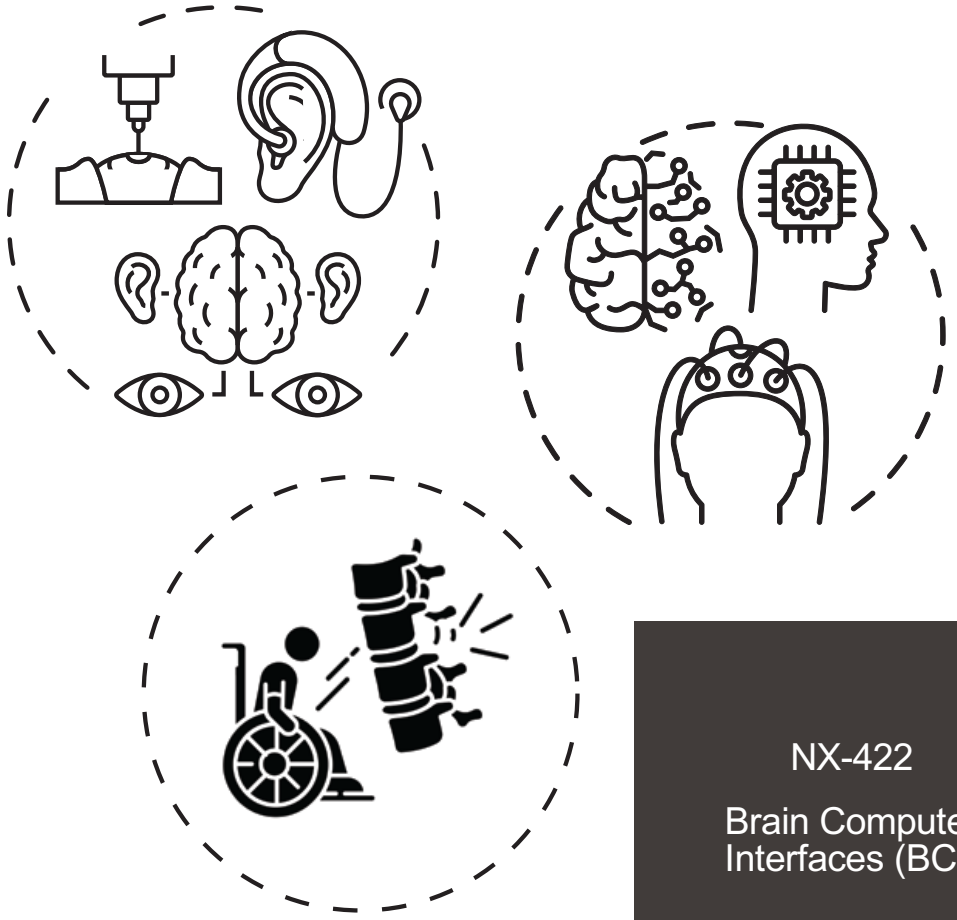


Neural Interfaces

NX-422

Brain Computer Interfaces (BCI)

Stéphanie P. Lacour

Neuro-X Institute

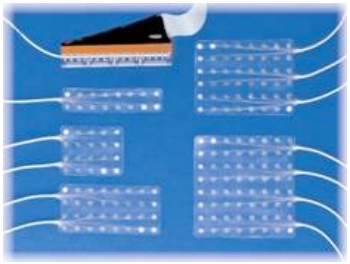
Brain computer interfaces

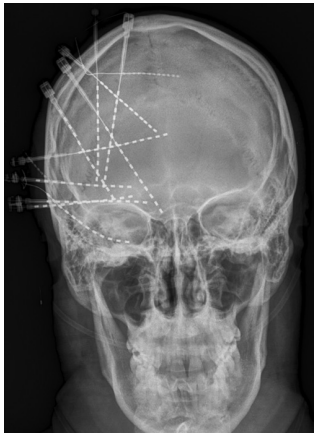
- Overview
- Silicon-based neurotechnology
- Flexible implantable neurotechnologies

