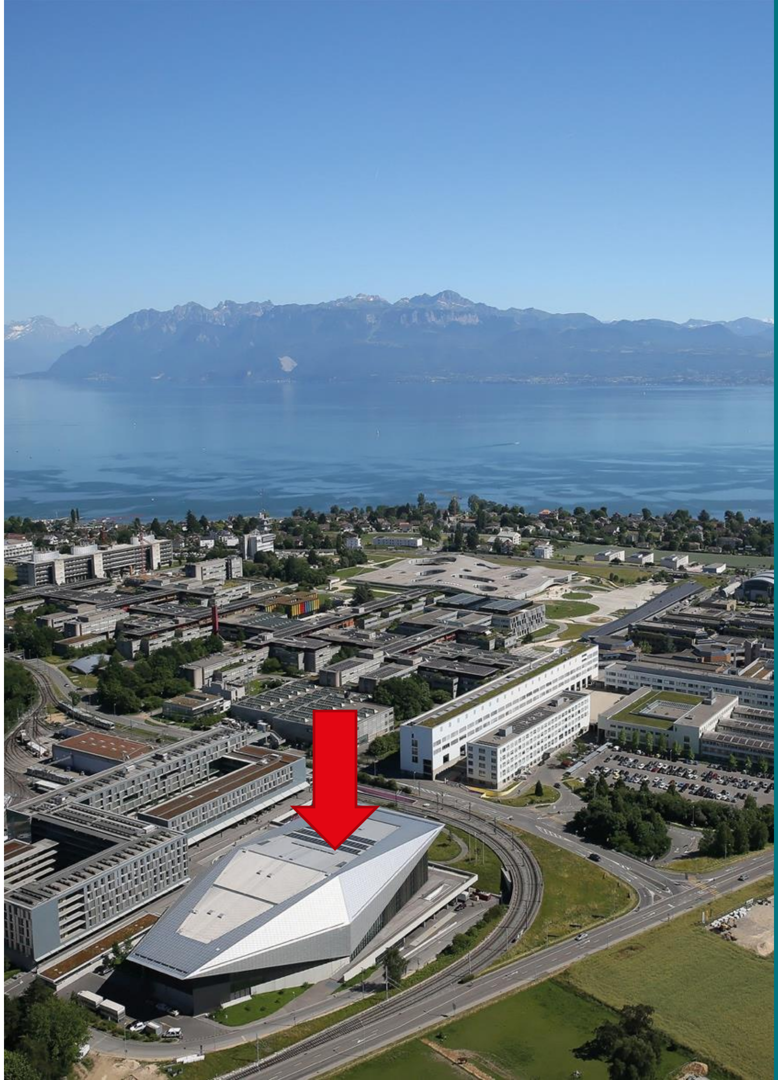


EPFL MicroNanoFabrication Annual Review Meeting

Philippe Flückiger, EPFL, May 13th, 2025

Next editions :

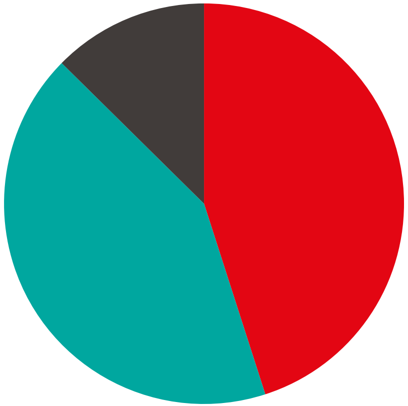
12.05.2026 – 25th edition

11.05.2027 – 26th edition

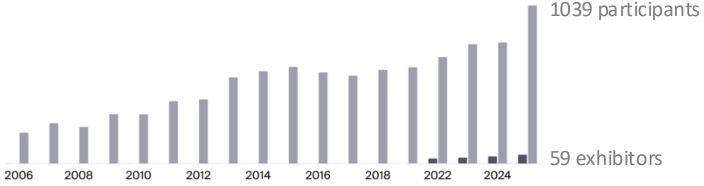
MicroNanoFabrication Annual Review Meeting

- 24th edition of the CMi MicroNanoFabrication Annual Review Meeting
- 1039 participants registered (with 42% from industry and 45% from EPFL)

- Global companies
- Local industry
- Startups
- Suppliers
- Government Agencies
- Researchers
- Faculty members
- Students
- Colleagues from other academic cleanrooms



