Spitzentechnologie: heiss, schnell und höchstauflösend

Juergen Brugger & team

Microsystems Laboratory

EPFL Lausanne
Switzerland

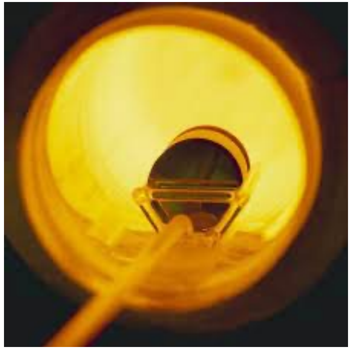
May 2023

École
polytechnique
fédérale
de Lausanne

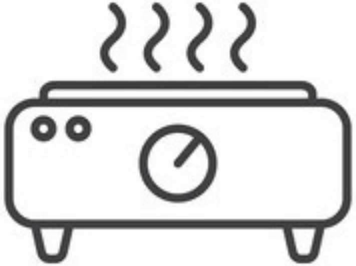
Heating in manufacturing

1) Furnaces
2) Hotplates
3) RTA
4) Laser

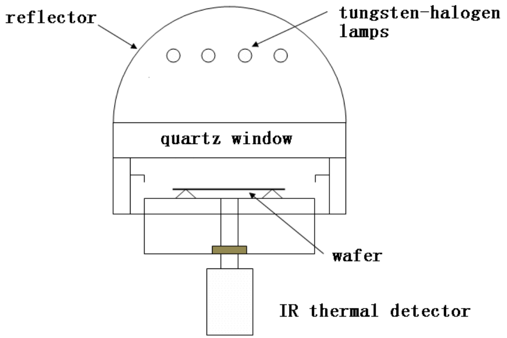
1) Batch process, slow



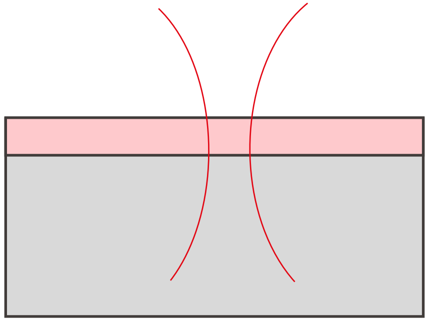
2) Wafer process
slow



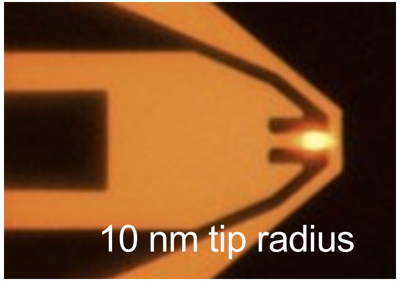
3) Surface heating ("fast")



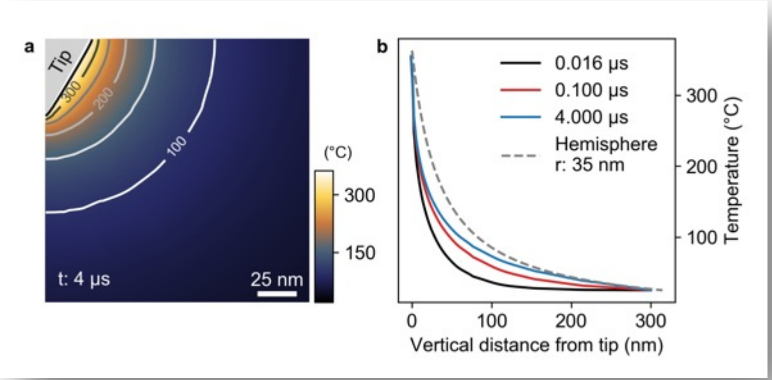
4) Very fast
Diffraction limited



Very hot, very short, and very local



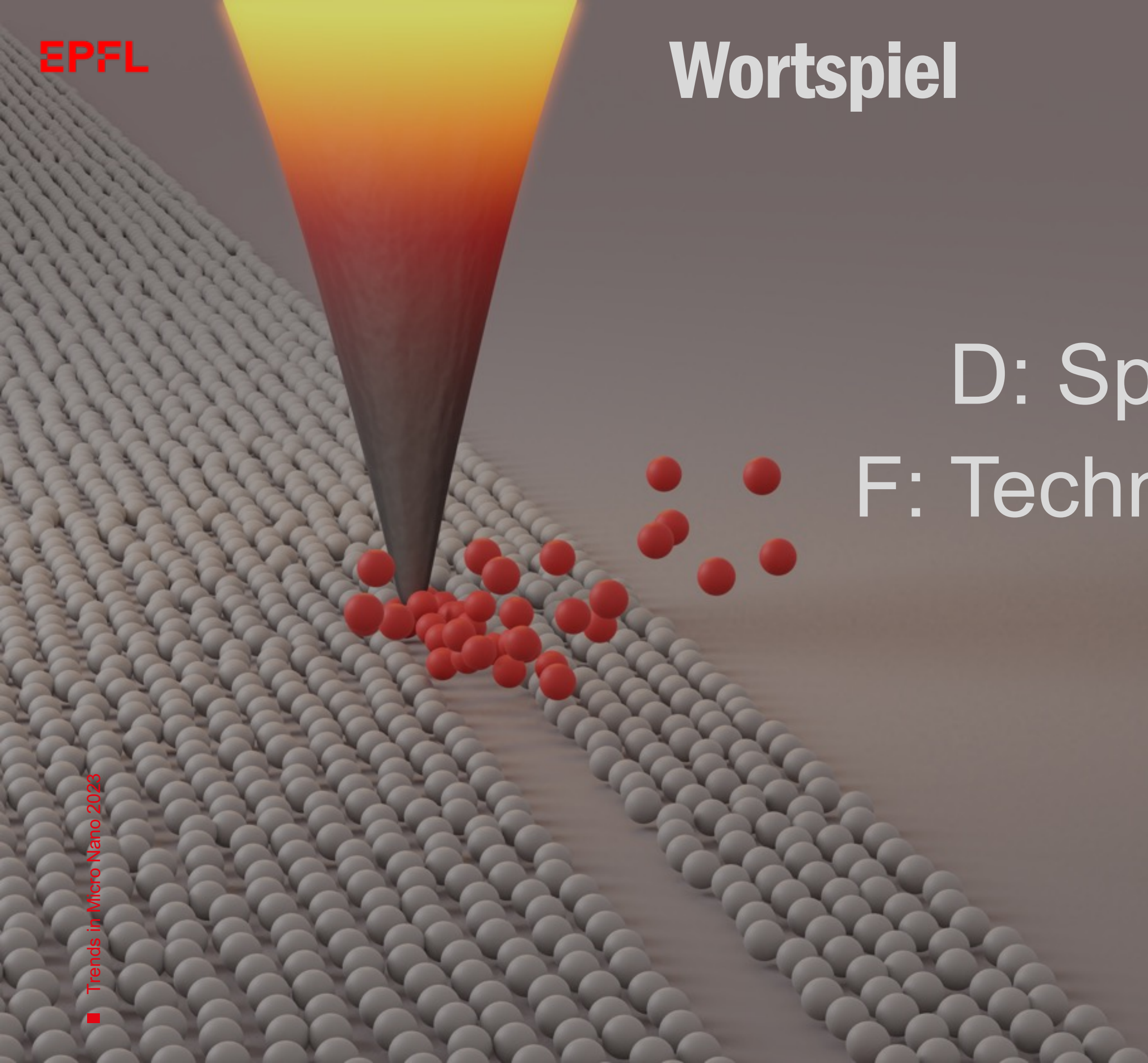
- T-SPL is fast:
  - Small thermal mass
  - Heating rate: 10E8 K/sec
  - ~ 400 deg C max in the material
  - Cooling by dissipation (10E8 K/sec)
- T-SPL is localized:
  - Tip size 10 nm, heat range
- Apply it to functional material that undergo fast property changes.