Invasive BCI / in the clinic

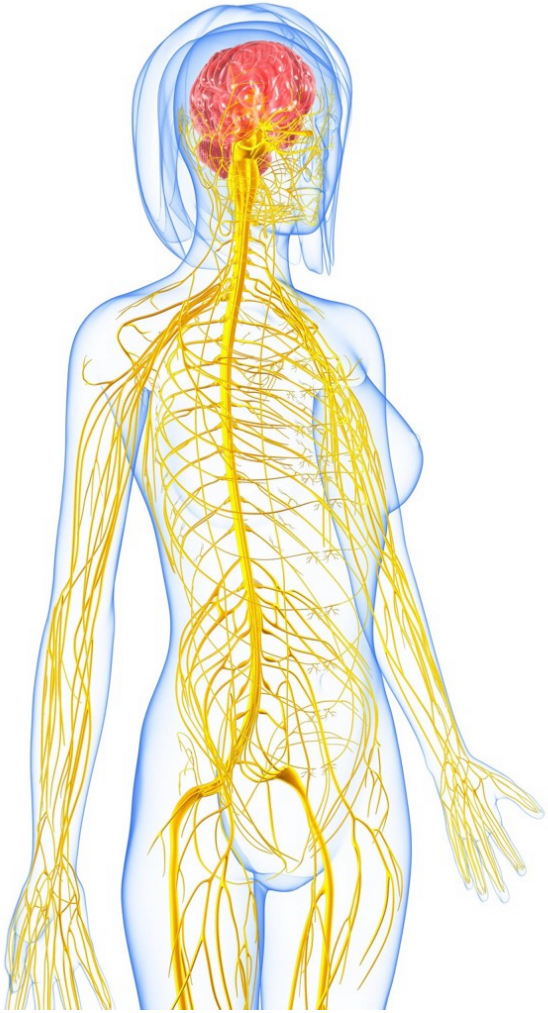
ECoG grids
sEEG

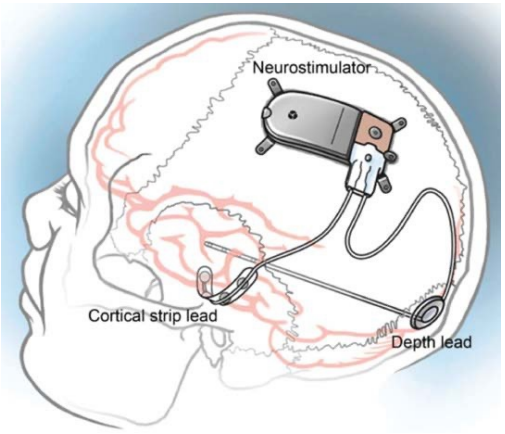
Adtech grids





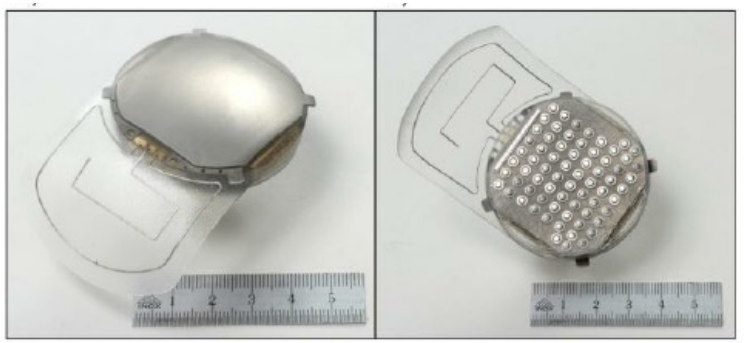
J Neurosurg Volume 123 • December 2015





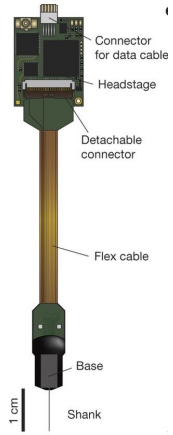
NeuroPace, USA

Clinatec ECoG, CEA, France



Invasive BCI / short-mid- term use in the clinic

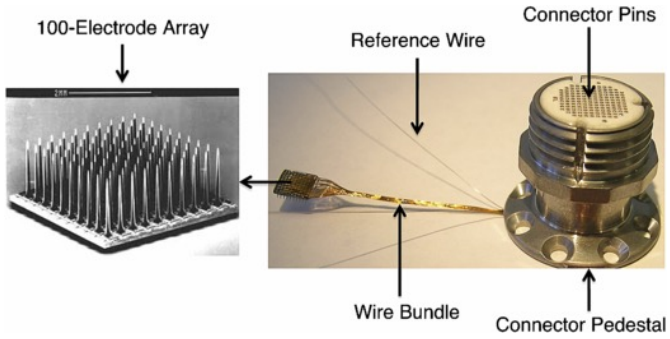
Neuropixel – IMEC Janelia



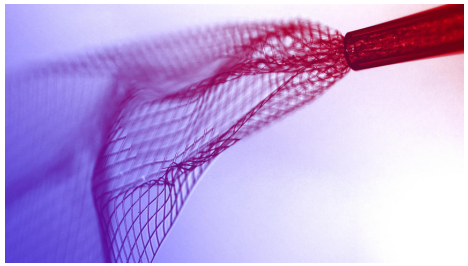
Synchron – stentrode

Utah array
BrainGate

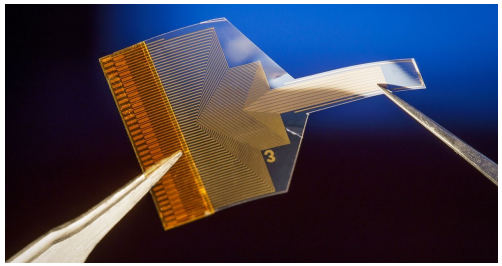
Blackrock Neurotech



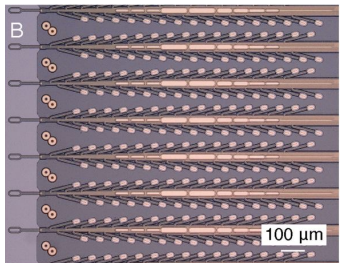
Miniaturised BCI

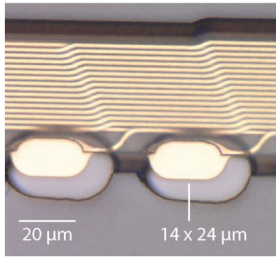


Nanomesh
Jia Liu - Harvard



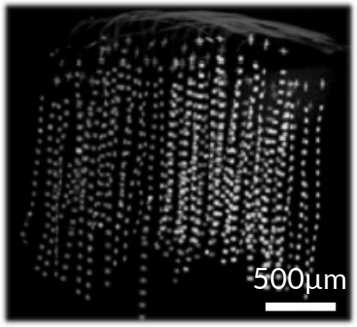
transparent ECoG
D Kuzum- UCSD





Neuralink

soft ECoG
SP Lacour – EPFL / Neurosoft Bioelectronics

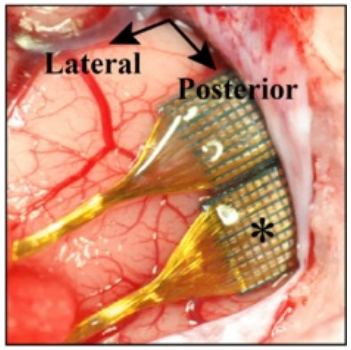


NET 1’024 électrodes
L. Luan, Rice Univ.

graphene electrodes
InBrain - Spain

All about connectors

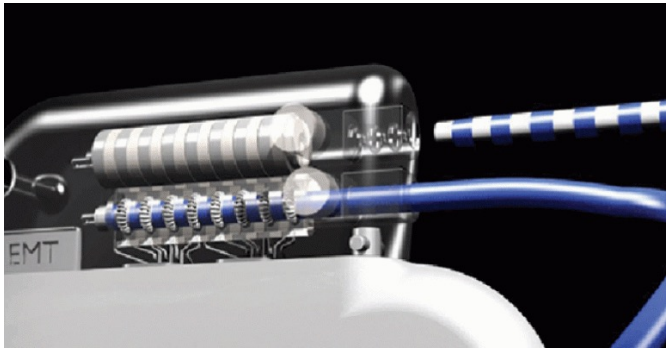
BrainGate



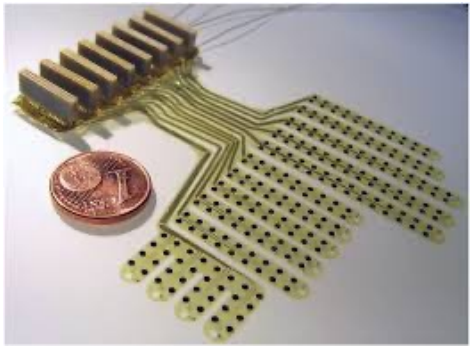
JNE | 2012 | 9(6)

Transcutaneous interface
Wire bonding

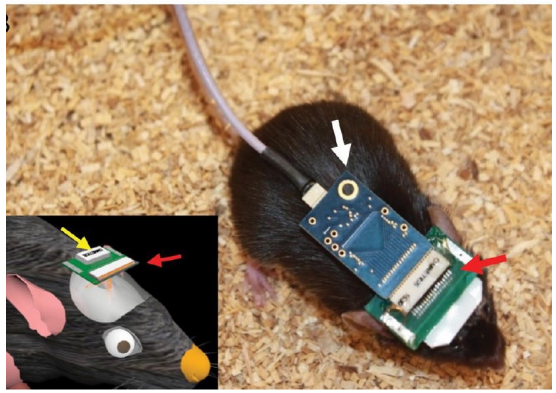
Utah implant system



Bal seal Engineering Inc.



