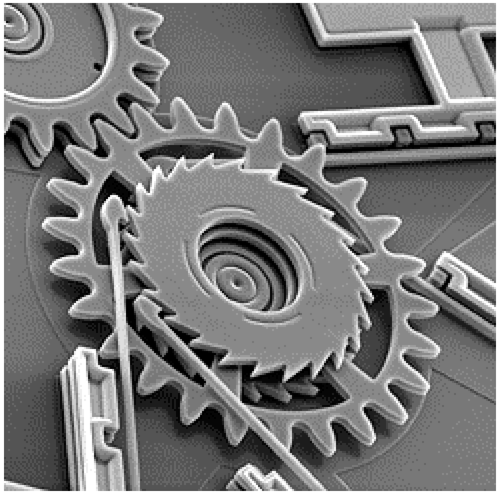

Surface Micromachining

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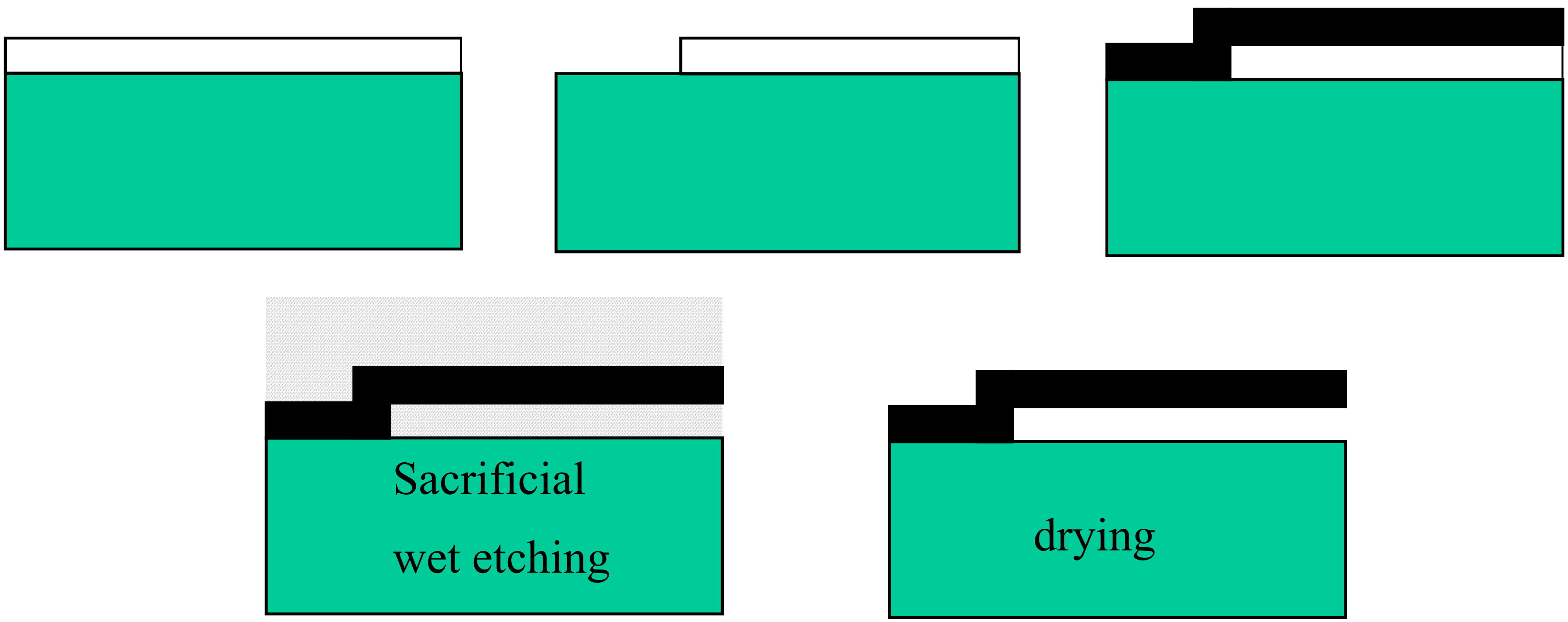
Outline

- Definition of surface micromachining
- Most common surface micromachining materials - polysilicon and silicon oxide
  - LPCVD deposition of polysilicon, silicon nitride, and oxide
  - plasma etching for patterning structural layer
  - micromachined hinges - fabrication process and assembly technique
  - micromachined dimples and scratch drive actuators
- Other sacrificial processing systems
  - metal sacrificial layer, plastics materials, etc.
- Stiction and anti-stiction solutions
- Multi User MEMS Process (MUMPS)
  - process definition and layer naming conventions

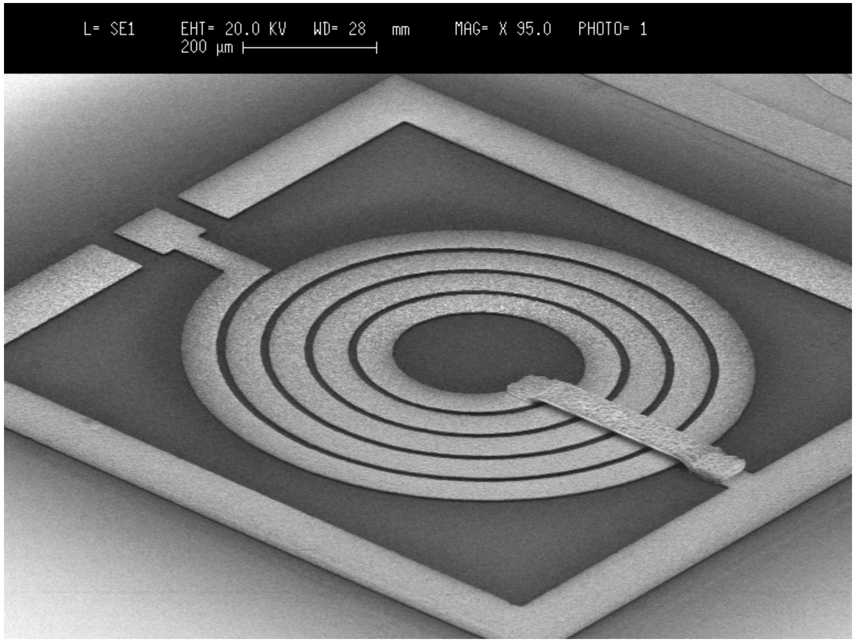
Basic Sacrificial Layer Processing

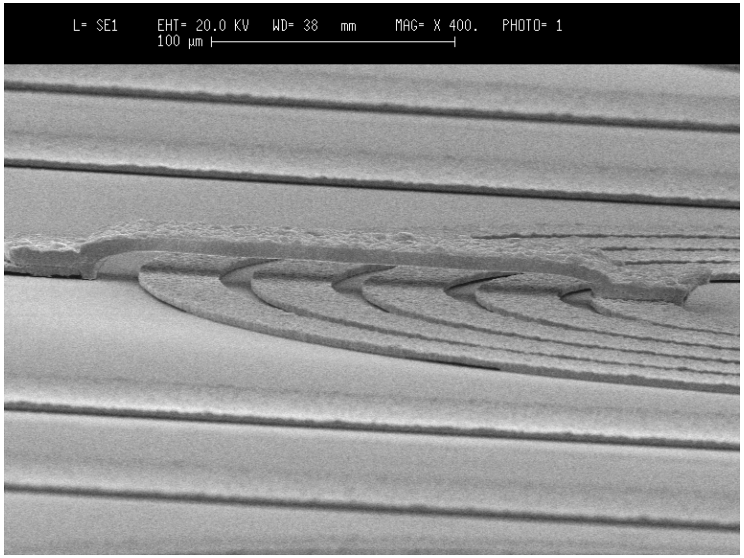
- Step 1: Deposition of sacrificial layer
- Step 2: patterning of the sacrificial layer
- Step 3: deposit structural layer (conformal deposition)
- Step 4: liquid phase removal of sacrificial layer
- Step 5: removal of liquid - drying.



Surface Micromachined Inductor

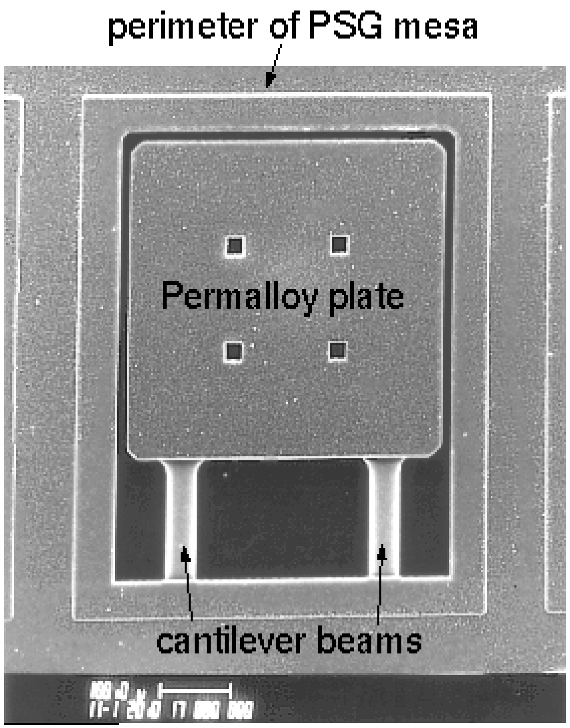
- Air bridge can be formed using sacrificial etching.



