Micromechanics: technologies and devices

Péter Fürjes

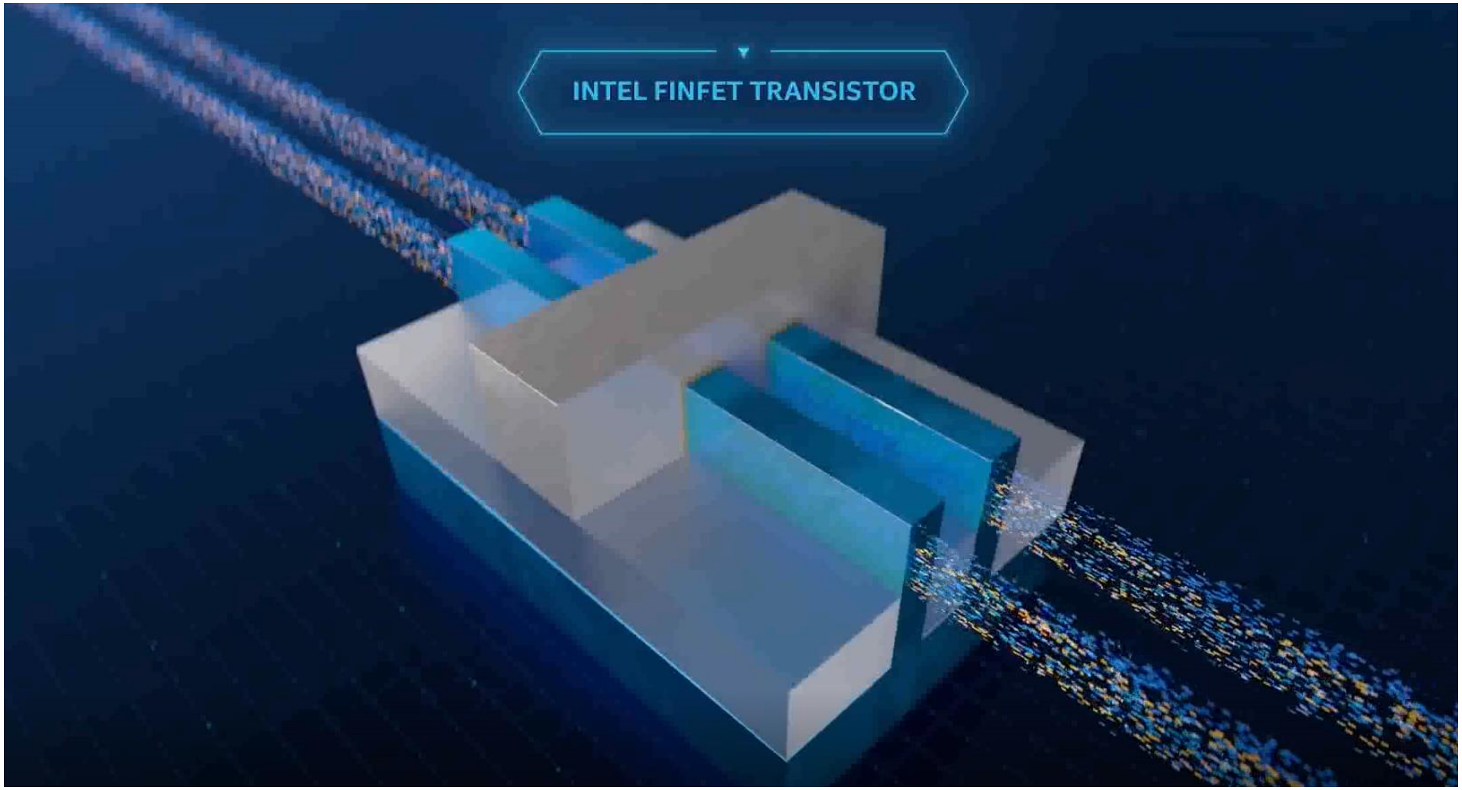
ELKH Centre for Energy Research
Institute of Technical Physics and Materials Science
Microsystems Laboratory

E-mail: furjes.peter @ ek-cer.hu

www.ek-cer.hu | www.mems.hu | www.biomems.hu

ELKH | Energiatudományi Kutatóközpont | Műszaki Fizikai és Anyagtudományi Intézet | Mikrorendszerk Lab | mems.hu | biomems.hu

SEMICONDUCTOR TECHNOLOGY – from sand to CPU



https://www.youtube.com/watch?v=_VMYPLXnd7E

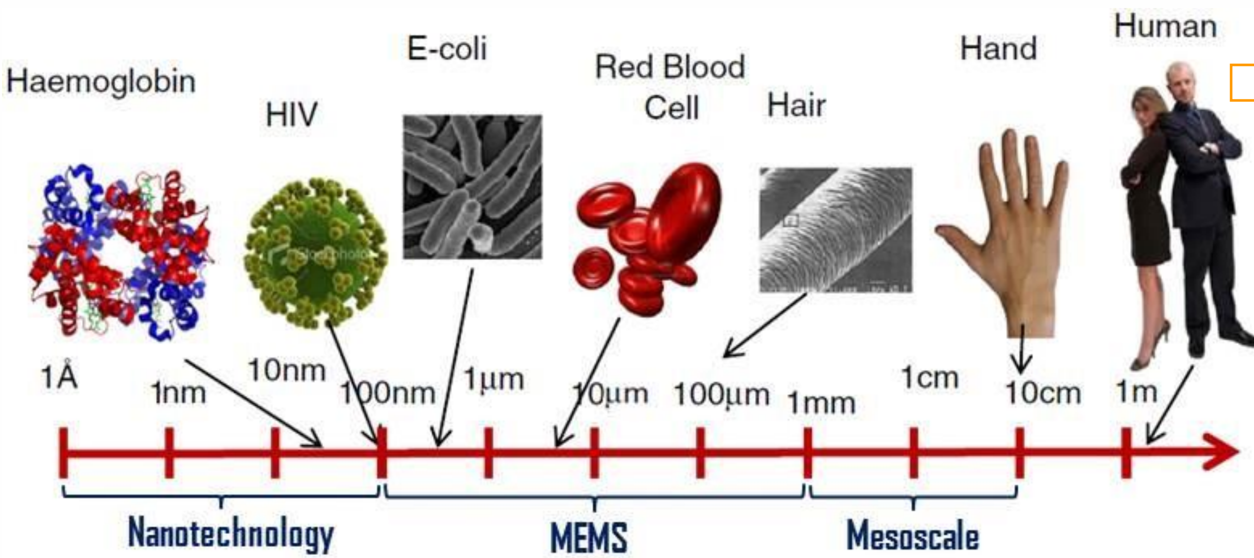
- Si single crystal (material)
- Lithography - pozitiv / negativ resist / lift-off
- Physical layer deposition: sputtering / evaportion
- Chemical layer deposition: CVD / ALD
- Etching: wet and dry (plasma), chemical / physical, isotrop / anisotrop
- High temperature processes
- **MEMS 3D micromechanics**

SMART…

MEMS / BIOMEMS - DEFINITION

MEMS: Micro-ElectroMechanical Systems

Miniaturised devices and systems: in the range between 100nm and 1000µm



- High sensitivity
- Low power consumption
- Integrability

Fabrication technology: SILICON micromachining

- Photolithography
- Physical and chemical layer deposition (metals, dielectrics)
- Wet and dry etching

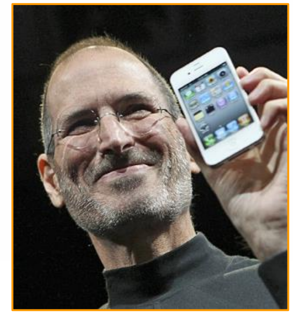
Batch processes

Low costs

SolidState Technology, Ramesh Ramadoss, MEMS devices for biomedical applications http://electroiq.com/blog/2013/10/mems-devices-for-biomedical-applications/

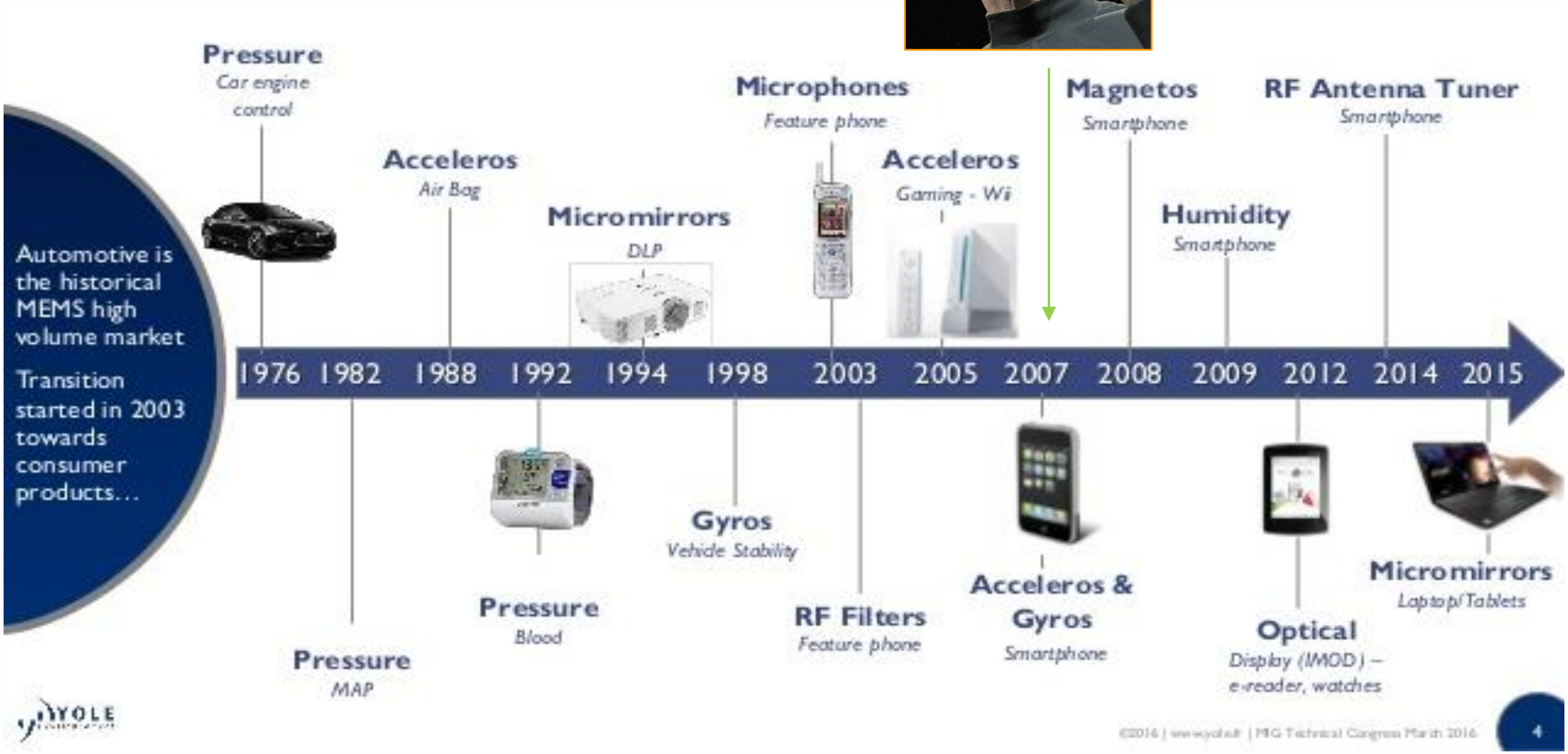
STORY of MEMS DEVICES

from automotive to consumer electronics

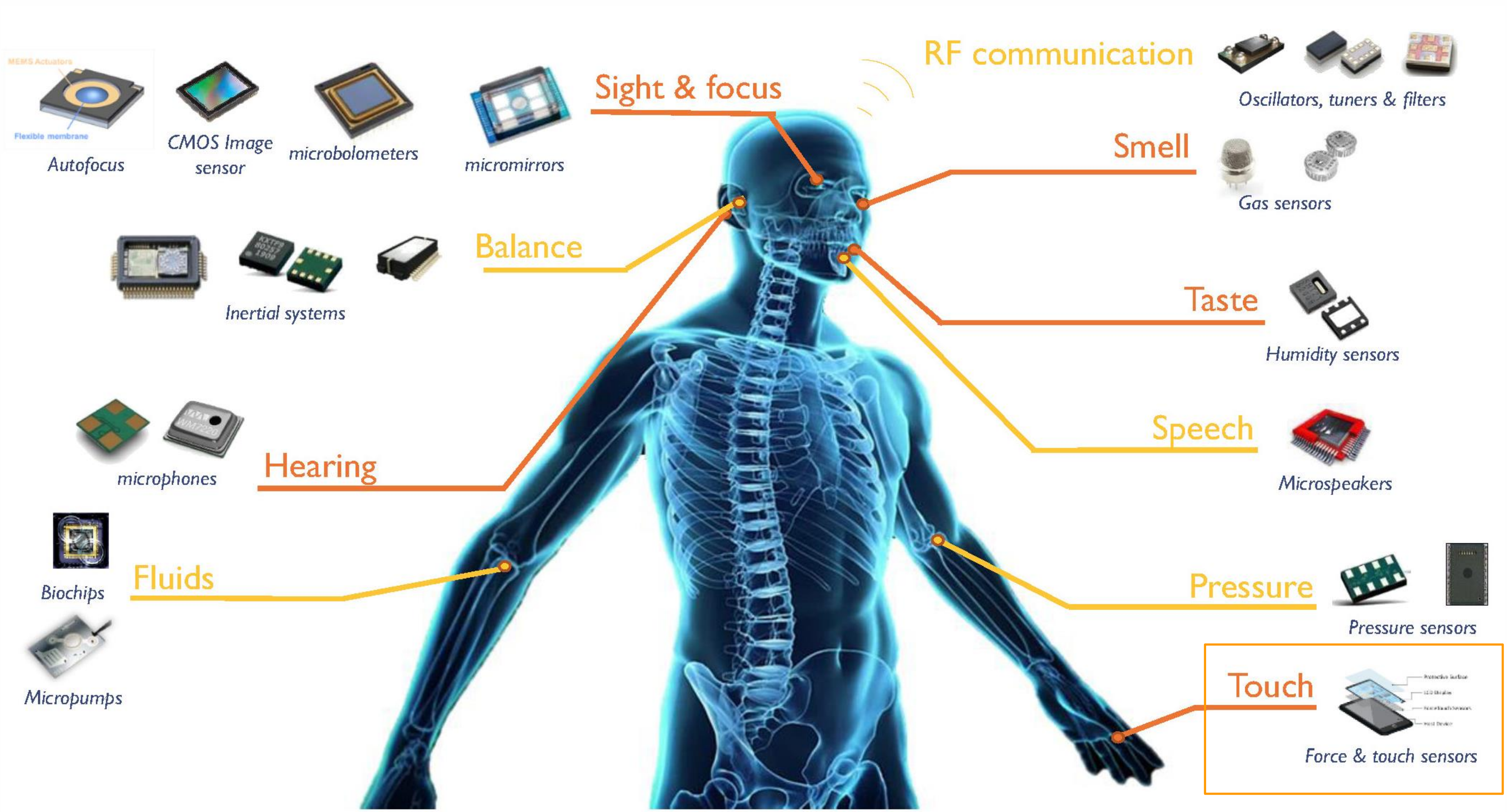


Steve Jobs

APPLE



HOW to MIMIC HUMAN SENSING?

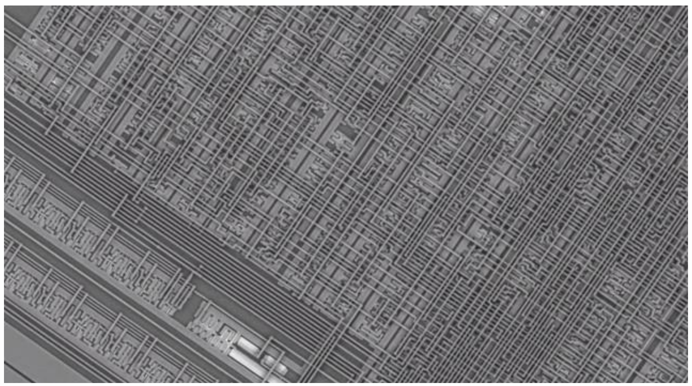


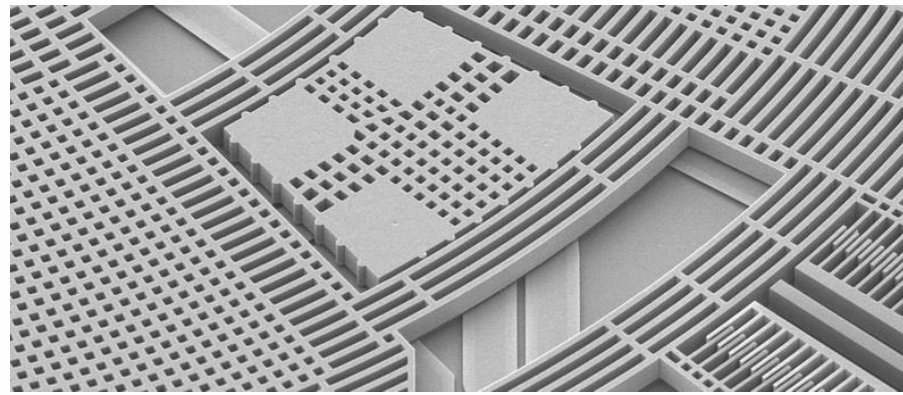
MICROMECHANICS

MICROMECHANICS

MEMS: „2D” IC technology ⇨ 3D structures

- membranes, suspended structures, movable elements,
- microfluidic applications: channels, chambers, reactors etc.

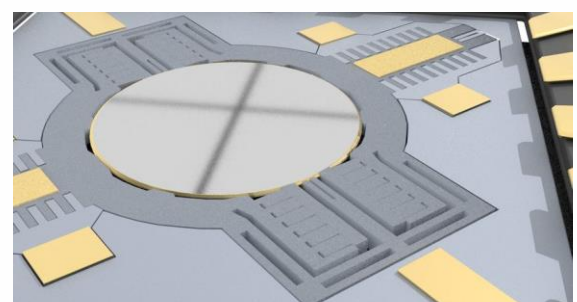




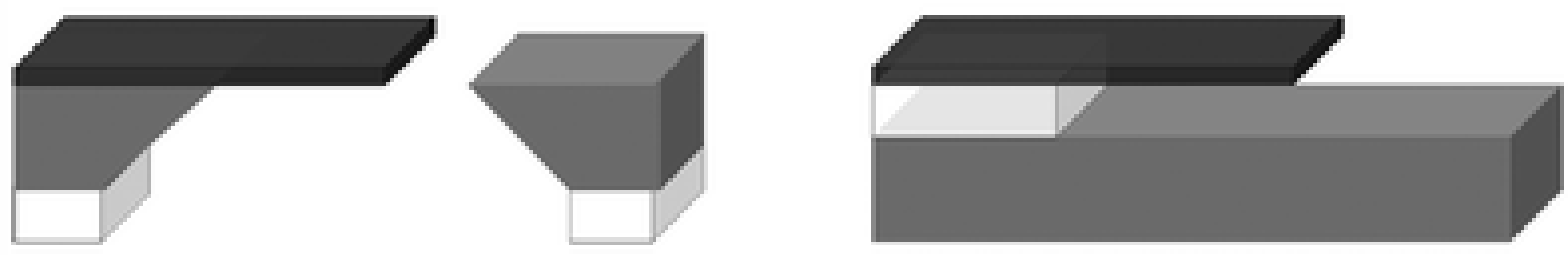
Microfabrications:

- processes and devices: different from traditional mechanical fabrication technologies
- mainly „dry” and „wet” chemical etching and electrochemical methods,
  BUT classic processes (laser or diamond blade cutting)

Typical dimensions: 1-500 mm
Thickness of the Si crystal: 380-500-1000 mm



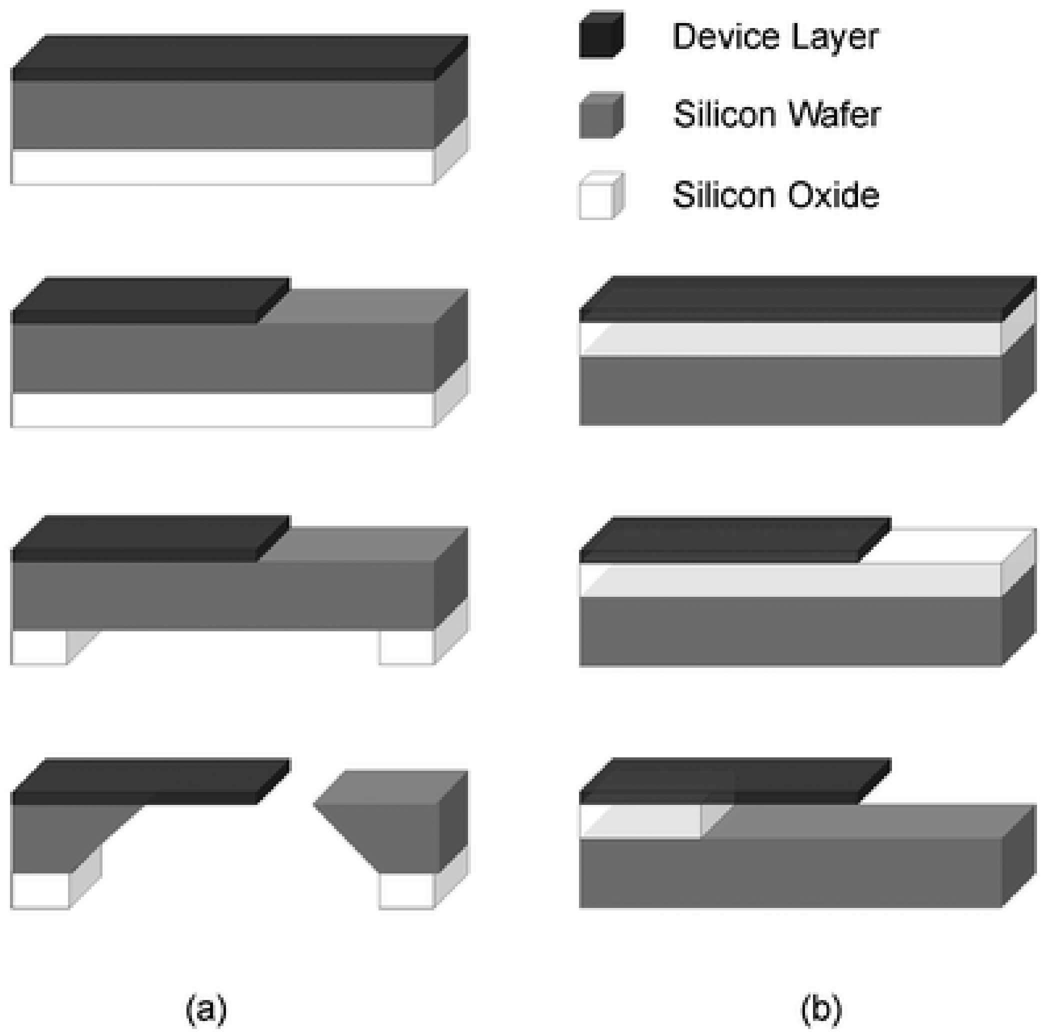
BULK vs. SURFACE MICROMACHINING



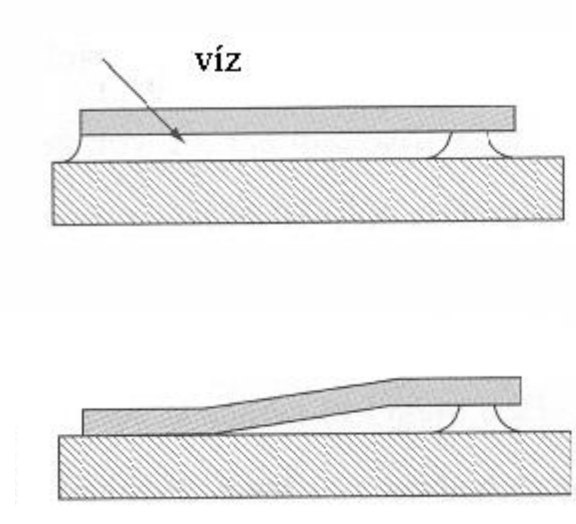
	Bulk	Surface
Dimensions	2-3 μm < a < 100-500 μm	a < 2-3 μm
Thermal isolation	+	-
Mechanical stability	+	-
Membranes	Single crystalline	amorphous or polycrystalline