Flexible ECoGs
T. Stieglitz's lab

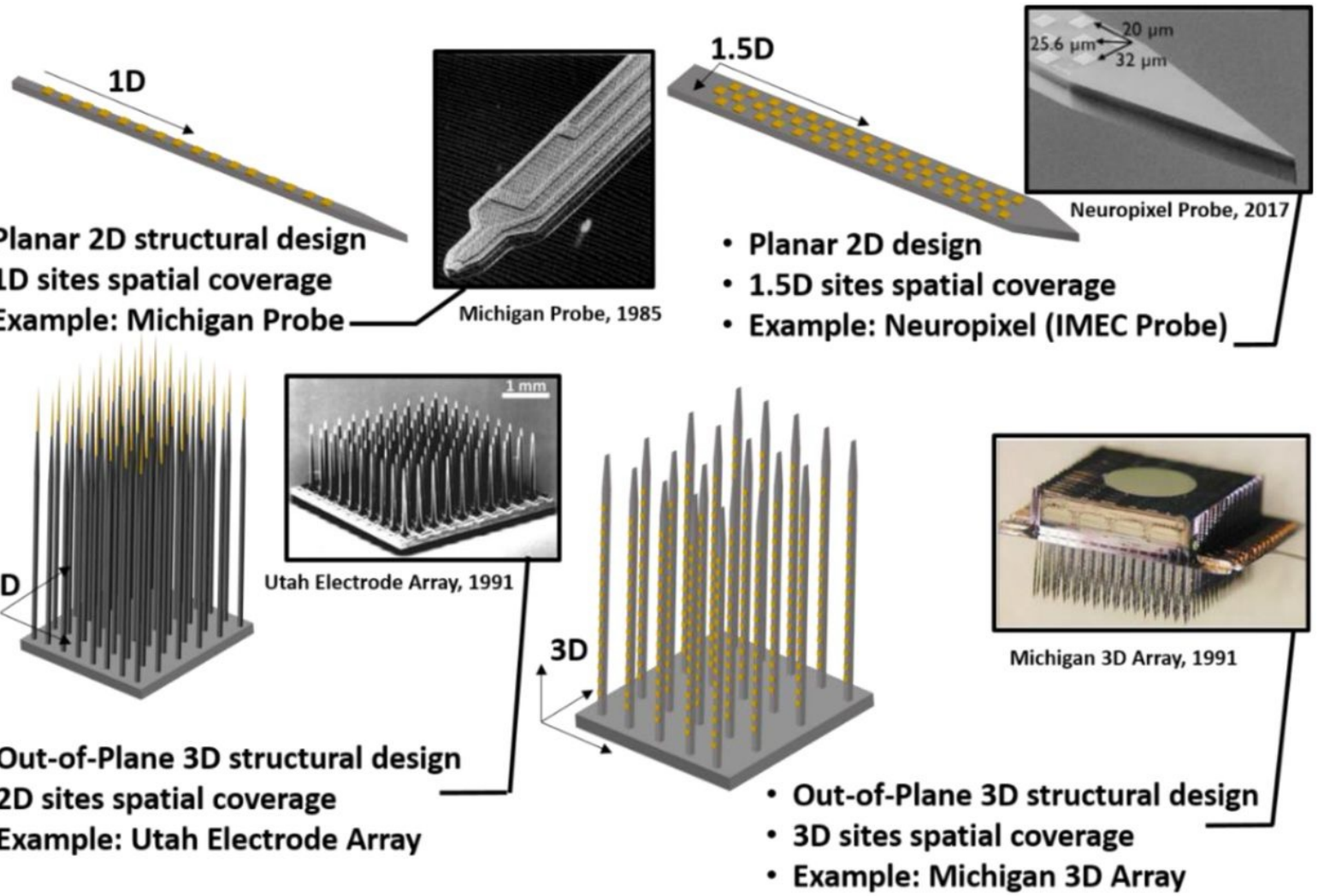


Nanomesh connector

Brain computer interfaces

- Overview
- **Silicon-based neurotechnology**
- Flexible implantable neurotechnologies

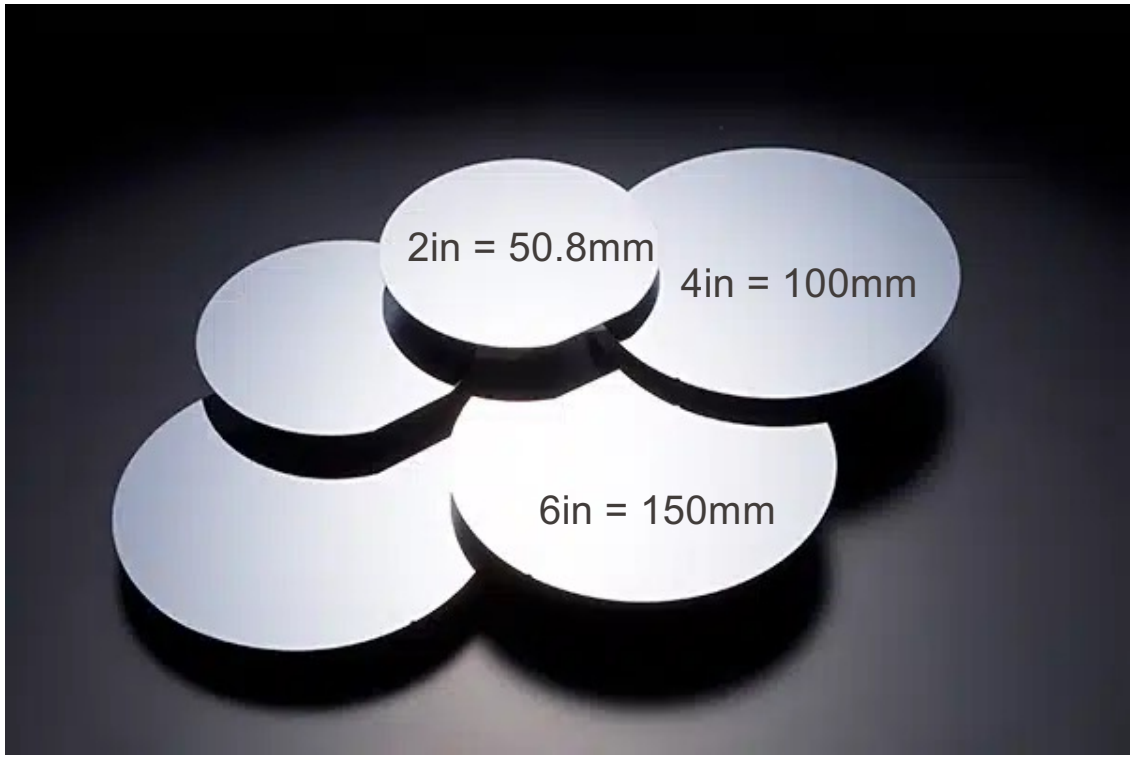
Silicon-based electrodes



https://doi.org/10.1101/2021.01.24.427975

Silicon

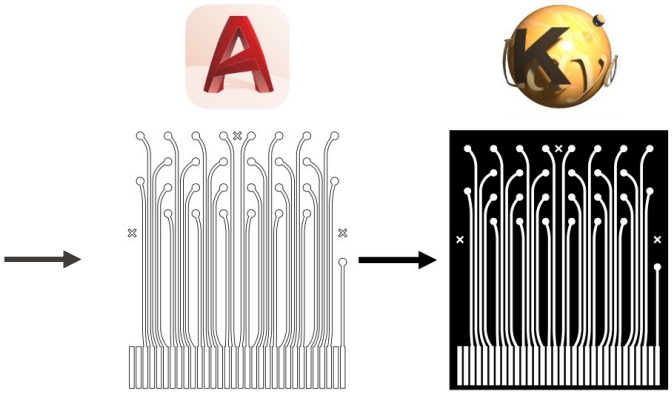
- diameter: 2in – 18in
- *12in: modern semicond. fab.*
- thickness: 275 - 1’000 µm
- flatness
- orientation flat and notch
- *(100) or (111) orientation*

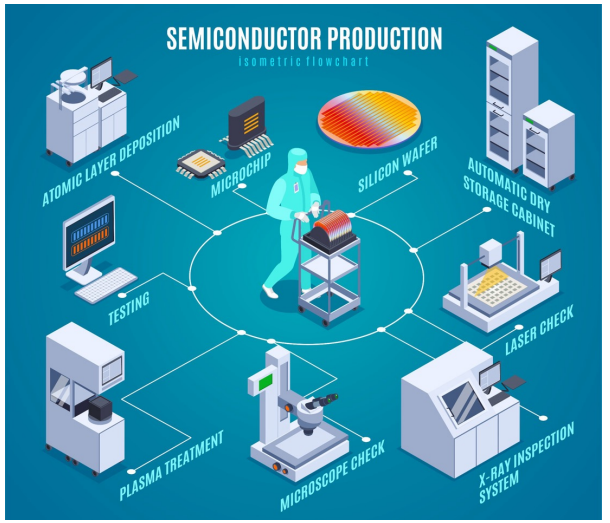


Microfabrication in a Cleanroom a highly controlled environment

- **Classification ISO**
  - ISO class 1: 10 particles per m^3 (particles > 0.1µm)
  - ISO class 5: 100’000 particles per m^3 (particles > 0.1µm)
- **Air filtration**
- **Temperature and humidity control**
- **Surface cleanliness**

microfabrication





1. Image

2. Design

3. Manufacture

Materials

- **thin-films**
  - metals
  - insulators
- deposition
  - evaporation
  - sputtering
  - ALD
  - CDV…
- etching