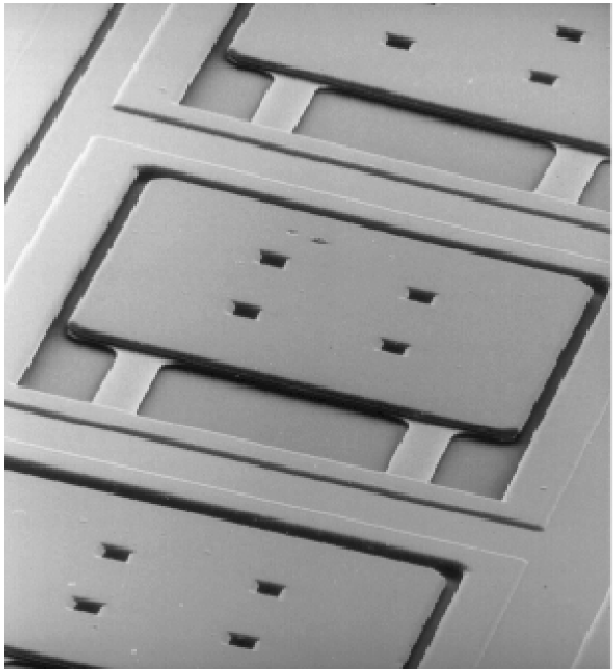


Typical Device Realized by Surface Micromachining

- Etch holes are required to reduce the time for removing sacrificial layer underneath large-area structures.

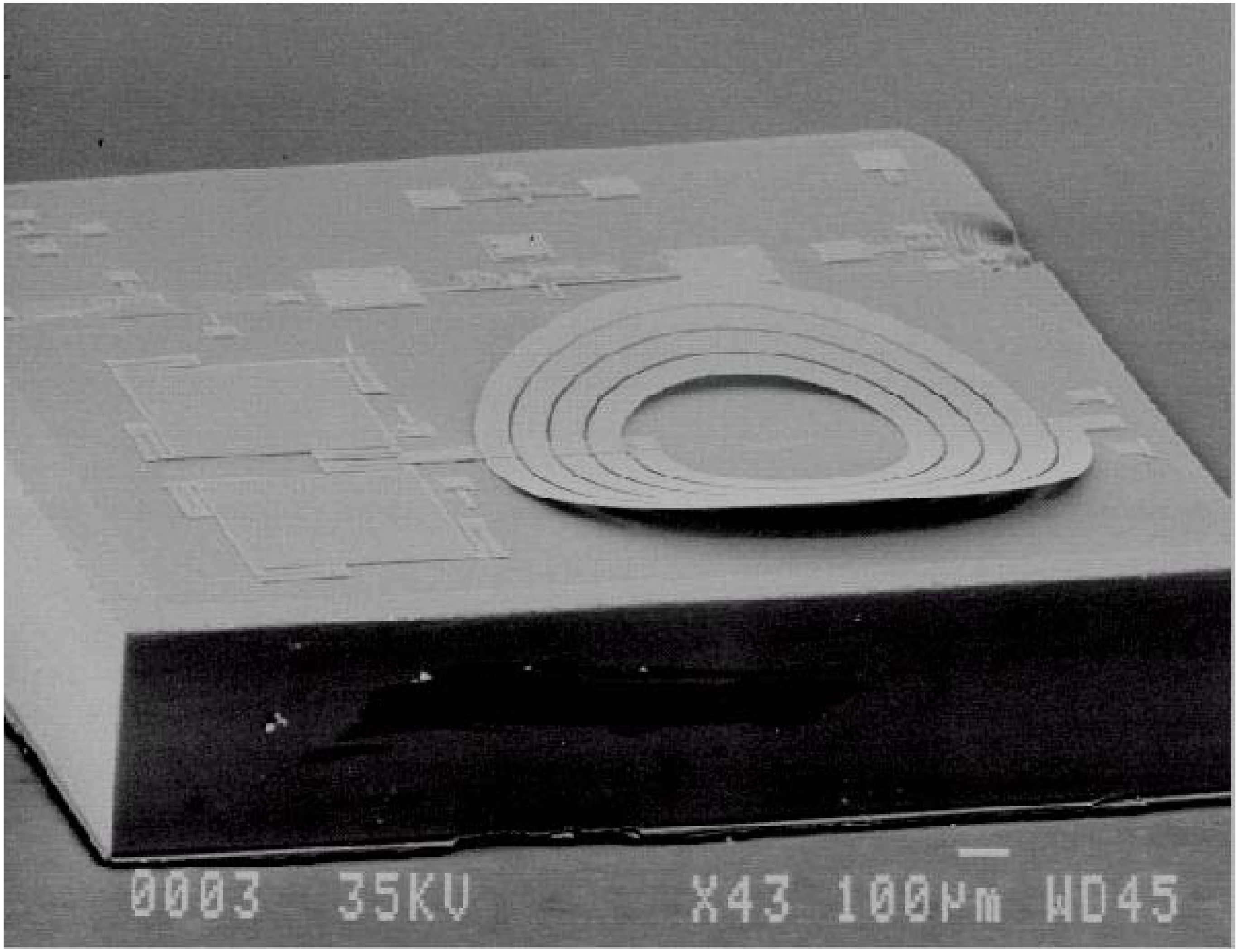


(a)

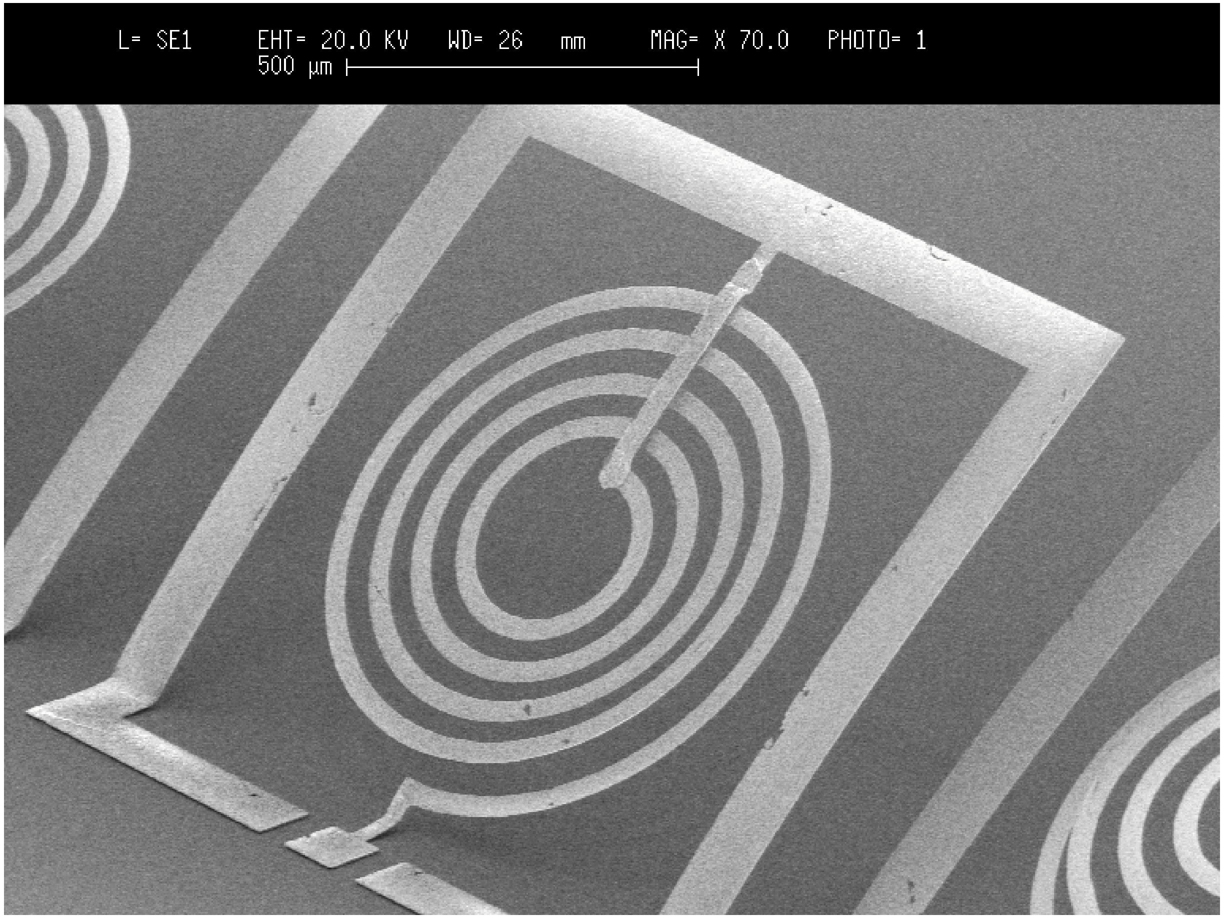


(b)