899	(86.53%)
44	(4.23%)
40	(3.85%)
10	(0.96%)
9	(0.87%)
8	(0.77%)
8	(0.77%)
5	(0.48%)
4	(0.38%)
2	(0.19%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)
1	(0.1%)



- The list of participants is available to everyone
- Traveling from 20 different countries
- Fantastic opportunity for networking

EPFL

MicroNanoFabrication Annual Review Meeting

Exhibitors

- 59 companies
- Thank you to all of them

59 exhibitors

EPFL

Program

List of posters

- The 192 posters presented today are available online
- Password is available on request
- A few paper brochures are available

hhttps://cmiaccess.epfl.ch/projects/

EPFL CMi

Merci

Thank you for your attention

Joffrey Pernollet

École polytechnique fédérale de Lausanne

Today's program

- 1st hour:
  - Teaching staff presentation (10')
  - Course objectives: "Learn how to make a microchip" (10')
  - Cleanroom (CMI) presentation / you can join CMI as AE (10')
  - Micro-331 course organization & assessment (10')
- 2nd hour:
  - Student-led-tutorials (SLT) (10')
  - A.I. Tutor Bot (5')
  - Mixed Reality in TP-332 (10')
  - How to use the MOOC (10')
  - Q&A (10')

Course organization & assessment

Teaching methods

- MOOC
  - self-paced
- Online quizzes
  - ungraded for self-assessment
- Ex-cathedra lectures (~6 times)
  - Professors with application examples
- Student-led-tutorials (SLT) (6 times)
  - student presents and discusses in groups

Week	Day / Date	Room	Lecture	MOOC	SLT
1	Wed / 10 Sep	CE 12	All		
	Thu / 11 Sep	CE 12		X	
2	Wed / 17 Sep	CE 12		X	
	Thu / 18 Sep	CE 12		X	
3	Wed / 24 Sep	+++			SLT_1 MEMS & CR
	Thu / 25 Sep	CE 12		X	
4	Wed / 1 Oct	CE 12	YZ		
	Thu / 2 Oct	CE 12		X	
5	Wed / 8 Oct	+++			SLT_2 CVD
	Thu / 9 Oct	CE 12		X	

6	Wed / 15 Oct	CE 12	YZ		
	Thu / 16 Oct	CE 12		X	
7	Wed / 22 Oct		break		
	Thu / 23 Oct		break		
8	Wed / 29 Oct	+++			SLT_3 PVD
	Thu / 30 Oct	CE 12		X	
9	Wed / 5 Nov	CE 12	Guest lecture by Minshen Zhu		
	Thu / 6 Nov	CE 12		X	
10	Wed / 12 Nov	+++		X	SLT_4 Litho
	Thu / 13 Nov	CE 12		X	

11	Wed / 19 Nov	CE 12	JB		
	Thu / 20 Nov	CE 12		X	
12	Wed / 26 Nov	+++			SLT_5 DE
	Thu / 27 Nov	CE 12		X	
13	Wed / 3 Dec	CE 12	Guest lecture by Giuseppe Schiavone		
	Thu / 4 Dec	CE 12		X	
14	Wed / 10 Dec	+++			SLT_6 WE
	Thu / 11 Dec	CE 12		X	
15	Wed / 17 Dec	CE 12	YZ		
	Thu / 18 Dec	CE 12	JB + YZ		

Everything will be on MOODLE

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

For all course relevant information and updates

Rehearsal quizzes

- MOOC & Moodle
- Not graded
- Recommended to self-assess your knowledge

ED Discussion forum

Class forum for Q&A

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

First year with A.I. Tutor Bot (to be activated)

TA's and AE will moderate

Grading Information

- Written exam in January (75%)
- 6 SLT sessions during semester (25%)
- Material from the MOOC and classroom teaching part of 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
  - SLT exercises in groups
  - Talk to the TA's, teaching staff, and Professors
  - Use the discussion forum

Today's program

- 1st hour:
  - Teaching staff presentation
  - Course objectives: Learn how to make a microchip?
  - Cleanroom (CMI) presentation / join CMI as AE and become an expert
  - Micro-331 course organization & assessment
- 2nd hour:
  - Student-led-tutorials (SLT)
  - Research in Micro-331 (SLT, AI Tutor Bot)
  - Mixed Reality study in TP-332
  - How to use the MOOC, with TA's / AE's
  - Start with MOOC

