Lecture#8:

Etching (2)

:Surface Micromachining

Etching (2): Surface Micromachining

- **Summary: micromachining**

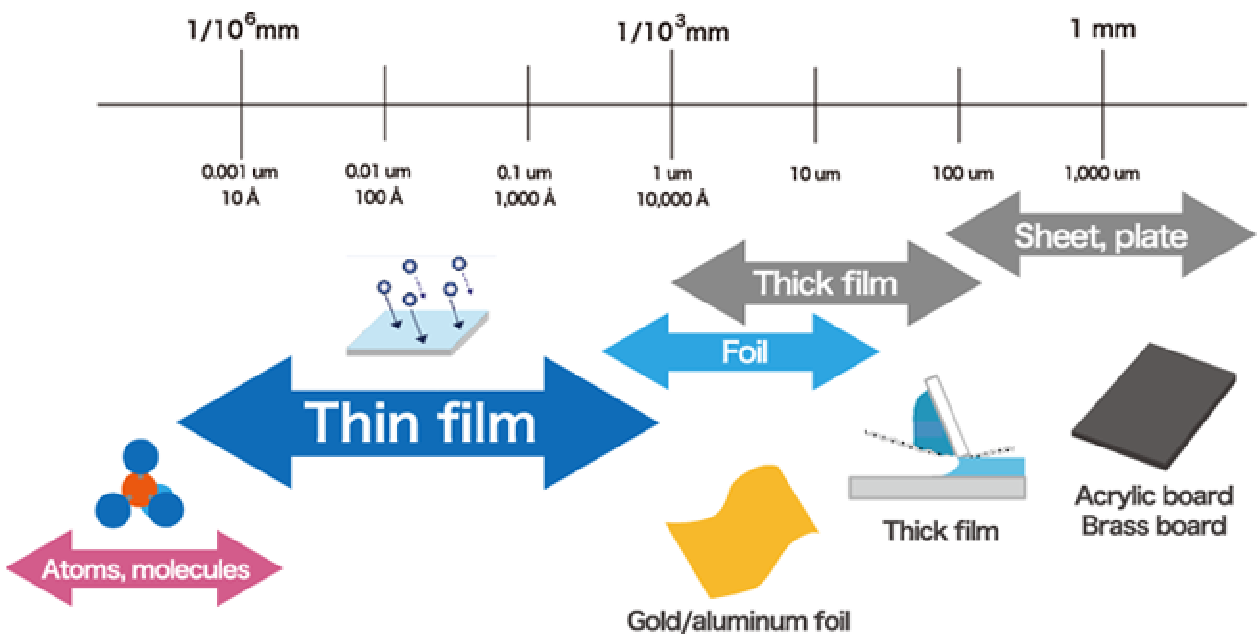
	Bulk-micromachining	Surface-micromachining
Birth	1960's	1980's
Structure (Material)	Single crystal silicon wafer	Thin film on wafer
Etching	Wet/Dry etching	Wet/Dry etching
Etch control	Crystal orientation, Diffusion layer	Material selectivity

Etching (2): Surface Micromachining

Features

- Excellent adhesion, low residual stress, low pinhole density, good mechanical strength, and chemical resistance may be required simultaneously.

- Although the properties of a bulk material might be well characterized, its thin film form may have properties substantially different from those of the bulk.