sputterer

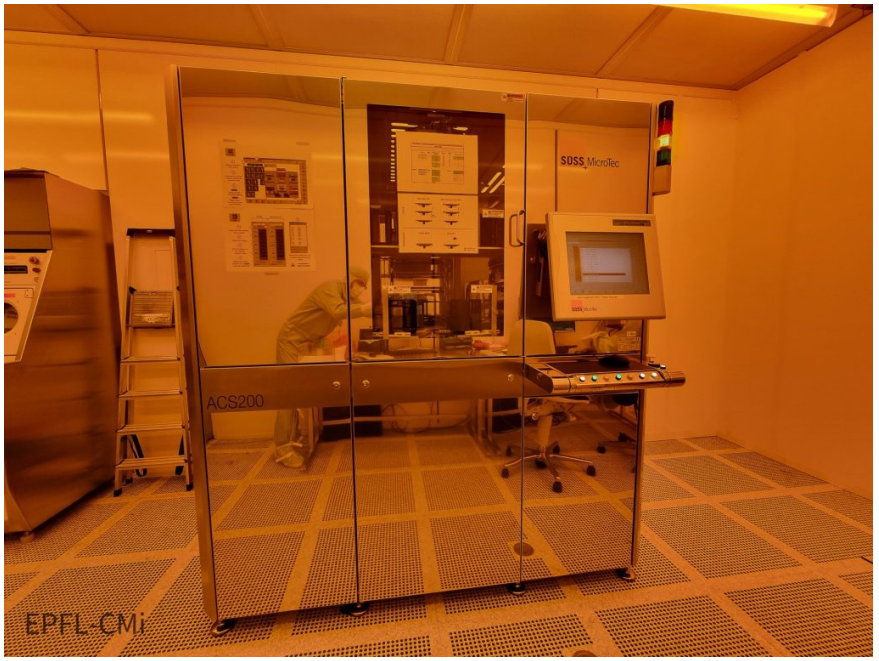
evaporator

Materials

- **photoresists**
  - positive
  - negative

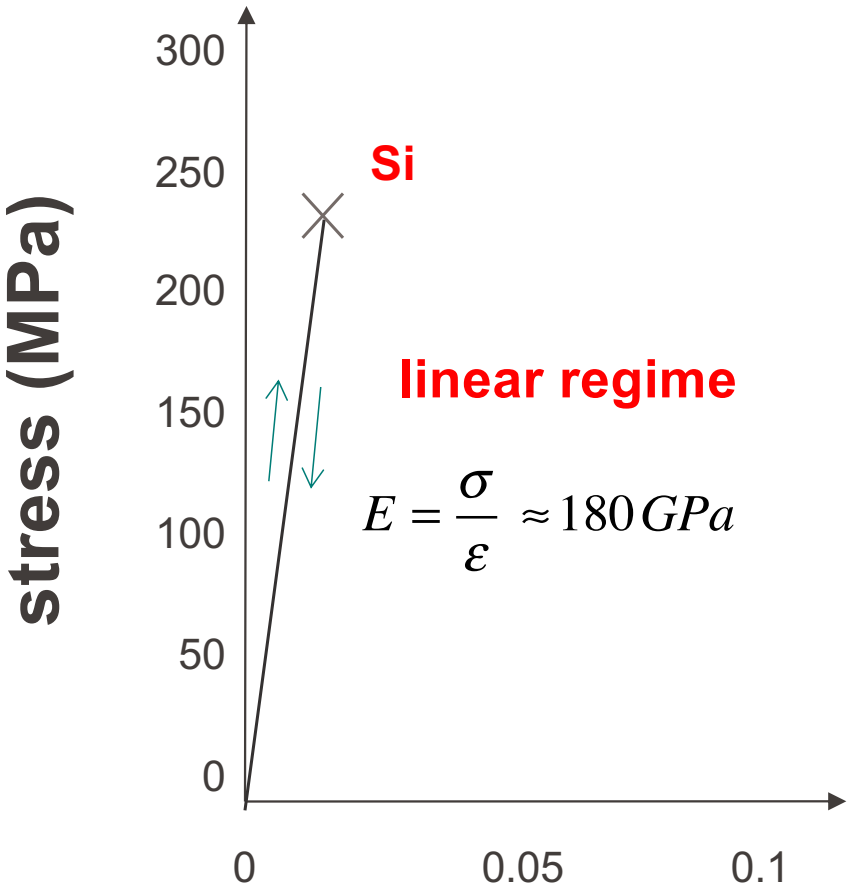
- parameters
  - Thickness range: 0.5 - 2 µm (thin)
  - Thickness range: 2 - 100 µm (thick)
  - spin-coating speed

  - DUV to UV sensitive
  - E-beam and X-ray



coater - developper

Silicon



A stiff and brittle material

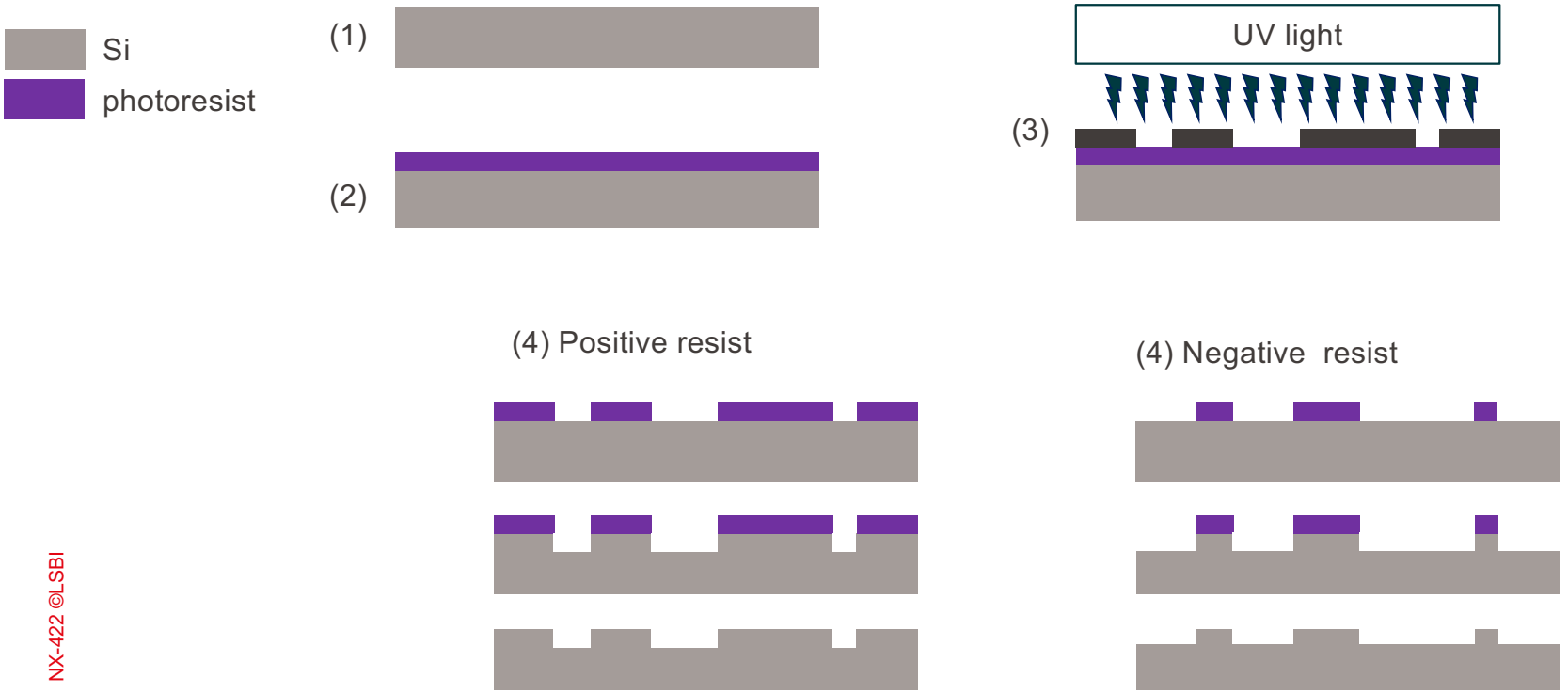
The process flow
a detailed sequence of steps and techniques

→ a roadmap outlining how various fabrication processing are combined to create the desired features on a silicon wafer

- **Recipe:** To define the roadmap.
- **Repeatability**: To ensure that devices are fabricated consistently with high yield.
- **Optimization**: To minimize defects and improve performance.
- **Documentation**: Provides a clear record of every step and parameter, essential for troubleshooting and improving processes.