FEM of heat distribution around a tip for silk. Heater temperature 700 deg C, tip temperature 363 deg C

PhD thesis Samuel Zimmermann (EPFL) Sep 2018

Wortspiel

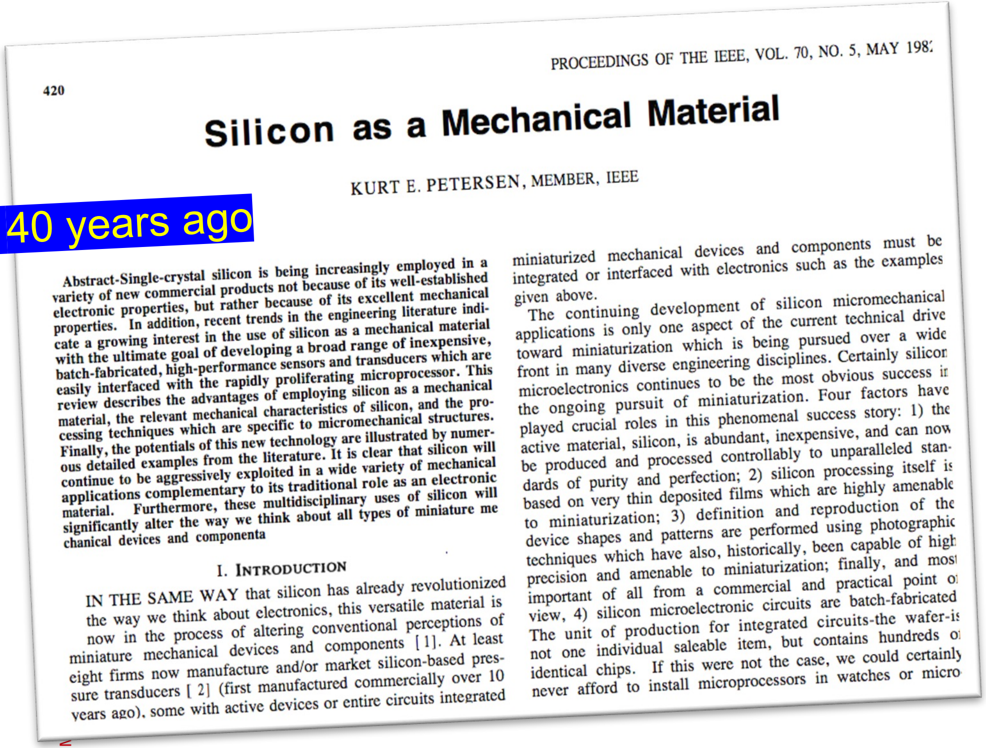


D: Spitzentechnologie

F: Technologie de pointe

E: High-tech …

Micro and Nanoengineering focus over the years



PROCEEDINGS OF THE IEEE, VOL. 70, NO. 5, MAY 1982

420

Silicon as a Mechanical Material

KURT E. PETERSEN, MEMBER, IEEE

Abstract-Single-crystal silicon is being increasingly employed in a variety of new commercial products not because of its well-established electronic properties, but rather because of its excellent mechanical properties. In addition, recent trends in the engineering literature indicate a growing interest in the use of silicon as a mechanical material with the ultimate goal of developing a broad range of inexpensive, batch-fabricated, high-performance sensors and transducers which are easily interfaced with the rapidly proliferating microprocessor. This review describes the advantages of employing silicon as a mechanical material, the relevant mechanical characteristics of silicon, and the processing techniques which are specific to micromechanical structures. Finally, the potentials of this new technology are illustrated by numerous detailed examples from the literature. It is clear that silicon will continue to be aggressively exploited in a wide variety of mechanical applications complementary to its traditional role as an electronic material. Furthermore, these multidisciplinary uses of silicon will significantly alter the way we think about all types of miniature mechanical devices and components

I. Introduction

IN THE SAME WAY that silicon has already revolutionized the way we think about electronics, this versatile material is now in the process of altering conventional perceptions of miniature mechanical devices and components [1]. At least eight firms now manufacture and/or market silicon-based pressure transducers [2] (first manufactured commercially over 10 years ago), some with active devices or entire circuits integrated miniaturized mechanical devices and components must be integrated or interfaced with electronics such as the examples given above.

The continuing development of silicon micromechanical applications is only one aspect of the current technical drive toward miniaturization which is being pursued over a wide front in many diverse engineering disciplines. Certainly silicon microelectronics continues to be the most obvious success in the ongoing pursuit of miniaturization. Four factors have played crucial roles in this phenomenal success story: 1) the active material, silicon, is abundant, inexpensive, and can now be produced and processed controllably to unparalleled standards of purity and perfection; 2) silicon processing itself is based on very thin deposited films which are highly amenable to miniaturization; 3) definition and reproduction of the device shapes and patterns are performed using photographic techniques which have also, historically, been capable of high precision and amenable to miniaturization; finally, and most important of all from a commercial and practical point of view, 4) silicon microelectronic circuits are batch-fabricated. The unit of production for integrated circuits-the wafer-is not one individual saleable item, but contains hundreds of identical chips. If this were not the case, we could certainly never afford to install microprocessors in watches or micro