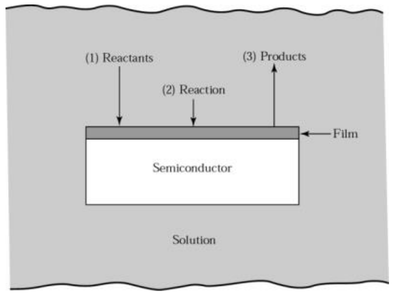


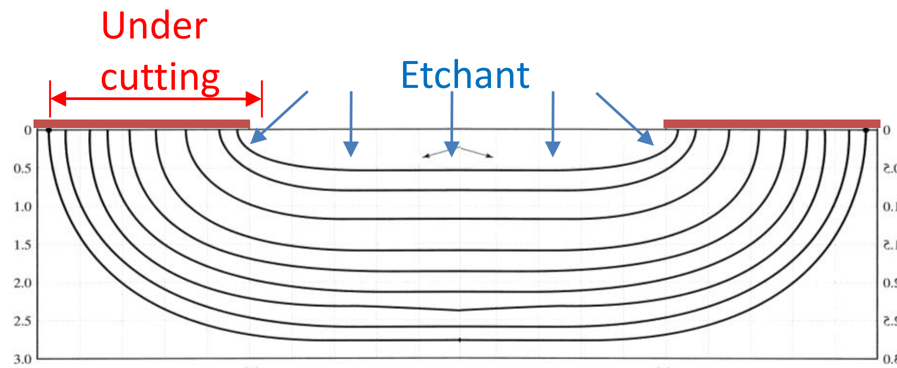
Wet Chemical Etching: Isotropic

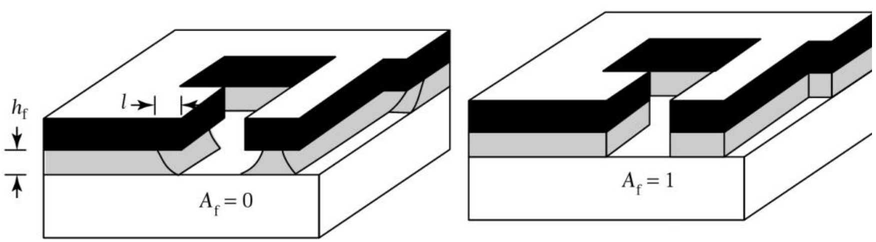
Etching (2): Surface Micromachining

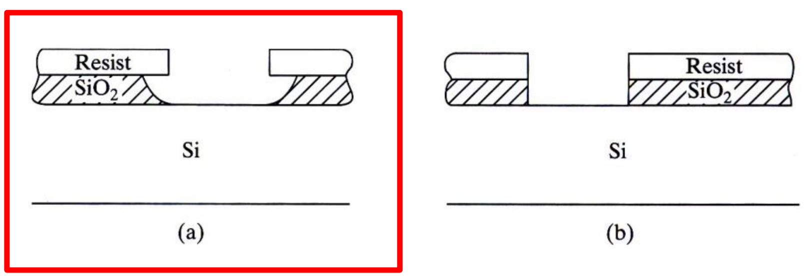
- **Wet etching**

  - **Immersion etching**; Wafer is immersed in the etch solution









$SiO_2 + 6HF \rightarrow H_2SiF_6 + 2H_2O$

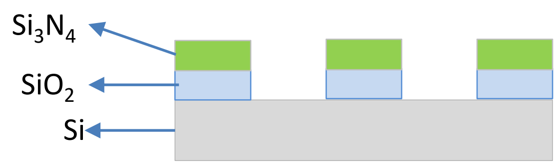
SiO_2 etching : Hydrofluoric acid (HF)