Inductor - By Lucent Technologies

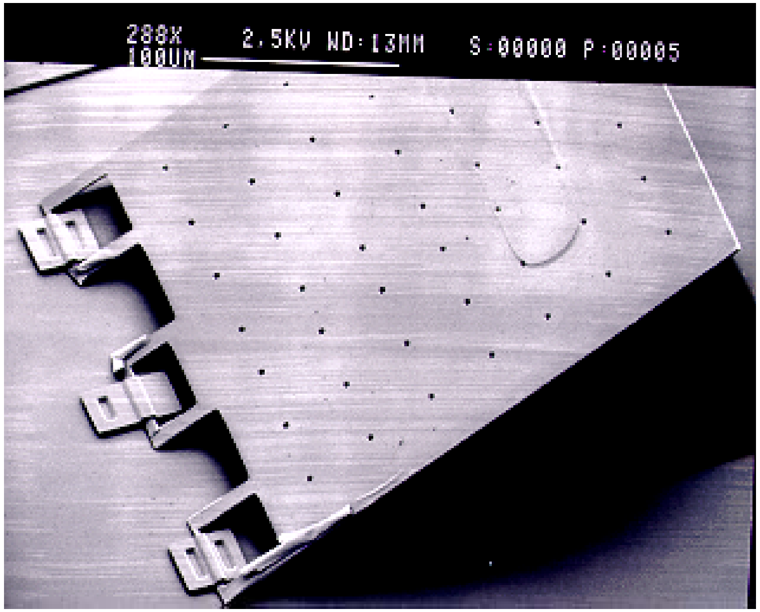


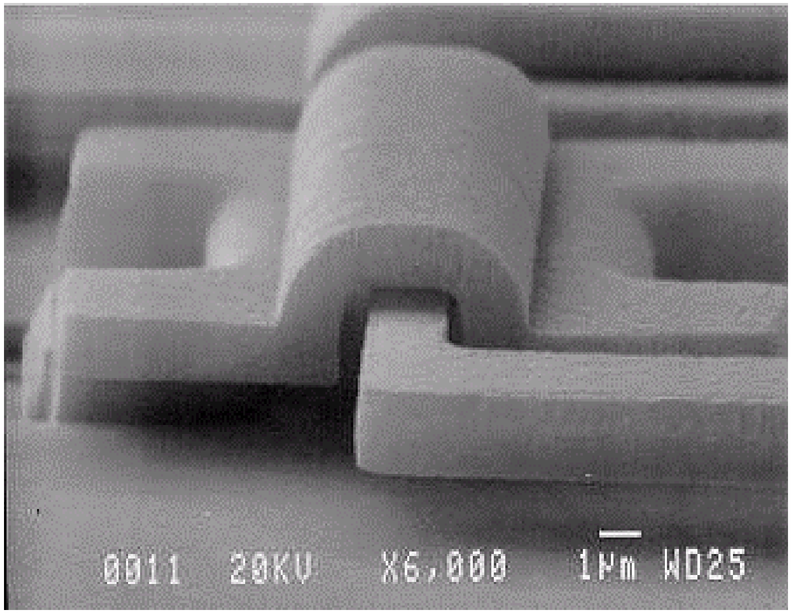
Surface Micromachined, Out of Plane Structures



Hinges

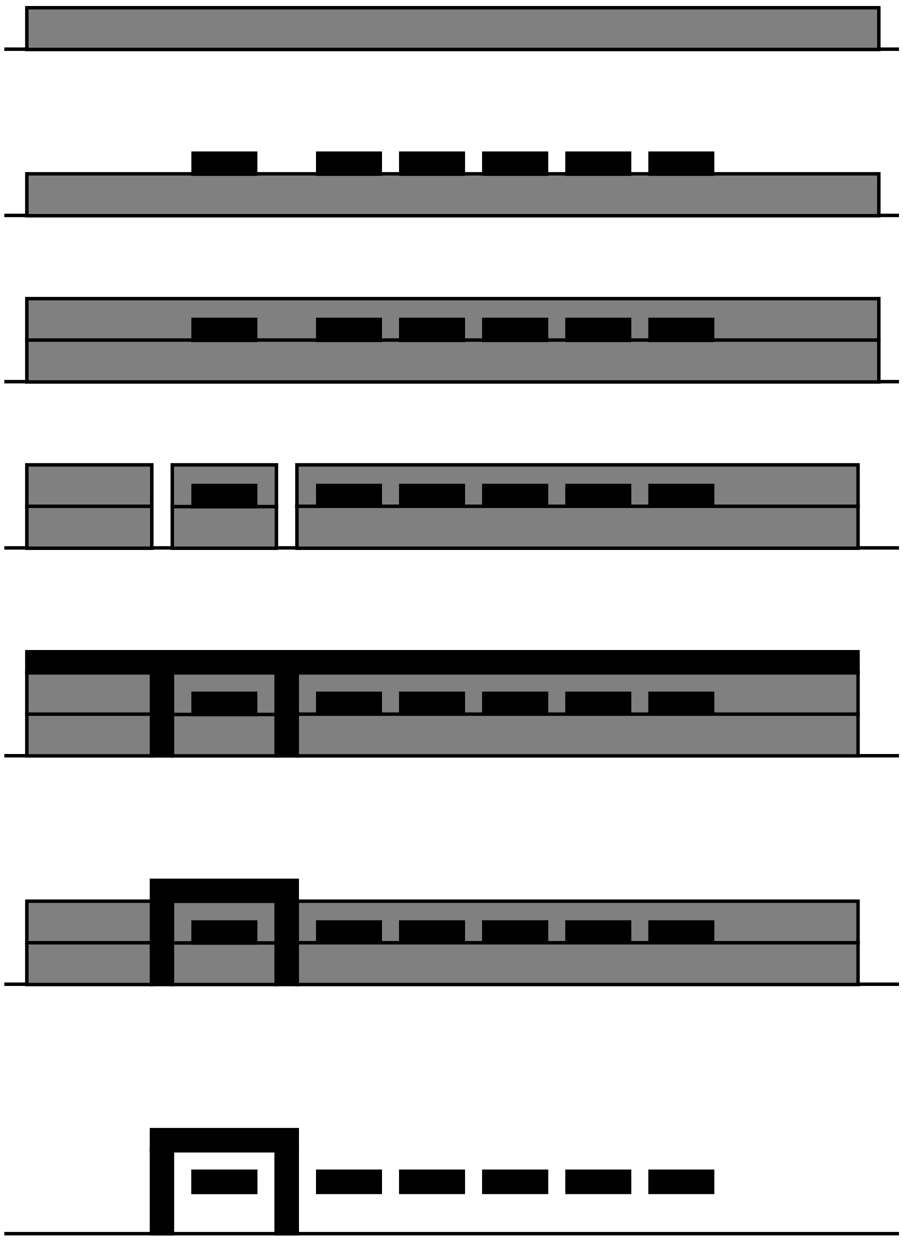
- Used in micro optics component assembly.