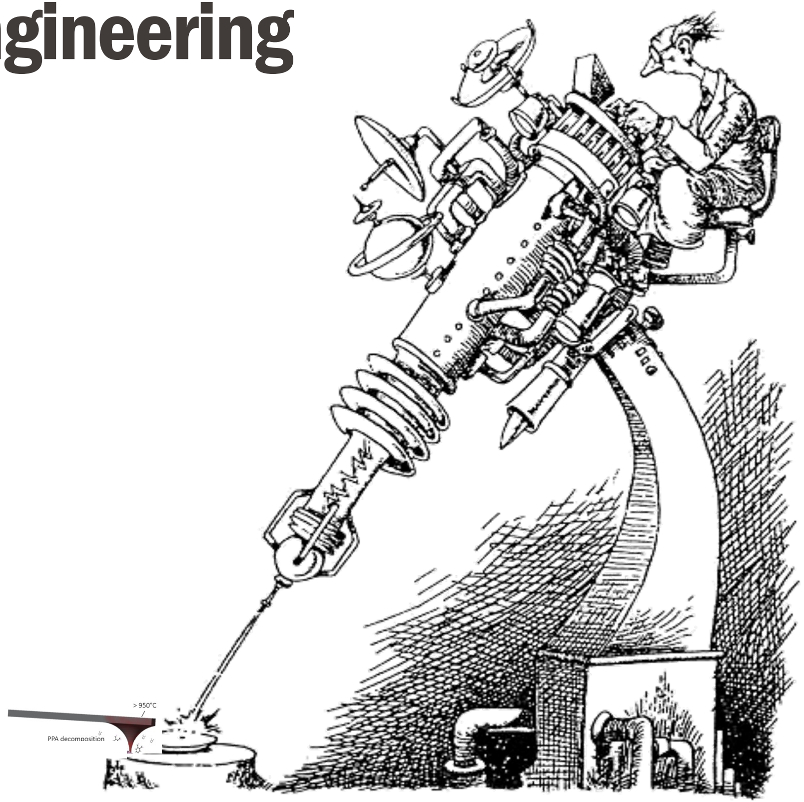
30+ years ago: Silicon related processing (PVD, CVD, etching, litho, CMOS driven)
20 years ago: resolution, thinner, new materials
10 years ago: 2D, polymer as structural material for microsystems (OE as electrical material)
Today: new toolbox to fabricate functional multi-material micro/nanosystems

Silicon: doping, crystal, mobility
Polymer: composites, intrinsic functionalities, nanomaterials

→ Need for gentle methods

EPFL

Big tools for small scale science/engineering

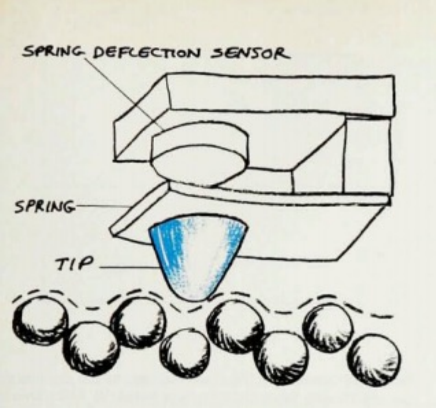


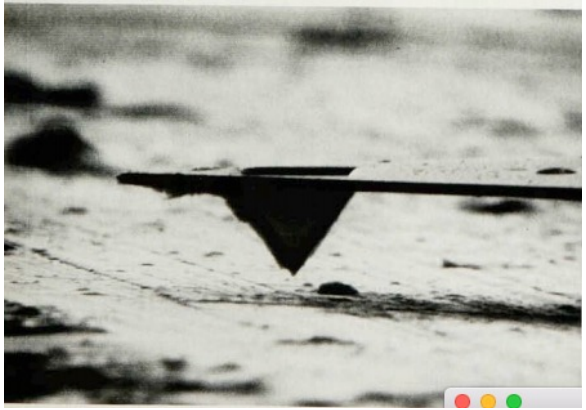
ATOMIC FORCE MICROSCOPY

It is surprisingly easy to make a cantilever with a spring constant weaker than the equivalent spring between atoms, allowing a sharp tip to image both conducting and nonconducting samples at atomic resolution.

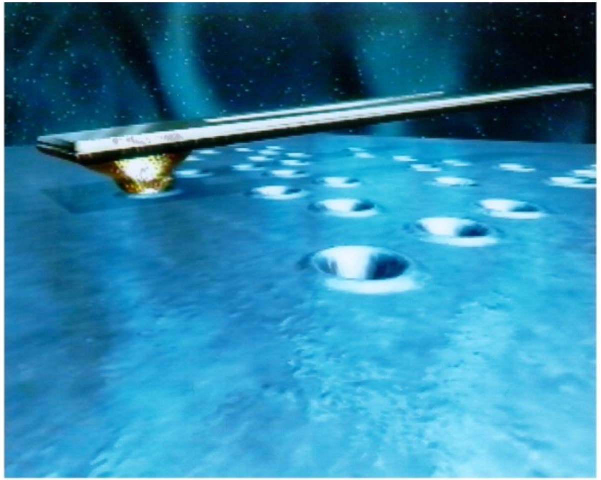
Daniel Rugar and Paul Hansma

1990 American Institute of Physics
PHYSICS TODAY OCTOBER 1990



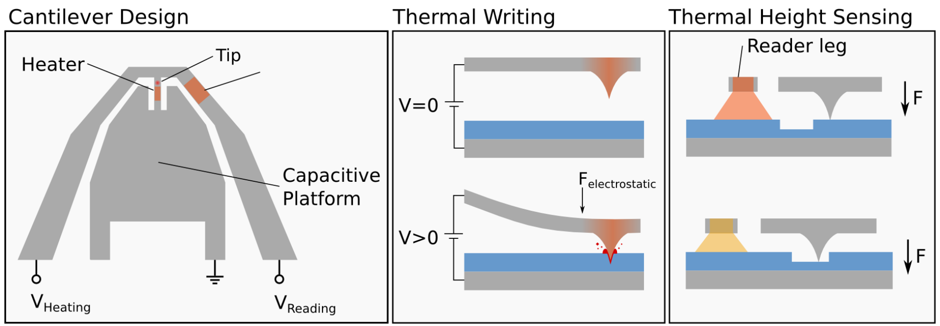


Thermal nanoprobe



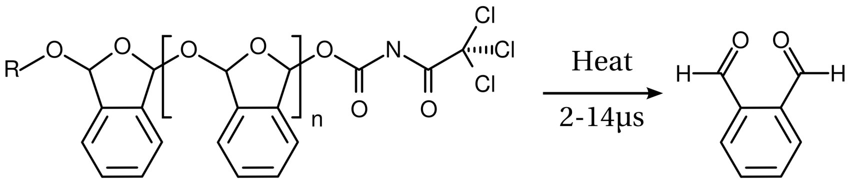
IBM Research

Patterning principle / Resist



- Electrostatic actuation
- Hot tip: Joule Heating
- Topography readout

Polyphthalaldehyde

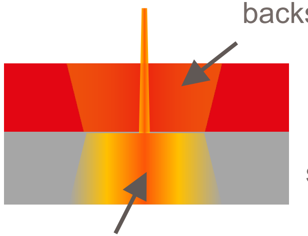


- Self-amplified depolymerization resist
- Metastable at room temperature
- Degrades when exposed to Heat or Acid

Heidelberg Instruments, Swisslitho, IBM

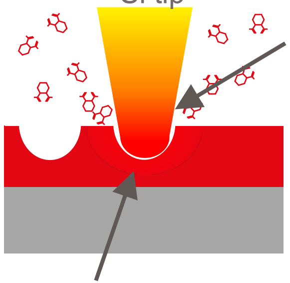
Electron beam versus thermal probe

Electron Beam Lithography



Possible damage of the substrate by lattice defects, vacancies or trapped charges
2D materials, organic molecules, dielectrics