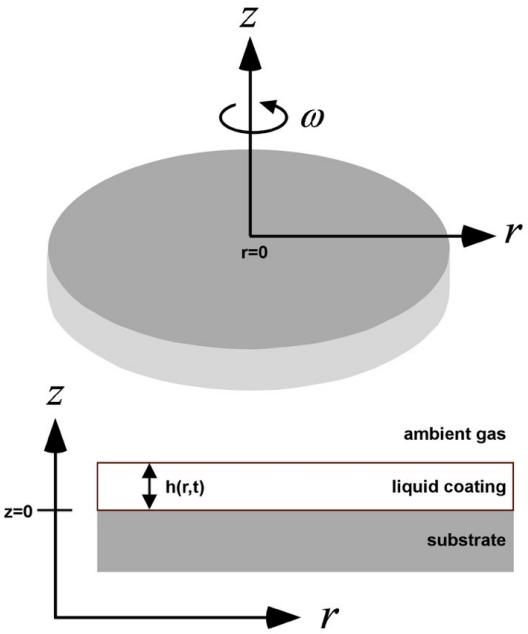
Photolithography

- Transfer of a geometric pattern through a photomask into a photosensitive polymer

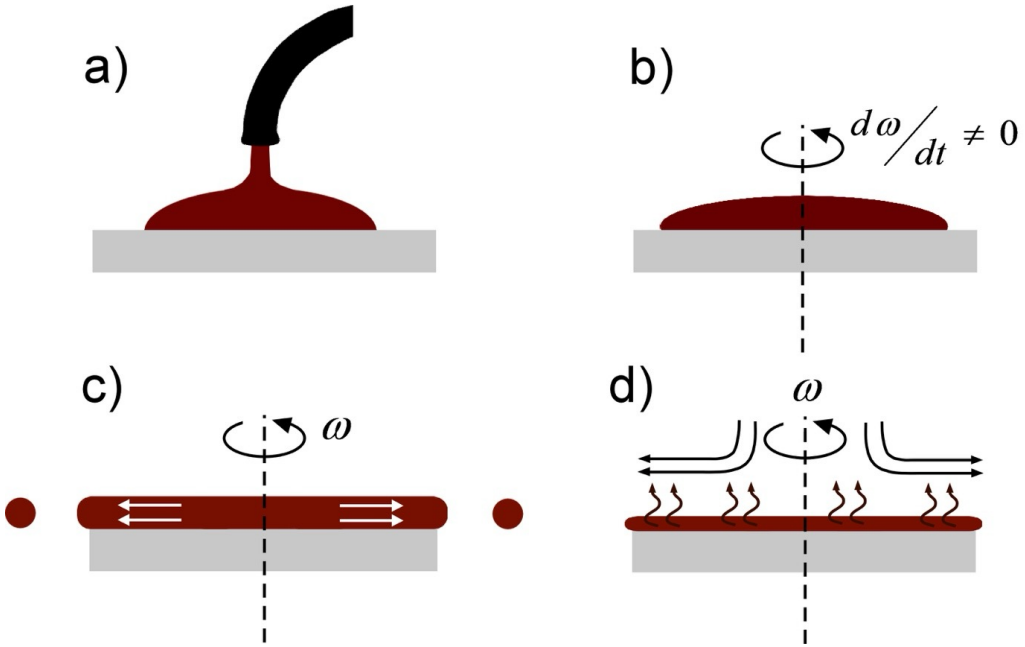


Spin-coating

Viscous fluid on a rotating disk



Dispense / Accelerate / Flow / Evaporate

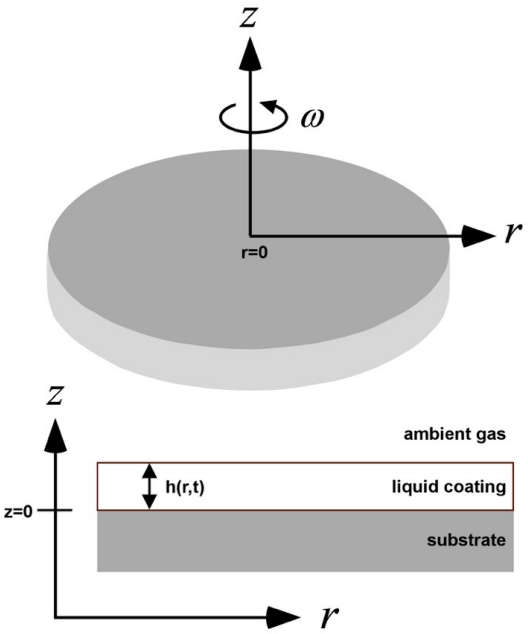


https://www.youtube.com/watch?v=uv1A7qAqgRk

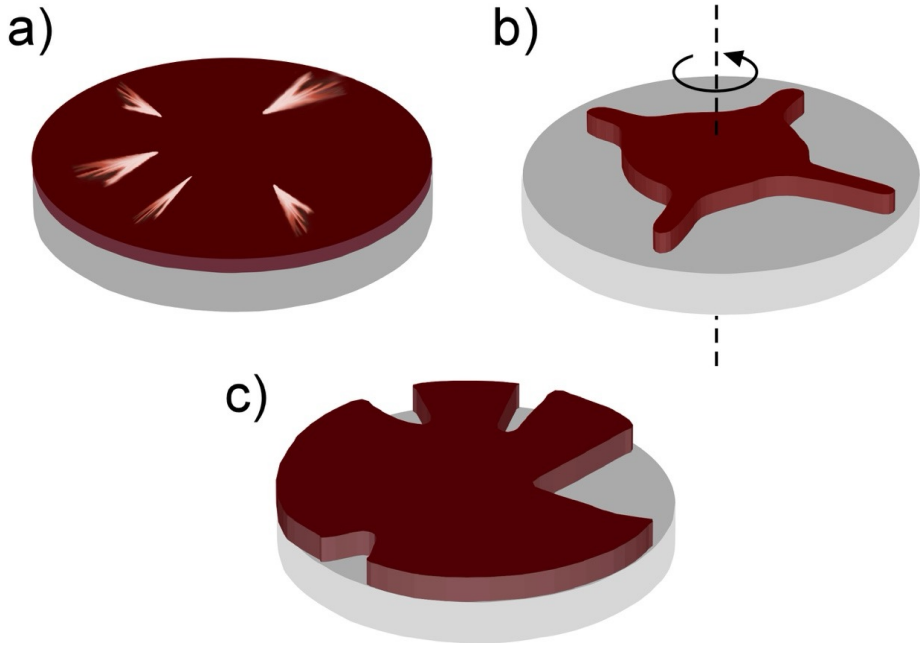
Adapted from S.L. Hellstrom, Stanford University

Spin-coating

Viscous fluid on a rotating disk



Deviation from ideal spin
Streaks / Non uniformity / uncoated areas



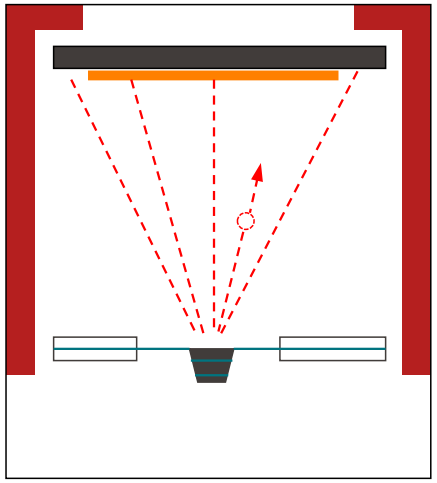
Adapted from S.L. Hellstrom, Stanford University

Metallization

Process parameters:

- Pressure
- Temperature
- Deposition rate

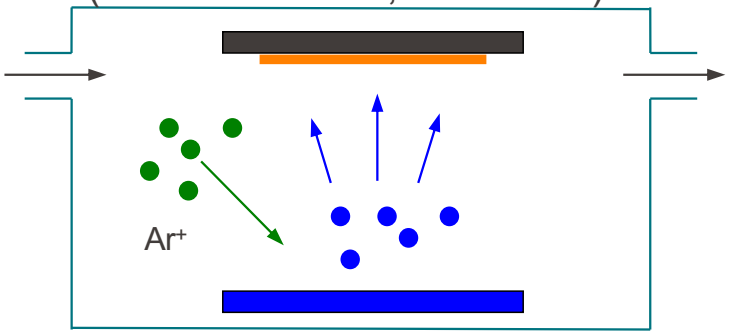
Evaporation



www.lesker.com

Sputtering

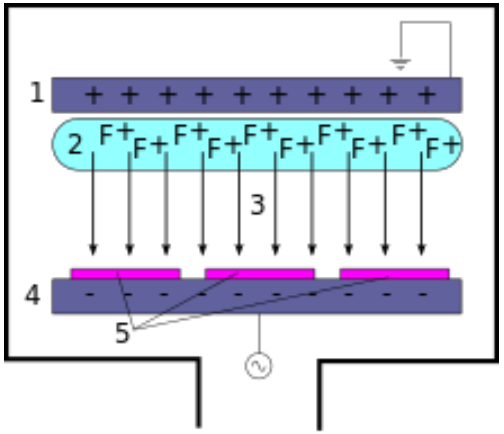
Also used for a wide range of inorganic materials (semiconductors, dielectrics)



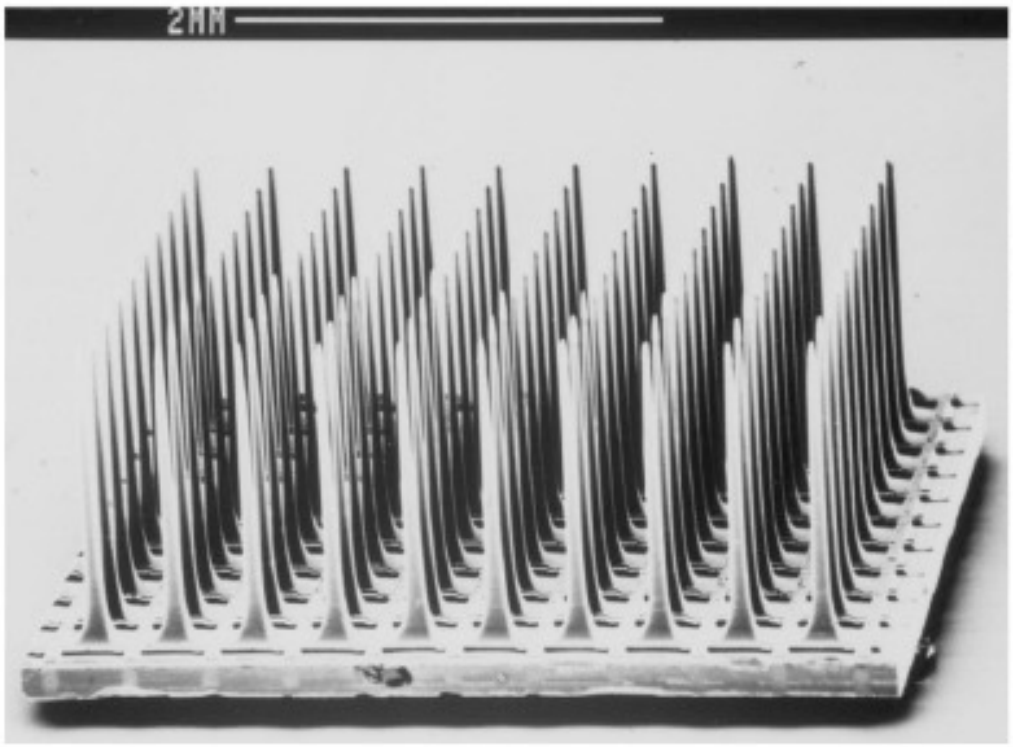
Silicon etching

- Wet etching
  - Selective, isotropic
  - e.g. KOH

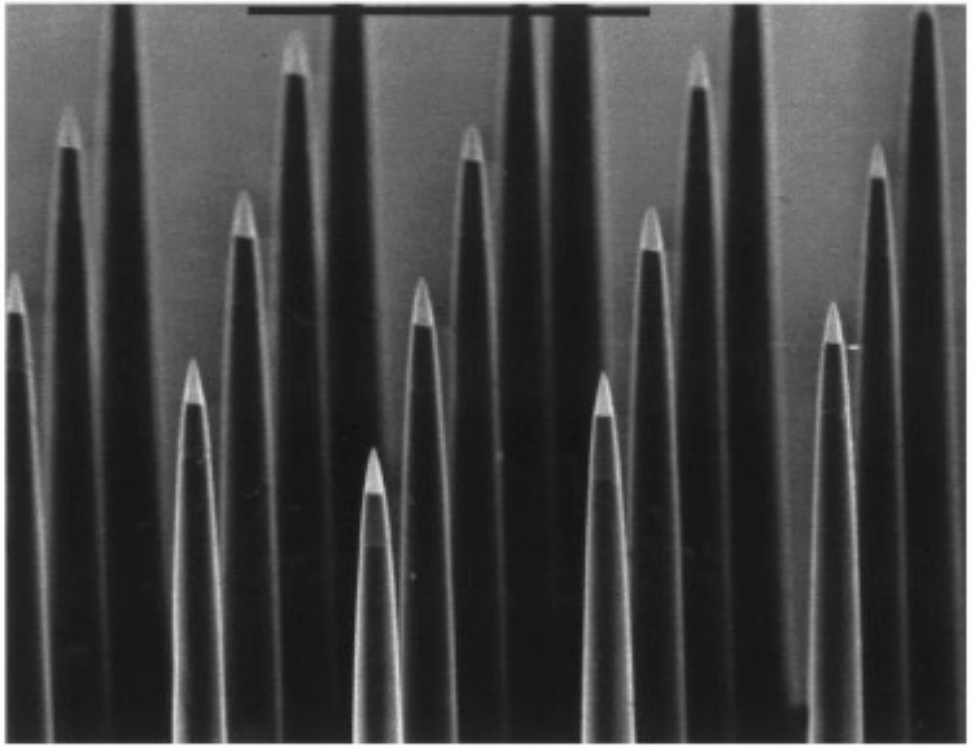
- Dry etching
  - usually selective, anisotropic
  - e.g. reactive ion etching (RIE)



The Utah array



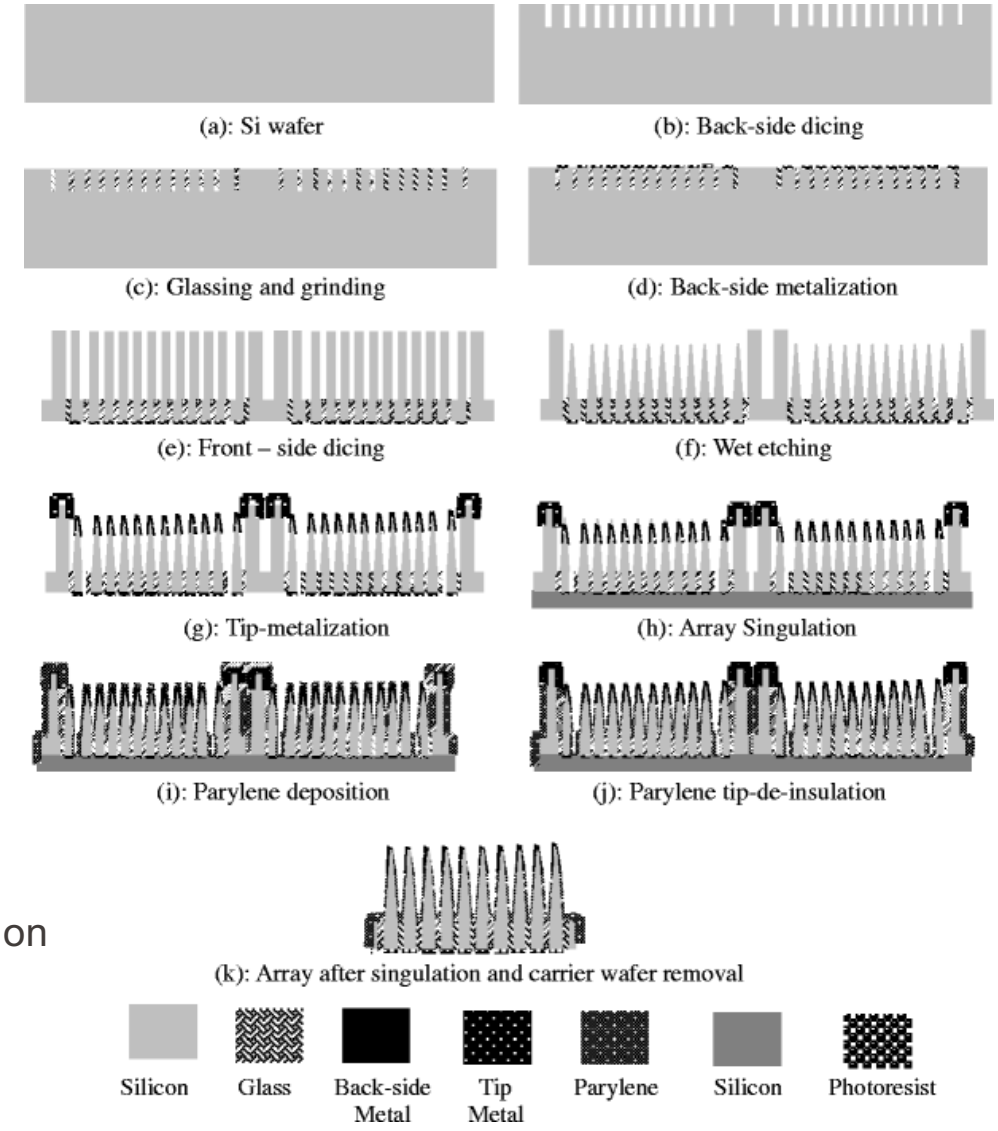
(a)