SLT’s

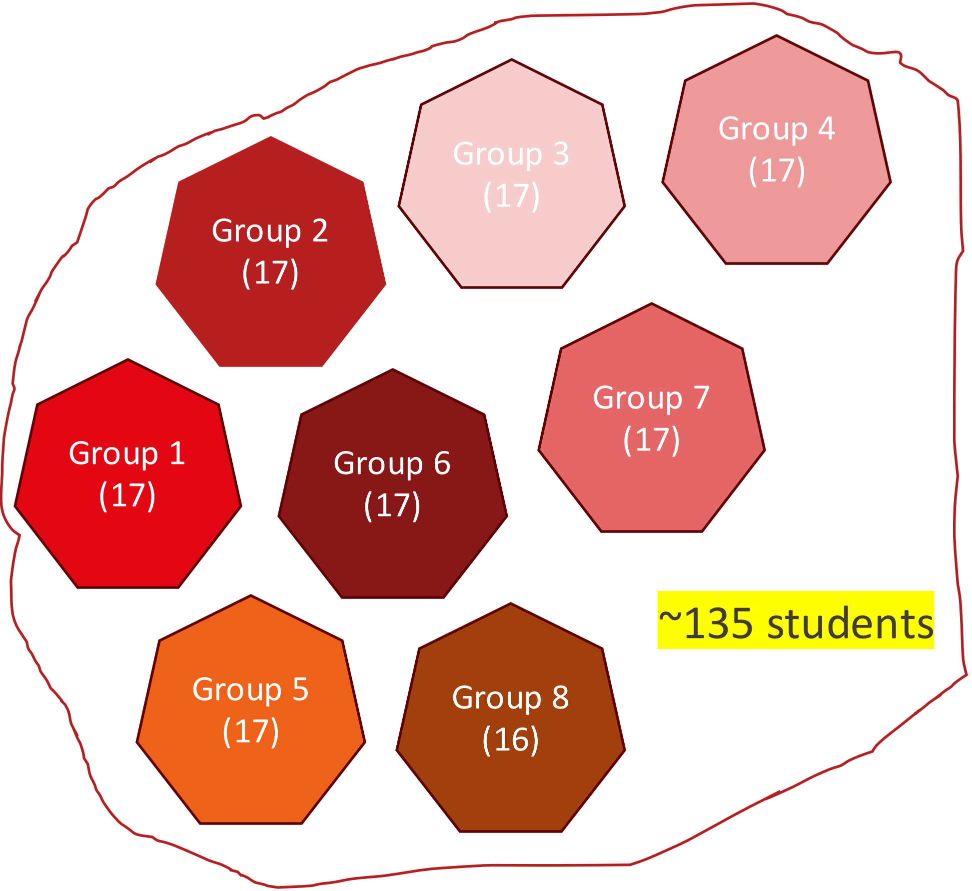
Student-led-tutorials

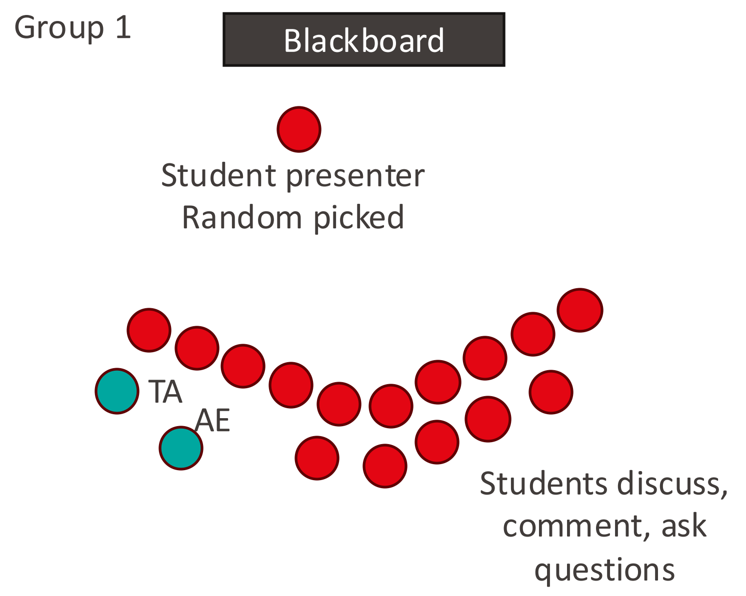
Student led tutorials (SLT)

- We will form 8 groups of 18-20 students
- We will conduct 6 SLT sessions throughout the semester (~biweekly)
- 1 week before each SLT session, 6 questions related to the course topic will be available to prepare.
- Before each SLT session, every students declares to be ready (or not) to present in the group, in case he/she is random picked.
- In each SLT session, TA will random pick 6 students (one after the other) to present the solution for one of the questions.
- Each question takes 15 min.
- SLT's are not an exam; the goal is to learn to present and discuss process flows for microfabricated devices (like sharing a recipe for a good meal).