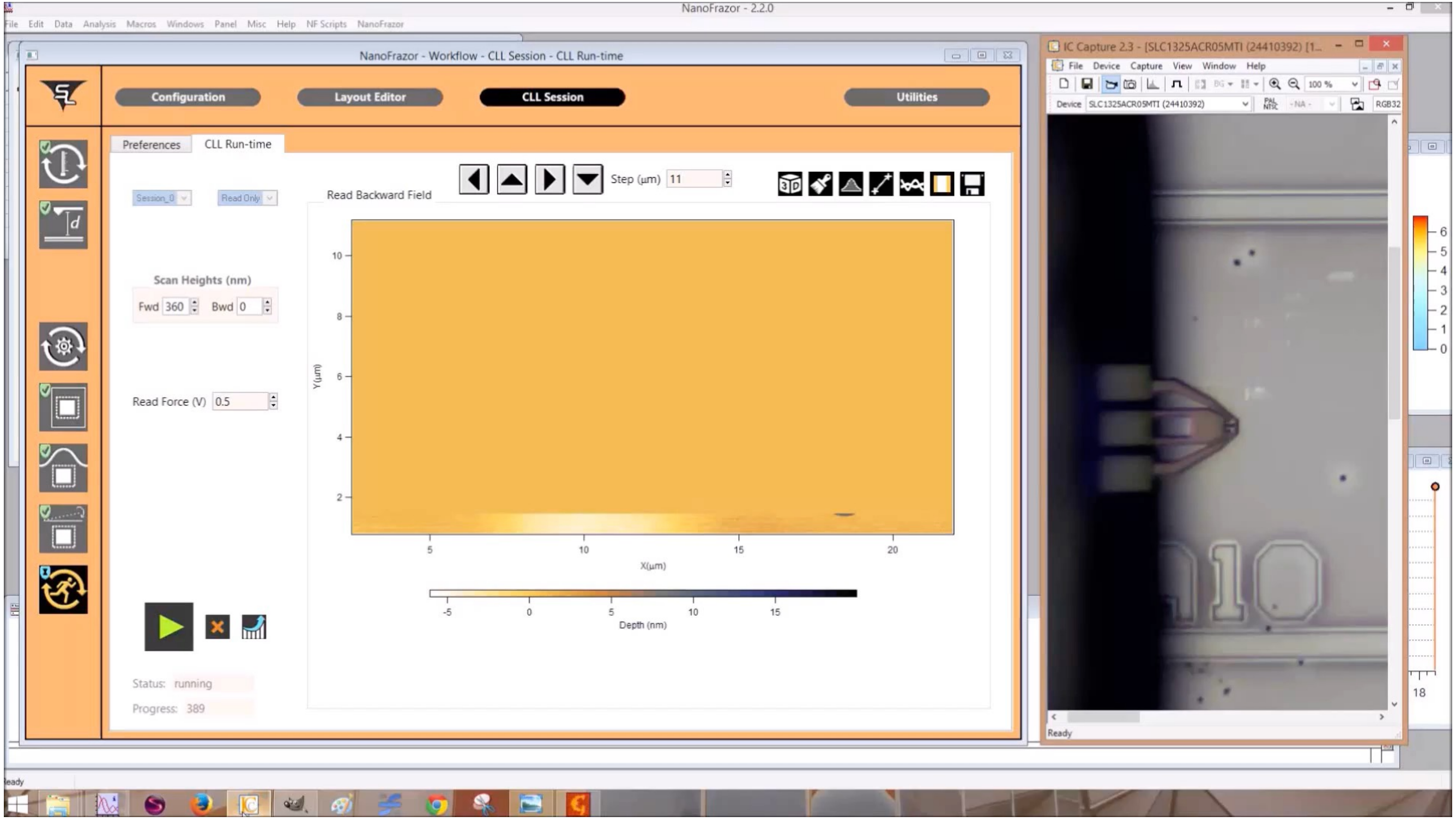
T-SPL



The substrate is hardly heated (in particular for substrates with a high heat conductivity or when a hard mask is applied under the PPA) and hence not damaged

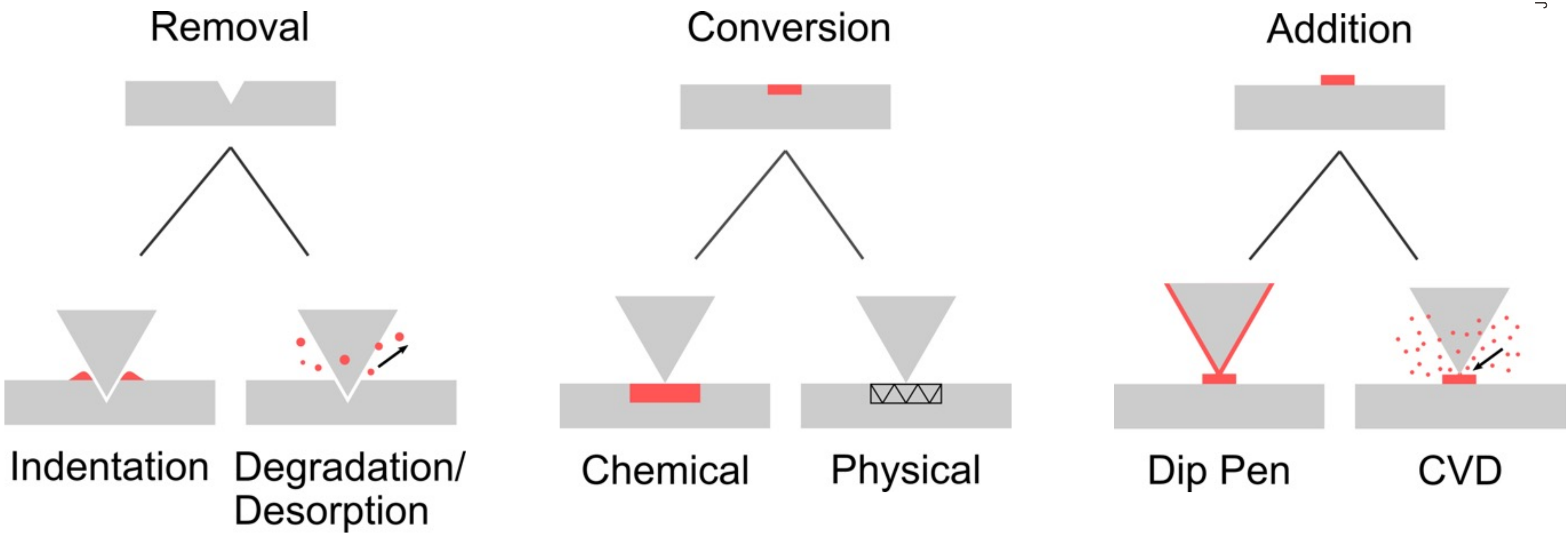
EPFL

Modern t-SPL system (closed loop)