(b)

Biomed Microdevices (2010) 12:797–807

The Utah array



a. Backside dicing
→ 10x10 0.5mm deep matrix

b. **Glassing**

c. **Grinding**

d. **Back-side metallization**
→ Pt/TiW/Pt sputtering

e. **Front-side dicing**
→ 1.5mm deep columns

f. **Wet etching**
→ HF:HNO_3 (1:19 ratio)

g. **Tip metallization**
→ sputtered Ti/Ir then electrochem. activation

i. **Parylene deposition**
→ LVPCD, 3µm thick

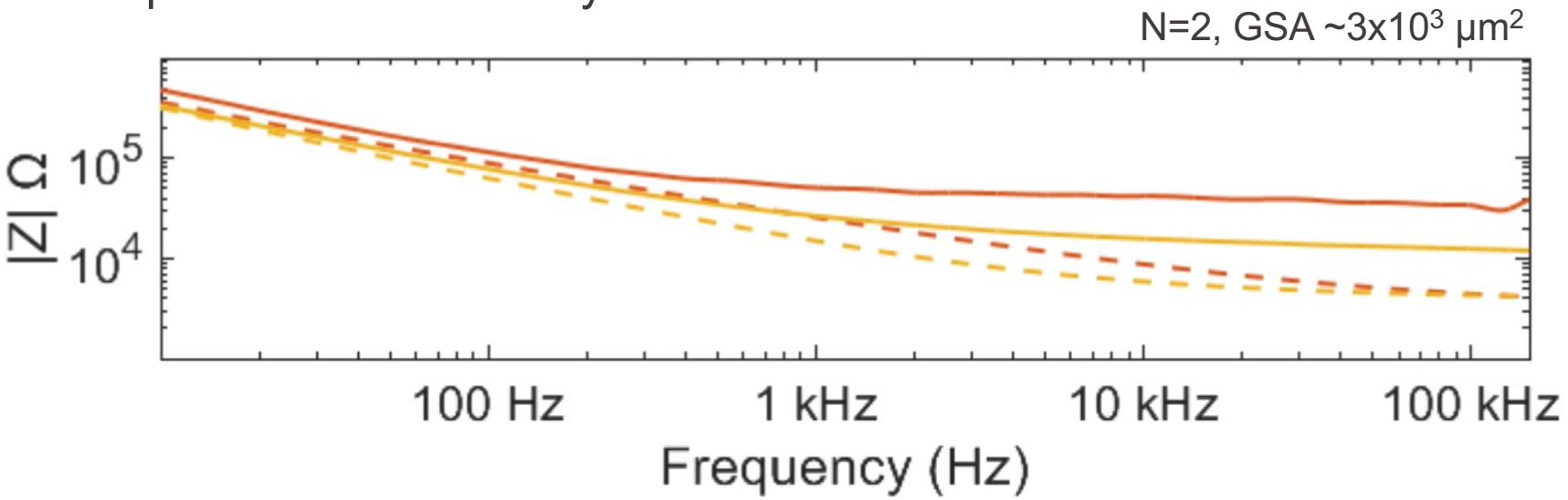
j. **De-insulation**
→ oxygen plasma etching, 30-350µm length

Biomed Microdevices (2010) 12:797–807

10.1109/JERM.2018.2862417

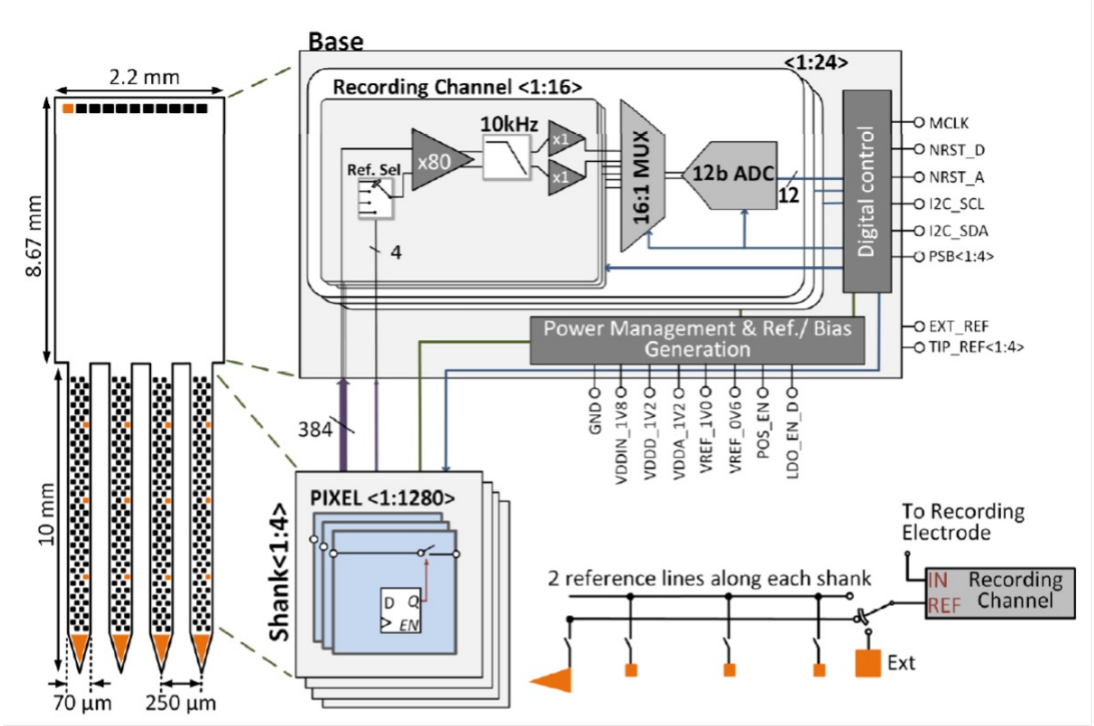
Measured impedance spectra

- In vitro electrodes (dashed)
- In vivo electrodes (plain)
- Impedance increase by x1.5 for f > 1kHz