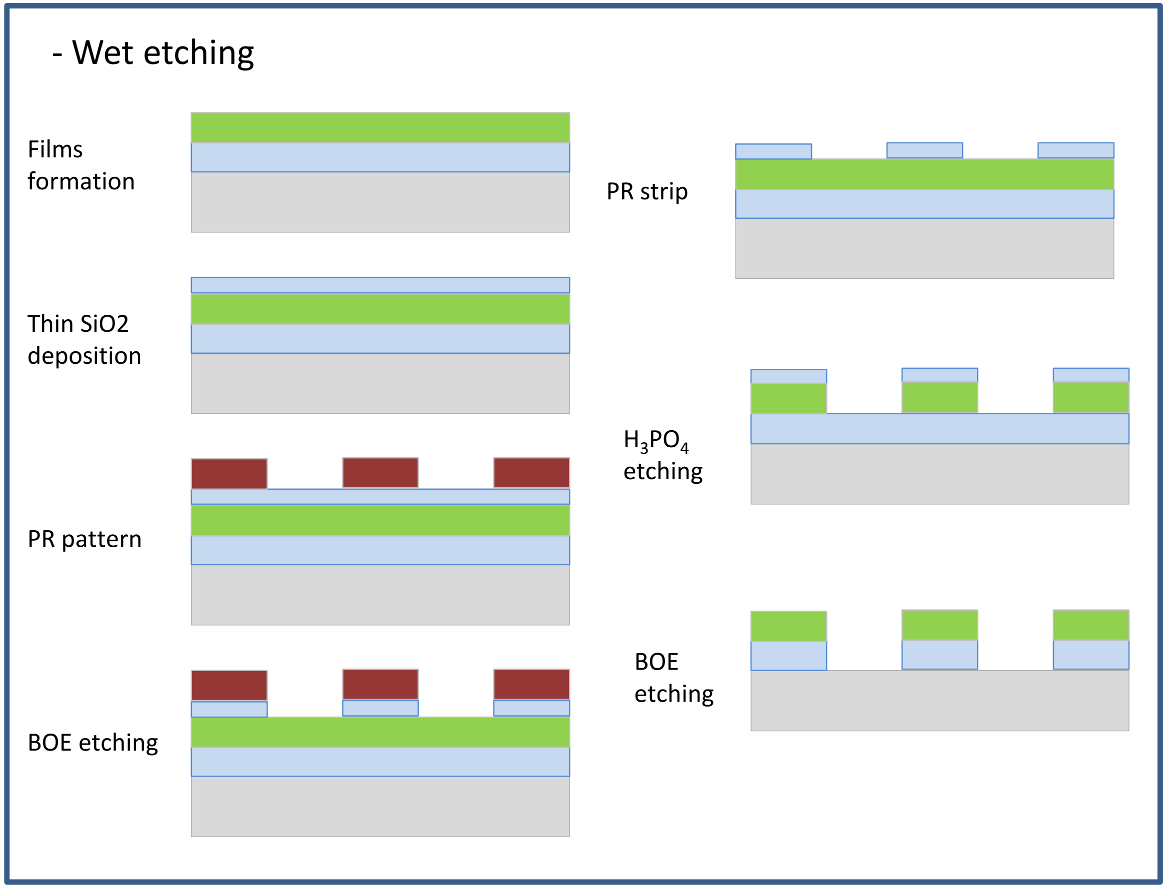
: Buffered oxide etch (BOE or BHF)

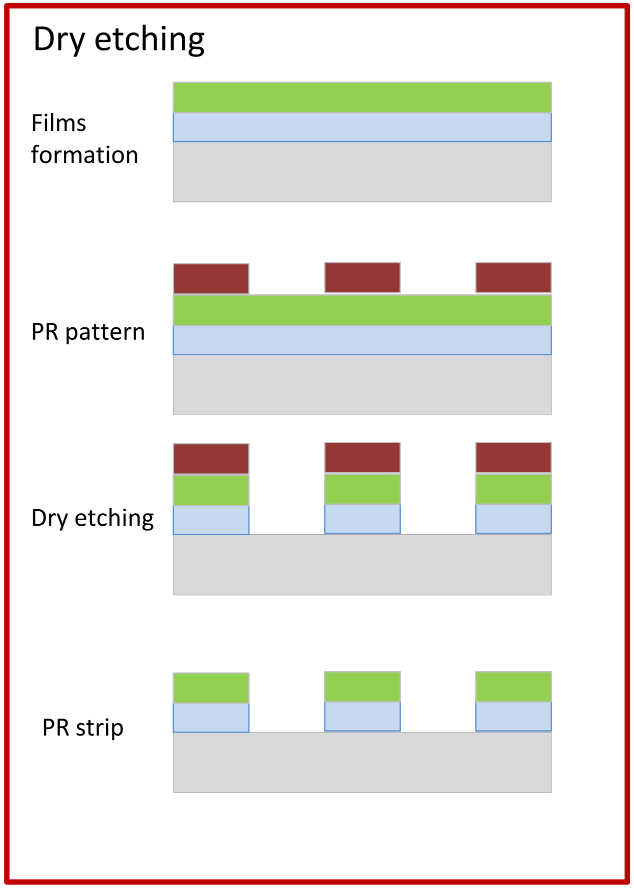
Wet etching of **Amorphous thin film** and **Metal thin film** shows isotropic etching result