Student led tutorials (SLT)

NOT an Exam





We have 8 rooms, 1 for each group
6 questions per SLT session, 15 min each

Grading of student led tutorials (SLT) = 25% of final grade

- Participation in SLT is part of the course and an essential learning activity
- Last years' students gave very positive feedback
- Come prepared to be able discuss is important to gain new knowledge
- Discussing possible routes is more useful than having the exact solution

# of SLT's attended and ready to present	# of SLT's with presentation(s)	Presentation quality		
		A Very good	B Good	C Insufficient
5 or 6	≥ 1	6	5.5	4
4	≥ 1	5	4.5	3
3	≥ 1	4	3.5	2
2	≥ 1	3	2.5	1
1	≥ 1	2	1.5	0
0	0	0	0	0

Research in Student-Led Tutorials (SLTs)

Iris Capdevila
Teaching advisor
EPFL teaching support center (CAPE)

Research in Student-Led Tutorials (SLTs)

- AIM: **Measure your engagement with SLTs and the impact on learning.**

- Relevant information:
  - No additional requirements on top of what you are supposed to do in your course.
  - No impact on your grade or your interaction with the course.
  - No obligation to participate
  - E-mail from Joelyn de Lima with more detailed information, including how to withdraw.

- More information, questions… contact us: iris.capdevila@epfl.ch or joelyn.delima@epfl.ch

A.I. Tutor Bot

A.I. Tutor Bot

- A pilot study conducted by the Center for Digital Education at EPFL
- LLM backed tutor which has access to the teaching material
- Tutor Bot supports teaching team in replying to student questions in the ED Discussion Forum
- Pilot phase to evaluate effectiveness
- How it works? (we are using the safe mode)
  - You ask your question on ED Discussion
  - A.I. Tutor Bot prepares answer
  - TA/prof will check answer
  - Vetted answer is provided to ED Discussion

Mixed reality: learning in microfabrication

If you are curious and interested, you have the opportunity to try out our MR googles during a scientific experiment in microfabrication.

Qinglan Shan, PhD student in EPFL/ETHZ learnings sciences.

Research in Mixed Reality (MR)

- AIM: **Measure your engagement, cognitive load, and learning gain with Mixed reality in the cleanroom.**

Relevant information:

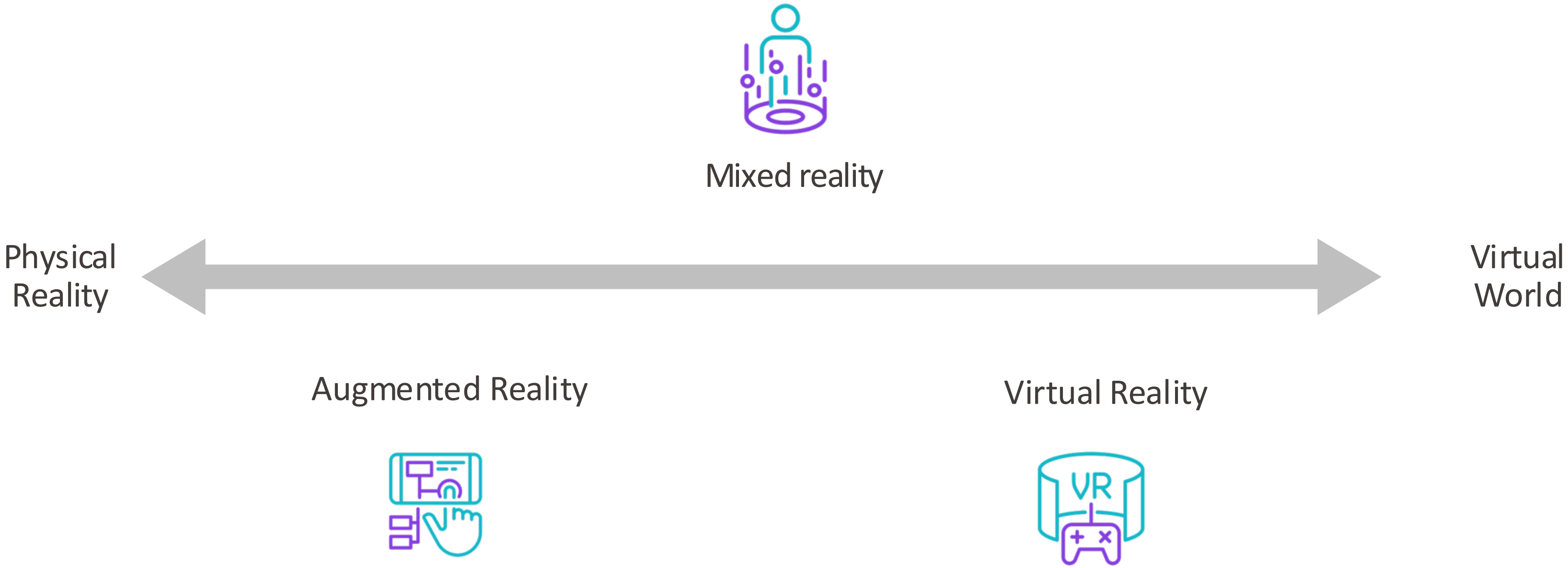
- Participation is on voluntary basis (opt-in).
- The hands-on TP Micro-332 is not replaced by MR.
- Only 20 minutes of pre-training is added to your TP.
- No impact on your grade.