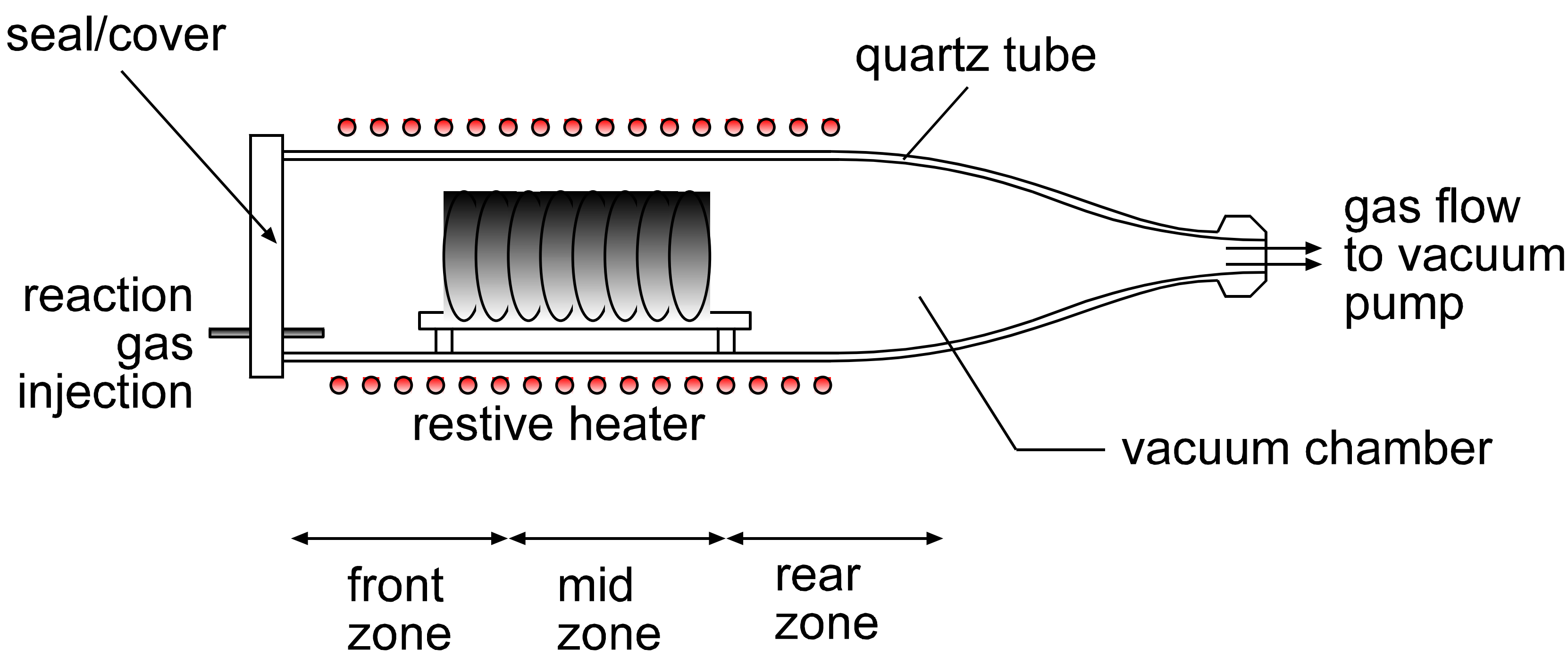
Hinge Fabrication

- Step 1: deposition of sacrificial layer.
- Step 2: deposition of structural layer.
- Step 3: deposition of second sacrificial layer.
- Step 4: etching anchor to the substrate.
- Step 5: deposition of second structural layer.
- Step 6: patterning of second structural layer
- Step 7: Etch away all sacrificial layer to release the first structural layer.

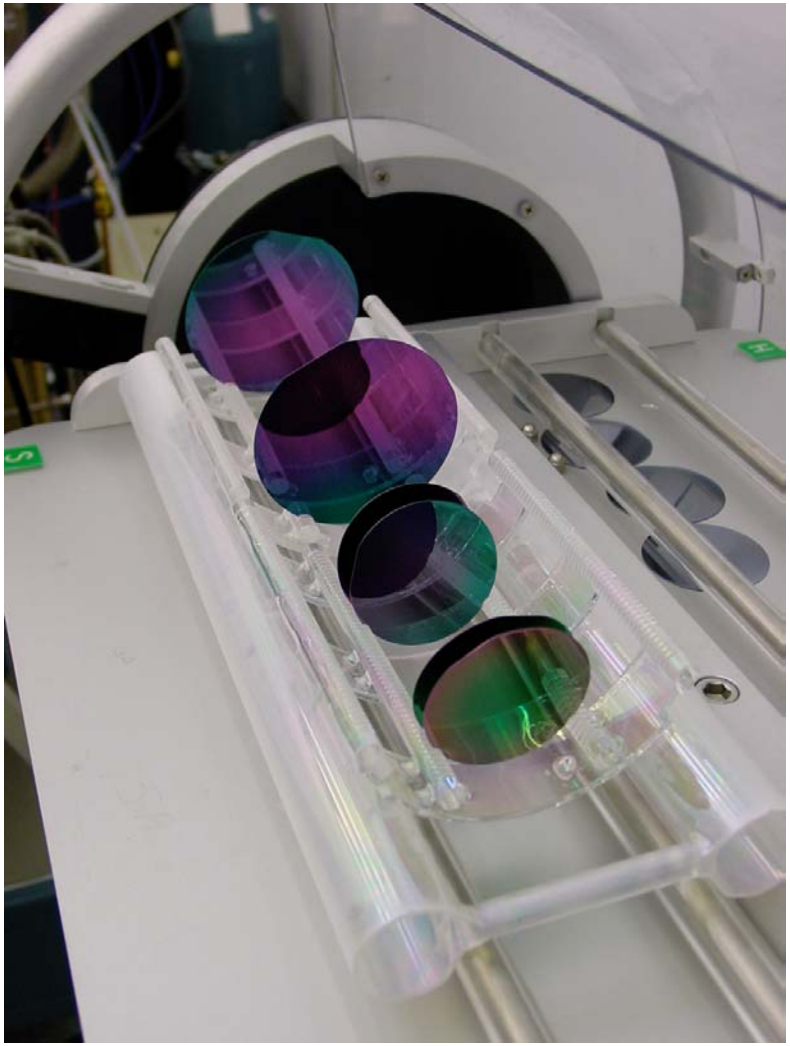


LPCVD Process

- Temperature range 500-800 degrees
- Pressure range 200 - 400 mtorr (1 torr = 1/760 ATM)
- Gas mixture: typically 2-3 gas mixture
- Particle free environment to prevent defects on surface (pin holes)



A Laboratory LPCVD Machine



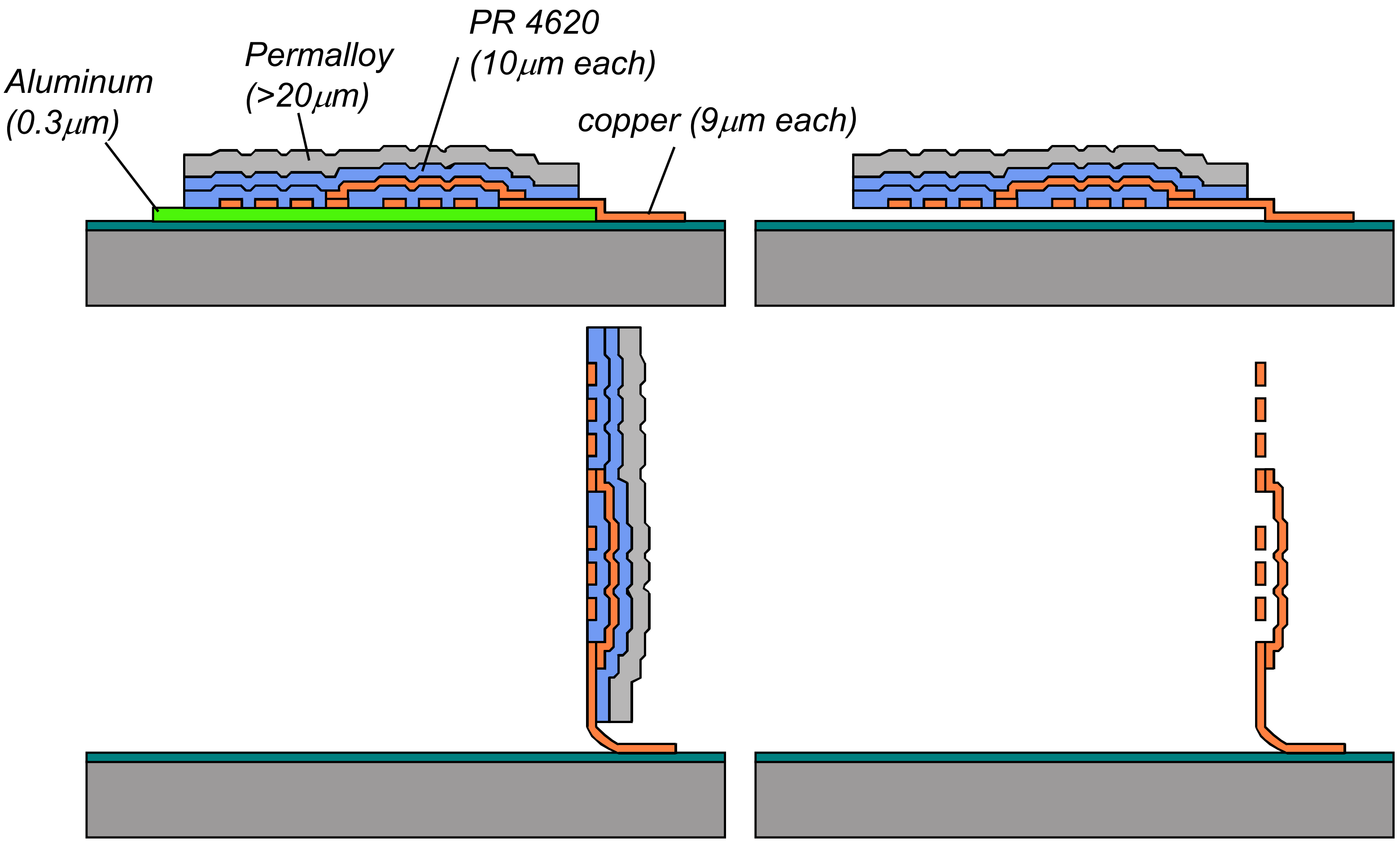
LPCVD Recipes for Silicon Nitride, Polysilicon, and Oxide

- Polycrystalline silicon
  - Polysilicon is deposited at around 580-620 ^oC and can withstand more than 1000 ^oC temperature. The deposition is conducted by decomposing silane (SiH4) under high temperature and vacuum (SiH_4> Si+2H_2).
  - Polysilicon is used extensively in IC - transistor gate
- Silicon nitride
  - Silicon nitride is nonconducting and has tensile intrinsic stress on top of silicon substrates. It is deposited at around 800 ^oC by reacting silane (SiH_4) or dichlorosilane ($SiCl_2H_2$) with ammonia (NH_3) - SiH_4+NH_3 -> Si_xN_y+ H.
- Silicon oxide
  - The PSG is knows to reflow under high temperature (e.g. above 900 ^oC); it is deposited under relatively low temperature, e.g. 500 ^oC by reacting silane with oxygen (SiH_4+O_2-> SiO_2+2$H_{2)}$. PSG can be deposited on top of Al metallization.
  - Silicon oxide is used for sealing IC circuits after processing.
  - The etch rate of HF on oxide is a function of doping concentration.