Dry Etching: Anisotropic

Etching (2): Surface Micromachining





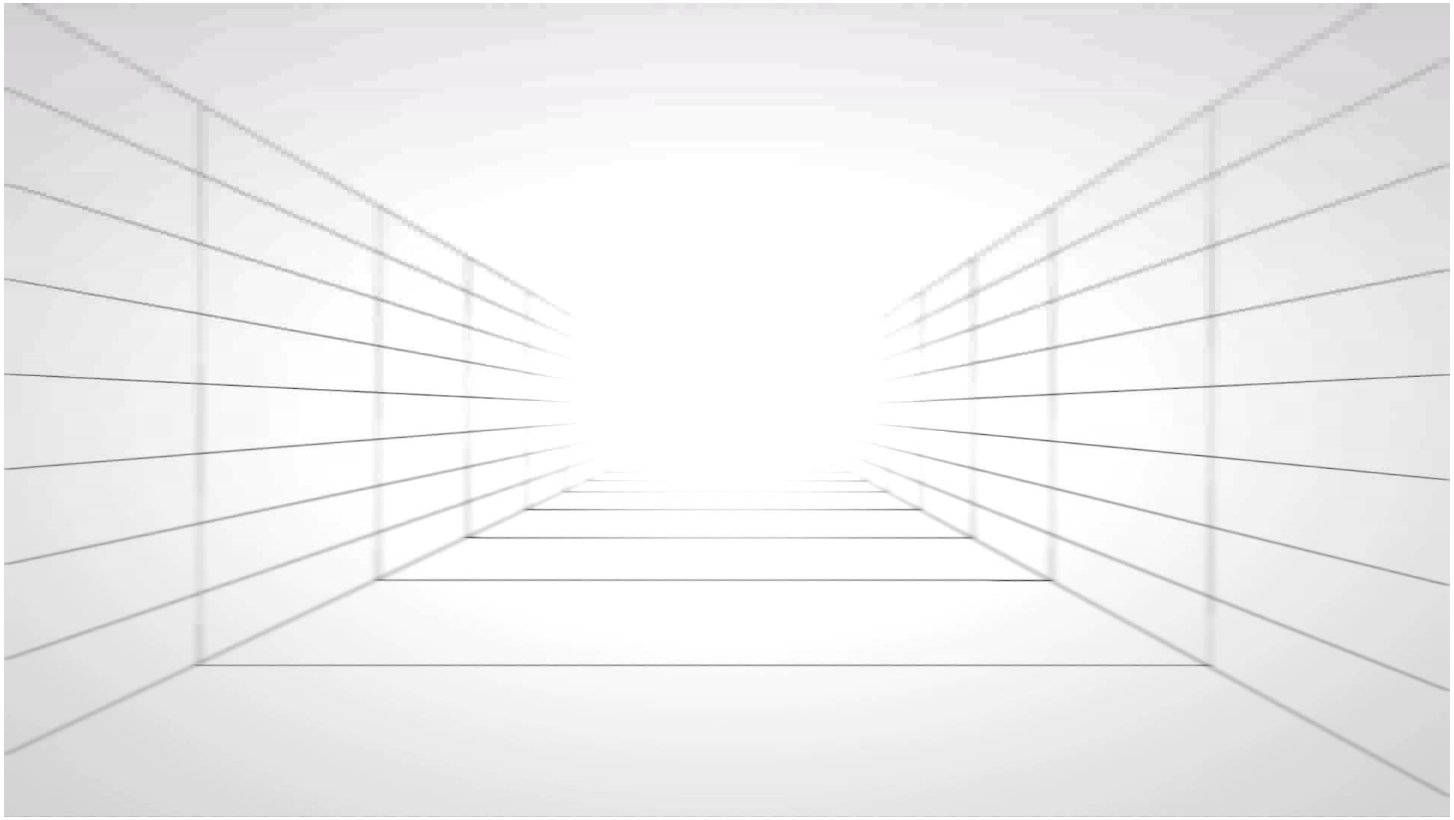


Atomic Layer Etching (1)