3rd solution: Thin single crystalline layers: ”Smart Cut” / SOI (silicon-on-insulator)

BULK vs. SURFACE MICROMACHINING

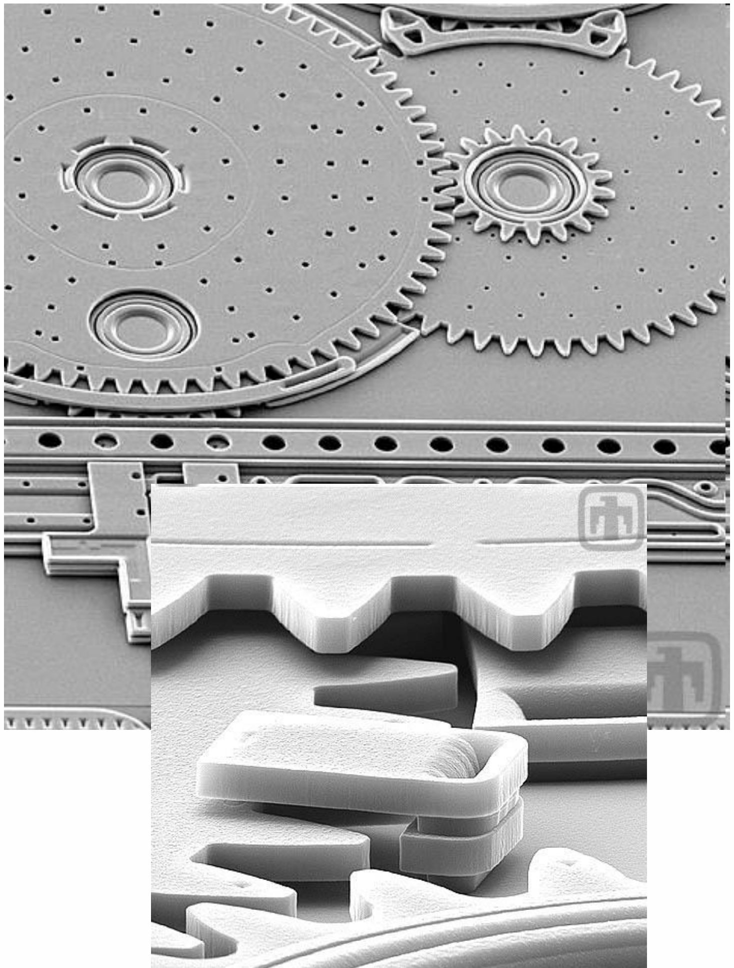


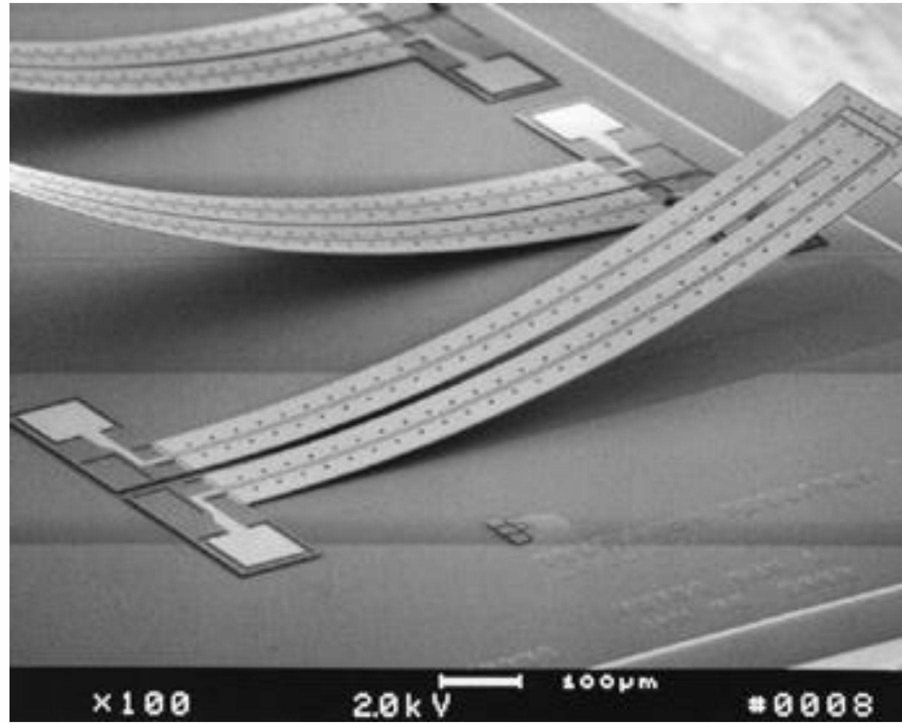
Typical problem: sticking



Solution:
inbuilt keeper
or perforated structures
or dry etching
or supercritical drying

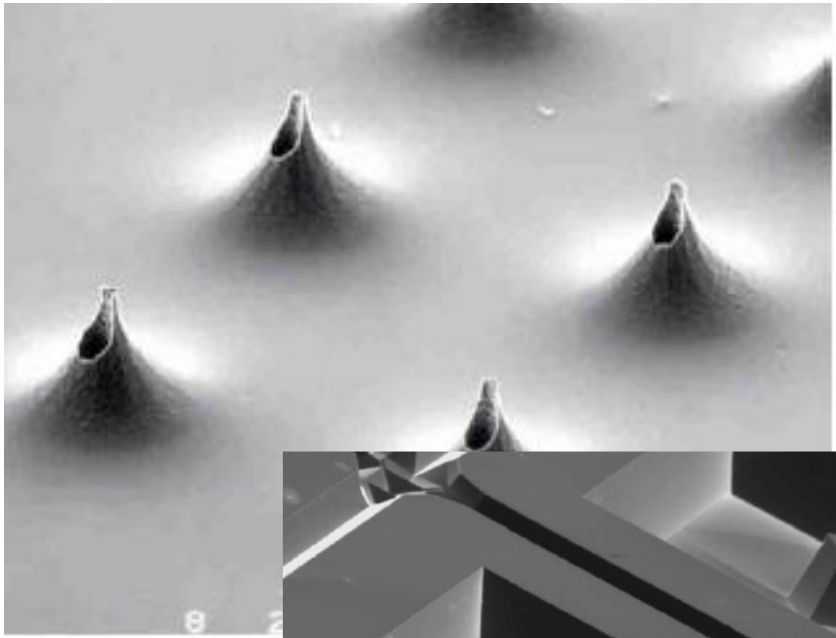
EXAMPLES: SURFACE MICROMACHINING

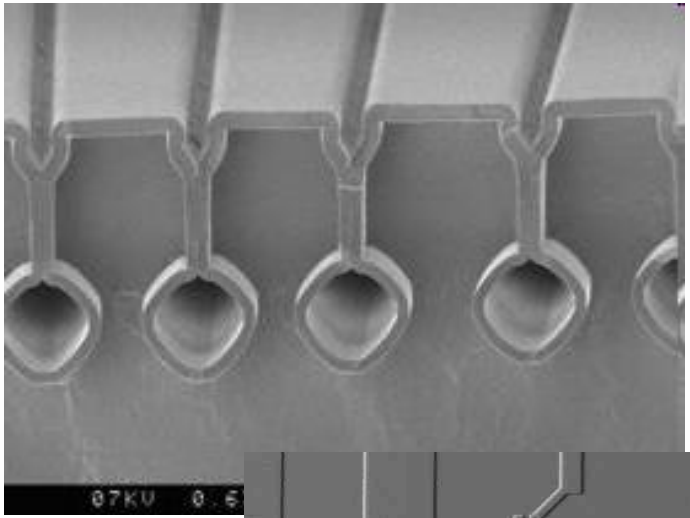


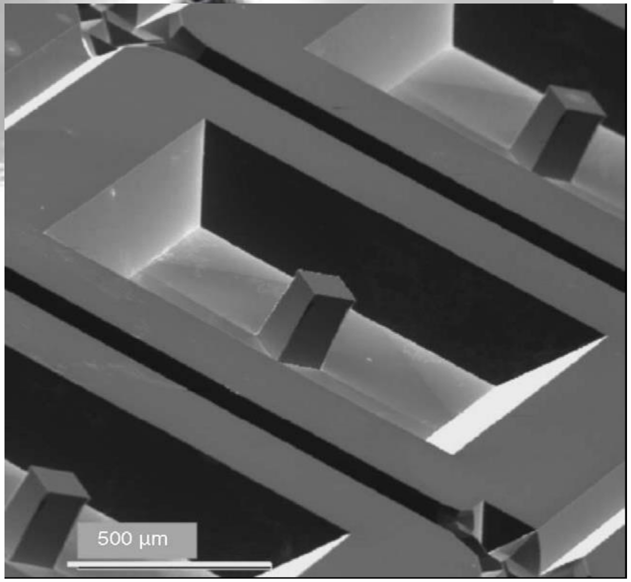


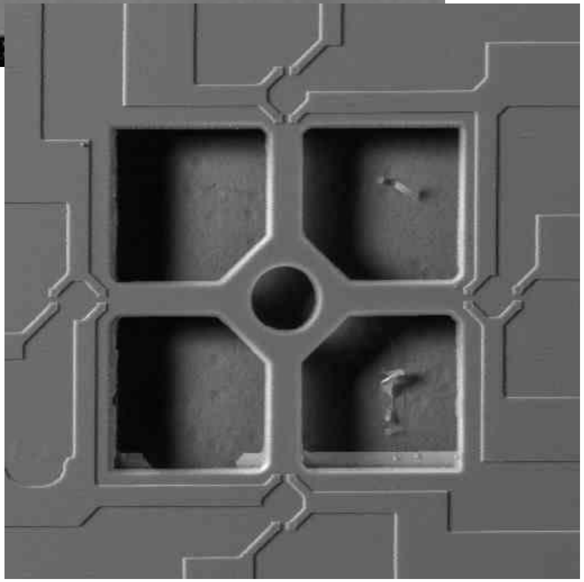
MEMS NEMS BIOMEMS

EXAMPLES: BULK MICROMACHINING









SINGLE CRYSTAL SILICON

MEMS NEMS BIOMEMS

SILICON FROM SAND (QARTZ)

$$SiC\ (solid) + SiO_2\ (solid) \rightarrow Si\ (solid) + SiO\ (gas) + CO\ (gas).$$

98% clean metallurgic Si

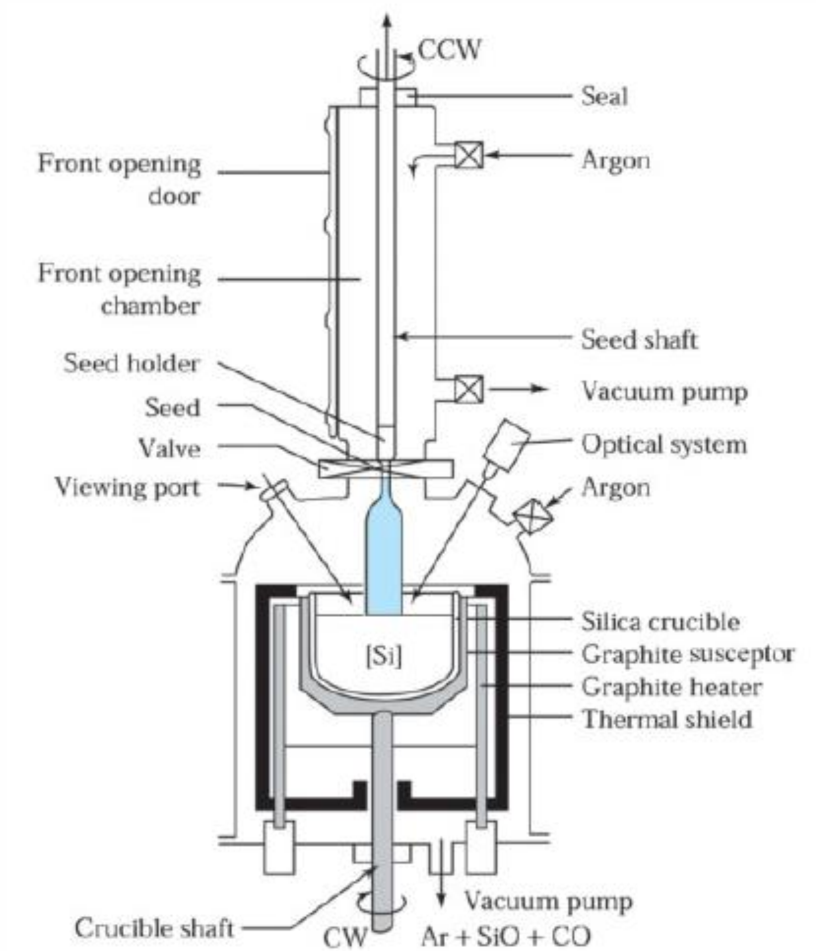
$$Si\ (solid) + 3HCl\ (gas) \xrightarrow{300^{\circ}C} SiHCl_3\ (gas) + H_2\ (gas).$$

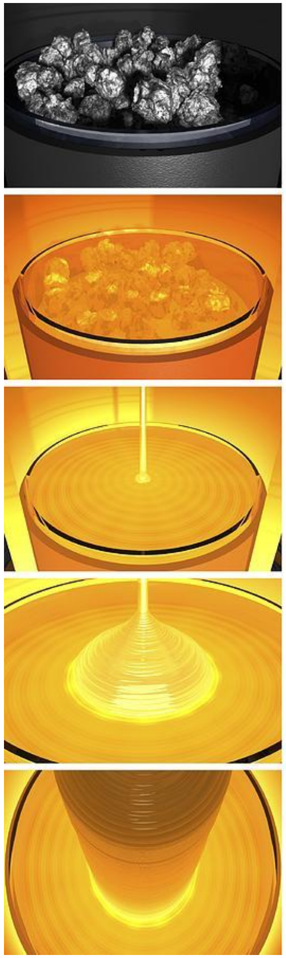
liquid, boiling point 32^{o}C

$$SiHCl_3\ (gas) + H_2\ (gas) \rightarrow Si\ (solid) + 3HCl\ (gas).$$

electronic quality polycrystalline Si

SINGLE CRYSTAL GROWTH: CZOCHLARSKI PROCESS



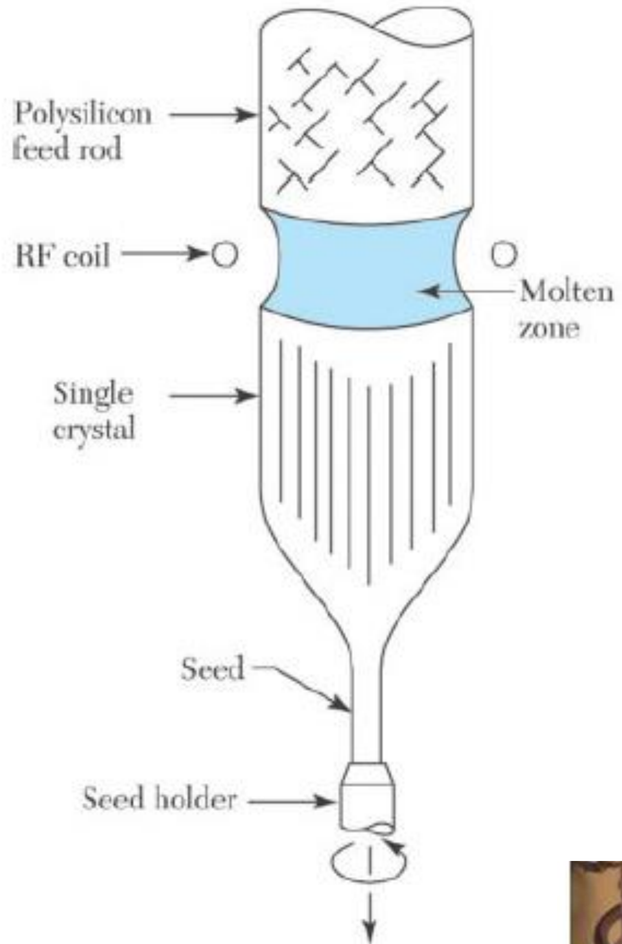


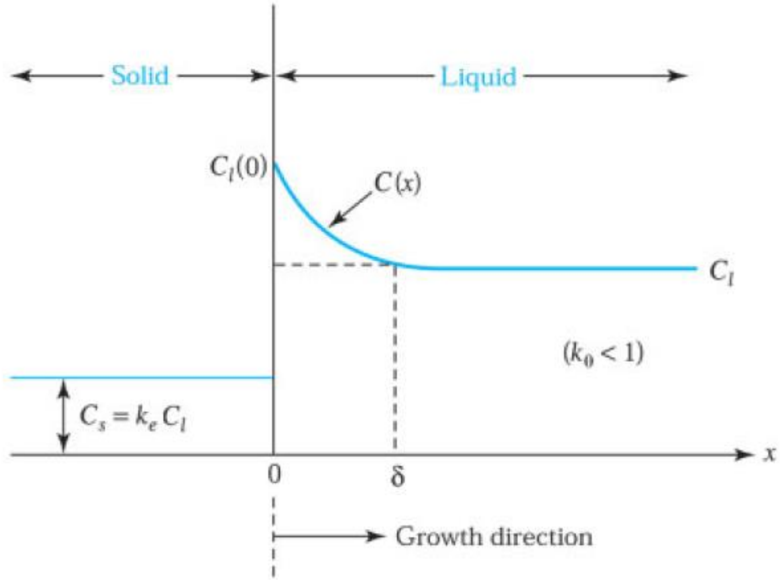
melting point: 1412°C

FLOAT-ZONE CLEANING

Surface concentration: $C_s = k_0 C_0 \left(1 - \frac{M}{M_0}\right)^{k_0 - 1}$ $k_0 = \frac{C_s}{C_l}$,

Effective segregation coefficient: $k_e \equiv \frac{C_s}{C_l}$.

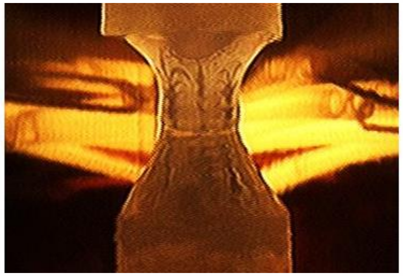




$$C = A_1 e^{-\upsilon x/D} + A_2$$

D – diffusion constant
ν – growth rate

RF



optical

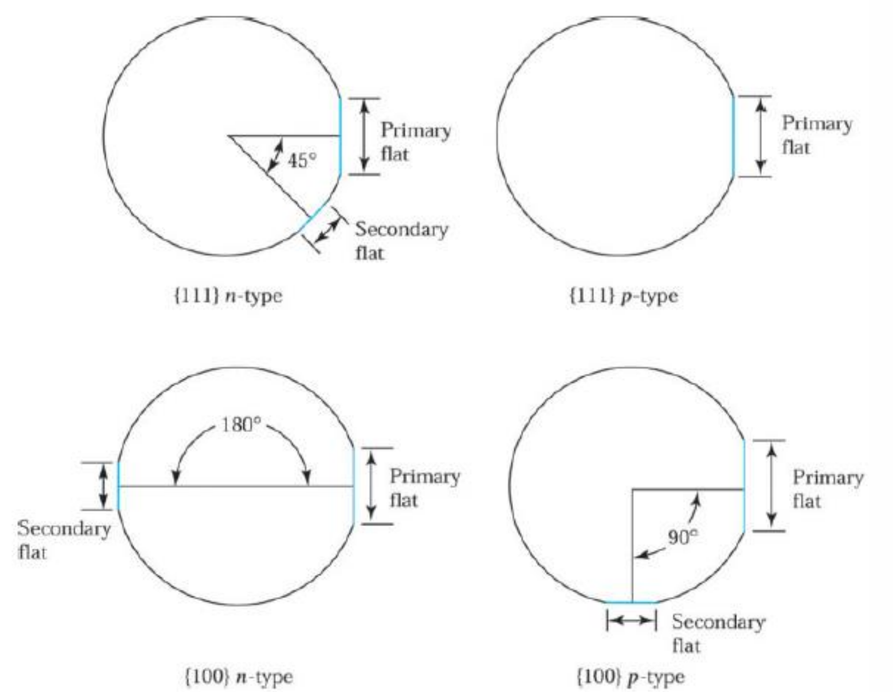
SILICON WAFER

Characterisation:

- X-ray diffraction
- SIMS

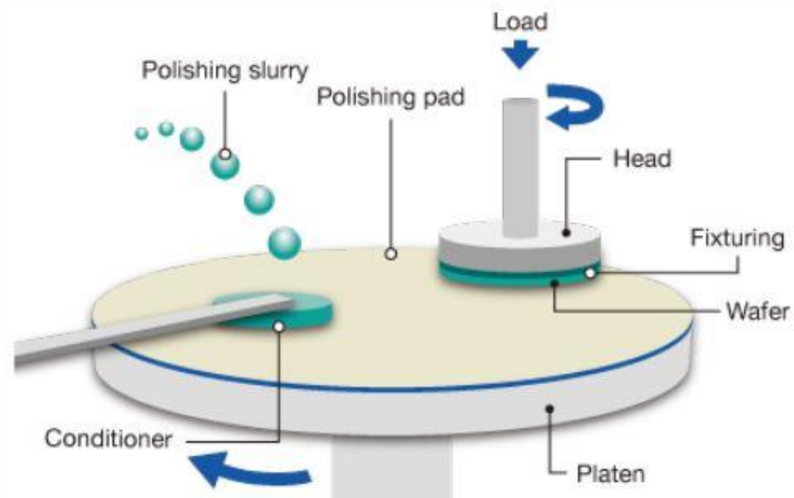
Parameter	125 mm	150 mm	200 mm	300 mm	450 mm
Diameter (mm)	125±1	150±1	200±1	300±1	450±1
Thickness (mm)	0.6–0.65	0.65–0.7	0.715–0.735	0.755–0.775	0.78–0.80
Primary flat length (mm)	40–45	55–60	NA[a]	NA	NA
Secondary flat length (mm)	25–30	35–40	NA	NA	NA
Bow (µm)	70	60	30	< 30	< 30
Total thickness variation (µm)	65	50	10	< 10	< 10
Surface orientation	(100) ± 1°	Same	Same	Same	Same
	(111) ± 1°	Same	Same	Same	Same

[a]NA: not available.



Surface polishing:

- Mechanical: Al_2O_3 + glicerin (2µm)
- CMP: chemical mechnaical polishing

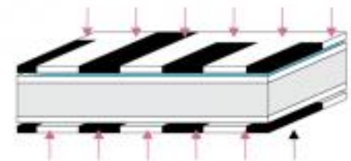


PHOTOLITOGRAPHY

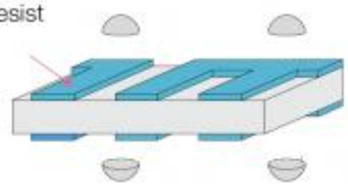
LAYER PROCESSING

1 - Cleaning
Material is cleaned to remove all surface contamination. This provides a suitable surface for resist adhesion later in the process.

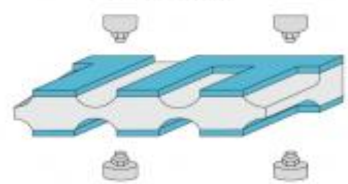
2 - Laminating
The cleaned metal 'blank' is then coated with a light-sensitive photoresist in a clean room.



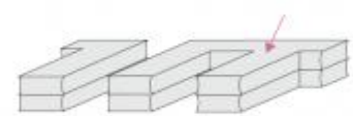
3 - Exposing
The metal sheet is then exposed to ultra-violet light, which hardens the photoresist.



4 - Developing
Unexposed areas are developed away, leaving behind the bare metal.



5 - Etching
Etching chemistry is sprayed on both sides of the metal at high pressure. This accurately removes the unwanted metal.