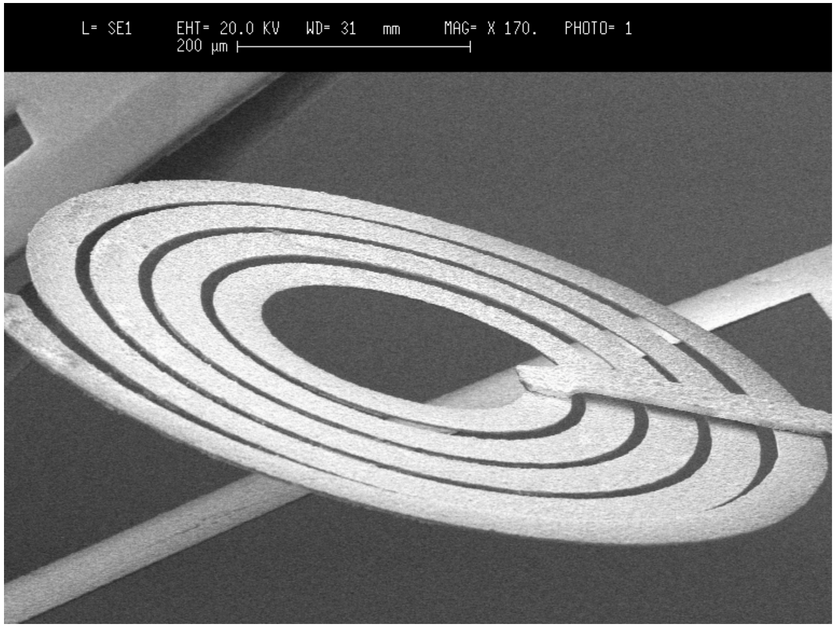
Other Structural or Sacrificial Materials

- Structural layers
  - evaporated and sputtered metals such as Gold, Copper
  - electroplated metal (such as NiFe)
  - plastic material (CVD plastic)
  - silicon (such as epitaxy silicon or top silicon in SOI wafer)
- Sacrificial layers
  - photoresist, polyimide, and other organic materials
  - copper
    - copper can be electroplated or evaporated, and is relatively inexpensive.
  - Oxide by plasma enhanced chemical vapor deposition (PECVD)
    - PECVD is done at lower temperature, with lower quality. It is generally undoped.
  - Thermally grown oxide
    - relatively low etch rate in HF.
  - Silicon or polysilicon
    - removed by gas phase silicon etching

Metal Sacrificial Layers



Out Of Plane Devices



A PECVD Machine

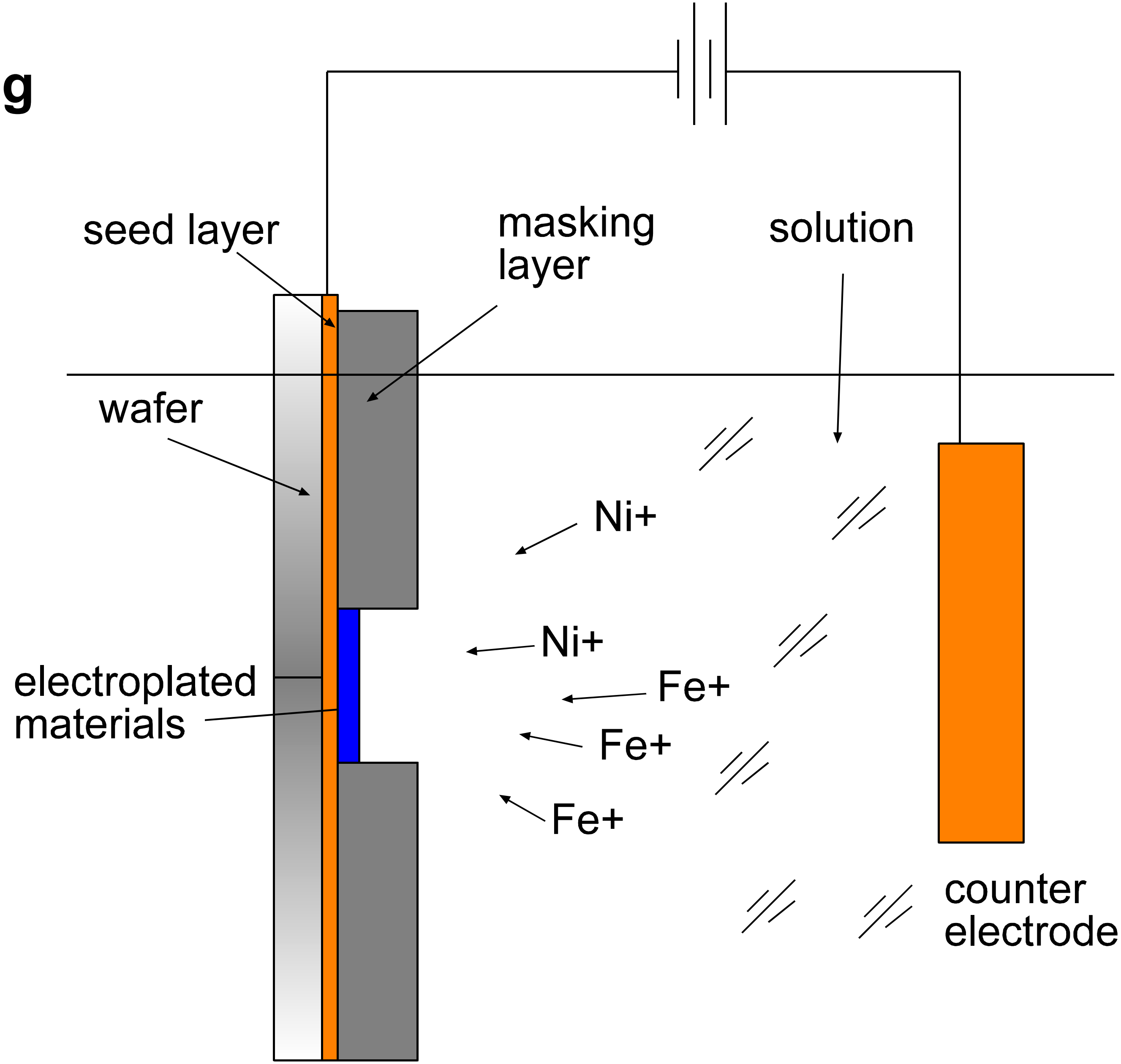
Processing gases

Reaction chamber

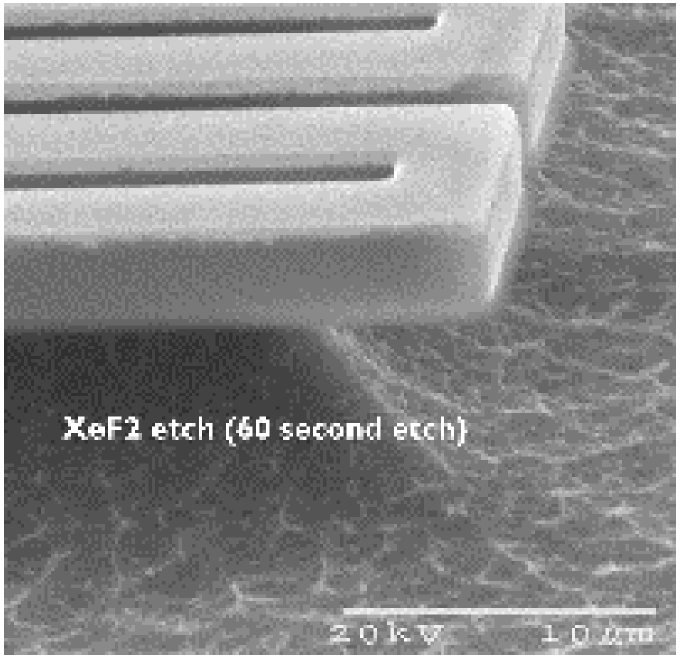
RF plasma generator

Electroplating

- Electroplating process description



Gas Phase Silicon Etching



- XeF_2
  - liquid phase under room temperature
  - $2XeF_2+Si \Rightarrow 2\ Xe + SiF_4$
  - vapor phase under low pressure
  - etches silicon with high speed
  - http://www.xactix.com/
- BrF_3
  - solid phase under regular pressure and room temperature
  - vapor phase (sublimation) under low pressure
  - BrF_3 when reacted with water turns into HF at room temperature.
- Both are isotropic etchants