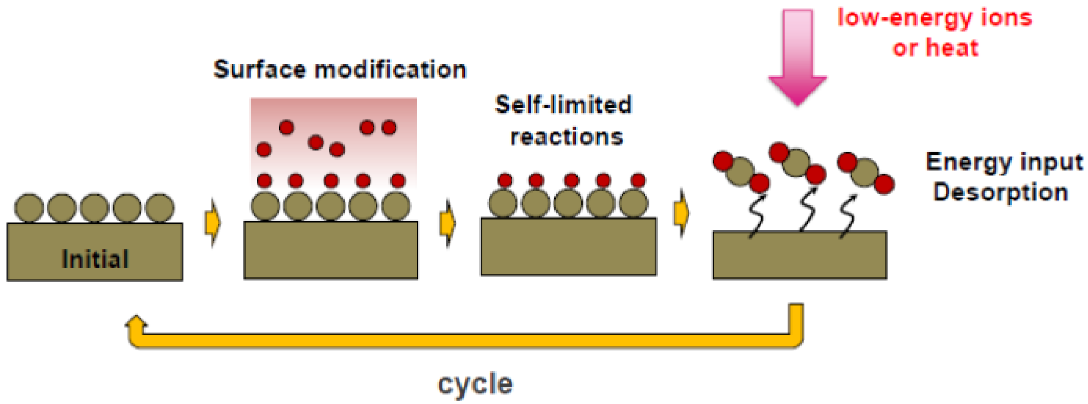
Etching (1): Bulk Micromachining

- **Atomic Layered Etch (ALE)**

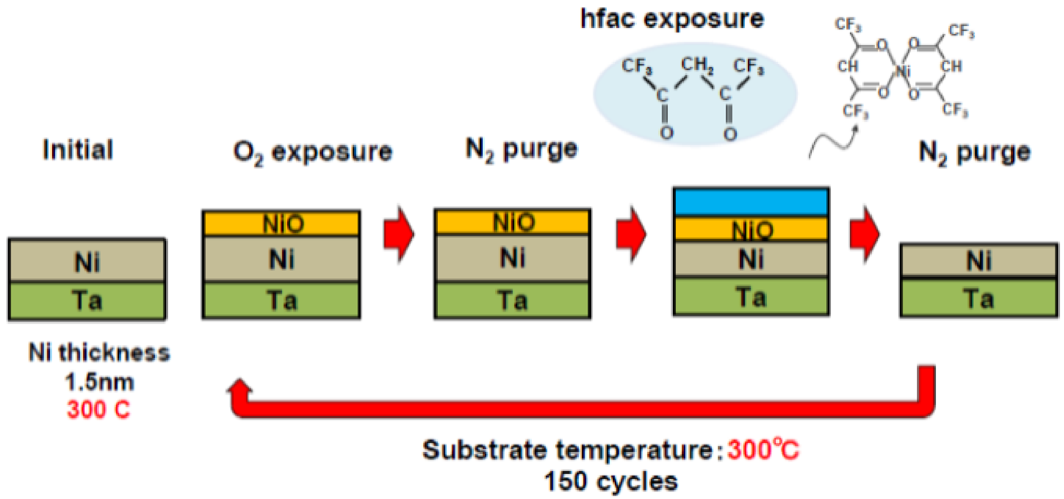
  : self-limiting chemical modification steps -> affect only the top atomic layers of the wafer -> etching steps which remove only the chemically-modified areas, allows the removal of individual atomic layers