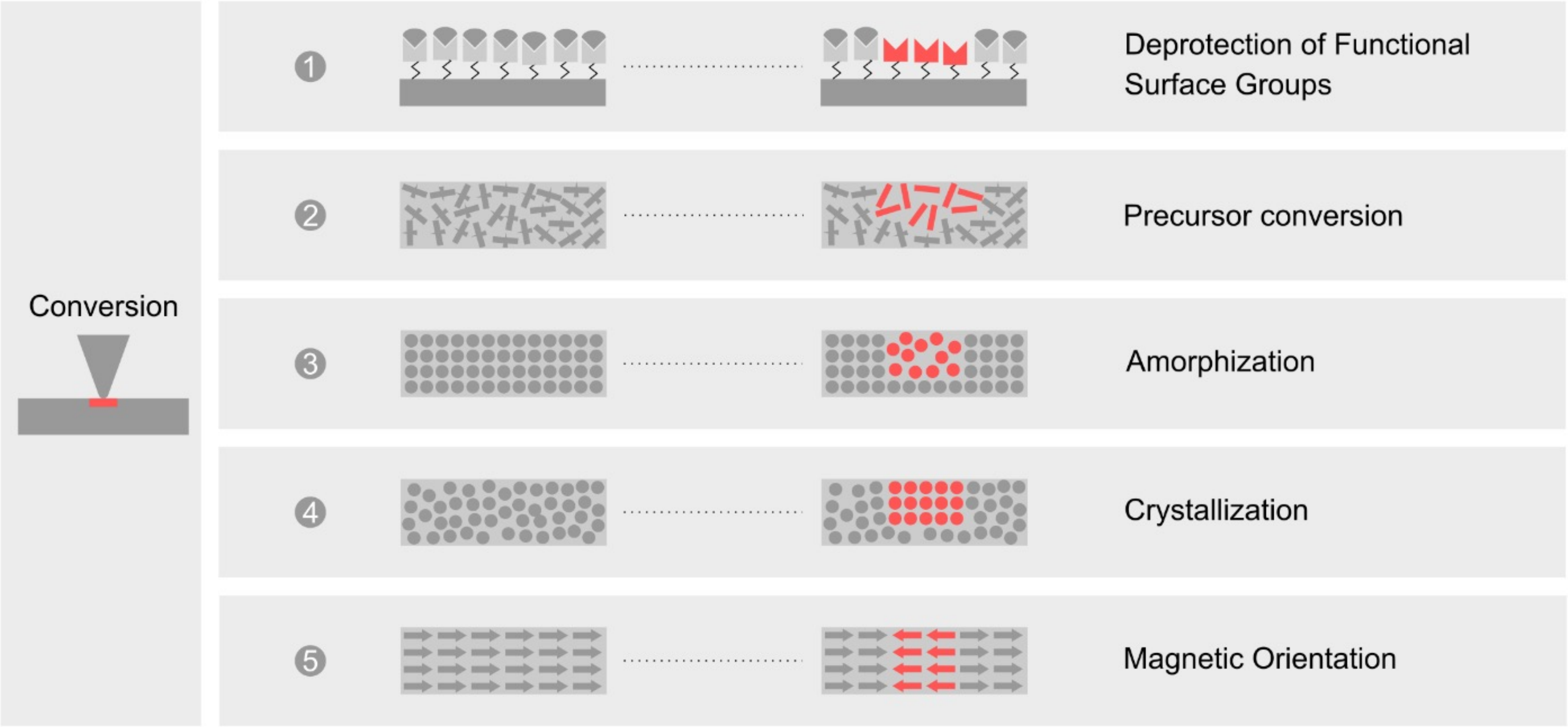
Heidelberg Instruments, Swisslitho, IBM

T-SPL surface patterning



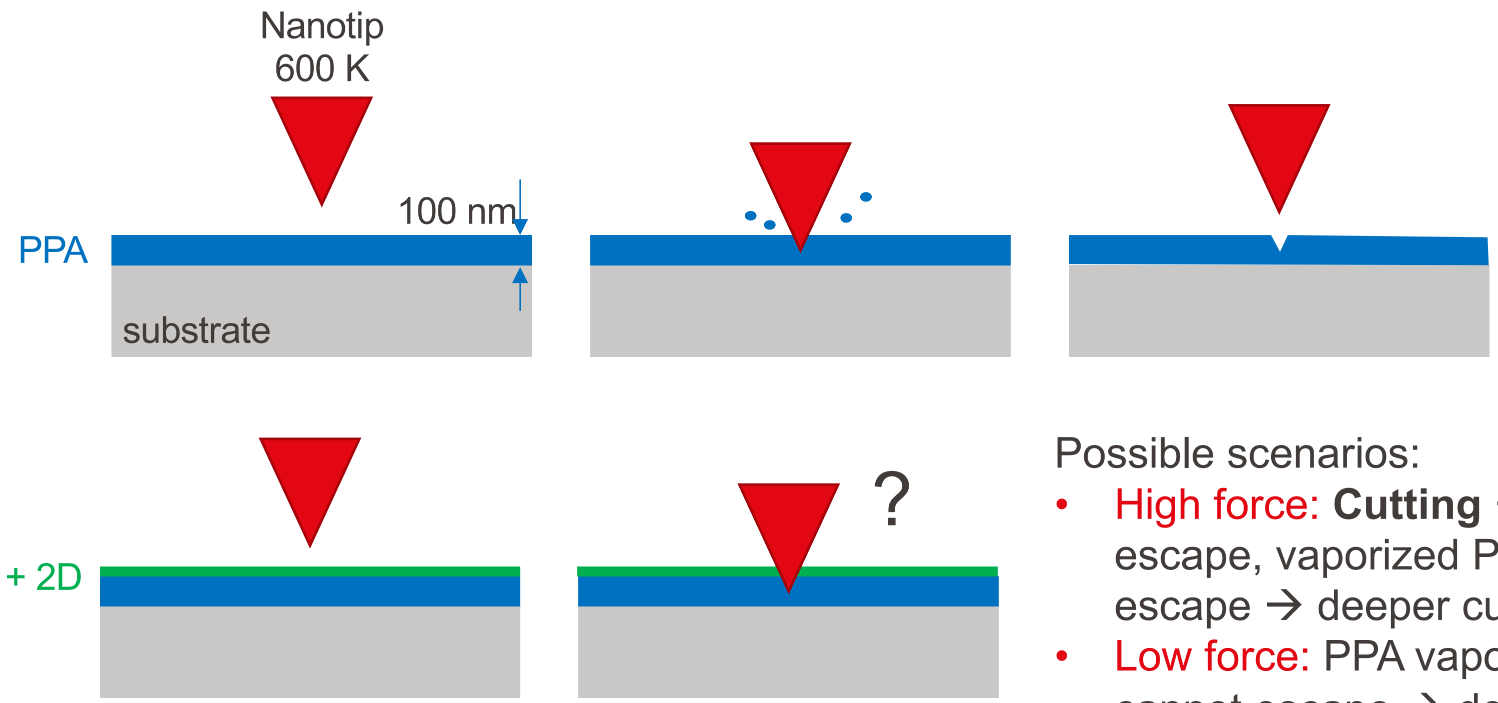
ST Howell et al. Microsystems & Nanoengineering, 2020