Organic Sacrificial Layer

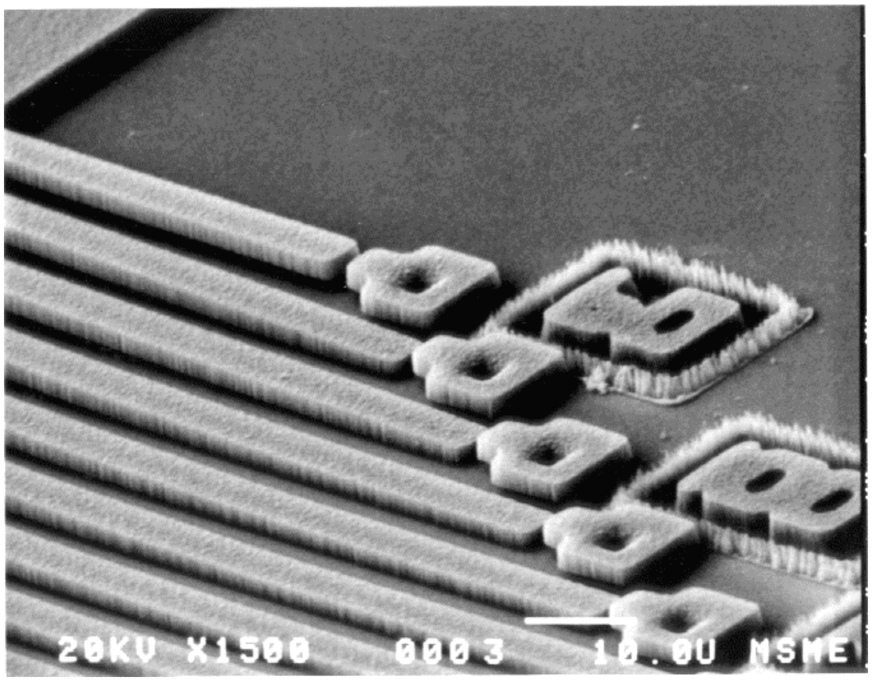
- Photoresist
  - etching by plasma etching (limited lateral etch extent)
  - or by organic solvents (acetone or alcohol)
- Polyimide
  - etching by organic solvents

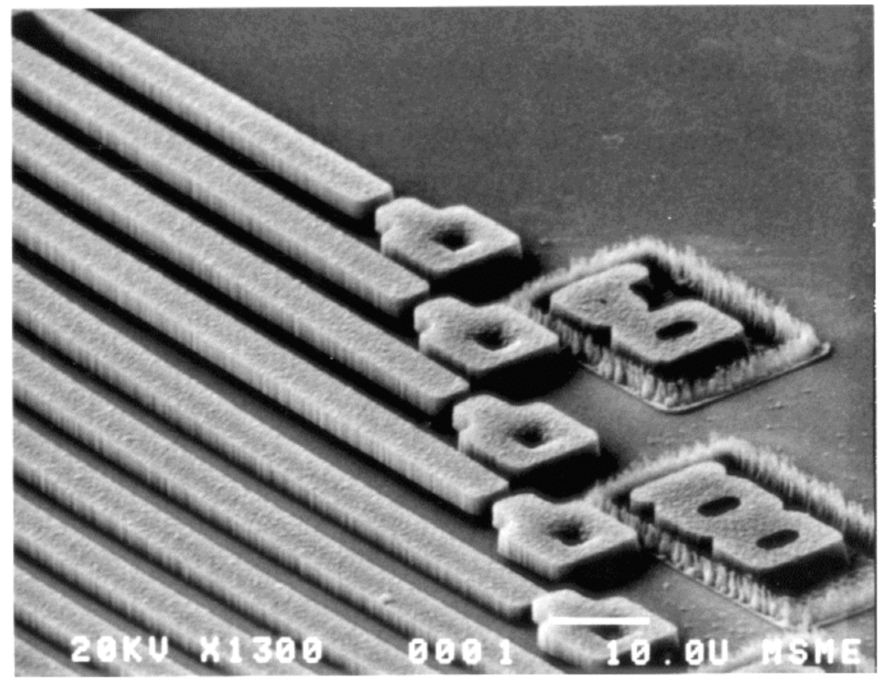
- Advantage
  - extremely low temperature process
  - easy to find structural solutions with good selectivity
- Disadvantage
  - many structural layers such as LPCVD are not compatible.
  - Metal evaporation is also associated with high temperature metal particles, so it is not completely compatible and caution must be used.

Criteria for Selecting Materials and Etching Solutions

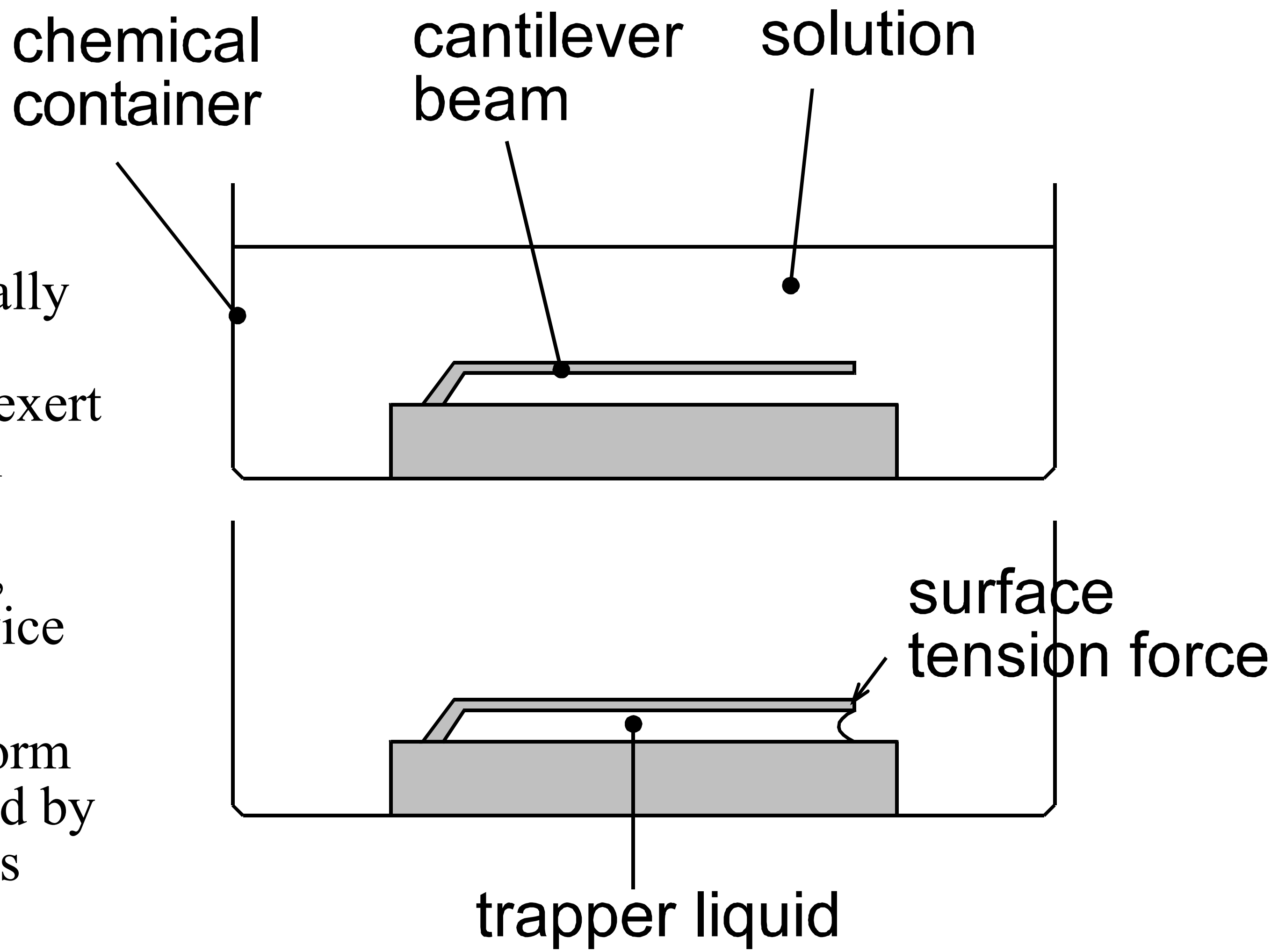
- Selectivity
  - etch rate on structural layer/etch rate on sacrificial layer must be high.
- Etch rate
  - rapid etching rate on sacrificial layer to reduce etching time
- Deposition temperature
  - in certain applications, it is required that the overall processing temperature be low (e.g. integration with CMOS, integration with biological materials)
- Intrinsic stress of structural layer
  - to remain flat after release, the structural layer must have low stress
- Surface smoothness
  - important for optical applications
- Long term stability