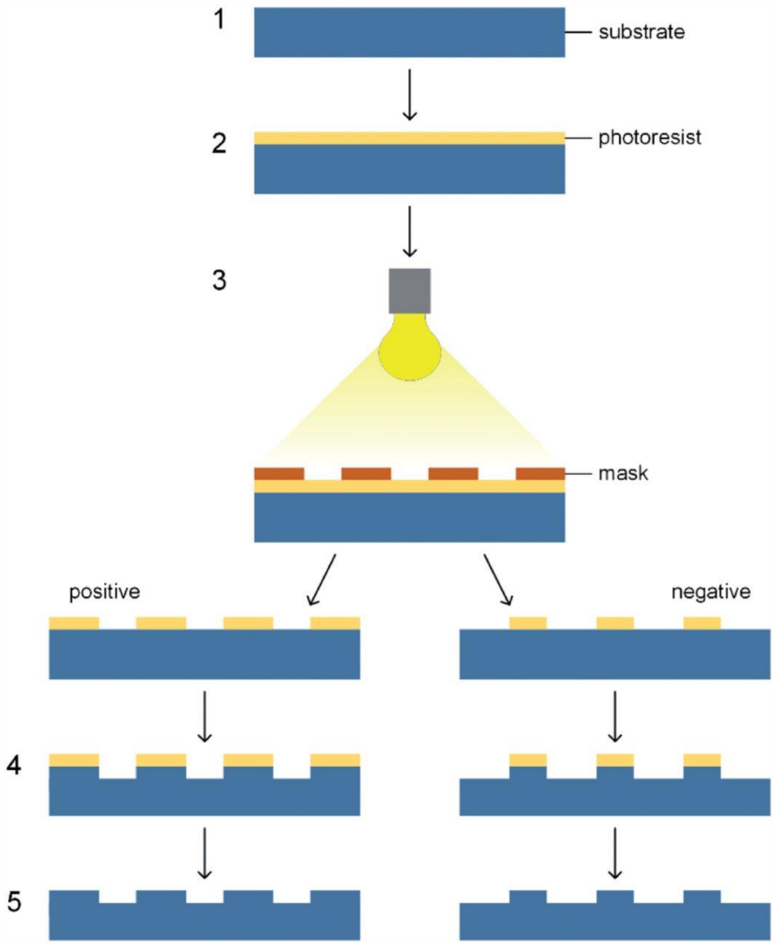


6 - Stripping
The resist is removed in the end to leave behind burr- and stress-free components.

MEMS NEMS BIOMEMS

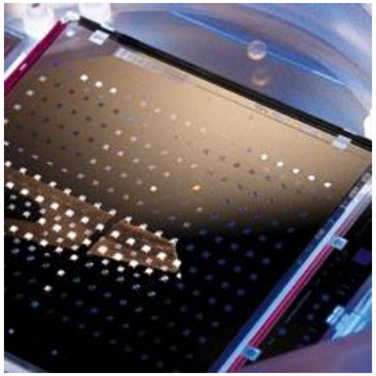
PHOTOLITHOGRAPHY PROCESS

SUBSTRACTIVE PHOTOLITHOGRAPHY



1. Surface treatments: cleaning, dehydratation
2. Photoresist spincoat / prebake
3. Exposure / development

   Postexposure bake / softbake hardbake

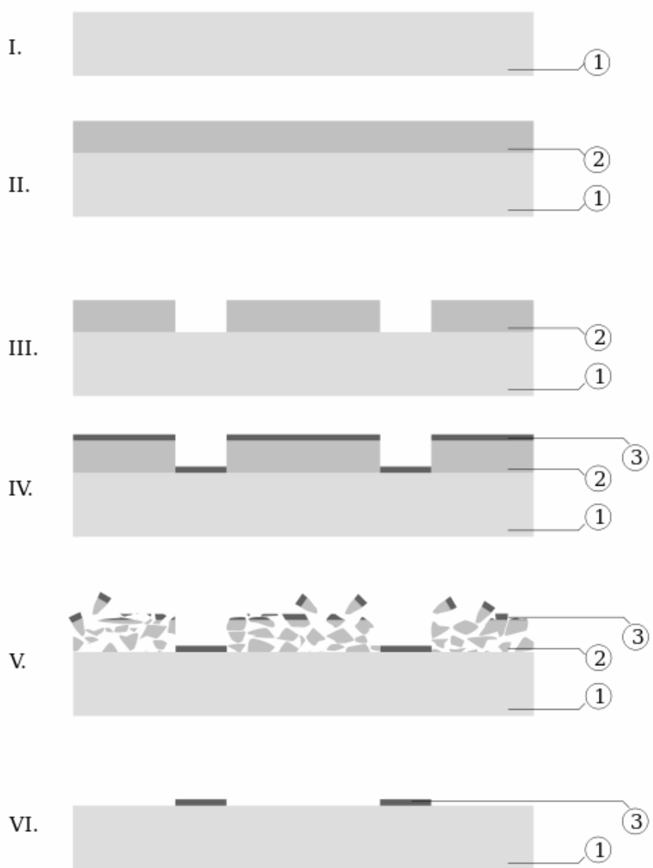


4. Processing with photoresist masking
5. Photoresist removal, stripping, cleaning

Energiatudományi Kutatóközpont | MEMS.HU

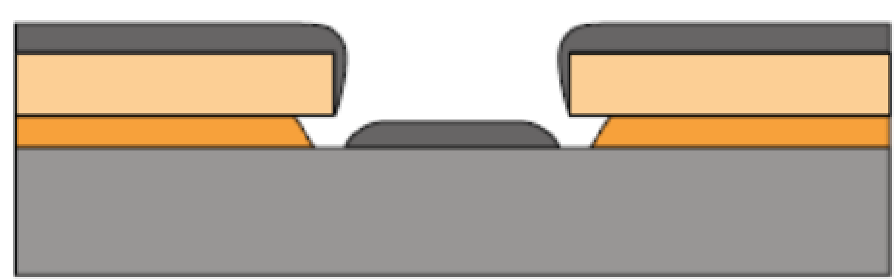
PHOTOLITHOGRAPHY PROCESS – LIFT-OFF

ADDITIVE PHOTOLITHOGRAPHY



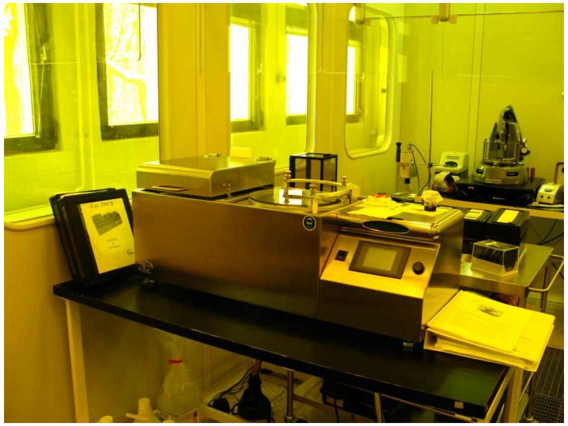
1. Surface treatments: cleaning, dehydratation
2. Photoresist spincoat / prebake
3. Exposure / development

   Postexposure bake / softbake
4. Layer deposition
5. Photoresist removal, stripping, cleaning

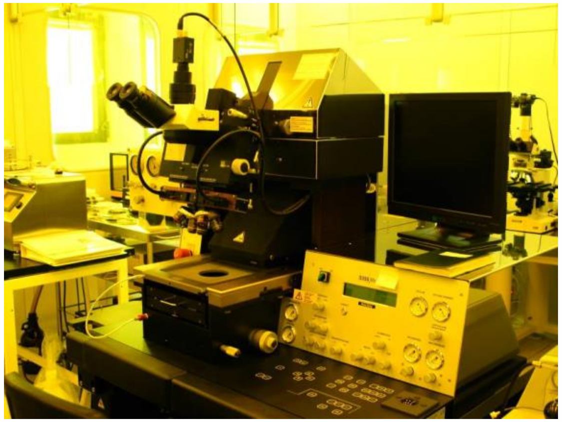


PHOTOLITHOGRAPHY PROCESS

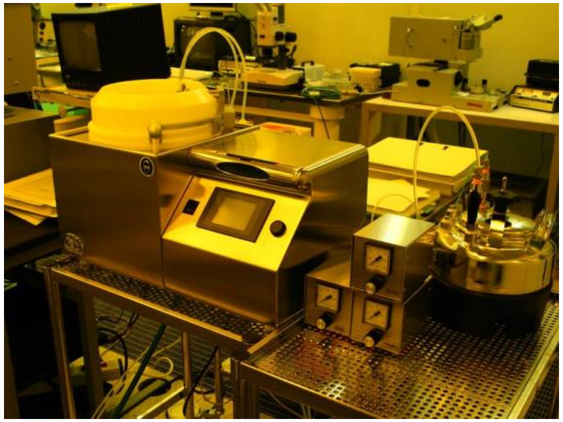
EQUIPMENTS - RADIATION



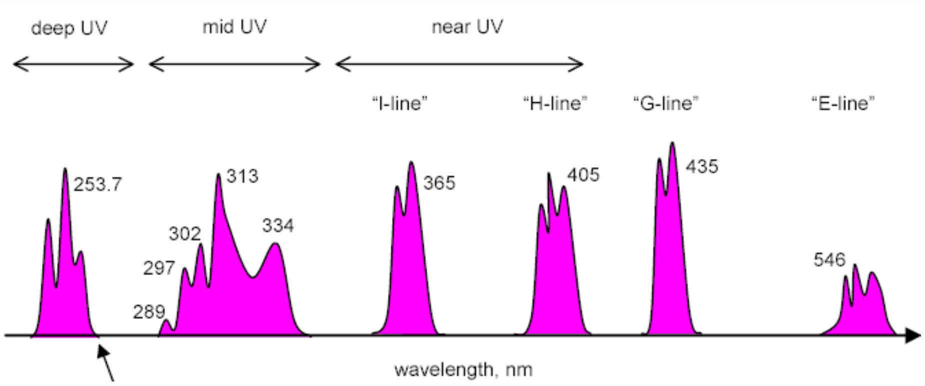
Spincoater – hotplate



mask alligner



developer



Hg lamp: 436 nm (g-line), 405 nm (h-line), 365 nm (i-line)

KrF laser: 248 nm / ArF lézer: 193 nm

Next generation: extreme UV (EUV): 13.5 nm

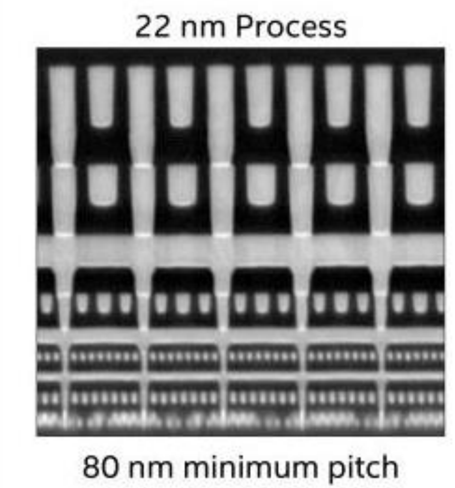
LAYER DEPOSITION

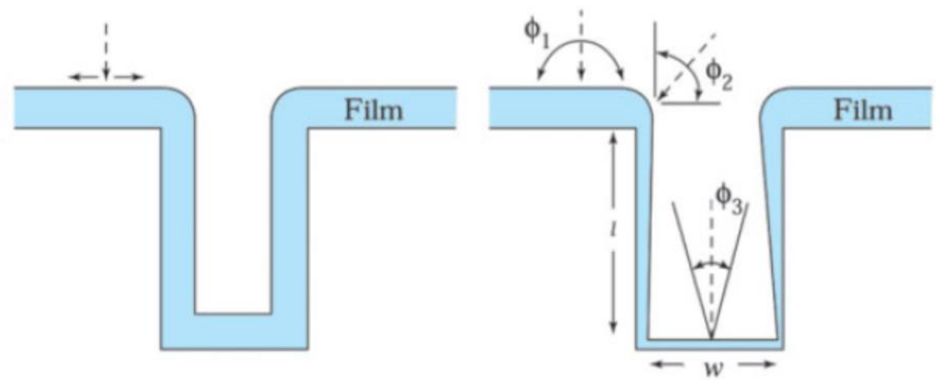
THIN FILMS - APPLICATIONS

- Microelectronics, semiconductor processing
- Micro-electromechanical systems (sensors, actuators, MEMS)
- Thermal conducting coatings (BeO, AlN, diamond)
- Photovoltaic devices (solar cells)
  - amorphous and microcrystalline Si layers on glass and polimer substrates
  - compound-semiconductors (CuInGaSe, CdTe)
  - single- and multicrystalline Si solar cells (HIT)
- Optical applications (filters, gratings, antireflexion layers, mirrors, etc.)
- Abrasion-resistant coatings
  - protection of optical devices (deposited diamond layers)
  - hard coating of tools (TiN, WC, B_4C, diamond, DLC)
  - coatings of human prosthesis
- Corrosion-resistant coatings
- Decoration coatings

THIN FILM - STANDARD REQUIREMENTS

- homogeneous thickness on the substrate
- homogeneous composition
- homogeneous structure (amorphous, polycrystalline, epitaxal)
- homogeneous physical and chemical properties
- compactness (sponge vs. layer, pinholes)
- adequate adhesion
- low thermomechanical stress
- special requirements (friction, wettability, biocompatibility, etc..)
- economical
  - deposition rate
  - infrastructural maintenance
- step coverage





conformal non-conformal

$$\phi_3 \cong \arctan \frac{W}{l},$$

THIN THILM TECHNOLOGIES

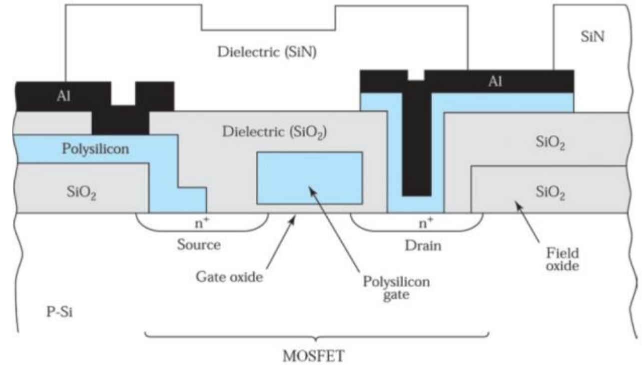
Physical methods (PVD, Physical Vapour Deposition)

Solid source:	vacuum evaporation
	sputtering: DC, RF, magnetron
	MBE (Molecular Beam Epitaxy)
Melt source:	LPE (Liquid Phase Epitaxy)
	(single crystal growing, Czohralsky, Floating zone)

Chemical methods

Electrolite source:	plating
(solution, suspension)	setting, sol-gel technics)
gázfázisból:	CVD (Chemical Vapour Deposition)
	VPE (Vapour Phase Epitaxy)
	MOCVD (Metal Organic ….)
	LPCVD (Low pressure…)
	PECVD (Plasma enhanced…)
	MWCVD (MicroWave…)
	PACVD (Photon assisted…, or plasma assisted)
	ALCVD (Atomic Layer.. ALD(ep..), ALEpitaxy)

OXIDATION – HIGH TEMP!!!

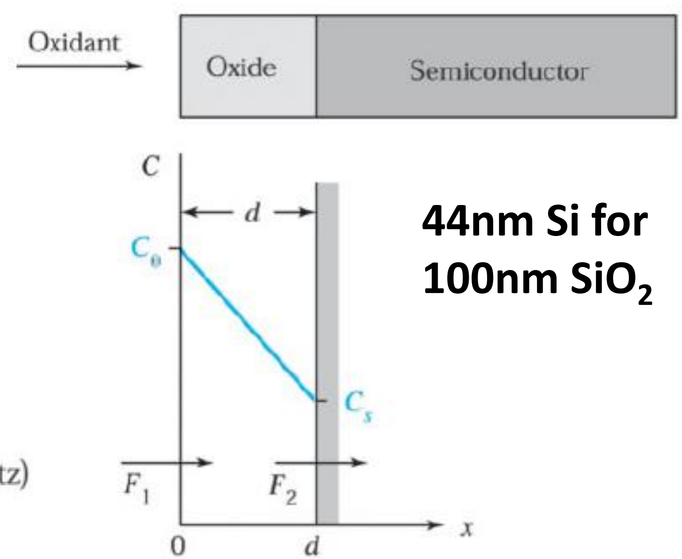


Oxidation temperature: 900°-1200 °C (±1°C)
Typical gas flow rate: 1 liter/min.

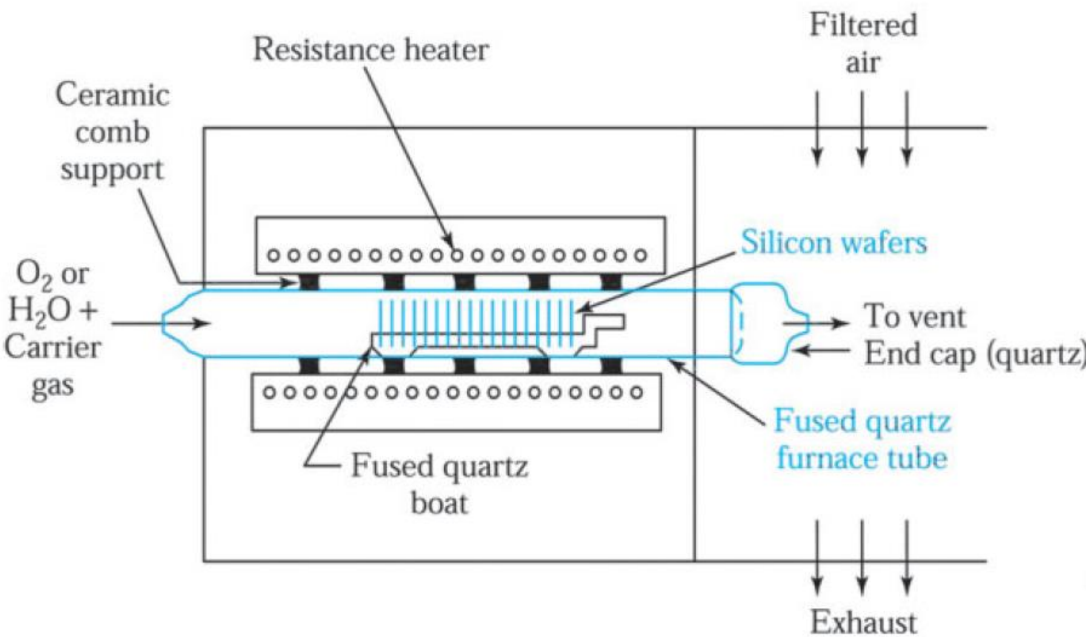
$$\mathrm{Si(solid)} + \mathrm{O_2\ (gas)} \rightarrow \mathrm{SiO_2\ (solid)},$$

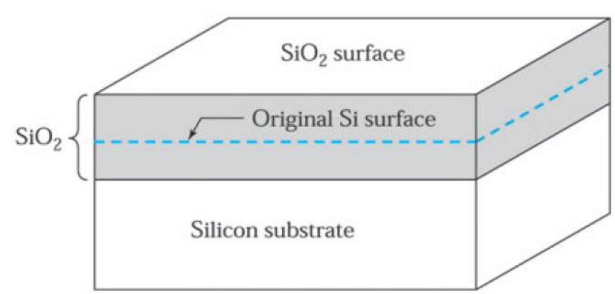
$$\mathrm{Si(solid)} + \mathrm{2H_2O\ (gas)} \rightarrow \mathrm{SiO_2\ (solid)} + \mathrm{2H_2\ (gas)}.$$

Kinetics of the layer growth:



44nm Si for 100nm SiO_2



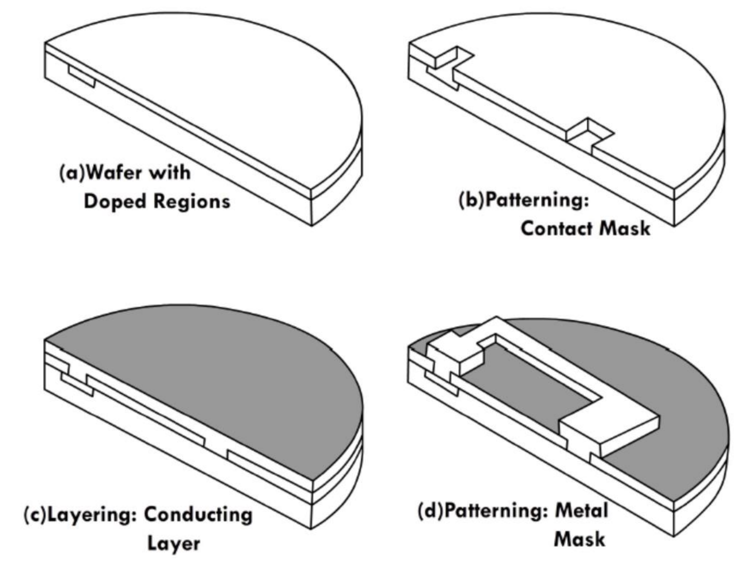


PHYSICAL LAYER DEPOSITION

- Typically metals and metal compounds: cca. Ti, Al, Cu, TiN, TaN
- Wires, contact pads, contacts, vias

Techniques:

- **Vacuum evaporation** (resistance or RF heating),
- **Electron beam evaporation**
- Plasma spray deposition
- **Vacuum sputtering**



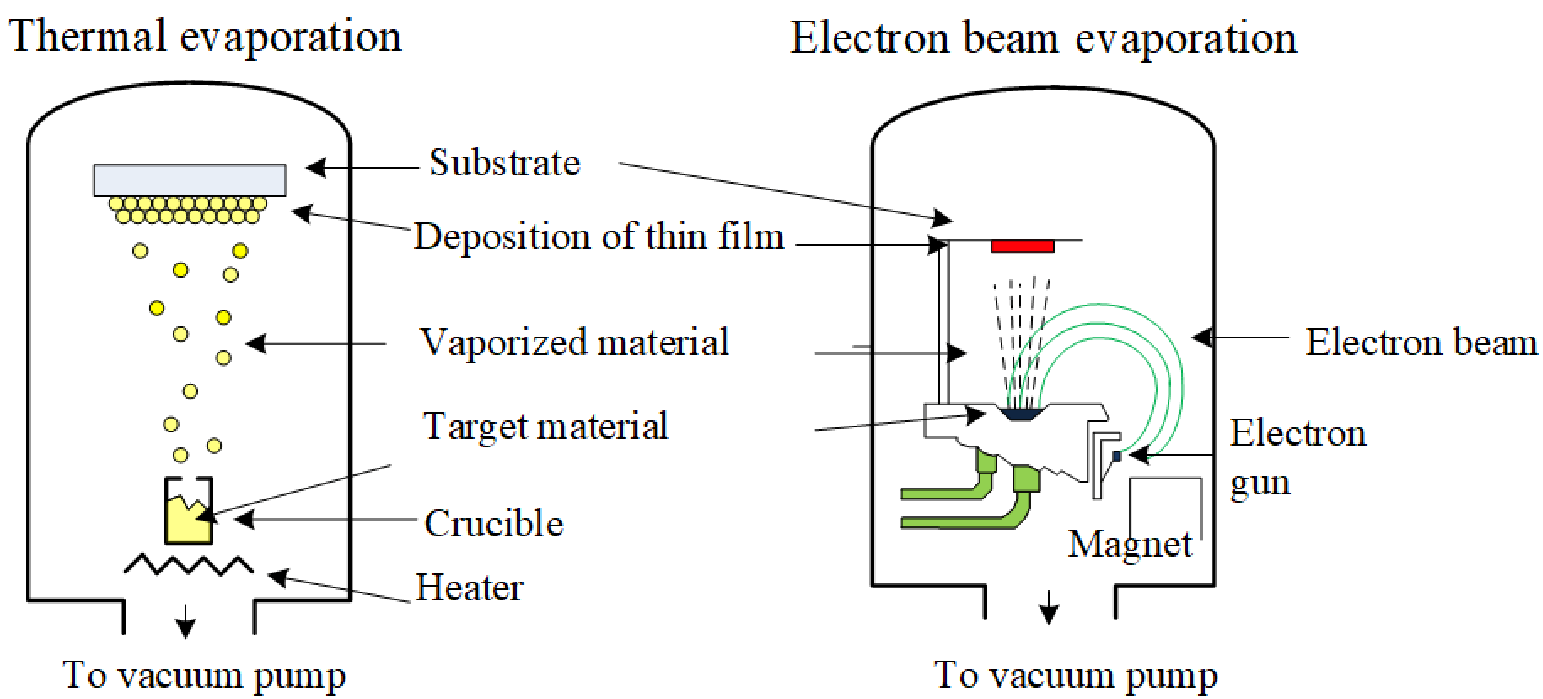
Vacuum parameters:

high vacuum range

- End vacuum: 10^{-6} mbar
- During deposition: 10^{-5} - 10^{-3} mbar
- Main free path: ~ 10cm ($\lambda > d / w$, no surface migration)

VACUUM EVAPORATION

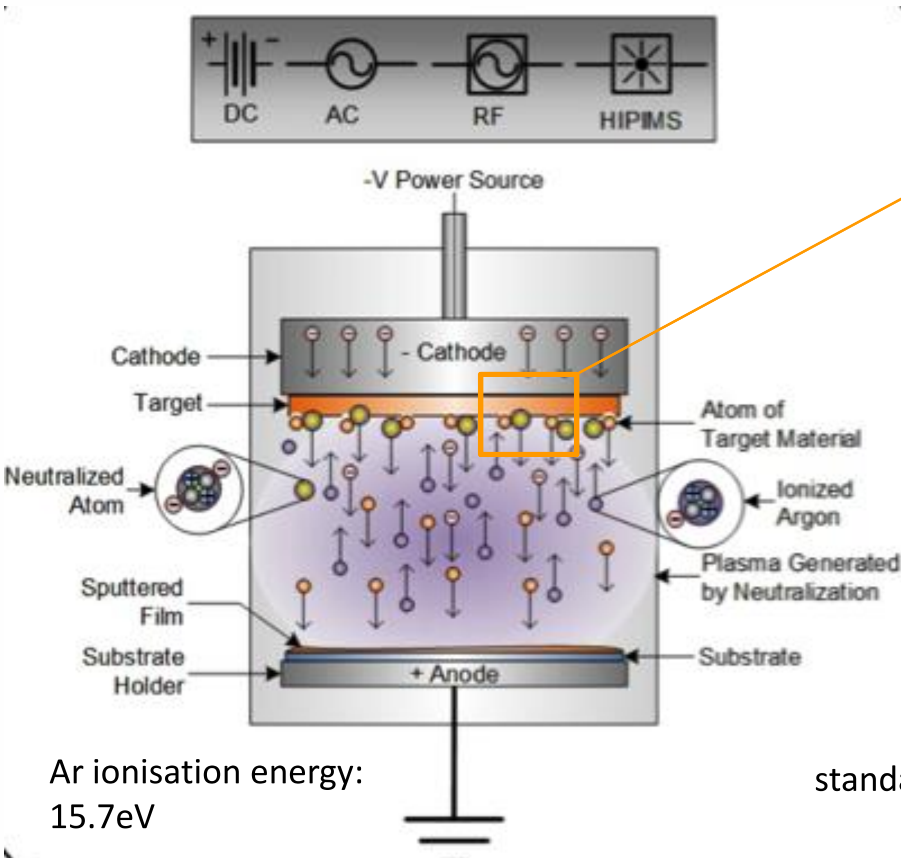
Over the melting point – the evaporated atoms travel with high velocity, on straight path in the vacuum chamber towards the substrate.