Conversion



ST Howell et al. Microsystems & Nanoengineering, 2020

Gedankenexperiment

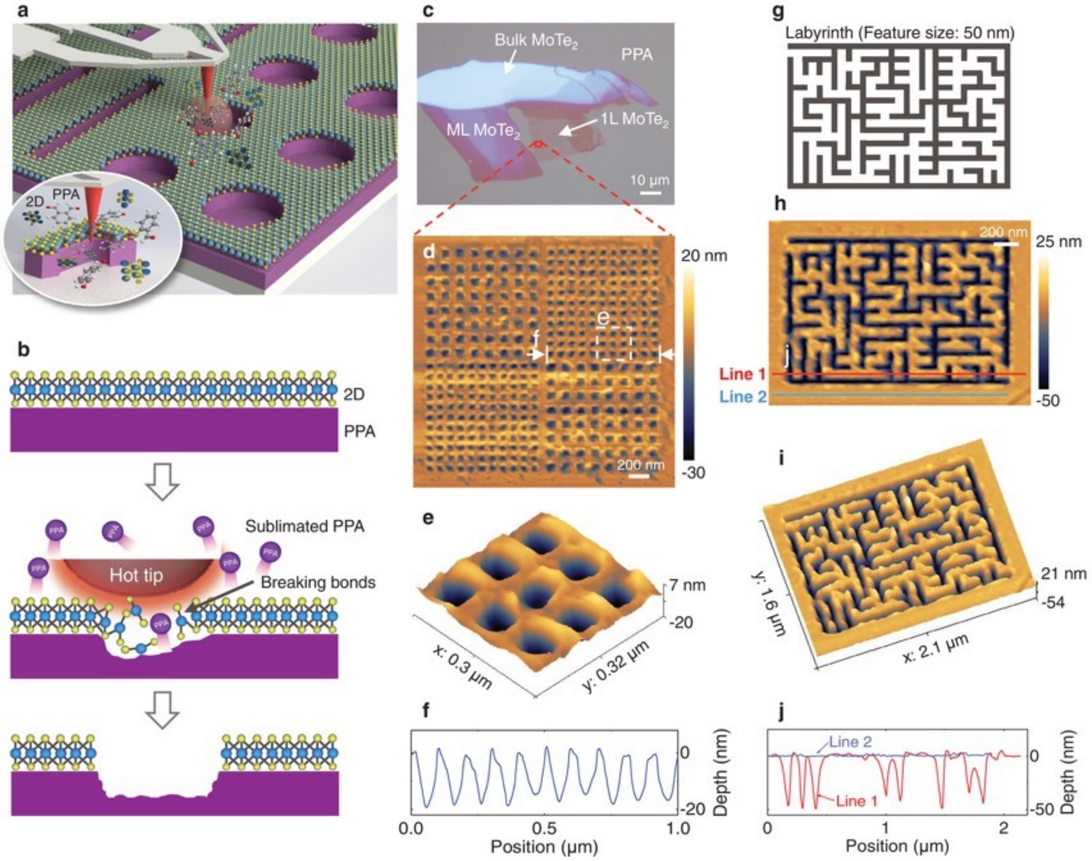


Possible scenarios:

- High force: **Cutting** → PPA can escape, vaporized PPA can escape → deeper cut
- Low force: PPA vaporizes but cannot escape → deformation → fast cooling → **Permanent Indentation**