Stiction = Sticking and Friction





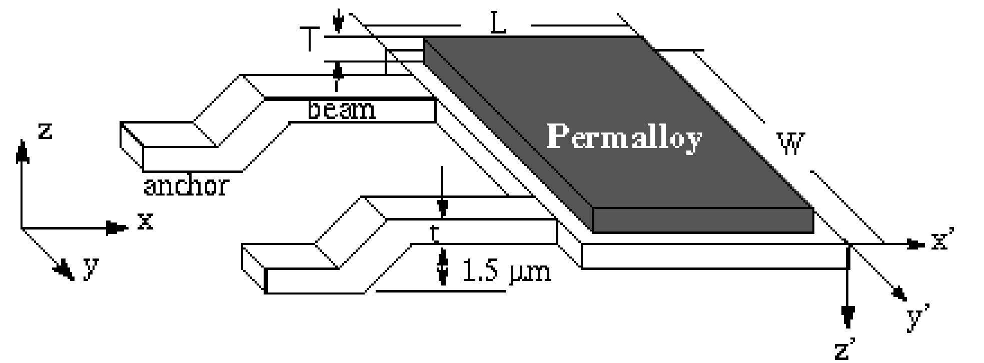
Origin of Stiction



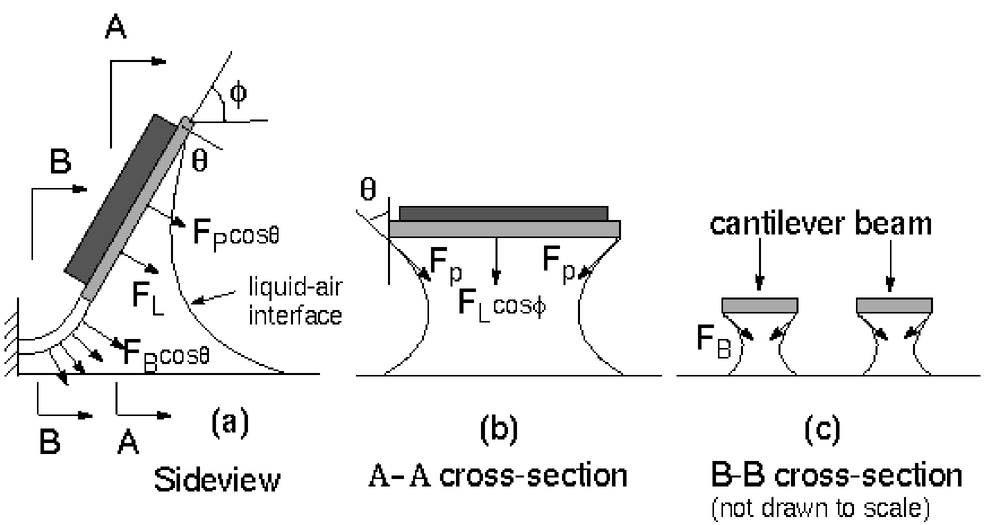
- As the liquid solution gradually vaporizes, the trapped liquid exert surface tension force on the microstructure, pulling the device down.
- Surfaces can form permanent bond by molecule forces when they are close.

Antistiction Method I - Active Actuation Method

- Use magnetic actuation to pull structures away form the surface
  - reduced surface tension length of arm

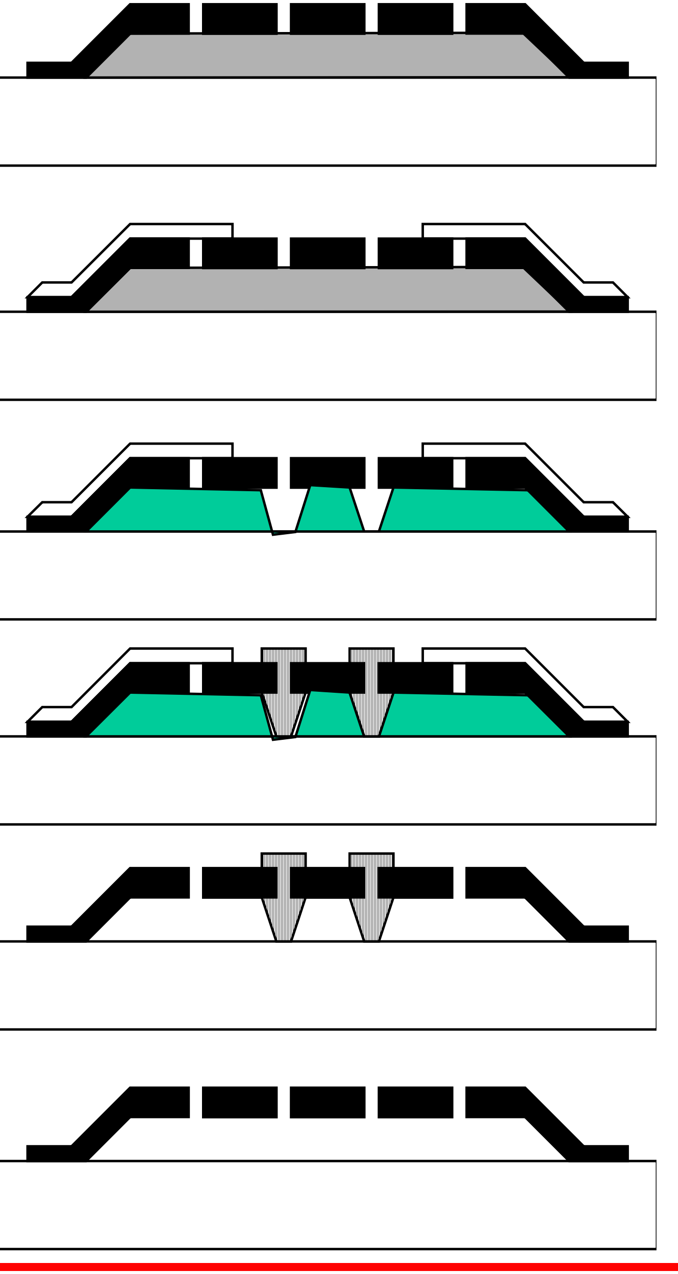


- Limitations
  - only works for structures with magnetic material.



Antistiction Method II - Organic Pillar

- Use organic pillar to support the structure during the liquid removal.
- The organic pillar is removed by oxygen plasma etching.



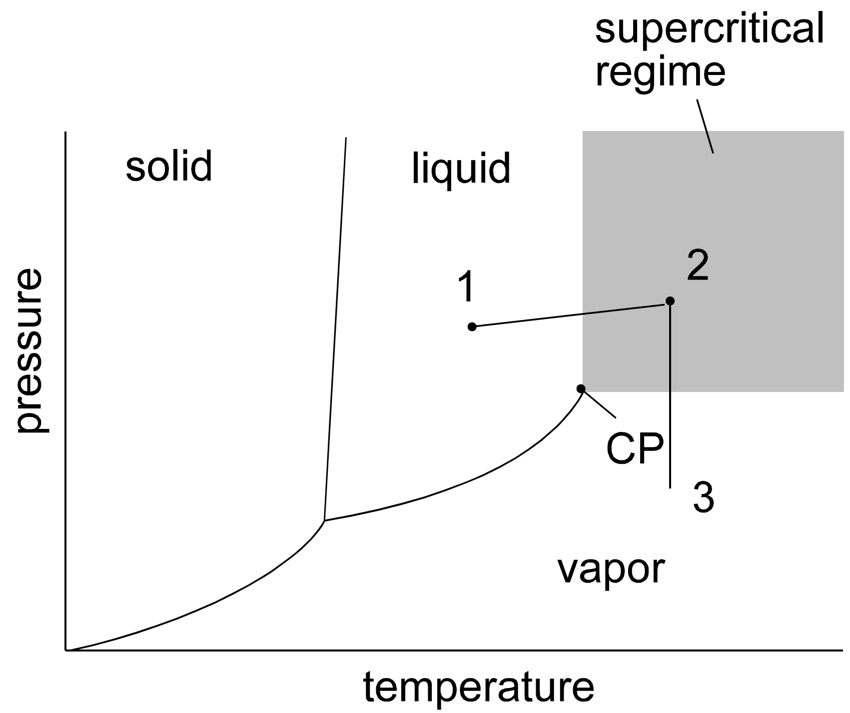
Antistiction Drying Method III - Phase Change Release Method
Supercritical CO_2 Drying

- Avoid surface tension by relaying on phase change with less surface tension than water-vapor.
- * p. 128-129
- Supercritical state: temp > 31.1 ^{o}C and pressure > 72.8 atm.
- Step 1: change water with methanol
- Step 2: change methanol with liquid carbon dioxide (room temperature and 1200 psi)
- Step 3: content heated to 35 ^{o}C and the carbon dioxide is vented.

- Free-standing cantilever beams upto 850 μm can stay released.

Super Critical Drying

- When a substance in the liquid phase at a pressure greater than the critical pressure is heated, it undergoes a transition from a liquid to a supercritical fluid at the critical temperature.
- This transition does not involve interfaces.