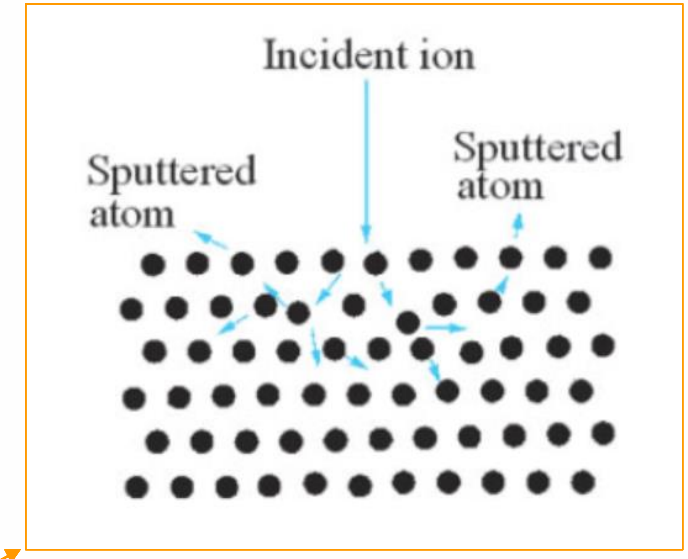
- 10^{-5}- 10^{-4} mbar $\rightarrow$ low step coverage
- Conductive and dielectric layers also (theoretically) / but NOT alloys

VACUUM SPUTTERING

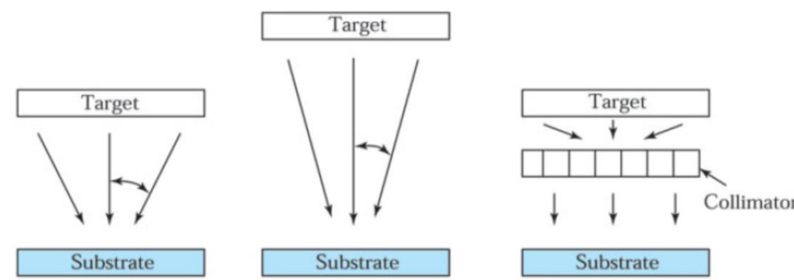
- cca. Materials with high melting point
- Metals and alloys
- compounds – reactive sputtering



Ar ionisation energy: 15.7eV



Irányított porlasztás nagy oldalarányú struktúrák (trench) kitöltéséhez:

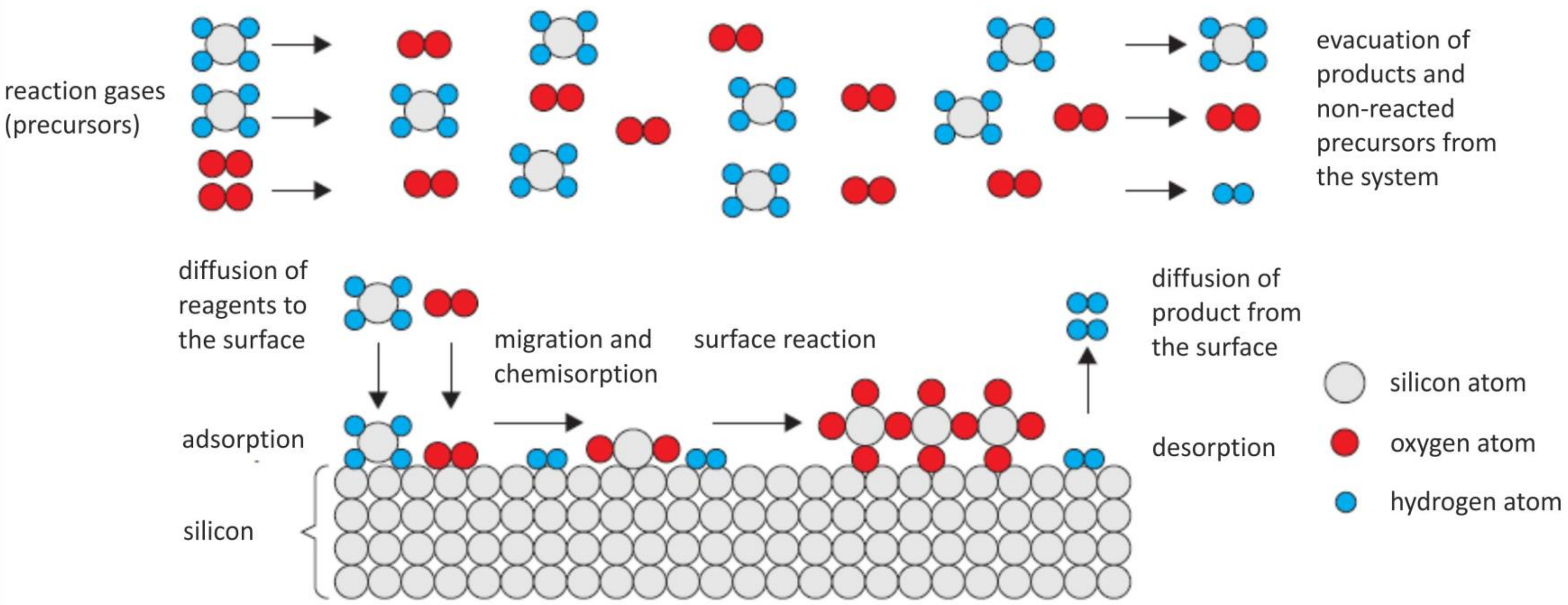


standard architecture / lond distance target / collimator

long free path – high vacuum

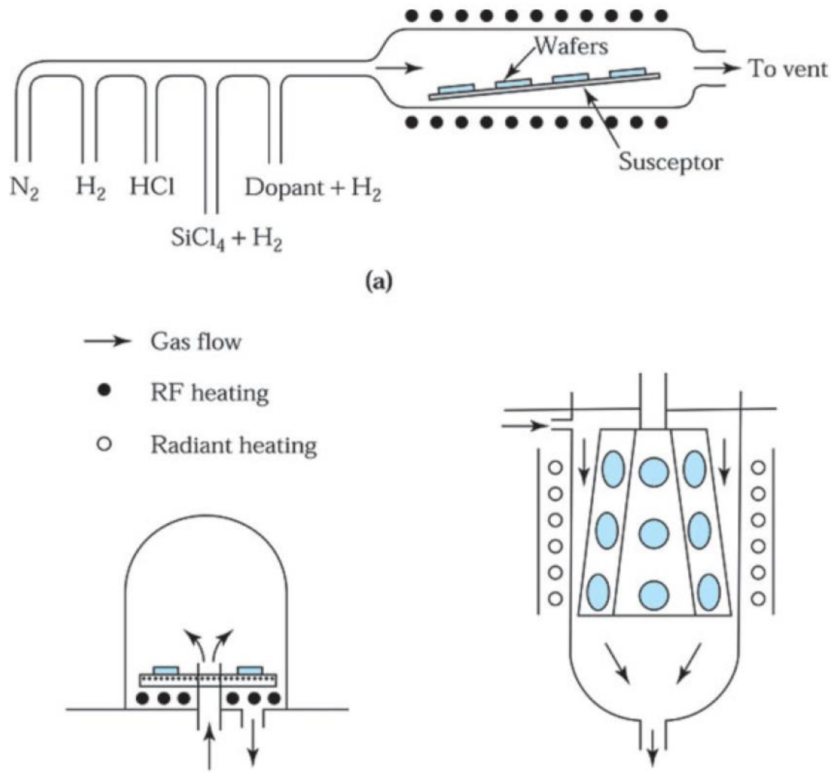
CVD – CHEMICAL VAPOUR DEPOSITION

- Chemical reaction of one or more gas phase reagents (precursors) on a solid substrate
- Surface catalysed reaction (not in the gas space)
- Solid product



CVD REACTOR TYPES

a. horisontal
b. pancake
c. barrel



Si deposition

$$SiCl_4\ (gas) + 2H_2\ (gas) \leftrightarrows Si\ (solid) + 4HCl\ (gas).$$

$$SiH_4 \xrightarrow{600^{O}C} Si + 2H_2\,.$$

GaAs deposition

$$As_4 + 4GaCl_3 + 6H_2 \rightarrow 4GaAs + 12HCl.$$

$$AsH_3 + Ga(CH_3)_3 \rightarrow GaAs + 3CH_4.$$

SiO_2 deposition

$$SiH_4 + O_2 \xrightarrow{450^{O}C} SiO_2 + 2H_2\,,$$

Si_3N_4 deposition

$$3SiCl_2H_2 + 4NH_3 \xrightarrow{\sim 750^{O}C} Si_3N_4 + 6HCl + 6H_2\,.$$

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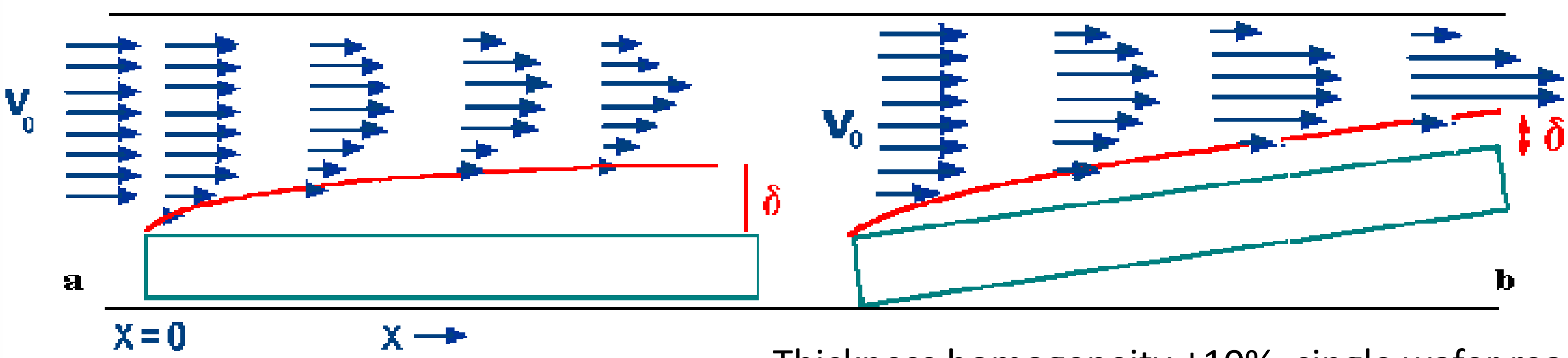
ATMOSPHERIC CVD - APCVD

- Small free path
- Reaction rate control: transport (reagent or product)
- Thermal activation



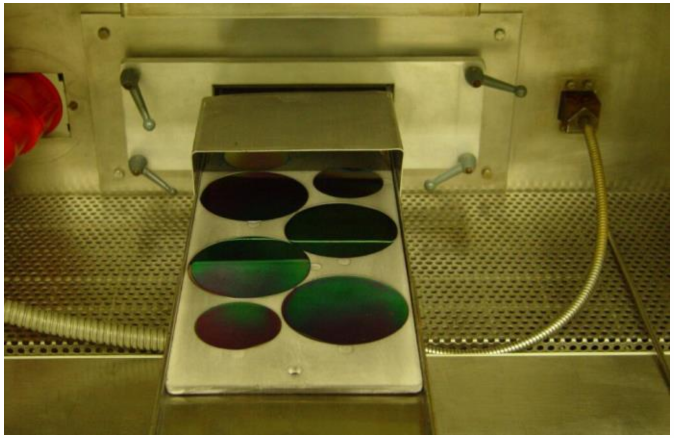
Thickness homogeneity ±10%, single wafer reactors

$$\delta(x) = \sqrt{\frac{\mu x}{\rho v_0}}$$

μ kinematic viscosity
r density

- SiO_2: silan and oxygen / 450°C

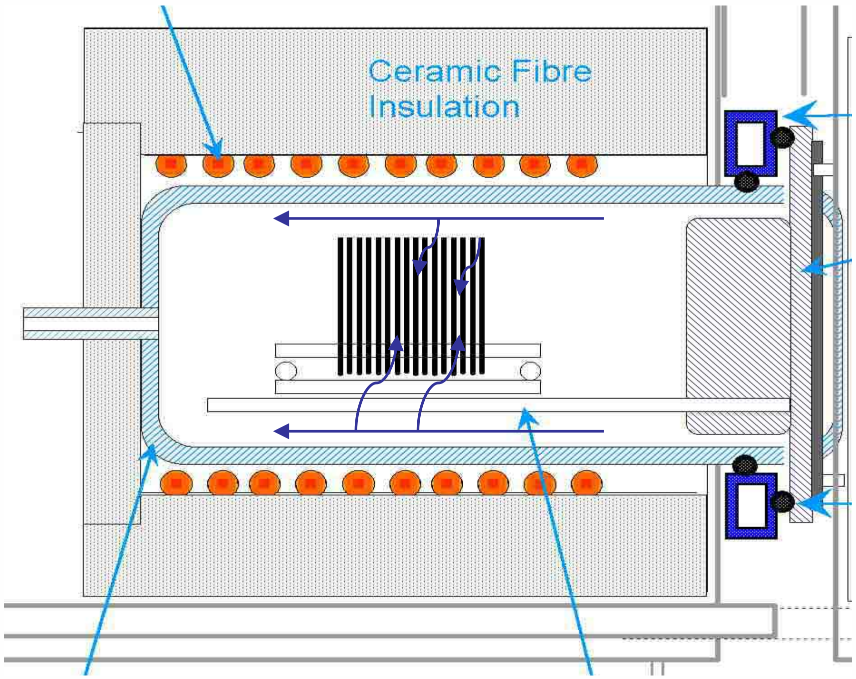
$$SiH_4 + O_2 \xrightarrow{450^0 C} SiO_2 + 2H_2 ,$$



MEMS NEMS BIOMEMS

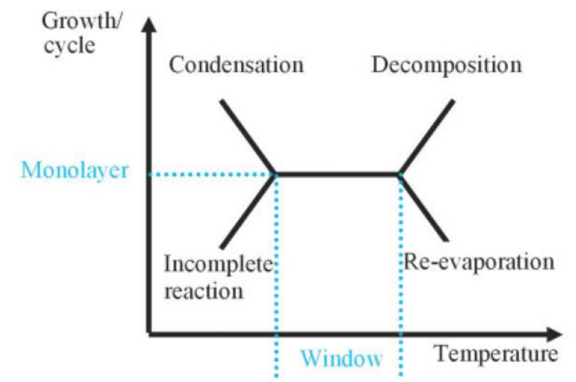
LOW PRESSURE CVD - LPCVD

- Long free path
- Reaction rate control: chemical reaction
- Thermal / plasma activation

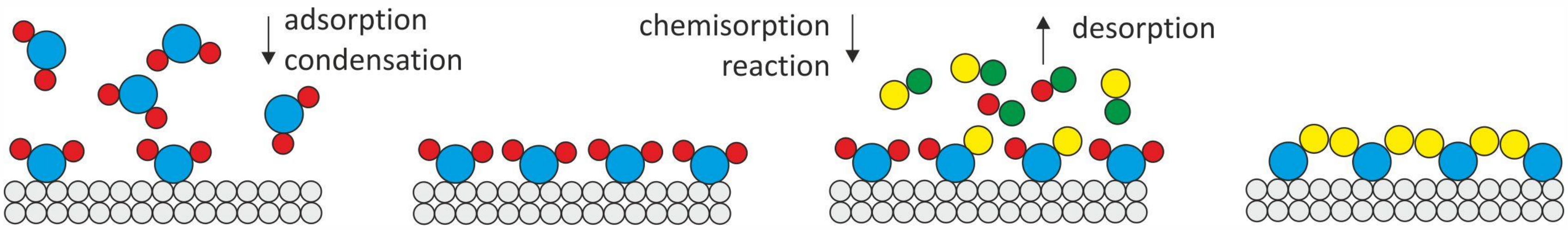


Thickness homogeneity ±2-6%, batch and single wafer reactors

ALD – ATOMIC LAYER DEPOSITION



- Reaction rate control: chemisorption
- Thermal / plasma activation



- atomic / molecular precision
- excellent homogeneity
- excellent step coverage
- batch and single wafer reactors

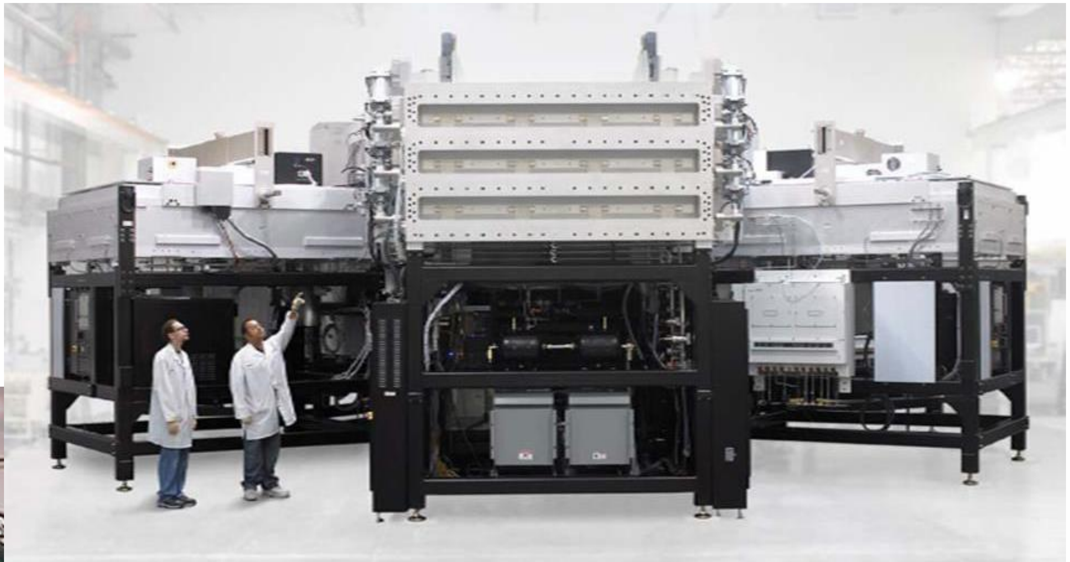
- oxides: Al_2O_3, TiO_2, SnO_2, ZnO, HfO_2,
- nitrides: TiN, TaN, WN, NbN
- metals: Ru, Ir, Pt
- sulfides: ZnS

$$OH \bullet Si + Al(CH_3)_3 \rightarrow AlO(CH_3)_2 \bullet Si + CH_4$$
$$AlO(CH_3)_2 \bullet Si + 2H_2O \rightarrow AlO(OH)_2 \bullet Si + 2CH_4$$

CVD and SPUTTERING – INDUSTRIAL SOLUTIONS

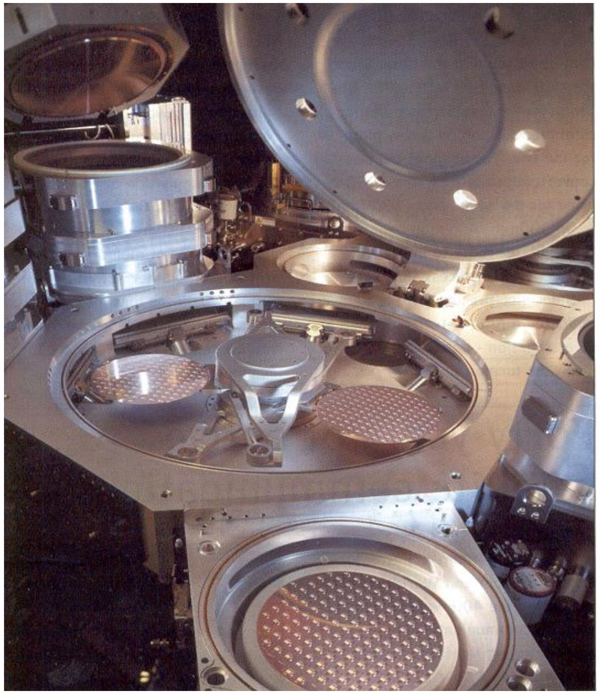
Same technology for larger substrates:

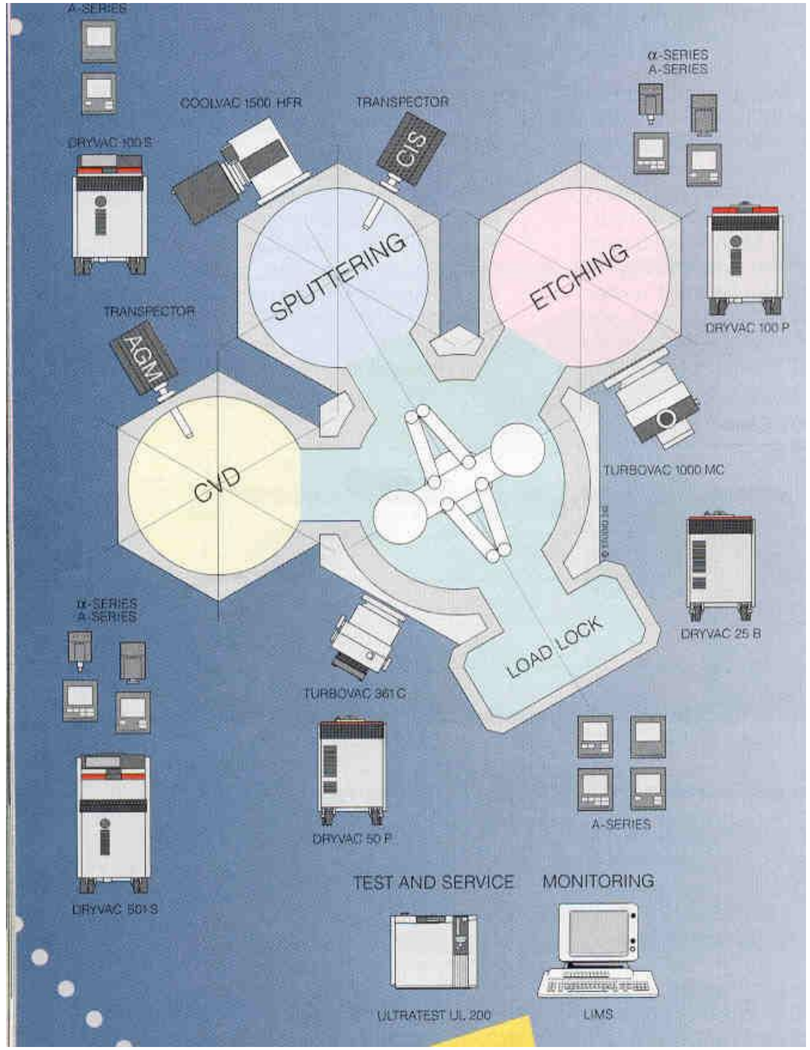
- Flat panel
- Thin Film Solar



CLUSTER TOOL

- Cleaning (plasma)
- CVD (any)
- PVD
- Automatic loading (load lock)





ETCHING

CHEMICAL ETCHING

Etching: removal of the solid material of the substrate by chemical reaction

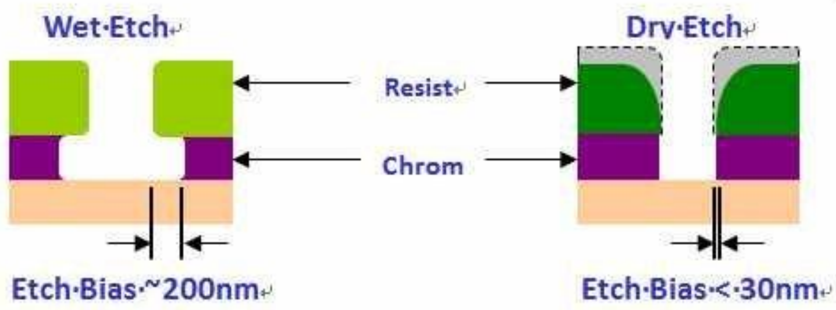
Reagent: liquid or gas (or vapour, or plasma)

Wet etching:

- **Chemical** reaction on the liquid / solid interface – causing dissolution of solid material

Dry etching:

- Gas or vapour phase reagents at high temperature
- Gas phase reagent at **low temperature and pressure, active particles with extreme high reactivity, generated by RF induced plasma** discharge (free radicals or excited neutral particles) – isotropic etching
- **Physical etching** – non or moderately selective **sputtering** of the substrate atoms and molecules – directional / anisotropic etching



ETCHING IN IC TECHNOLOGY

Semiconductor wafer processing

- Elimination of mechanical defects by chemical polishing
- High quality surface development by chemical-mechanical polishing

CMOS technology / micromachining

- Photoresist development
- Selective or total removal of oxides or nitrides
- Patterning of metal layers
- Selective or total removal of organic layers
- Contour etching: engineered undetcut profiles
- Anisotropic etching of Si in MEMS structures
- Etching of polycristalline Si in MOS structures (poly-gate)

Analitical applications:

e.g. exploring foults (pinholes, crystalline foults

Packaging semiconductor devices: e.g. refreshing metal surfaces

MEMS
NEMS
BIOMEMS

WET CHEMICAL ETCHING

Requirements against the etching processes:

- uniform etch rate on the whole substrate surface
- high selectivity for the masking layer
(for photoresist or other layer)
- high selectivity for substrate material
(v_{layer} / $v_{substrate}$ >10..100)
- adequate etch rate corresponding to the
thickness of the layer to be etched (≈ 0,1-1 μm/min)
- possibly controlled by chemical reaction
(not by transport)

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WET ETCHING TECHNIQUES

Immersion etching

- High wafer number / economic
- Rate control: temperature / stirring (bubbleing / stirring / ultrasonic tub)

Spray etching

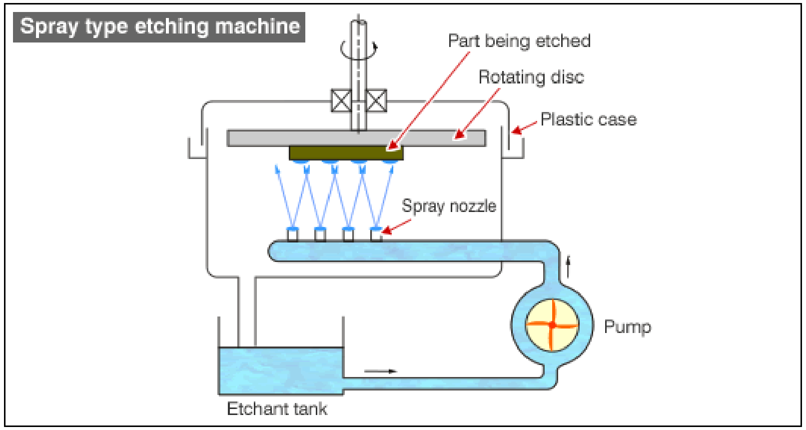
- Effective etch rate control (parameters: vaporisation drop size / pressure)
- Enhanced etch rate due to the continously fresh etchant
- Single wafer

Chemo-mechanical etching

- Wafer polishing (Si or polymers)

Electrochemical etching

- Selectivity and etch rate control (parameters: potential or current)



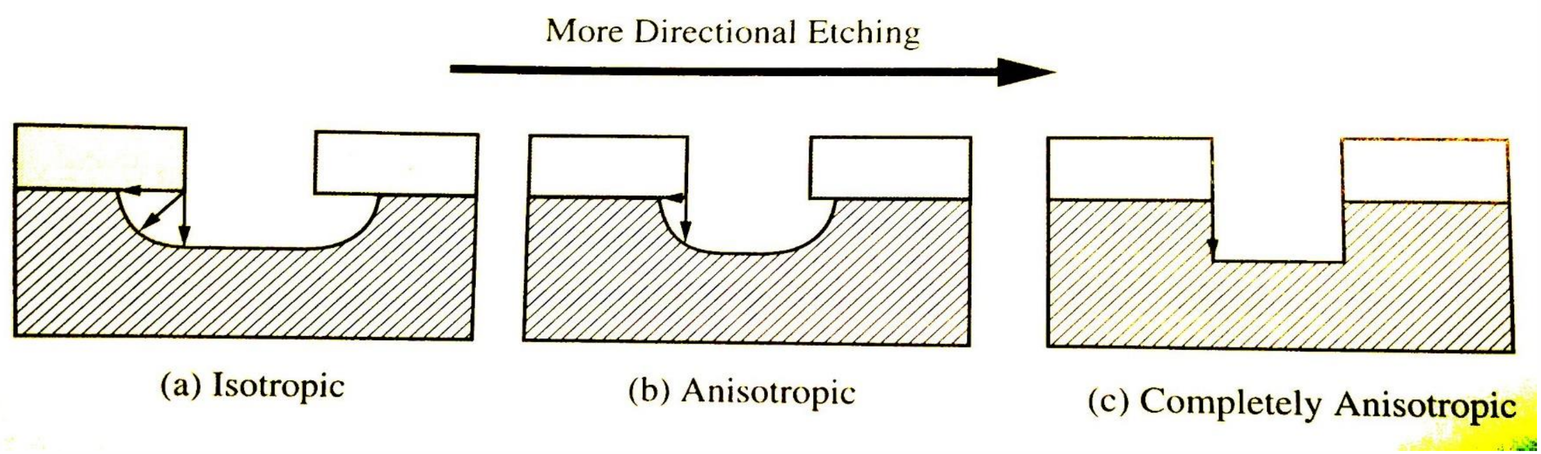
DIRECTION DEPENDENCY OF WET ETCHING

Isotropic etching: direction independent etch rate

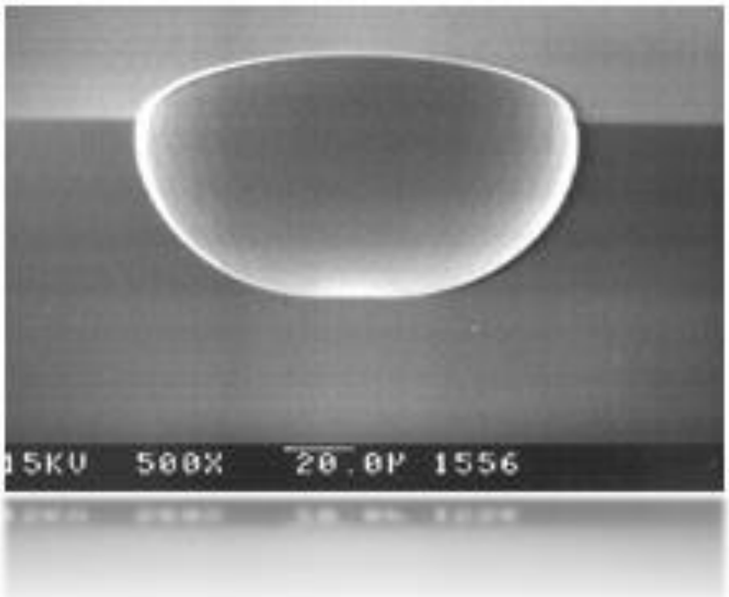
- Etching of amorphous and polycrystalline materials is typically isotropic
- Typically diffusion limited processes

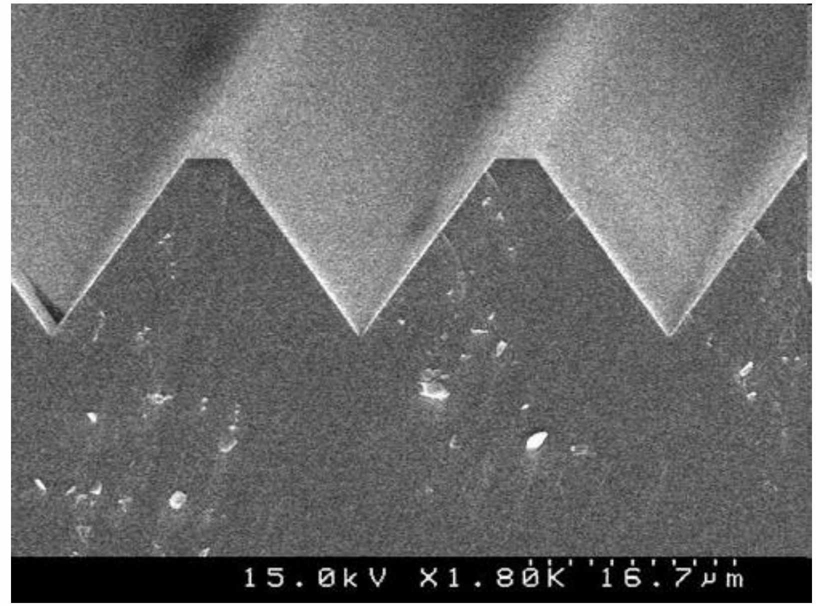
Anisotropic etching: direction dependent etch rate

- Etching of crystalline materials could be isotropic and anisotropic according to the composition of the etching solution and the reaction kinetics
- Typically reaction limited processes



WET ETCHING OF SILICON



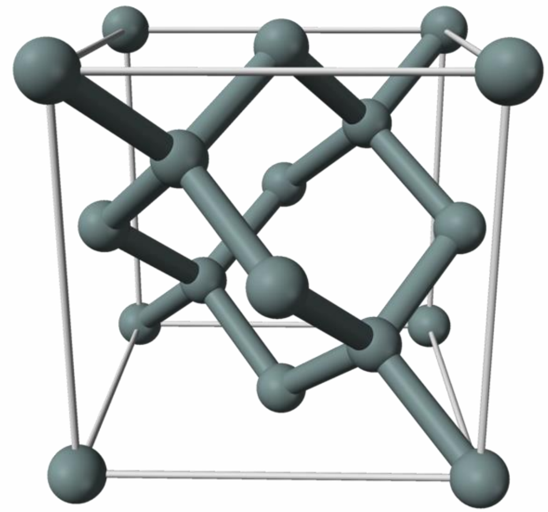


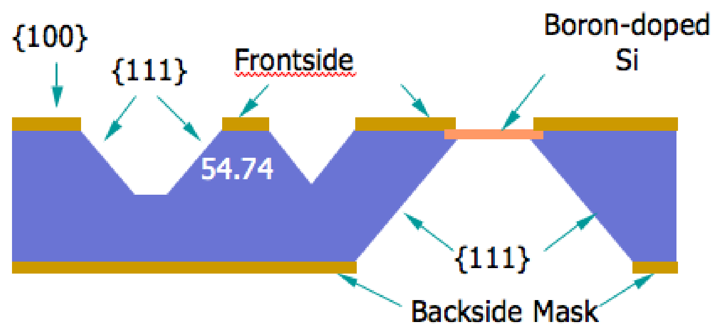
Isotropic:
uniform etch rate in each crystallic directions
(e.g. poly-Si etchant - HF-HNO_3-CH_3COOOH)

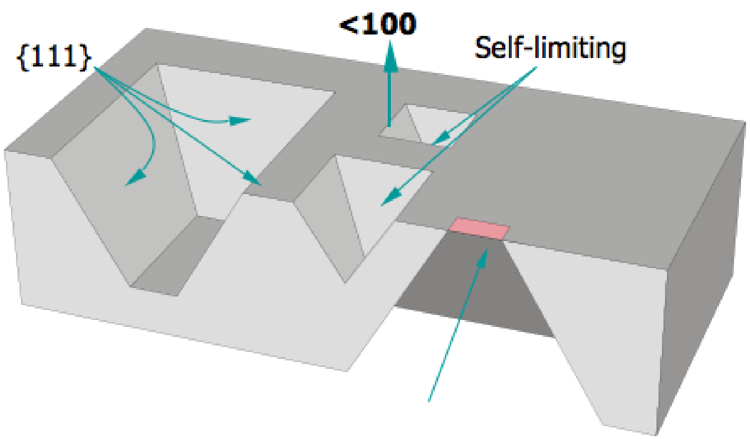
Anisotropic:
etch rates are altering according to the different crystallic directions
(e.g. alkaline etchants – KOH)

ANISOTROPIC SI ETCHING
in ALKALINE KOH SOLUTION

Crystalline structure of silicon: face centered cubic

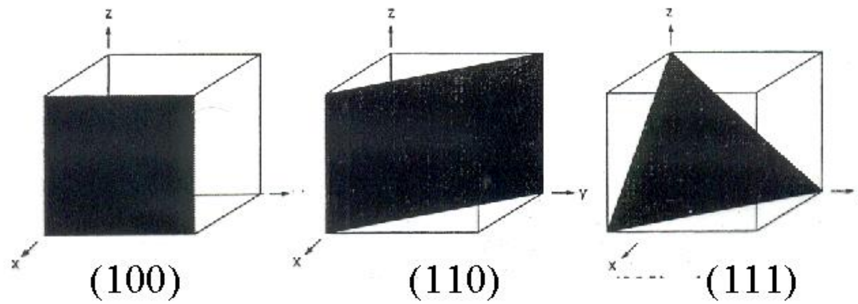






Type and orientation dependency

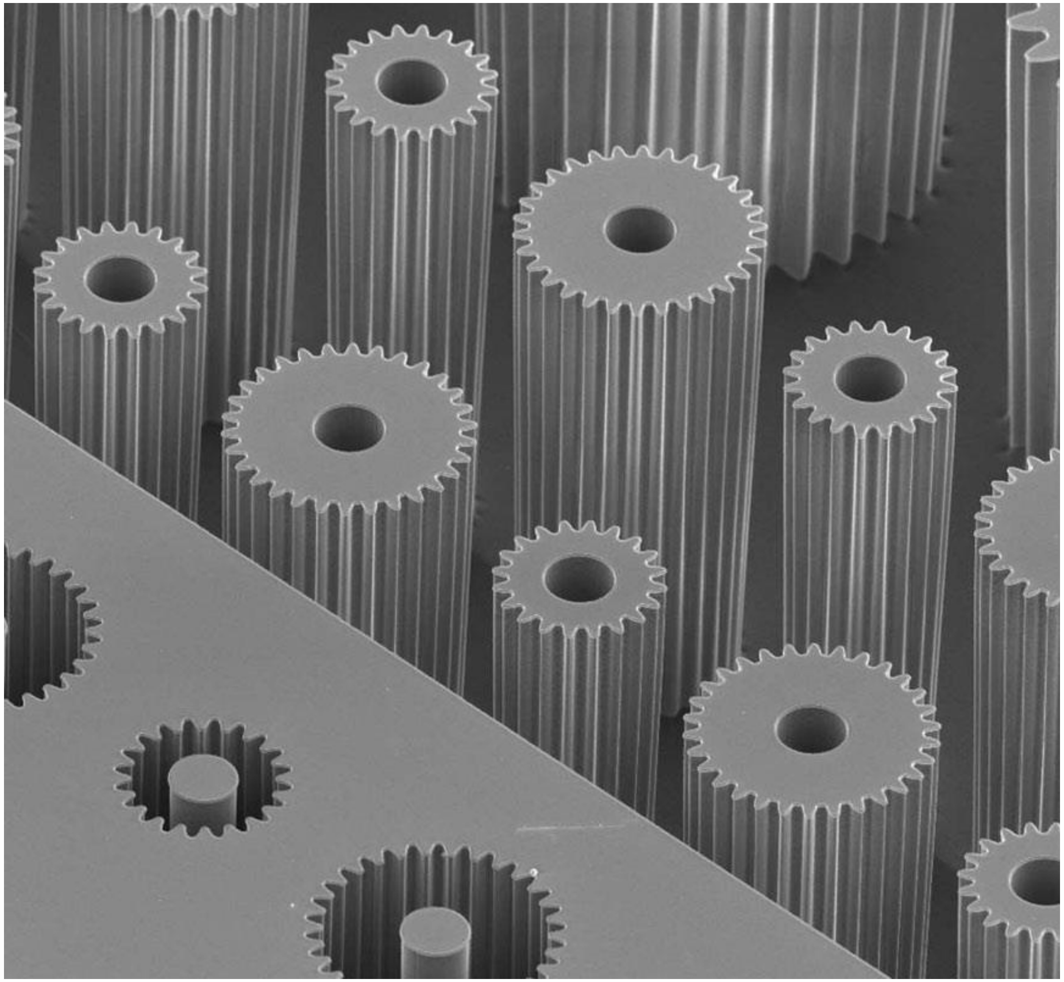
Typical crystalline planes:

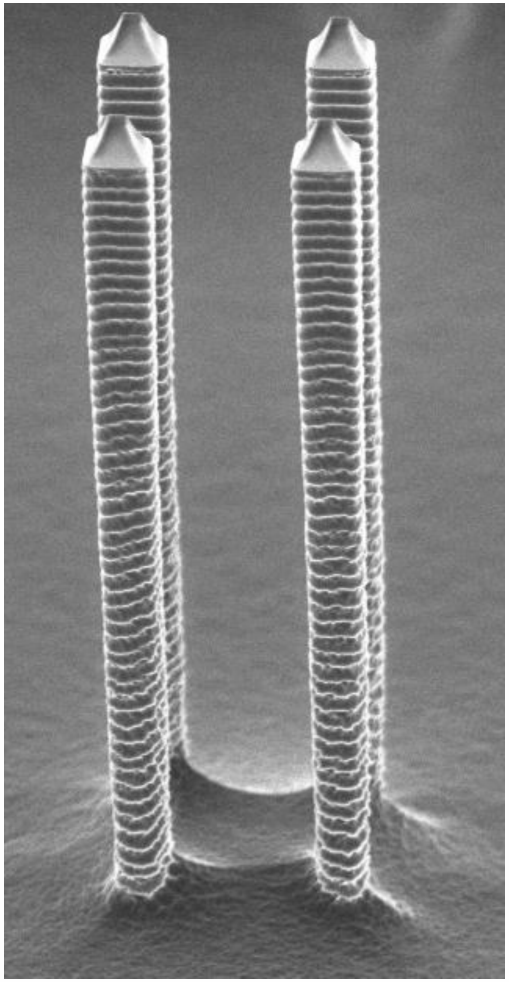


Si-Si bond energies: $E_{\sigma(SiSi)(111)} >> E_{\sigma(SiSi)(100)} > E_{\sigma(SiSi)(110)}$

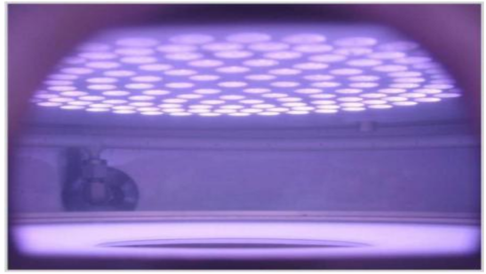
Etching rate: $v_{<111>} << v_{<100>} < v_{<331>}$

DRY ETCHING





PLASMA / DRY ETCHING

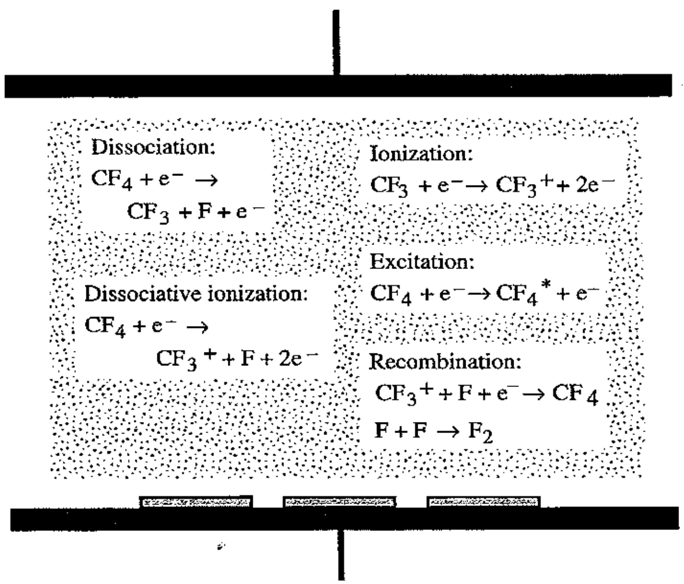


conducting gas (ions, free radicals, electrons, natural particles),

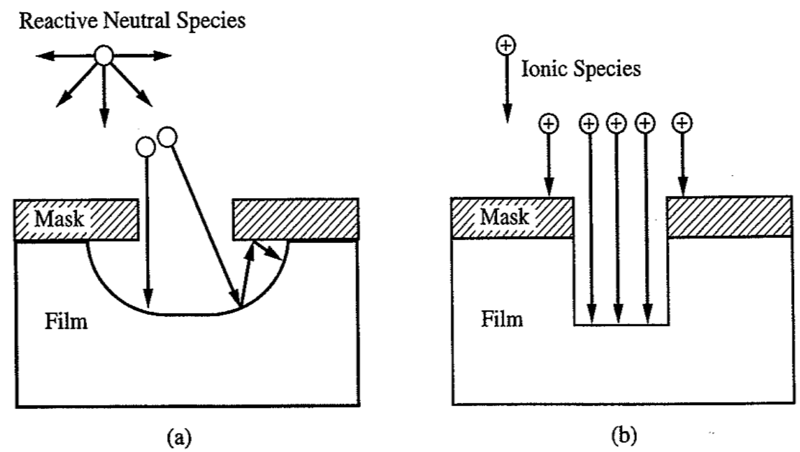
Particles are excited by the quick electrons and emit photons after relaxation.