- More information from Micro-332 teachers by email, moodle or presentation by Qinglan Shan.

- More information, questions… contact: qinglan.shan@epfl.ch


SIGN UP NOW
New Experience In Learning

Robert Snider


Mixed reality
Physical Reality
Virtual World
Augmented Reality
Virtual Reality
VR

What will you get from the MR experiment?

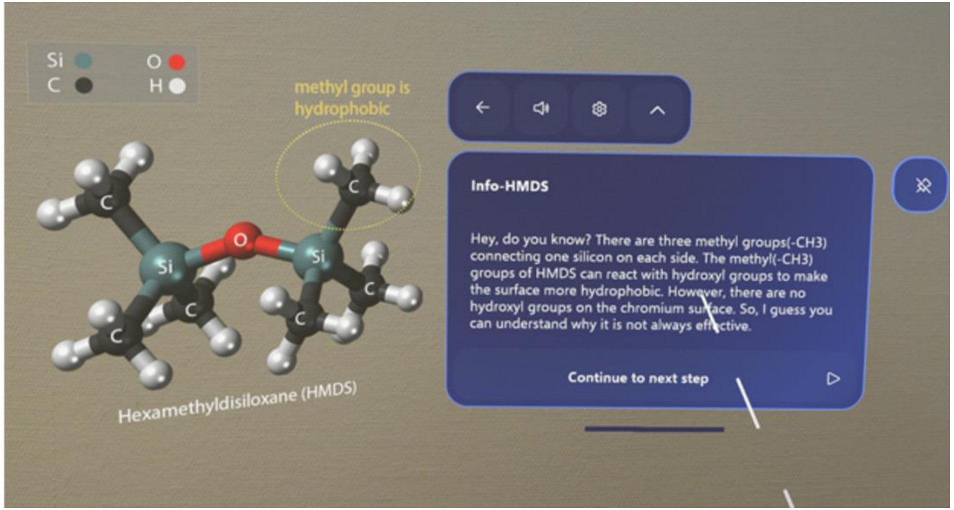
- Mixed Way of learning photolithography in both virtual and physical space
- New opportunities for learning from mistakes, visualization, interactions, inquiries
- Personalized speed for the learning process and steps
- Independent evaluation of your knowledge
- *Chocolates….*