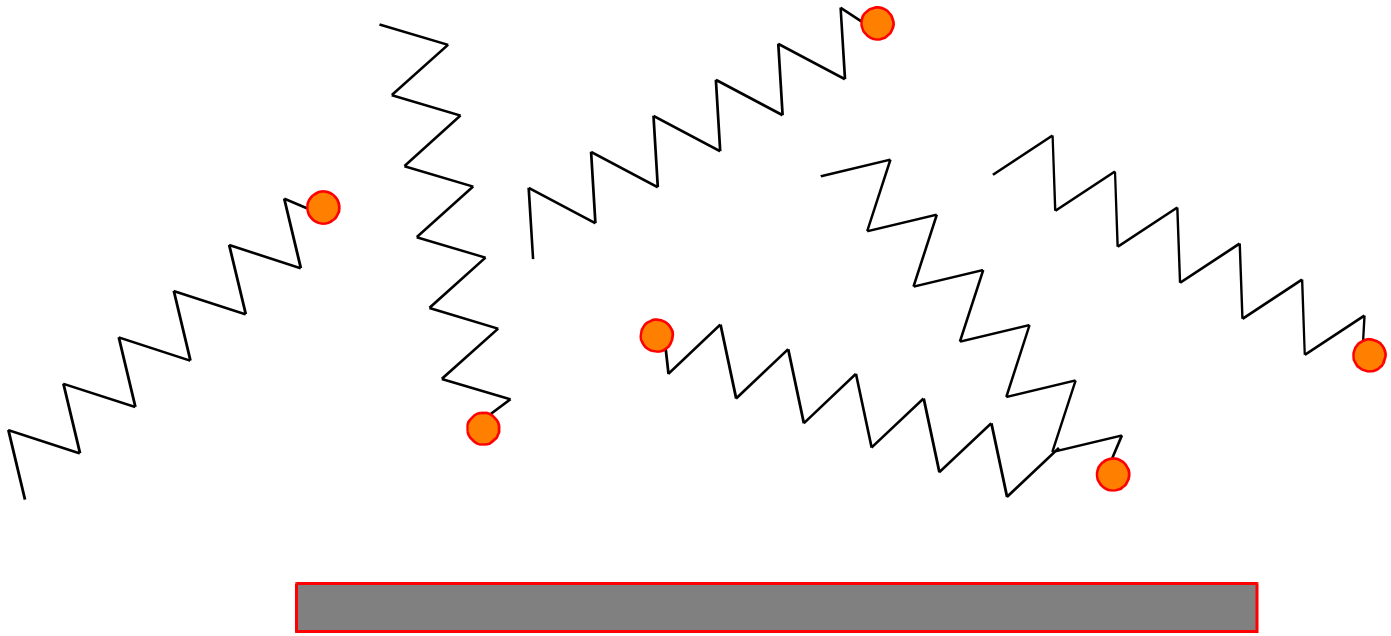


- Criteris
  - chemically inert, non-toxic
  - low critical temperature
- CO_2
  - critical temperature 31.1 ^{o}C
  - critical pressure 72.8 atm.(or 1073 psi)

- Exchange methanol with liquid CO2 at 25^{o}C and 1200 psi
- closeoff vessel and heated to 35 ^{o}C, no interface is formed.
- Vent vessel at a constant temperature above critical temperature.

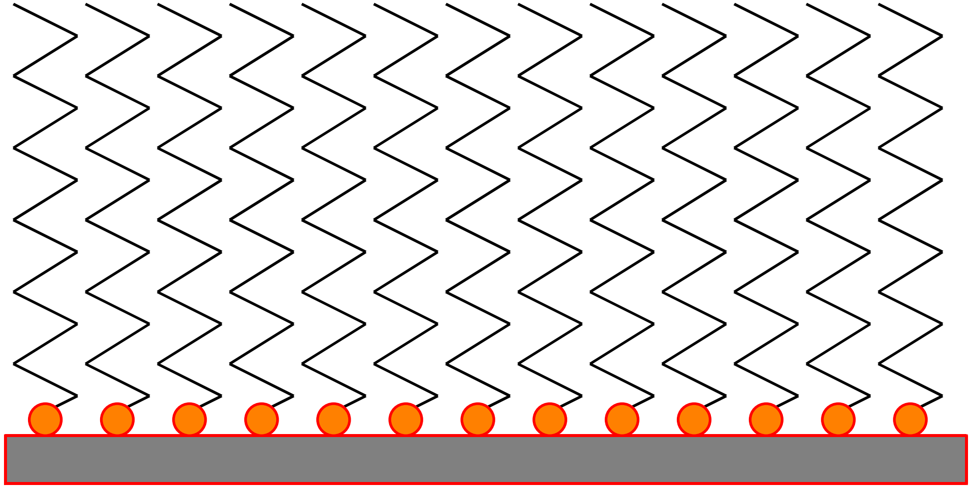
Antistiction Method III - Self-assembled Monolayer

- Forming low stiction, chemically stable surface coating using self-assembly monolayer (SAM)
- SAM file is comprised of close packed array of alkyl chains which spontaneously form on oxidized silicon surface, and can remain stable after 18 months in air.
- OTS: octadecyltrichlorosilane (forming $C_{18}H_{37}SiCl_3$)

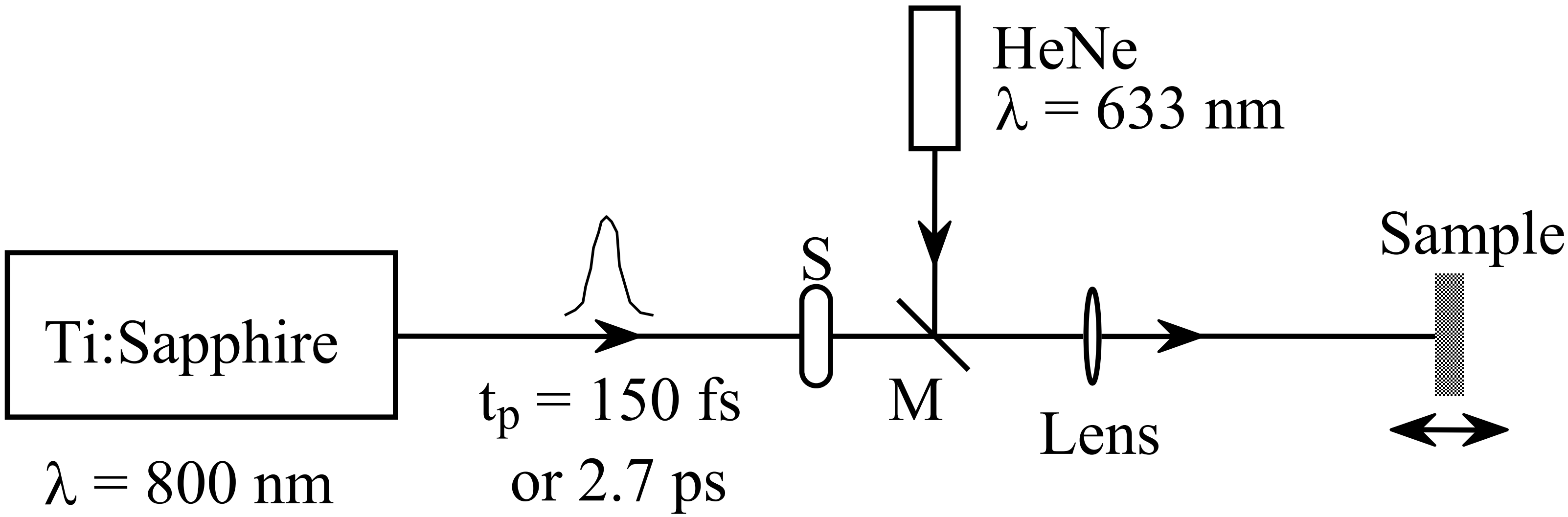


Result of SAM Assembly

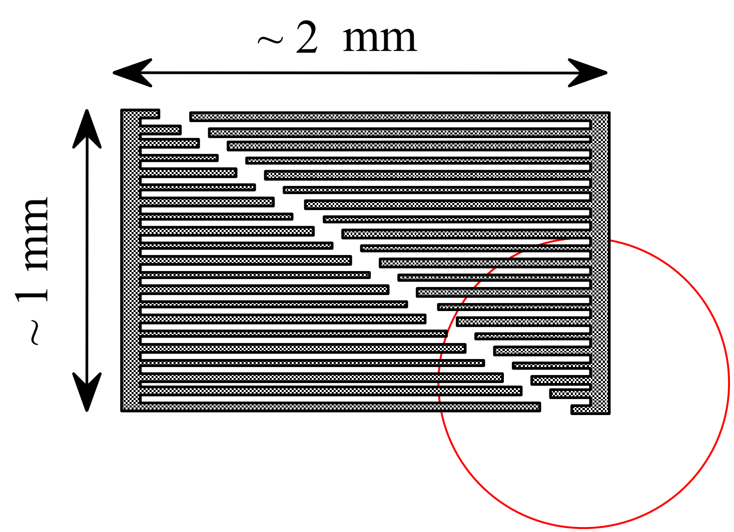
- Surface oxidation: H2O2 soak
- SAM formation
  - isopropanol alcohol rinse
  - CCl_4 rinse
  - OTS solution
  - CCl_4 rinse



Short Pulse Laser Irradiation



Undoped Polysilicon
Cantilever Array
length: 60 µm to 1 mm
width: 5 µm
thickness: 2 µm
gap height: 1.5 µm



Faculty: Phinney