Plasma Glow

- Low gas pressure (1 mtorr-1 torr)
- High electric field on the electrodes, 13.56 MHz RF
- Ionisation of the gas atoms: e^- + ions



Plasma etching



- Effective **chemical etching** by reactive radicals (atomic F)
- Directional / anisotropic **physical etching** by charged particles

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DRY CHEMICAL ETCHING

Free radicals (neutral, having non-bonding electron pair) – extremely reactive

$$CF_4 + e^- \rightarrow CF_3 + F + e^-$$
$$4F + Si \rightarrow SiF_4$$

Volatile products – must get away from the surface for continuous etching

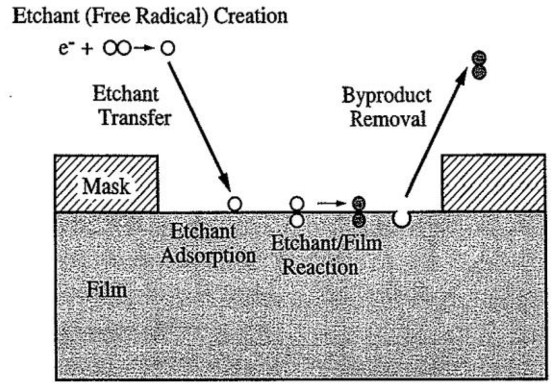


Figure 10–10 Processes involved in chemical etching during plasma etch process.

Additive gases: possibly support the generation of reactive free radicals, enhancing etch rates!

e.g. ***O_2 gas*** *reacts with dissociated CF_3, CF_2 molecules, preventing the recombination to CF_4, enhancing the concentration of free F radicals*
BUT: O_2 dilutes the etchant gas!

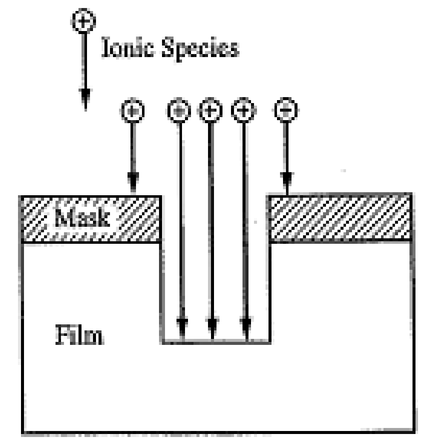
Isotropic etching:

1. Isotropic angular distribution of the incident velocity vector (particles)
2. Low surface adhesion / sticking coefficient (long path till reaction

HIGH SELECTIVITY

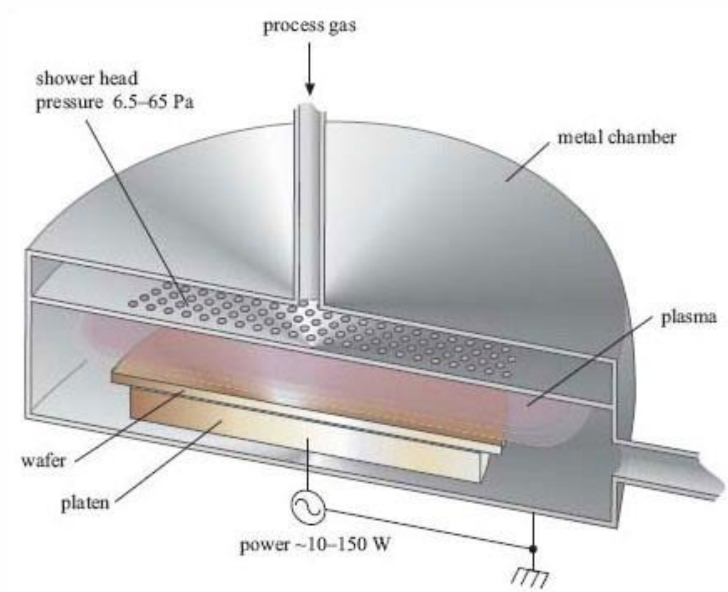
DRY PHYSICAL ETCHING

- **Positive ions are accelerating towards the electrodes** due to V_p (one is the substrate holder)
- Anisotropic etching:
  - Direction dependent etching rate of the incident ions due to the directional electric field
  - High adhesion / sticking coefficient – reaction at the moment of incidence
- **LOW SELECTIVITY**



Technologies:

- Sputtering or ion etching
- Focused Ion Beam etching (FIB)
- Magnetically localised ion etching



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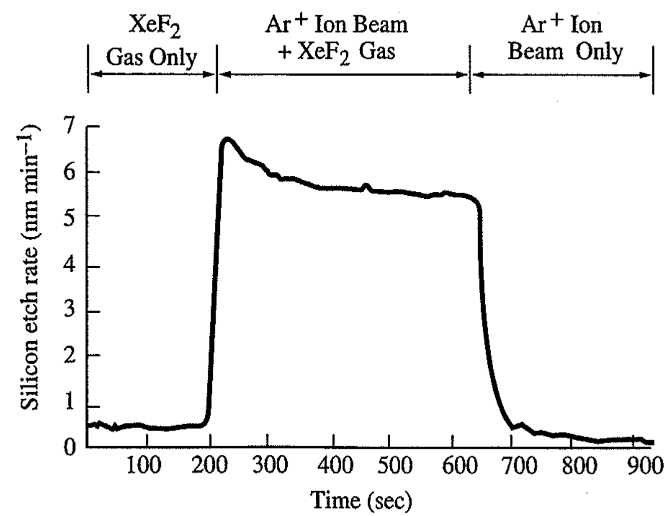
ION-ASSISTED ETCHING

Chemical-physical dry etching

(combination of the two processes)

Ions + natural free radicals etch dependently:

- Can increase **selectivity and orientation dependent reaction rate**
- The etch rate is not the sum (higher)
- The etch profile is not a linear combination, but similar to physical etching (vertical etch rate increases)



The ion bombardment enhances one of the component of the chemical etching (surface adsorption, etching reaction, generation / removal of the product) anisotropic way

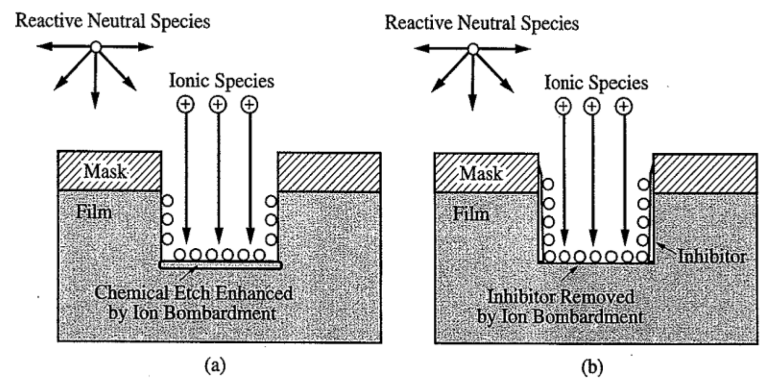


Figure 10–13 Illustration of ion-enhanced etching. In (a) the chemical etch reaction is enhanced by ion bombardment. In (b) an inhibitor is formed which is removed by ion bombardment, allowing chemical etching to proceed. In both cases, anisotropic etching results.

Technics:

- Reactive ion etching, sputtering
- Reactive ion beam etching
- Chemical enhanced ionbeam etching

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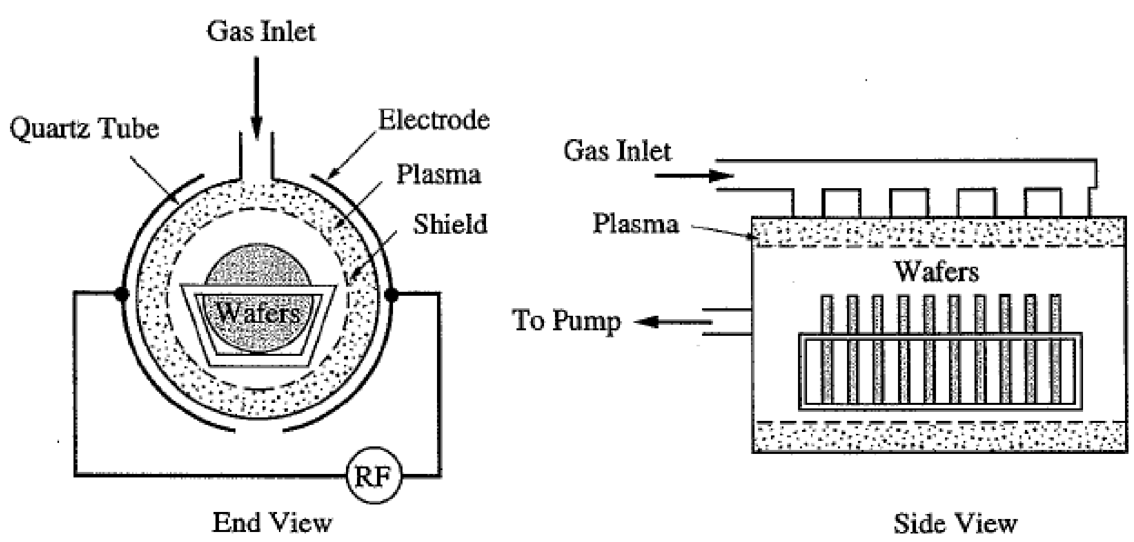
PLASMA ETCHING EQUIPMENTS I.

Cylindrical / barrel type plasma etcher

- Wafer in holder (not on the electrode), multiwafer process
- Isotropic chemical etching, high selectivity, low fault generation
- Inhomogeneous etch rate on the wafer
- p=10-1000mtor

For not critical etching steps
resist removal
in O_2 (ashing)



PLASMA ETCHING EQUIPMENTS II.

Planar type plasma etcher - Plasma mode

- The wafer is on the (bigger) grounded electrode facing to the oposite electrode – higher homogeneity, mainly chemical, adequate selectivity, slight anisotropy
- Weak ion bombardment , potential difference 10-100V
- The smaller electrode is sputtered
- p=10-500mtorr
- Ion concentration ~ 10^{9}-$10^{10}cm^{-3}$

For not critical etching steps
resist removal in O_2 (ashing)
Isotropic silicon-nitride etching

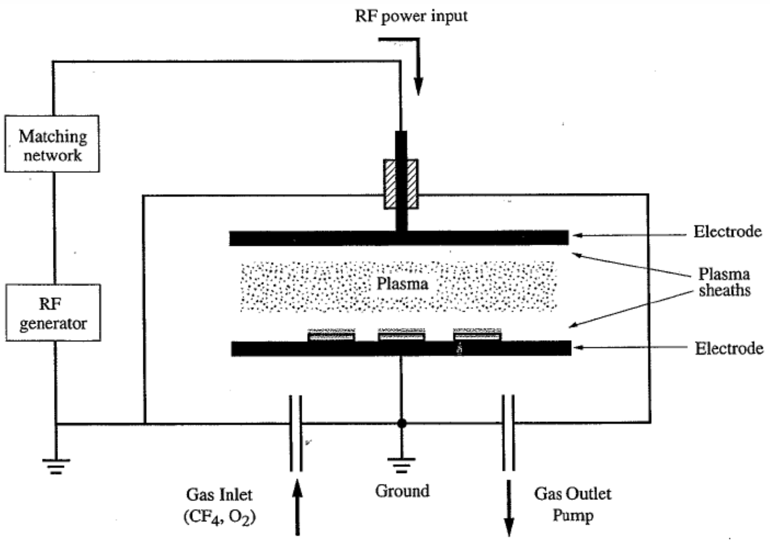


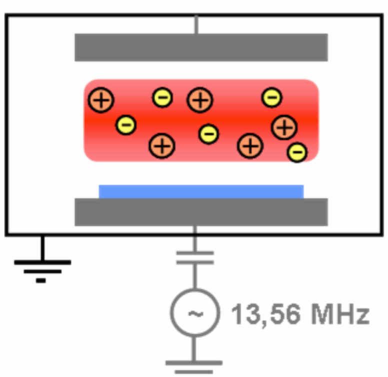
Figure 10–7 Schematic diagram of an RF-powered plasma etch system.

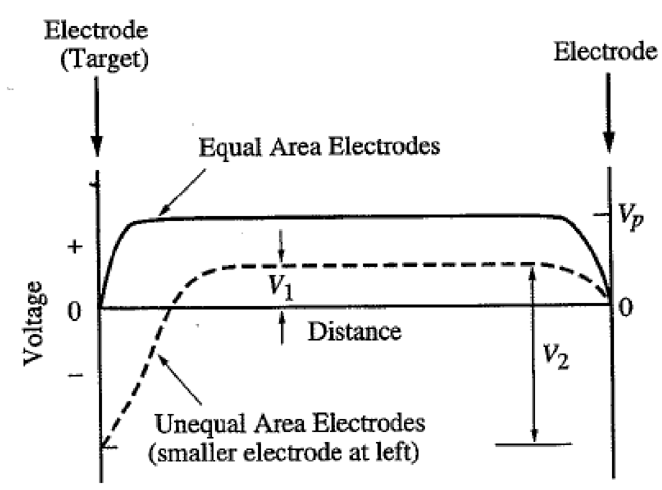
PLASMA ETCHING EQUIPMENTS III.

Planar type plasma etcher – RIE (Reactive Ion Etching) mode

- The wafer is on the smaller electrode – single wafer process
- The bigger electrode is grounded and connected to the chamber wall, higher potential difference in the range of 100-800V (bias) - ion enhanced / assisted anisotropic etching
- More directional etch in case of low pressure, but lower plasma density (10-100 mtorr), ion concentration ~ 10^9-10^{10} cm^{-3}
- Moderate etching rate 100 nm/min
- Lattice faults, charging, trenching

Examples:
SiO_2: CHF_3
poly-Si, Si_3N_4: SF_6+ O_2, NF_3
Al: Cl_2, BCl_3

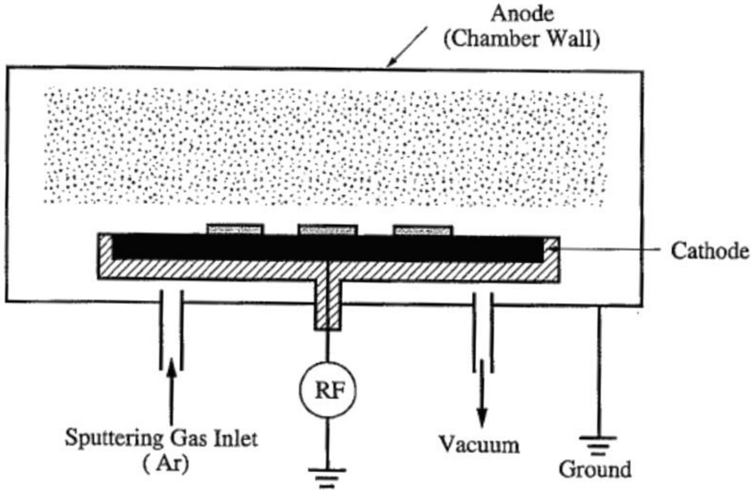




PLASMA ETCHING EQUIPMENTS IV.

Sputter etching, ion milling:

- ONLY physical etching
- Chemically inert precursor (Ar)
- The wafers are laying on the smaller electrode – the chamber wall is set to be anode
- Fully anisotrop
- The sputtering rate of Ar is similar for different materials - not selective for materials



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PLASMA ETCHING EQUIPMENTS V.
HDPE - High Density Plasma Etching

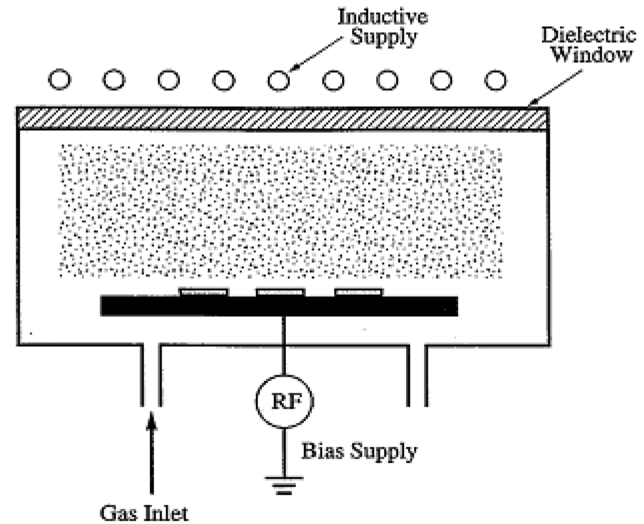

Figure 10-16 Schematic diagram of High-Density Plasma (HDP) etch system. This configuration is powered by an Inductively Coupled Plasma (ICP) source which produces and controls the high-density plasma. The RF wafer bias independently controls the ion energy.

- **Independent plasma density** and **ion energy**
- ECR (electron-cyclotron-resonance) or ICP (inductively coupled plasma) source generates 10^{11}-10^{12} ion/cm^3 plasma density, without high sheath bias – lower pressure can be applied 1-10 mTorr – highly directional (less collision in the sheath)
- RF source develops the potential difference, defines the bombarding ion energy, (can be decreased besides high ion density – decreased substrate deterioration
- high etch rate: some μm/min

Similar effect as in case of ion enhanced etching!

DRIE INTRO

DRIE – Deep Reactive Ion Etching

Etching depth / trench width > 10:1 (MEMS, DRAM capacitors)

Doubled power sources:

- ICP to achieve extremely high density reactive radicals + ions
- CCP DC self-bias for definition ion energies

Si DRIE

Gas composition: halogen based accelerated plasma etching

- F-based, (e.g. SF_6) quick isotropic etching
- Cl-, Br-based (e.g. Cl_2, HBr) anisotropic with ion assisted etching, but slower and poisoning

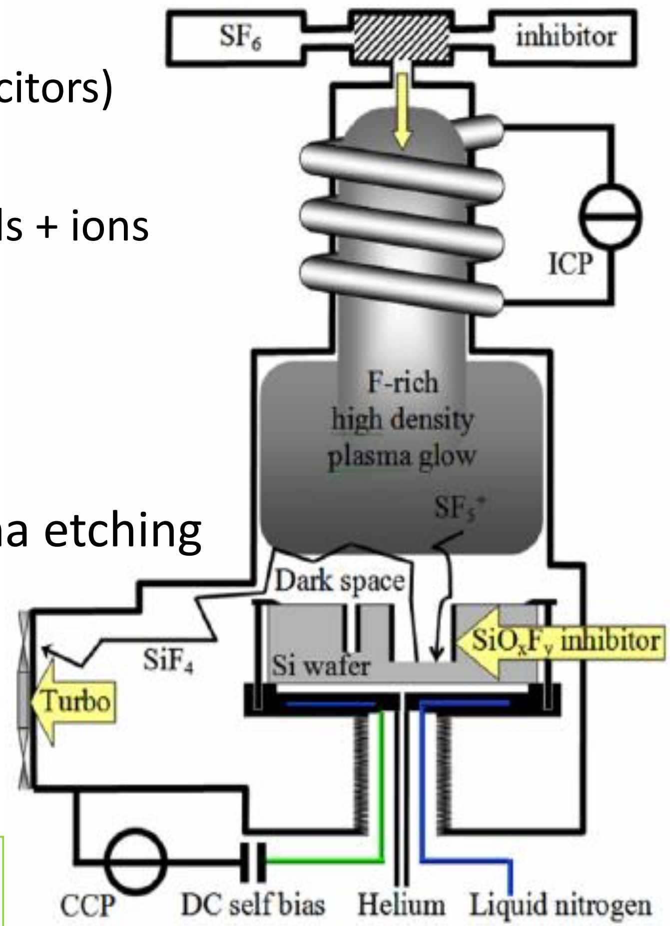

Figure 1. A dual source DRIE system.

Mixed mode DRIE / Cryo	Pulsed mode DRIE / Bosch
$SF_6 + O_2$ @ cryo °C	$SF_6 + C_4F_8$ @ RT

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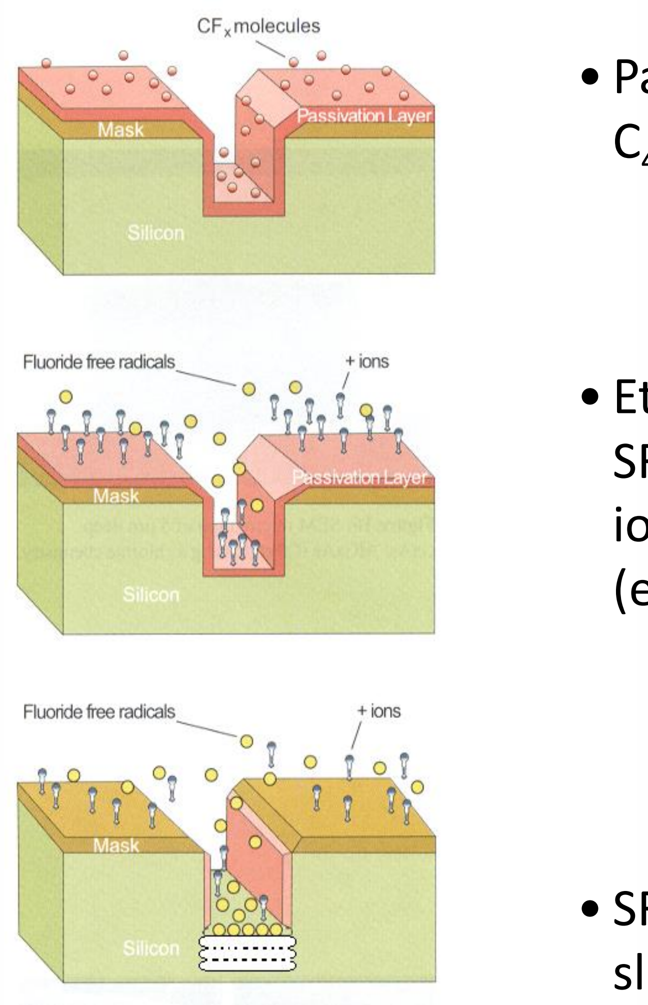
DRIE – BOSCH PROCESS



- Passivation
  $C_4F_8 \rightarrow n\ CF_2$ (PTFE)

- Etching
  $SF_6 \rightarrow F$ + ions
  ion bombardment + polymer etching
  (excluding the vertical walls)

- SF_6 isotropic or
  slightly anisotropic Si etching

DRY ETCHING

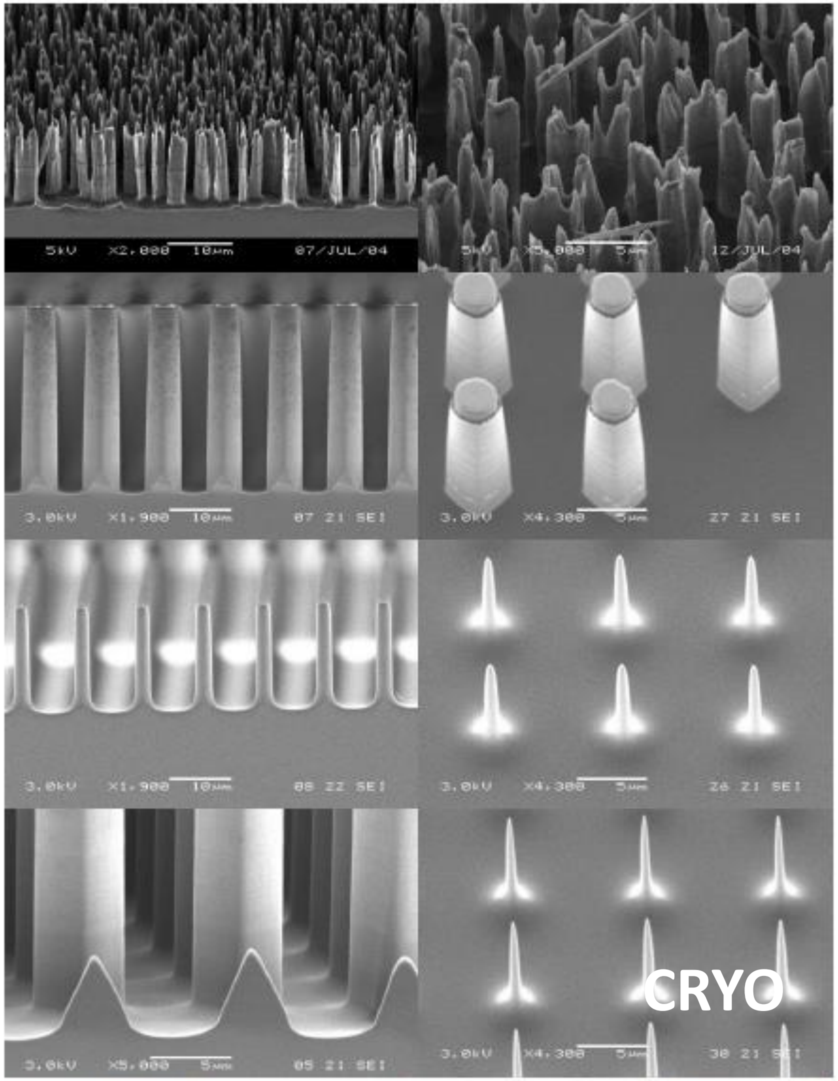


Figure 19. (Top) Black silicon and (rest) optimized result for cryogenic temperature mixed-mode DRIE (see figure 27).