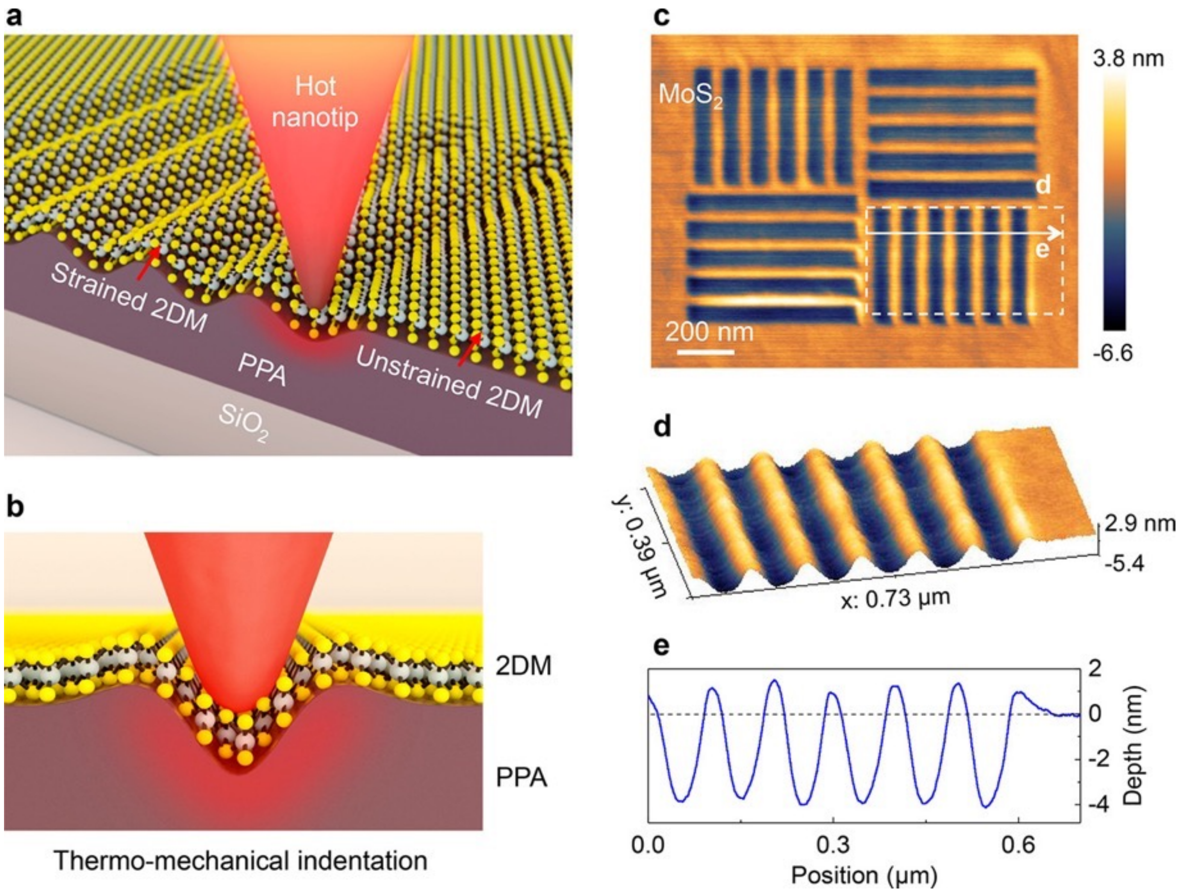
EPFL

Direct nanocutting of 2D materials



X. Liu et al. *Advanced Materials (2020)*

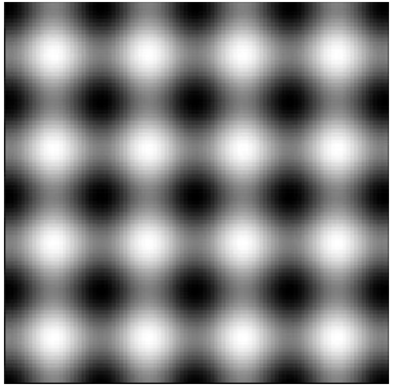
Straining of 2D materials at nanoscale



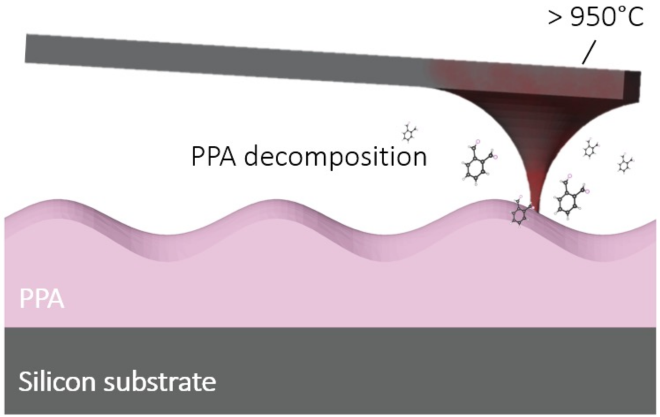
Xia Liu et al., *Nano Lett.* 2020

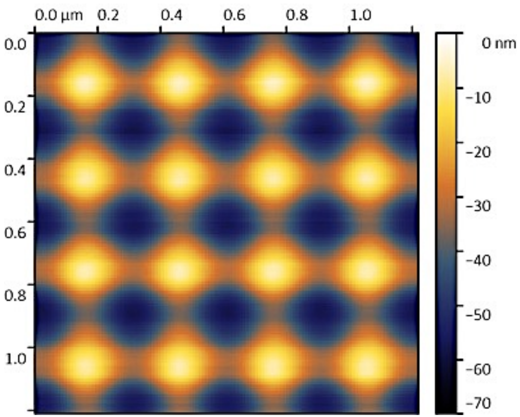
EPFL

T-SPL grayscale nanopatterning



2D grayscale bitmap

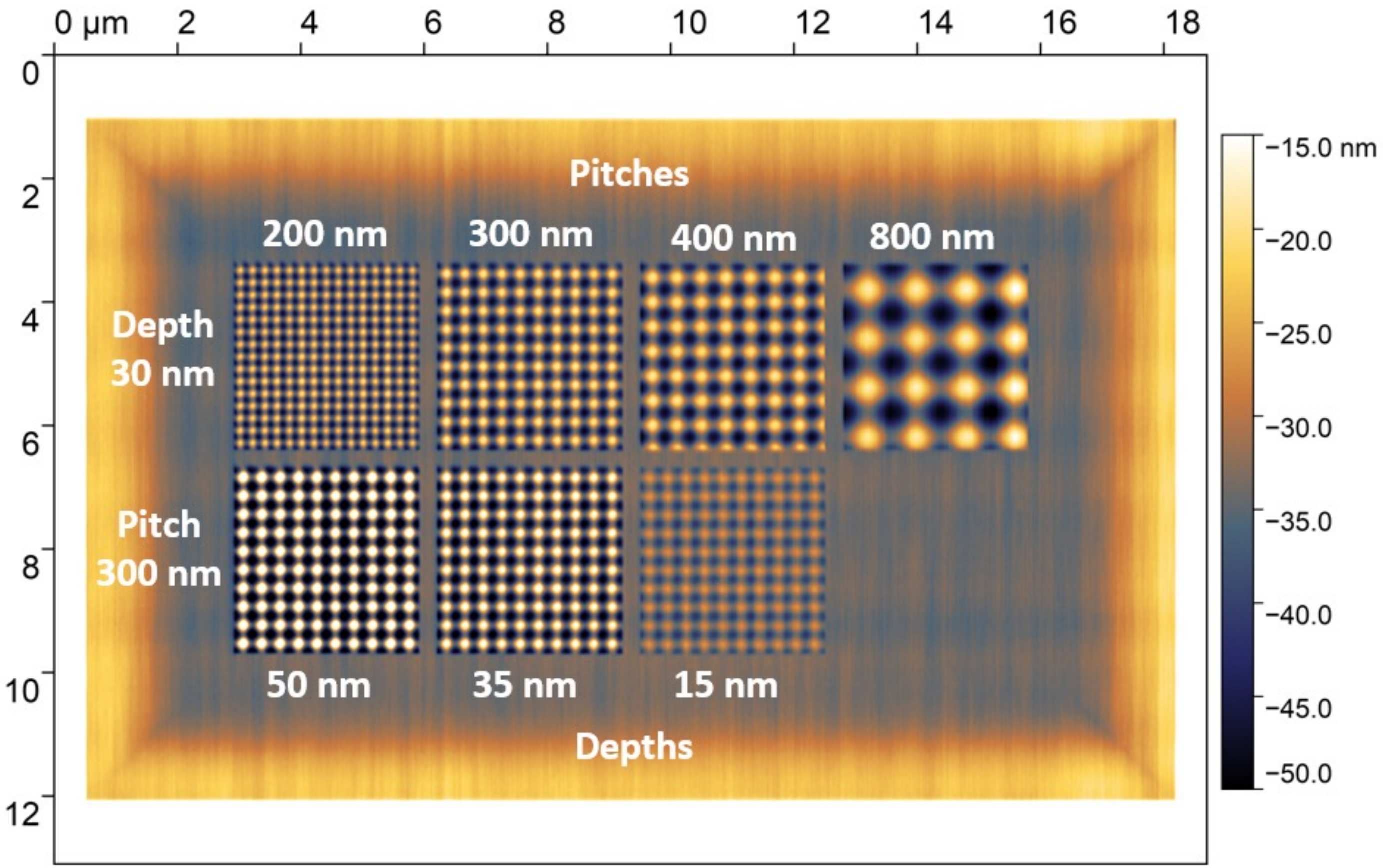




AFM image on PPA during T-SPL patterning

Berke Erbas et al. *MNE 2022*

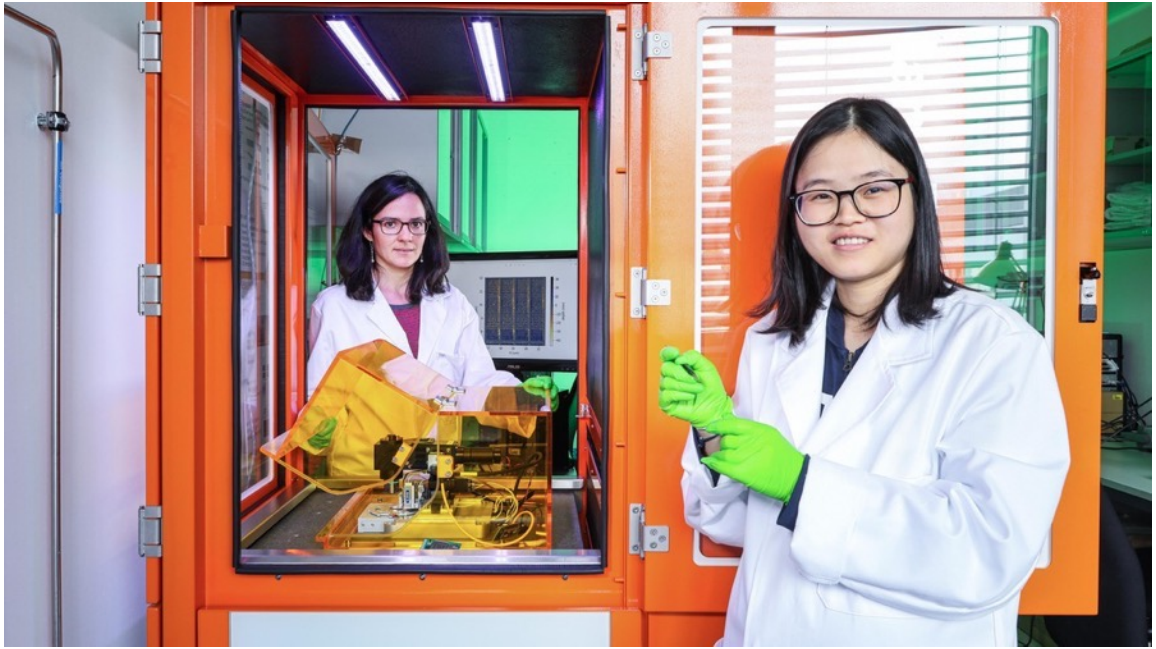
Grayscale nanopatterning for 2D material strain