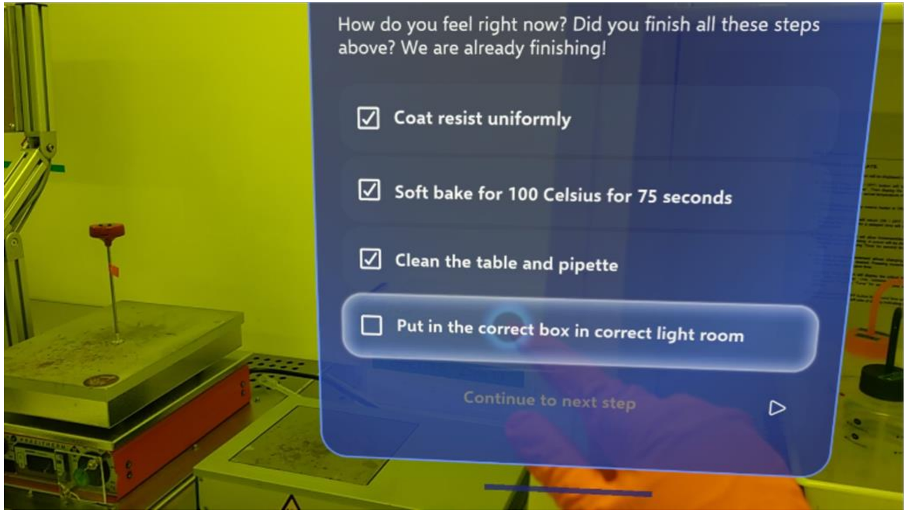

Screenshot

Photo taken

Screenshots

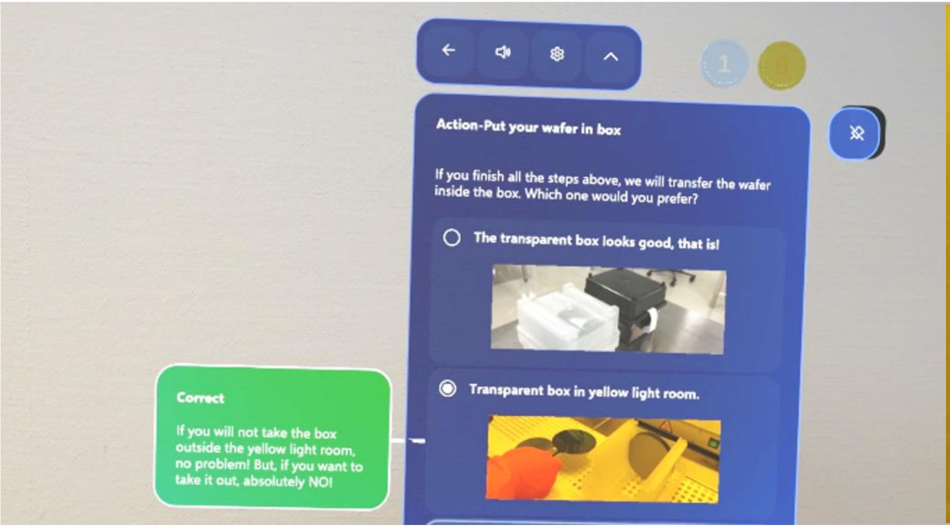
From previous semester

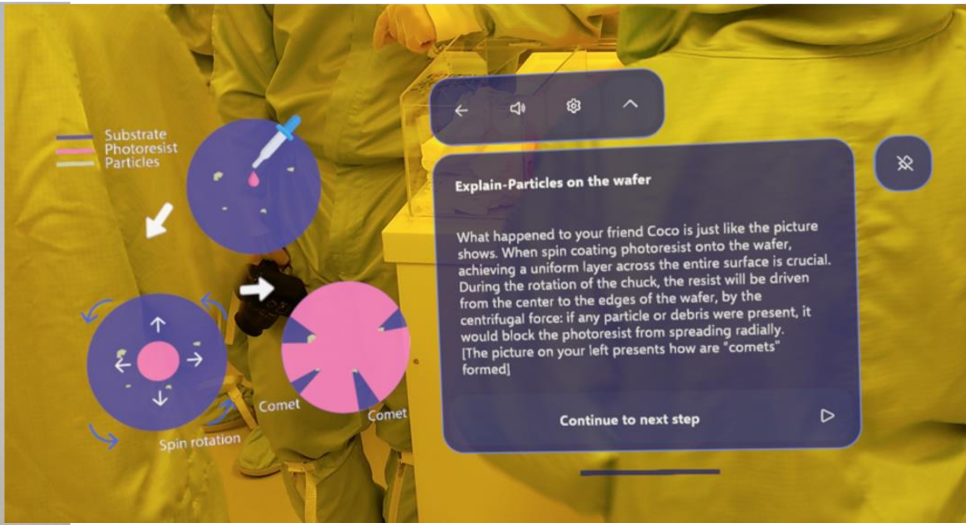




Screenshots

From previous semester





Your Privacy Matters

- You can join the experiment anonymously
- Your grades are independent of this study, the assessments during the training will be used for research only.
- NOT related to the academic evaluation
- Personal data collection with consent (Ethical approval HREC000439, EPFL)

EPFL

How can I join?