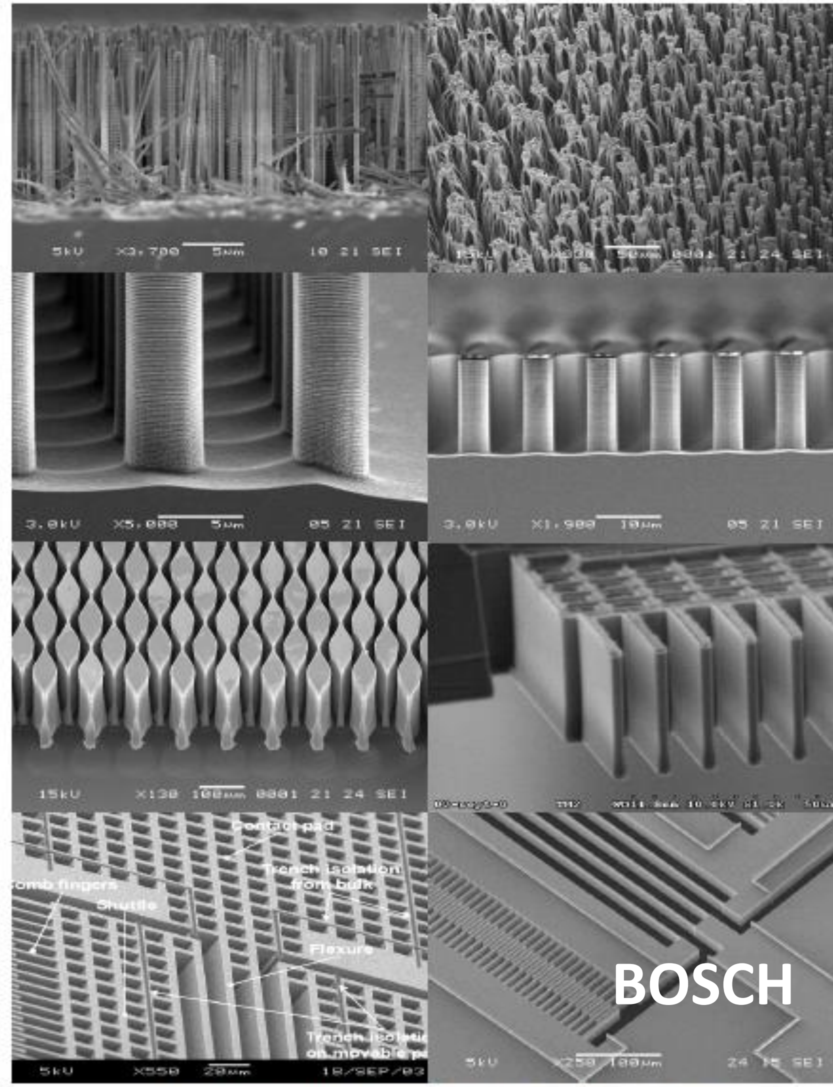
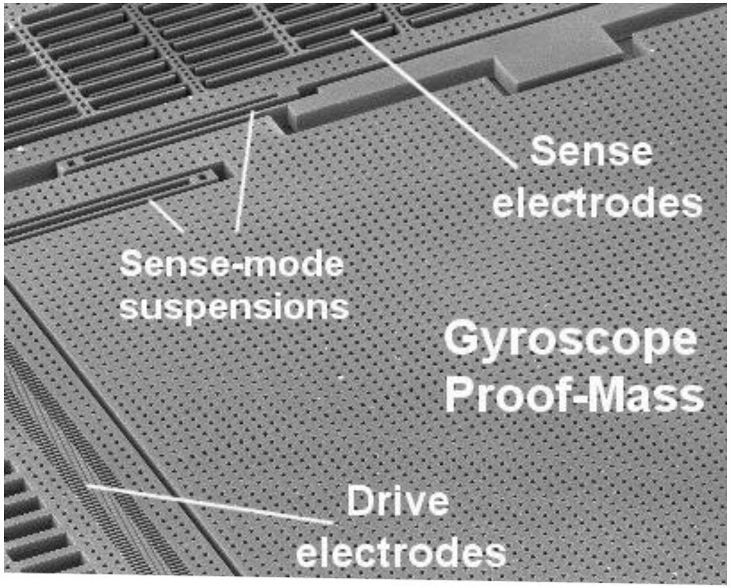
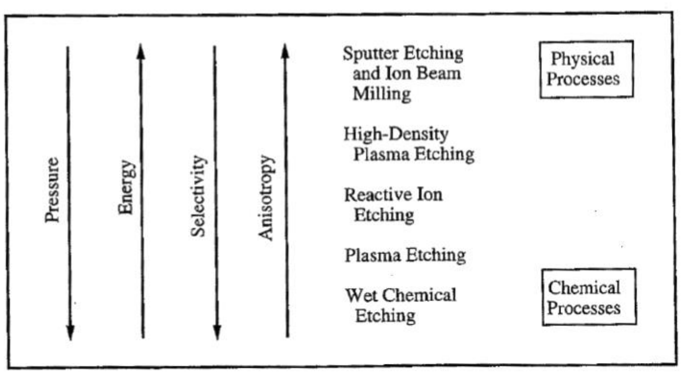


Figure 27. Typical result for room temperature pulsed-mode DRIE (see figure 19).

MEMS NEMS BIOMEMS

ETCHING - SUMMARY





▪ WET ETCHING:	▪ DRY ETCHING:
▪ Chemical process	▪ Plasma: reactive ions
▪ Atmospheric, bath	▪ Vacuum chamber
▪ Low cost ▪ Simple solution	▪ Expensive and complicated ▪ Toxic and corrosive gases ▪ Automatisation
▪ Perfect selectivity ▪ Non-applicable under 1µm resolution ▪ Non constant etch rate ▪ Contamination	▪ Low selectivity ▪ Deep etch in the 1-100nm range ▪ High etch rate
▪ Isotropic etch (exept in case crystalline materials)	▪ Isotropic / anisotropic

MEMS
NEMS
BIOMEMS

WAFER BONDING

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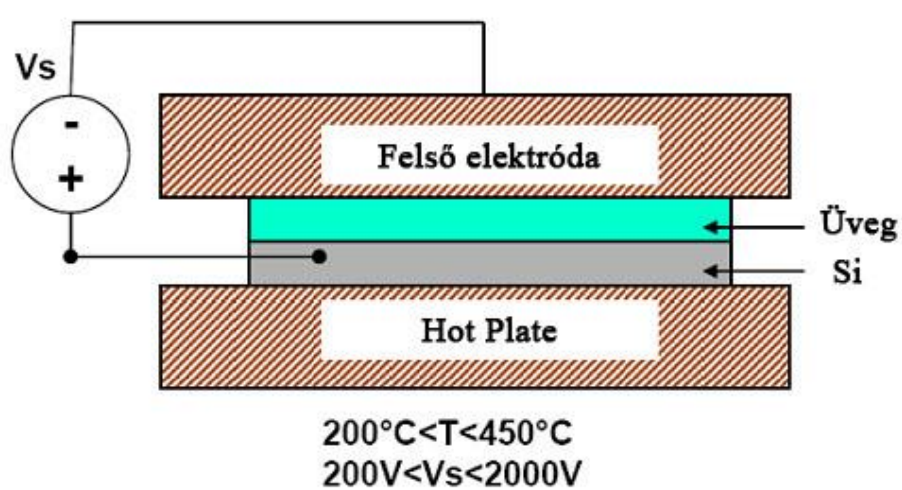
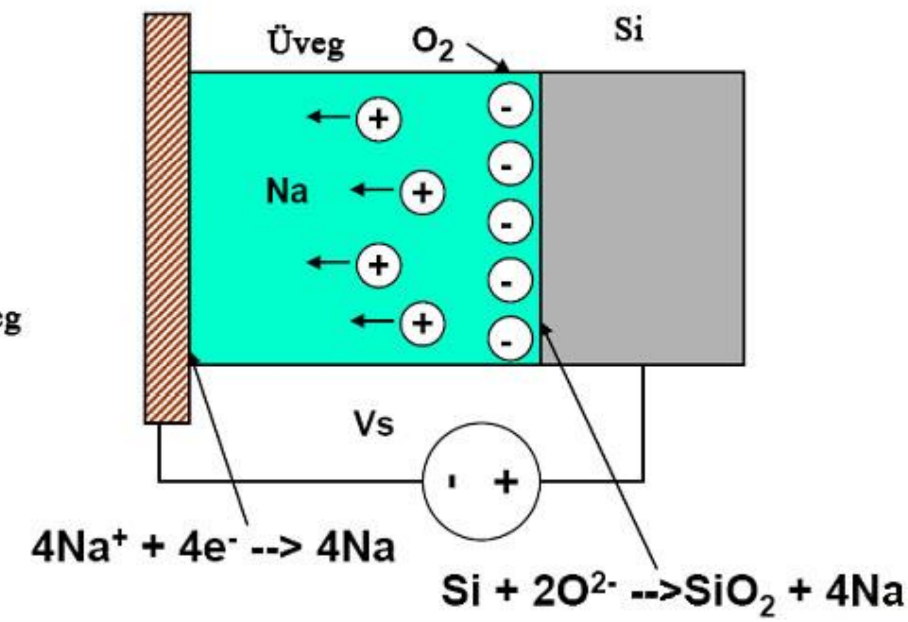
ANODIC BONDING

- Si + Special glass (high alcaline-ion concentration)
- Moving Na^{+} ions – depleted space-charge layer
- Covalent bonding of silicon and oxygen

- Low sensitivity for surface roughness



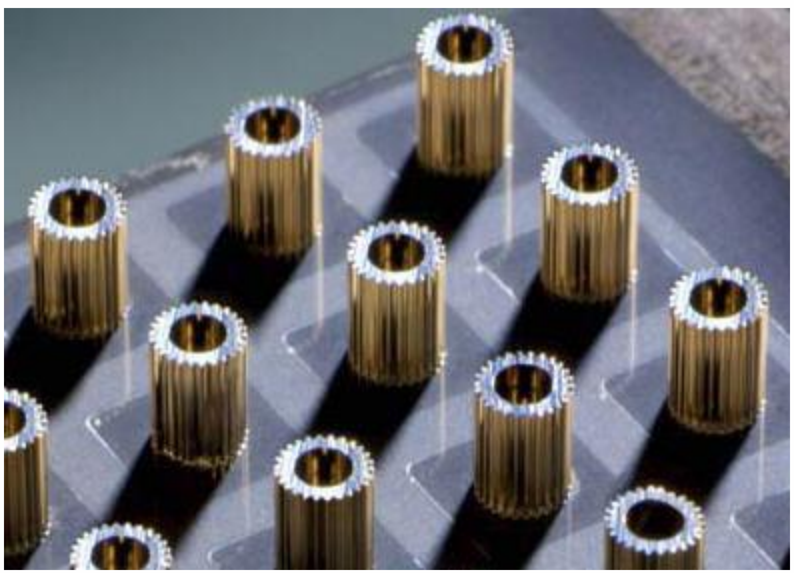


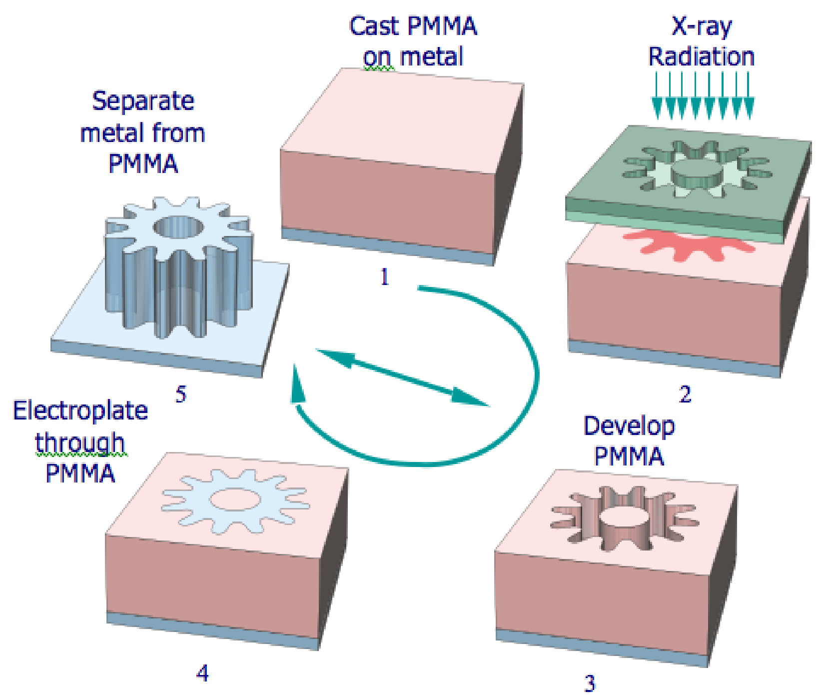
LIGA

LIGA (KIT)

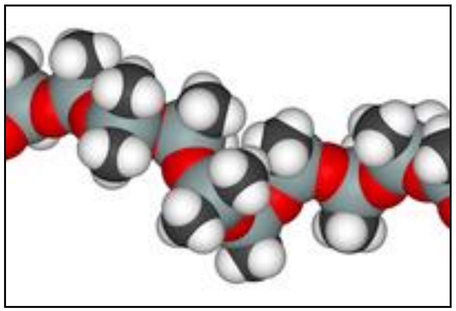
Lithographie, Galvanoformung, Abformung (Lithography, Electroplating, Moulding)

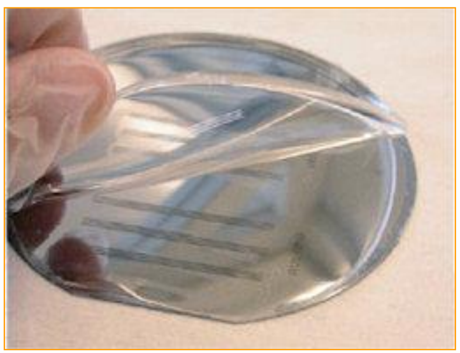
- High aspect ratio microstructures (100:1)
- Vertical sidewalls, 10nm surface roughness (optical parts)
- Height: from 10μm to 1-2mm
- X-ray LIGA (PMMA) / UV LIGA (SU-8)

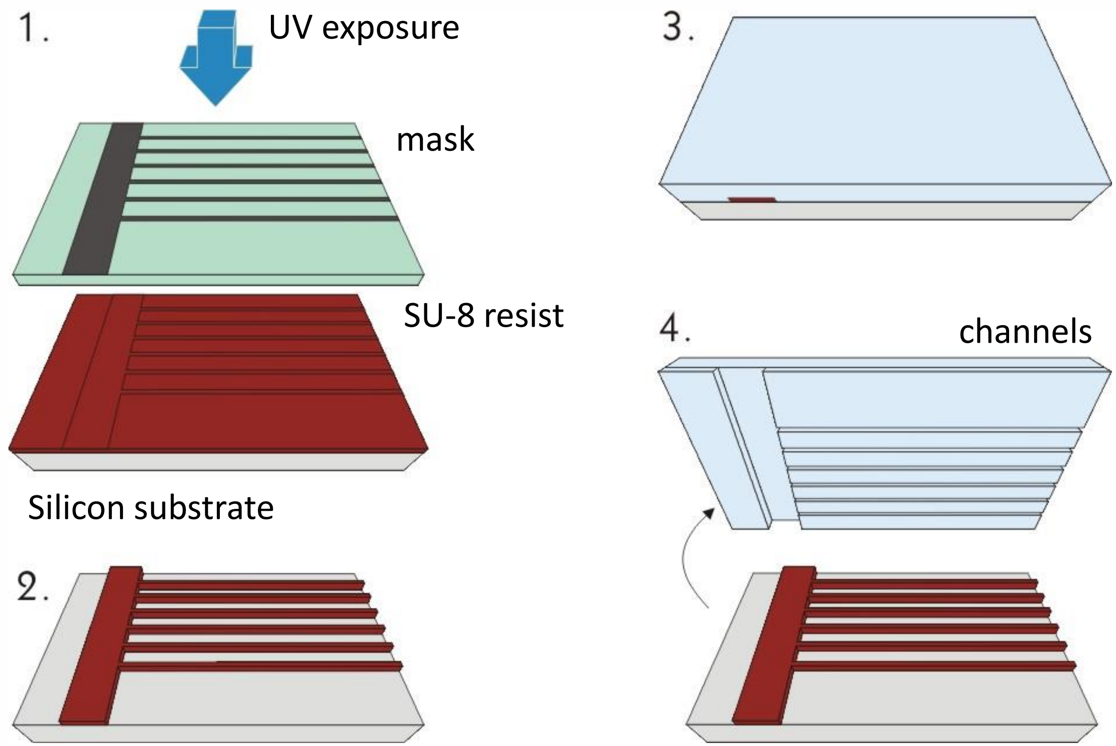




SOFT LITO – MICROFLUIDICS IN PDMS





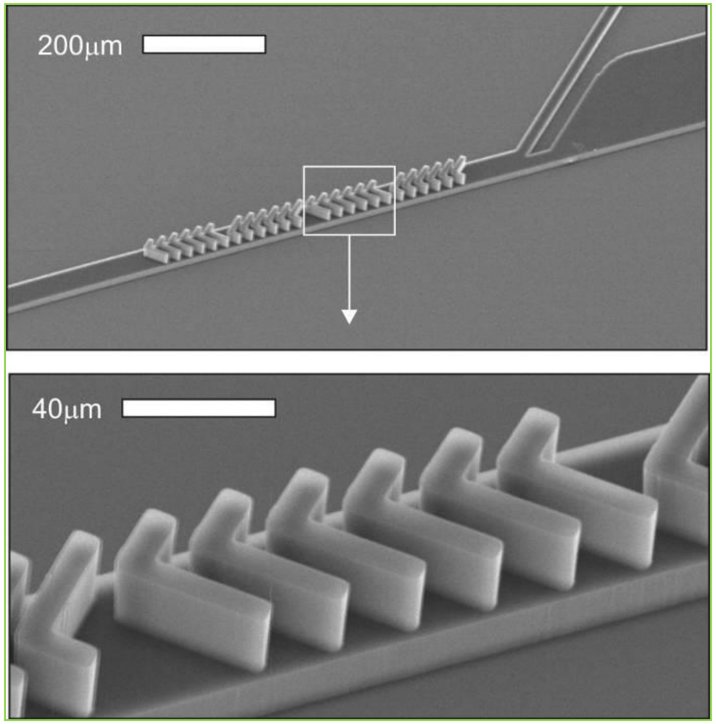


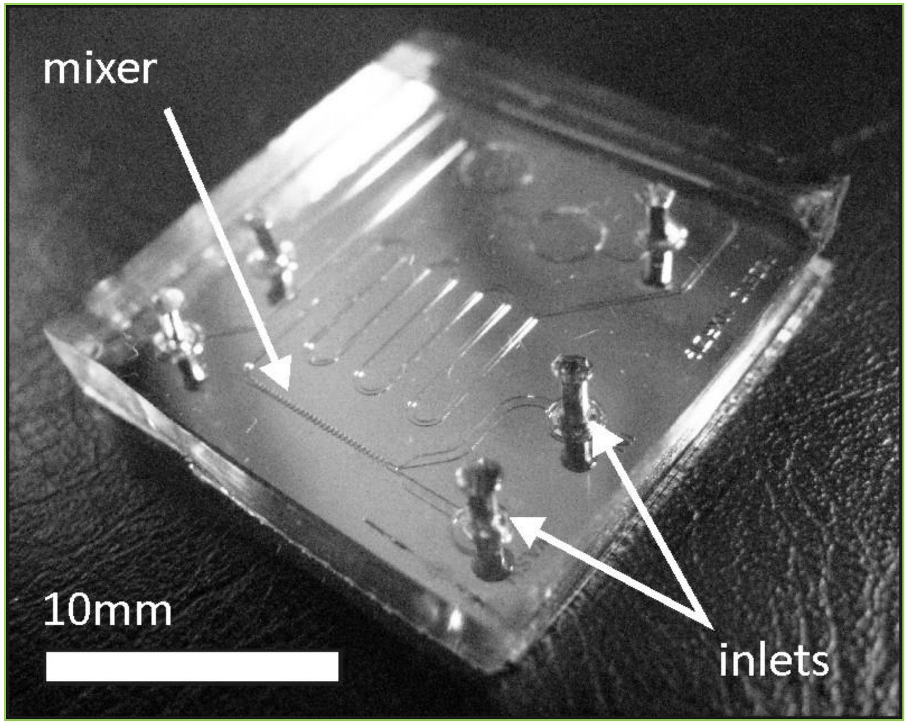
Advantages:

- biocompatible, flexib, transparent
- cheap, fast and simple application
- covalent bonding to PDMS, Si and glass surfaces

SOFT LITO – MICROFLUIDICS IN PDMS

- Multiple layer 3D SU-8 technology for moulding master
- Fast prototyping – PDMS moulding