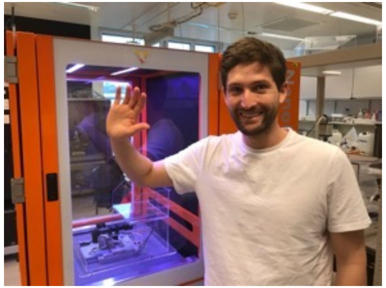
Berke Erbas et al. MNE 2022

Student nanoselfies created in 10 min

T-SPL at EPFL*



Ana Conde-Rubio & Xia Liu



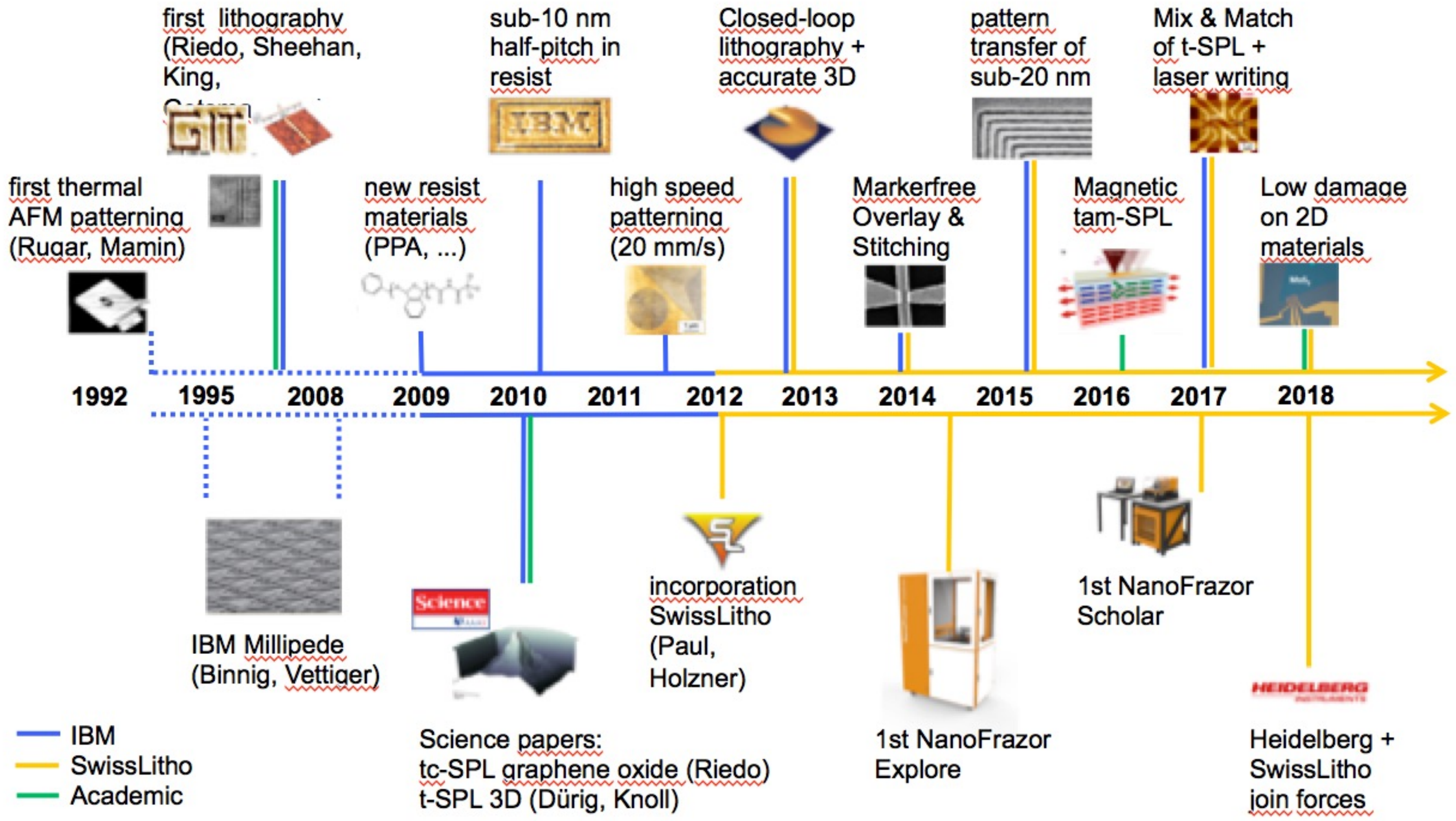
Samuel
Howell

Berke Erbas

FNSNF Requip
Swiss National Science Foundation

*available for others to use

30 years of t-SPL .. and counting



EPFL

Merci

Thank you for your attention

Juergen Brugger

École
polytechnique
fédérale
de Lausanne

All credits go to the team…

SWISS NATIONAL SCIENCE FOUNDATION

European Research Council
Established by the European Commission