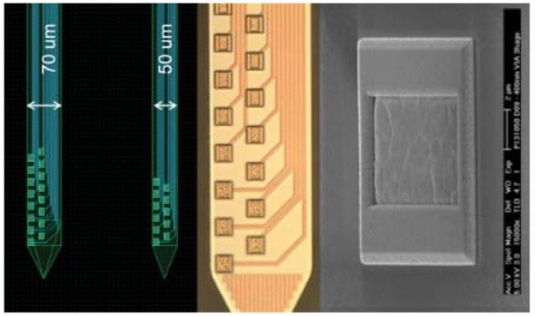
Active silicon probes
Neuropixel

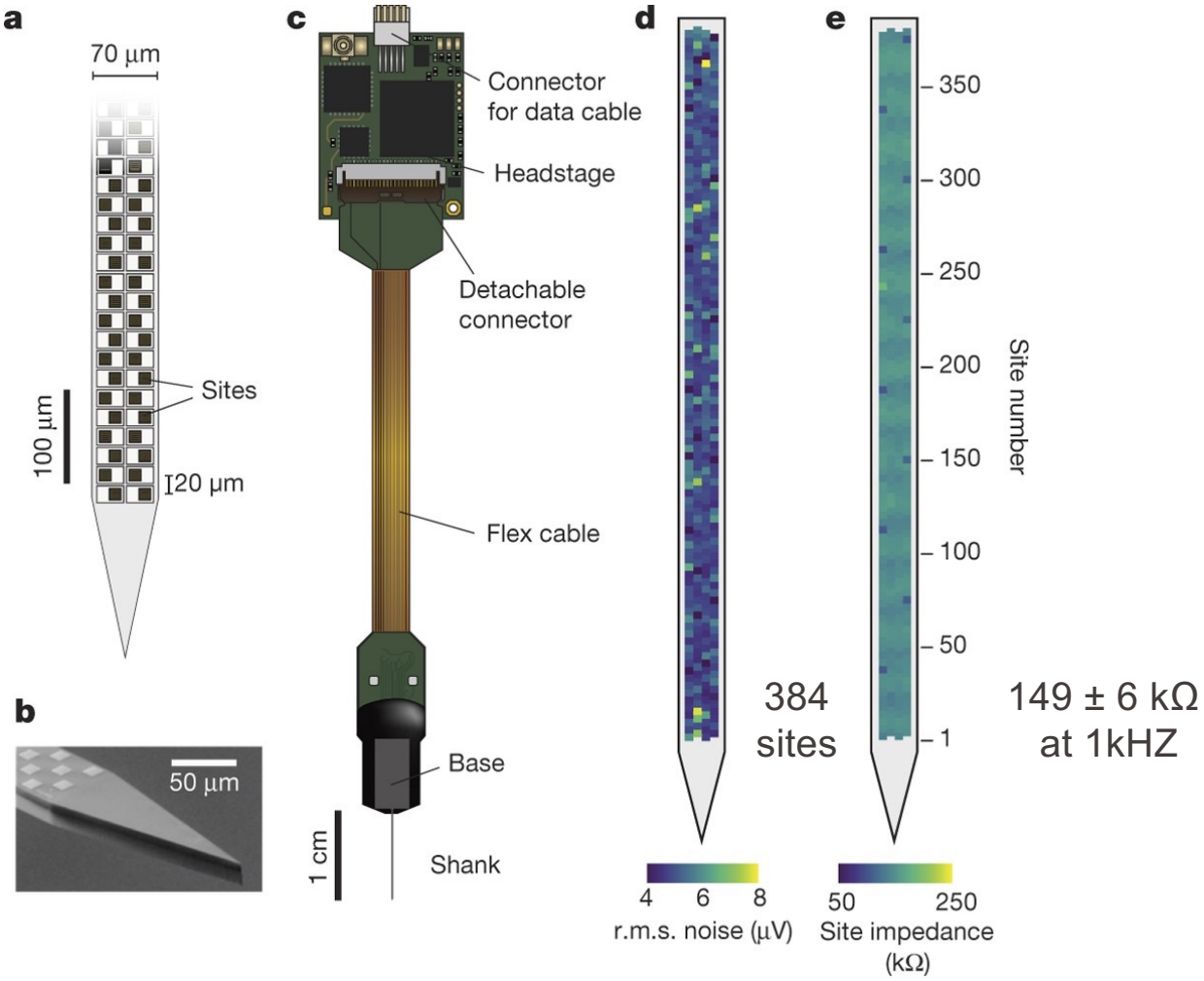
user-programmable switches that allow the recording channels to address 384 of the **960 total sites** simultaneously
130nm CMOS technology



Active silicon probes
Neuropixel

TiN coating
12 x 12 µm^2 contact





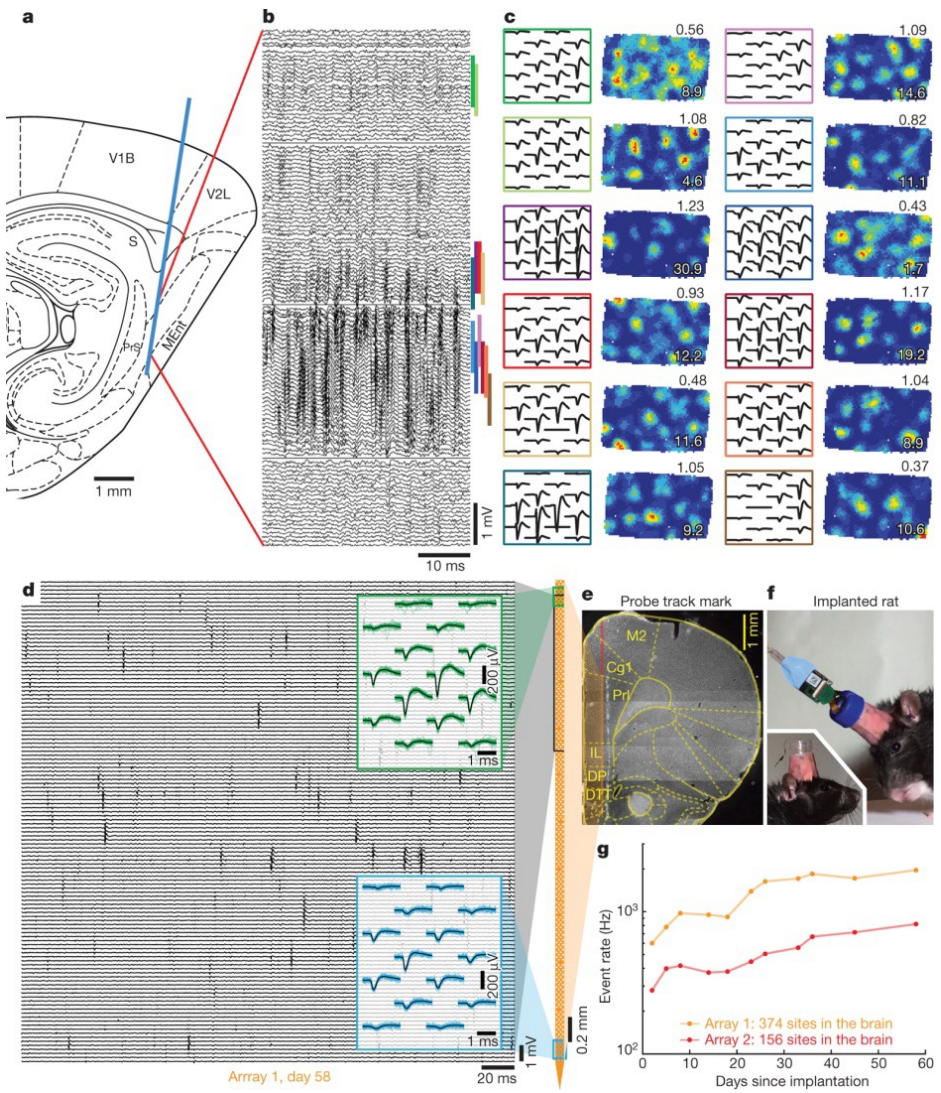
384 sites

149 ± 6 kΩ at 1kHZ

J J Jun *et al. Nature* **551**, 232–236 (2017) doi:10.1038/nature246

Active silicon probes
Neuropixel

Recordings from entorhinal and medial prefrontal cortices using chronic implants in unrestrained rats



J J Jun *et al. Nature* **551**, 232–236 (2017) doi:10.1038/nature246

Take-home messages

- Silicon is a material of choice for microfabricated neural probes
- Leveraging MEMS/microelectronic microfabrication to
  - miniaturise probes
  - integrate on-board processing