If you like the idea, join by scanning the QR code!

https://forms.gle/s1FxWiVEwdjuXdqc7
(updated)

Time: Around 20 mins preparation in advance + 30 mins in-lab experiment

Date: The same time for the cleanroom session (according to your schedule)

Topic: Photolithography learning/mask fabrication

Seats **Only the group that all students registered**

Treats: For extra hours spent we provide lottery vouchers and snacks

Reference:Shan, Q., Chatain, J., Kapur, M., & Brugger, J. (2024). MixedLAB: Mixed Reality to Teach Students Experimental Knowledge in Microfabrication. Proceedings of the 52nd Annual Conference of SEFI, Lausanne, Switzerland.https://doi.org/10.5281/zenodo.14256909

Guide how to use the MOOC

Why a MOOC for this course?

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

- Videos in CMI
- Animations
- Show how the microfabrication is done in the cleanroom

- Learn at your personal pace
- Prepare for TPs

Hands-on in microfab Micro-332

- TP Micro-332 with Jalil Sayah and TA's
- Do microfab by yourself.

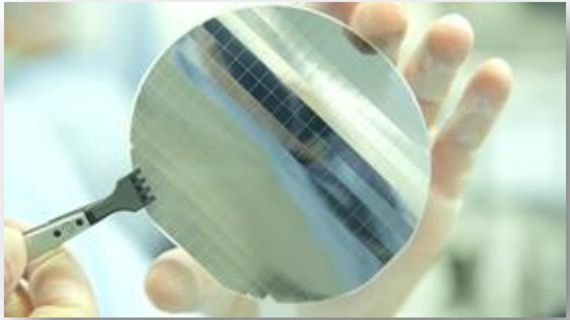
Class quiz #1

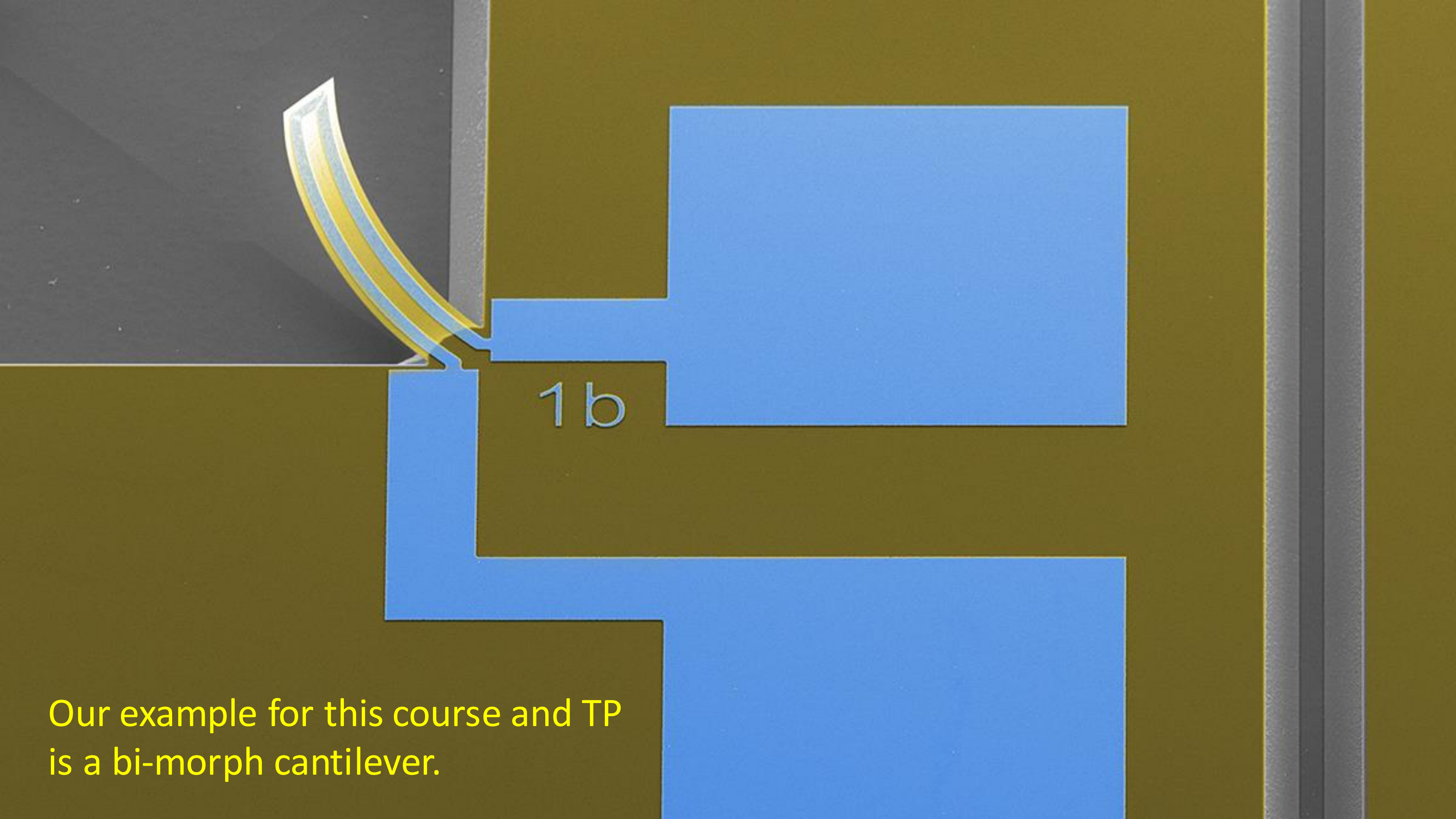
Questions for the course organization?