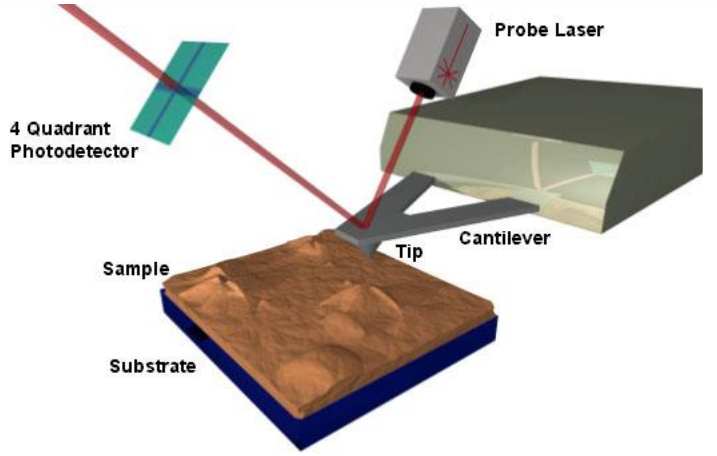


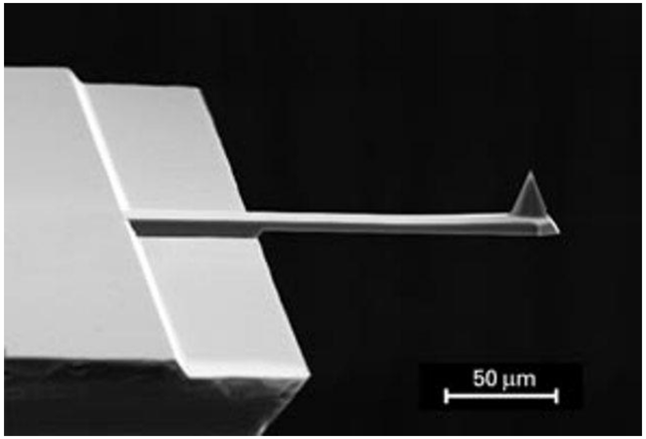


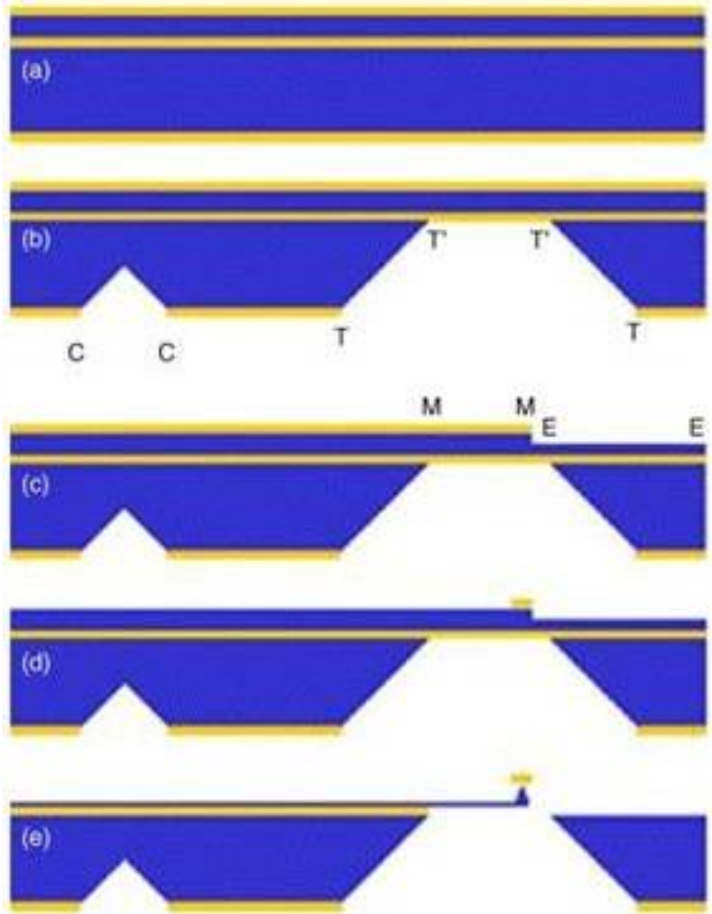
Herring-bone type chaotic mixer

HOW TO PREPARE …

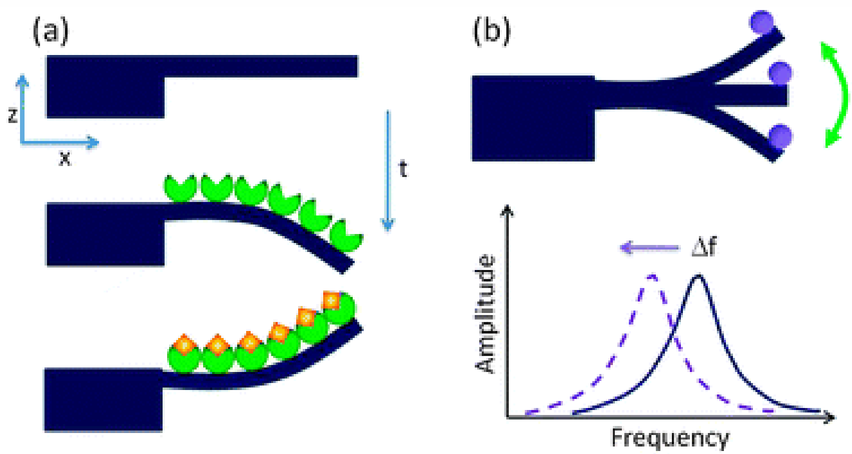
CANTILEVER – BULK MICROMACHINING

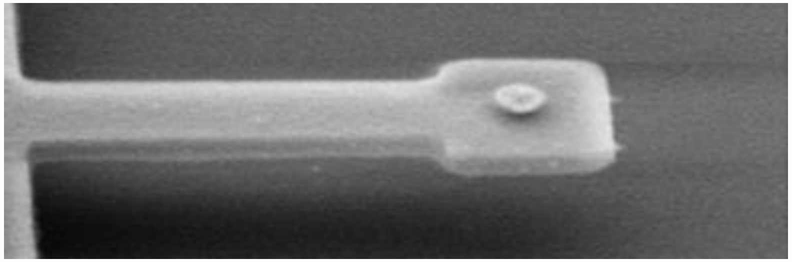


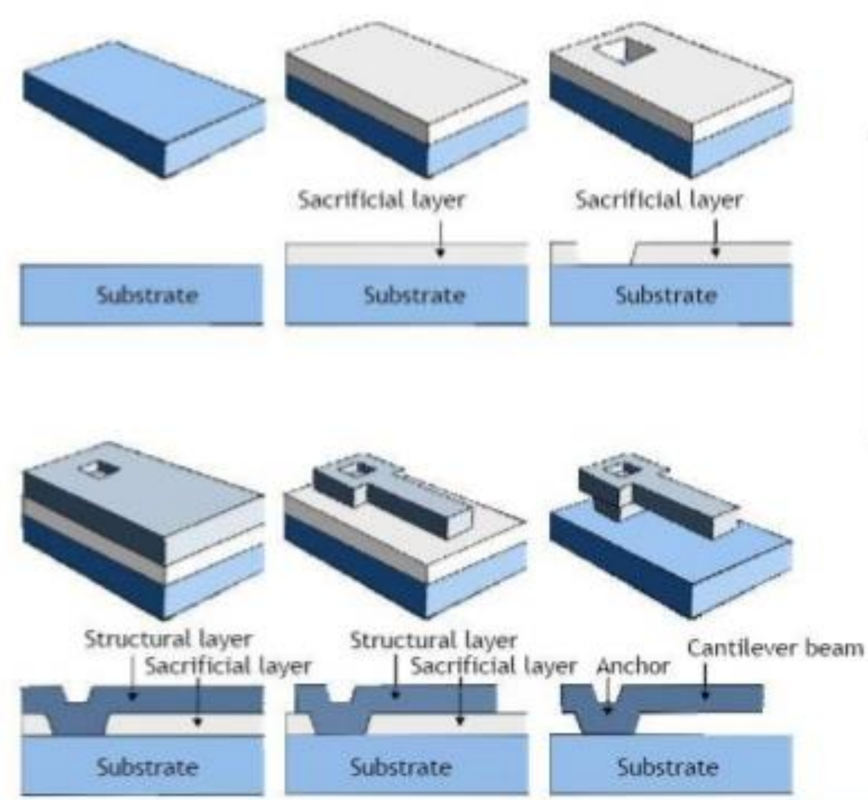




CANTILEVER – SURFACE MICROMACHINING

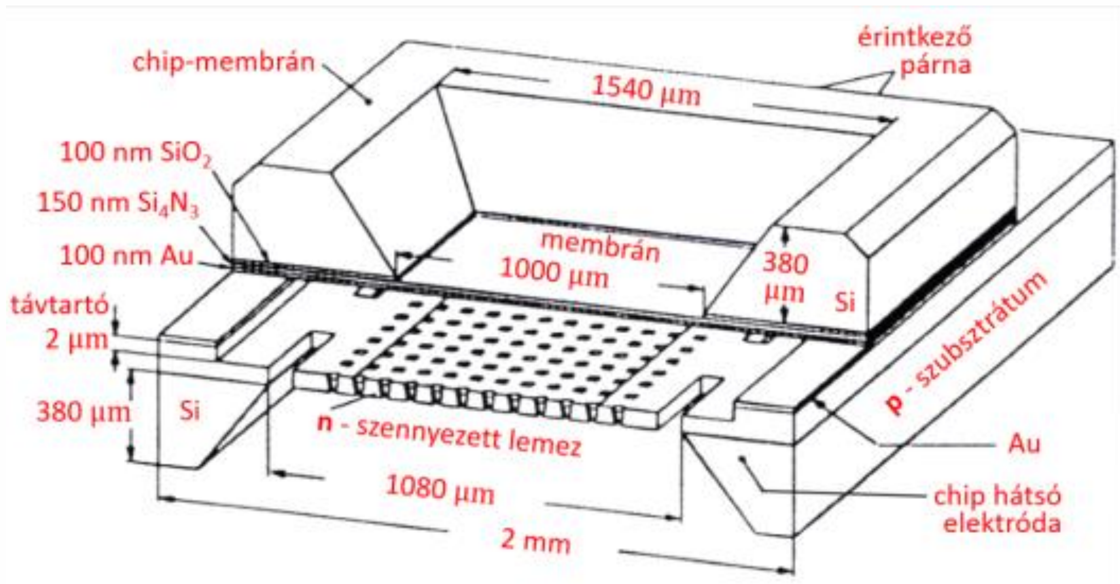


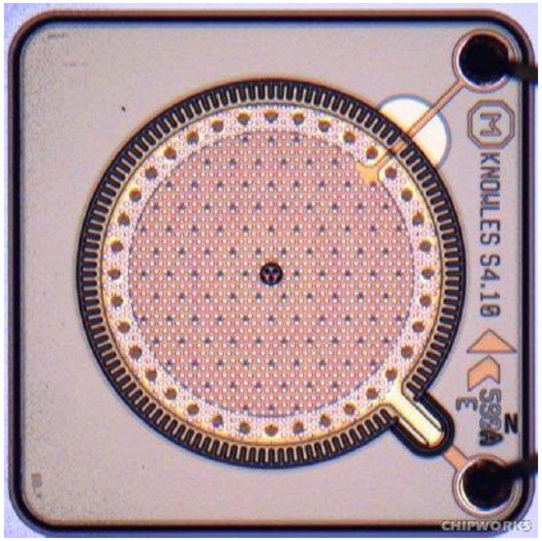




MICROPHONE

High Performance MEMS microphones (3-4 pcs / phone)



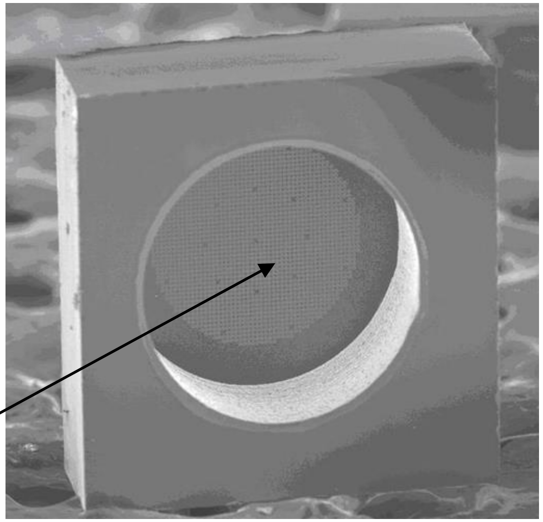


Top electrode: Au SiO_2 / SiN_x membrane
Bottom-electrode: n-Si

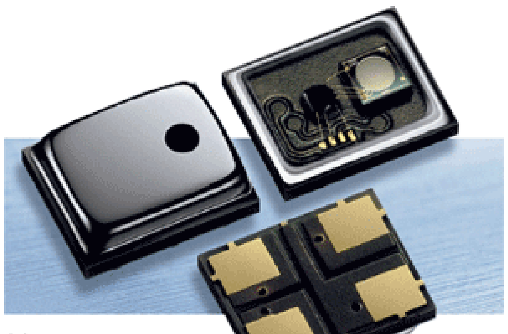
$$C_0 = \varepsilon \frac{A}{d}$$

$$\frac{\Delta C}{\Delta d} = -\varepsilon \frac{A}{d^2}$$

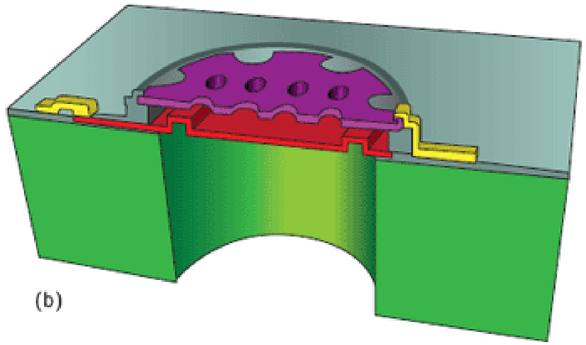
DRIE (deep reactive ion-etching) etched membrane



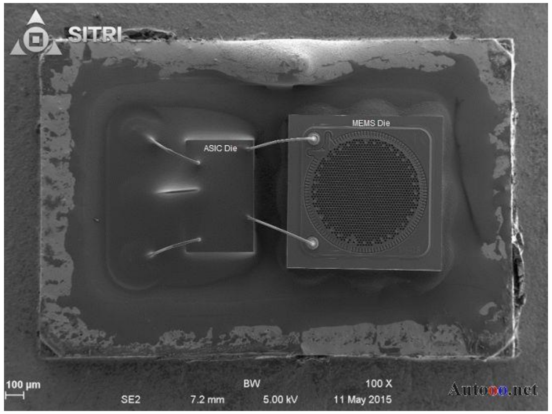
MICROPHONE – BULK / SURFACE MICROMACHINING (COMBO)

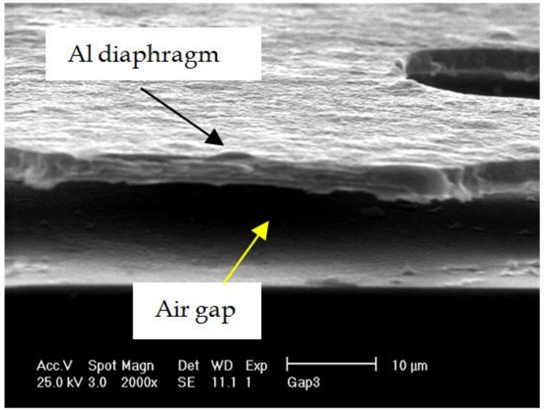


(a)

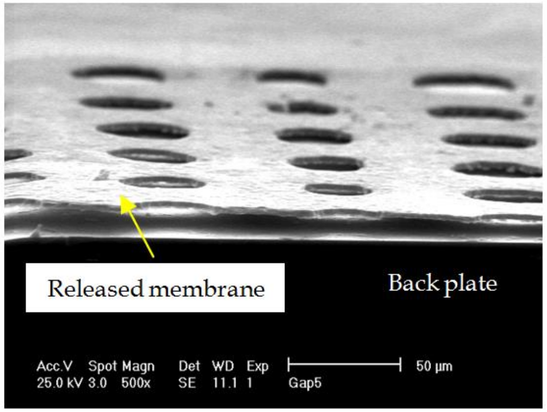


(b)

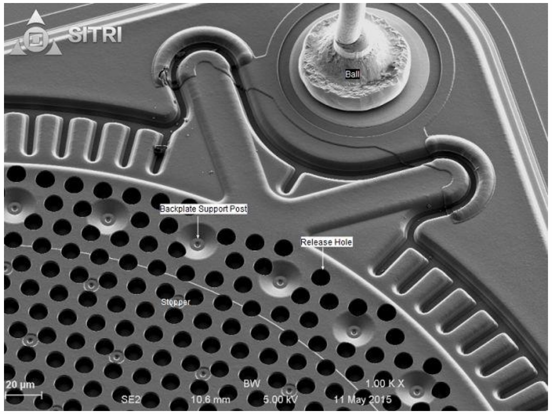




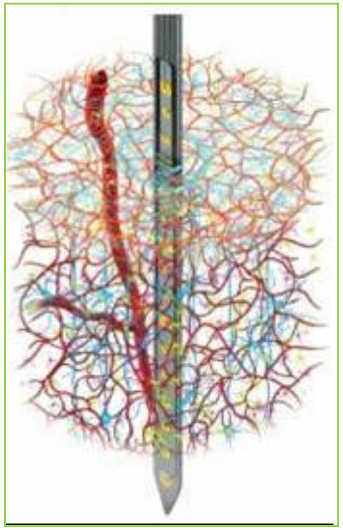
(a) Air gap of microphone

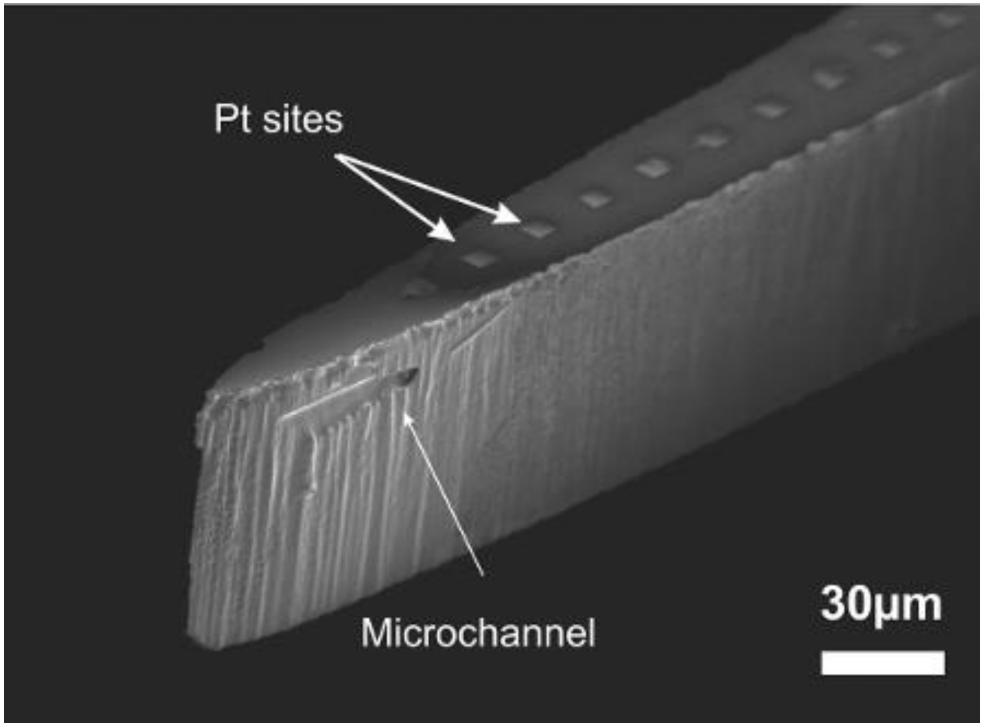


(b) Released membrane structure



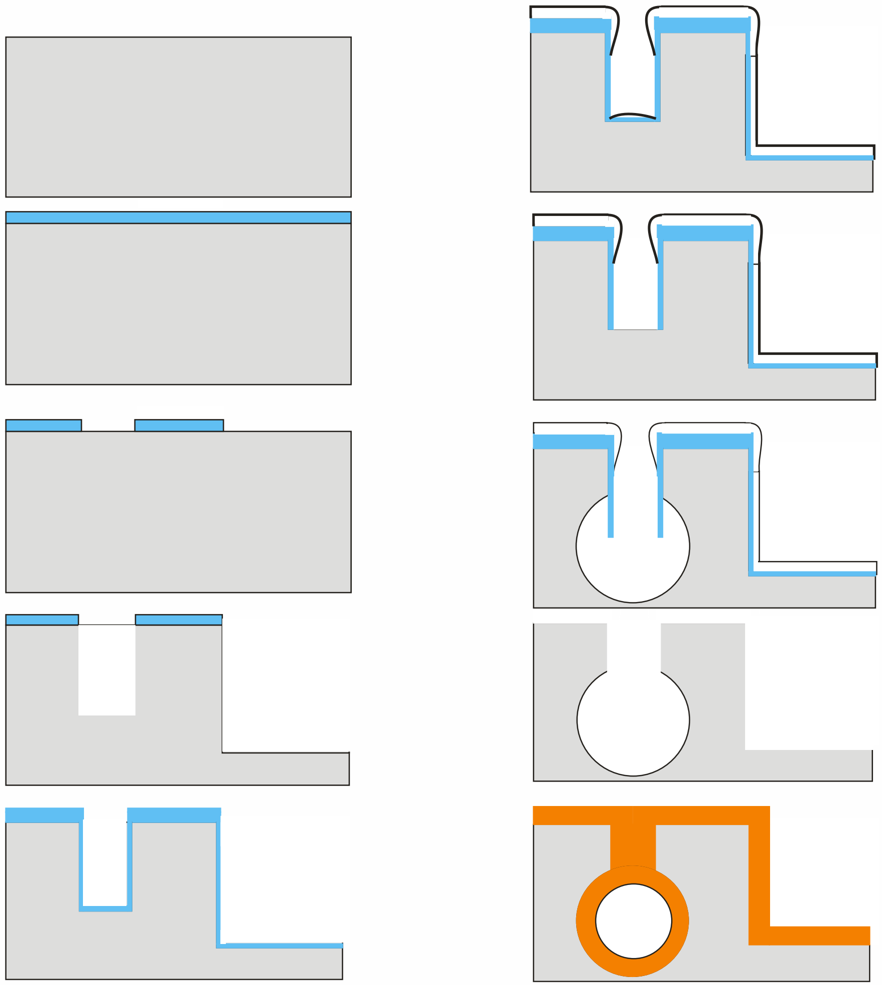
DRUG DELIVERY CHANNELS IN SILICON NEURAL PROBE

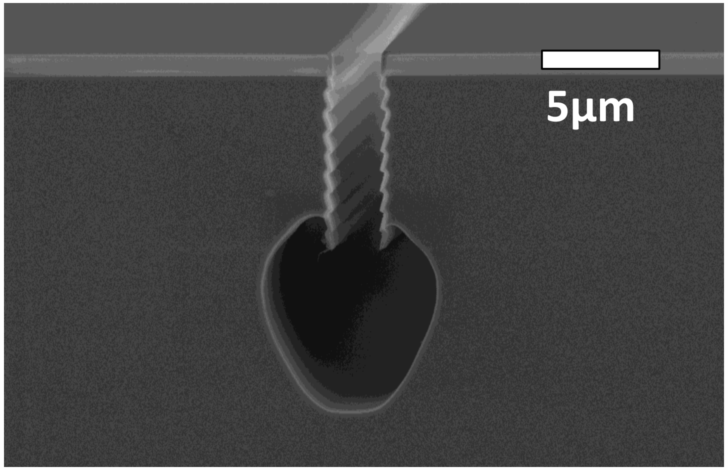


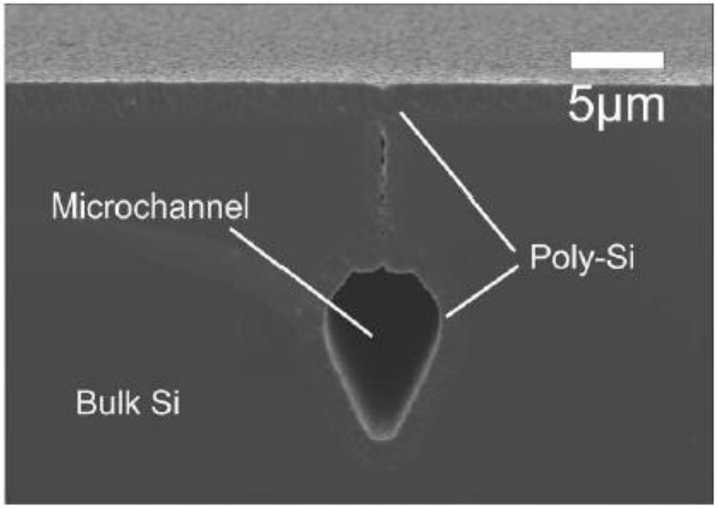


- High throughput channel array in a single substrate
- Utilysing the whole cross-section of the shaft
- Orientation independent positioning
- CMOS compatible fabrication technology
- High quality surface applicable for further lithographic steps

FABRICATION TECHNOLOGY OF BURRIED CHANNELS







INTRO - MRL

MEMS/NEMS INFRASTRUCTURE in CER MICROSYSTEMS LAB

RAITH 150 E-BEAM
Ultra high resolution (8nm)

Micromachining techniques:

- Patterning – mask design, laser pattern generator, 1μm photolithography, (double side) alignment, electron beam lithography (E-Beam), Focused Ion Beam processing – FIB milling, nanoimprinting
- Structured polymer layers – PMMA, PI, SU8 patterning, micromoulding, soft lithography – PDMS
- Wet chemistry – chemical wafer cleaning, isotropic and anisotropic etching techniques
- Dry etching – deep reactive ion etching, plasma etching techniques (DRIE, RIE)
- High temperature processes – thermal oxidation, diffusion, annealing, rapid thermal annealing (RTA)
- Physical thin film depositions – Thermal and electron beam evaporation, DC and RF Sputtering
- Chemical thin film depositions – Atmospheric and Low Pressure Chemical Vapour Deposition (CVD, LPCVD, LTO) thermal and plasma enhanced Atomic Layer Deposition (ALD)
- Liquid Phase Epitaxy (LPE) of III-V compound semiconductors (LED manufacturing)
- Wafer bonding – Si-glass, glass-glass, polymer-glass anodic and thermal bonding
- Chip dicing, wire bonding especially for sensor applications
- Special packaging techniques and methods

- multi-domain Finite-Element Modelling (FEM), and process simulation.

Zeiss-SMT LEO 1540 XB SEM/FIB
SCIOS-2 type dual-beam SEM/FIB
nanoprocessing systems

- SEM with focused ion beam (FIB),
- gas injection system (GIS for EBAD/IBAD)

Characterisation techniques:

- optical (fluorescent) and electron microscopy (SEM / TEM and EDS), atomic force microscopy (AFM), profilometry, electrochemical impedance spectroscopy (EIS), mechanical vibration and climate test chambers, UV / VIS / IR / FTIR spectroscopy, etc.

MEMS
NEMS
BIOMEMS

THX FOR ATTENTION