Backup slides

Learning objectives

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

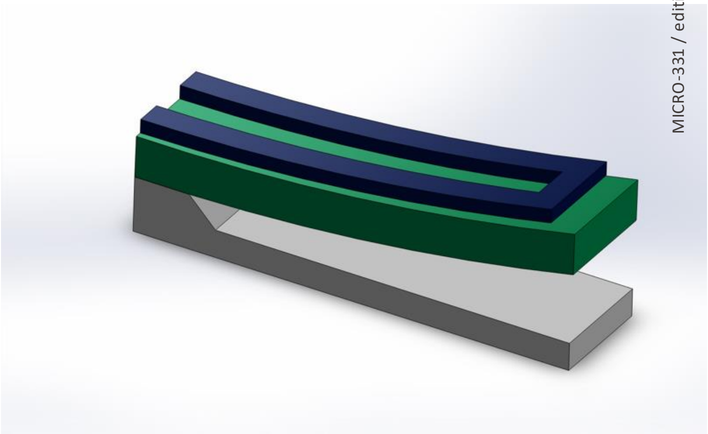




Our example for this course and TP is a bi-morph cantilever.

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



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

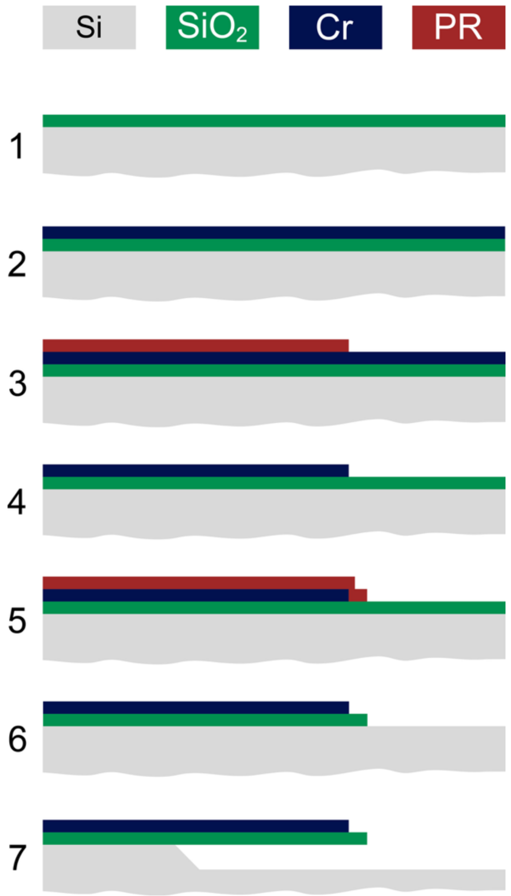
r: radius of curvature
β: constant, f(t, E)
α: thermal expansion coefficient [K^{-1}]
ΔT: temperature difference [K]

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

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.