General process flow



Example: ALE of Ni of O2 exposure



S. Hamaguchi, Semicon Korea, 2021

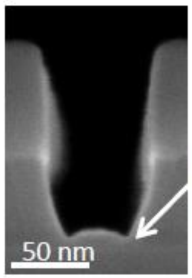
Atomic Layer Etching (3)

Etching (1): Bulk Micromachining

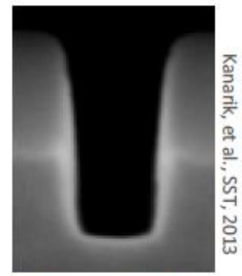
- **Advantage: flat and smooth etch front**

Traditional RIE Processing	ALE Processing

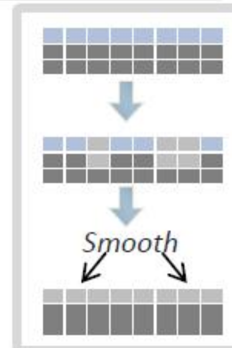
Patterned poly trench wafers:



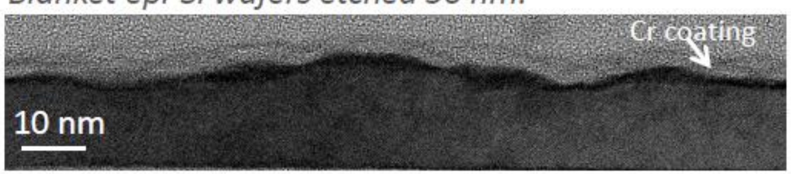
Micro-trenching

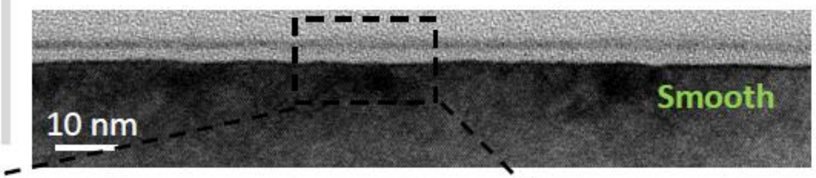


Flat etch front

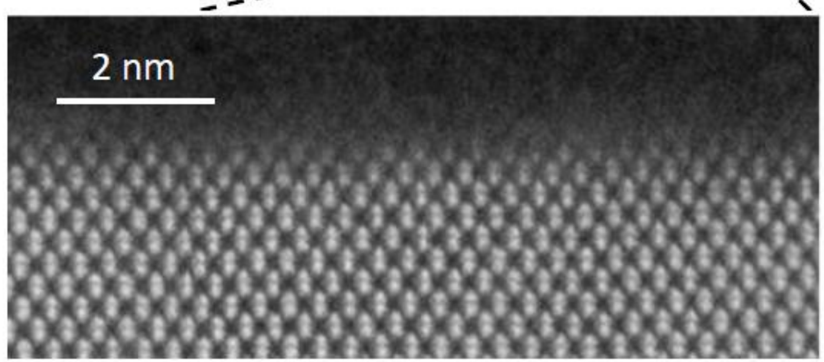


Blanket epi-Si wafers etched 50 nm:





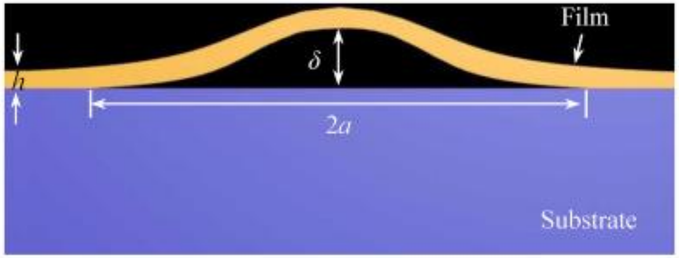
ALE:



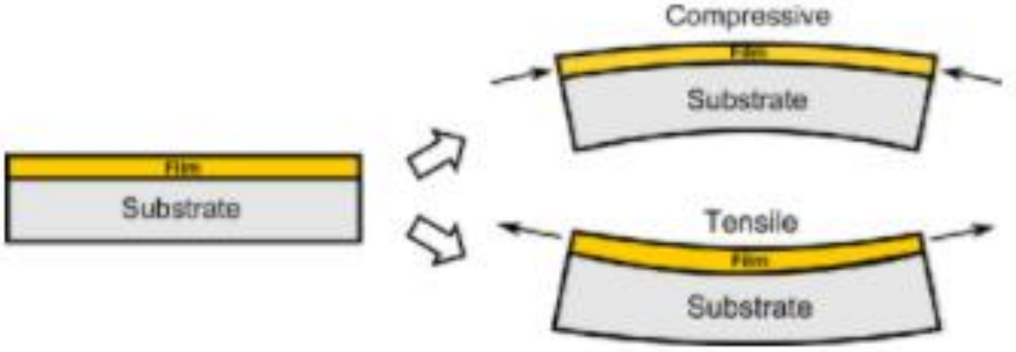
Kanarik, et al., SST, 2013

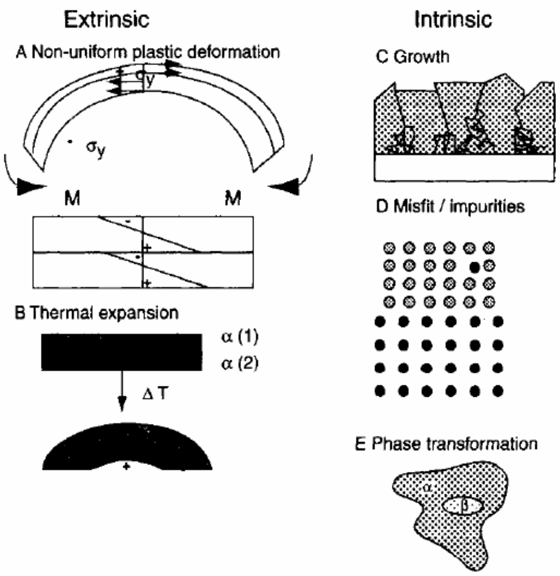
Etching (2): Surface Micromachining

- **Adhesion**
  - Cleanliness and roughness of a substrate are factors for good film adhesion.



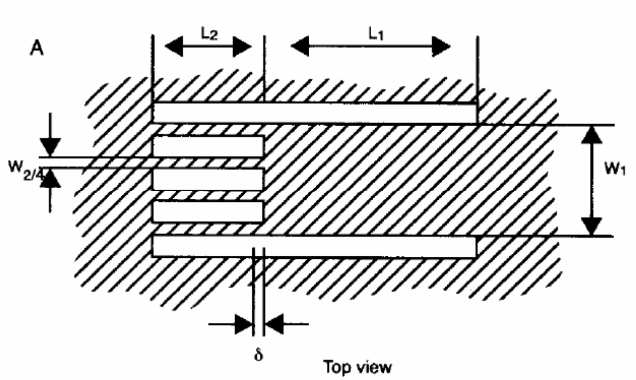
- **Stress**
  - Nearly all films foster a state of residual stress, due to mismatch in the thermal expansion coefficient, non-uniform plastic deformation, lattice mismatch, substitutional or interstitial impurities, and growth process.
  - High stress can result in bucking or cracking of films.

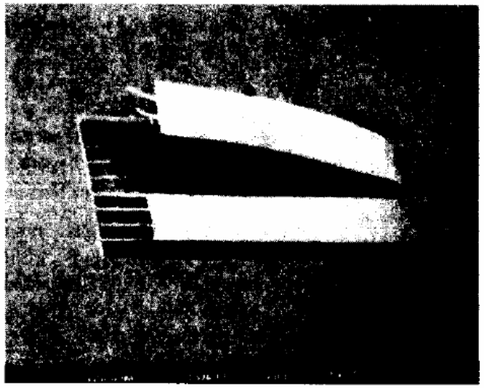




Etching (2): Surface Micromachining

1) Uniaxial Measurements

A


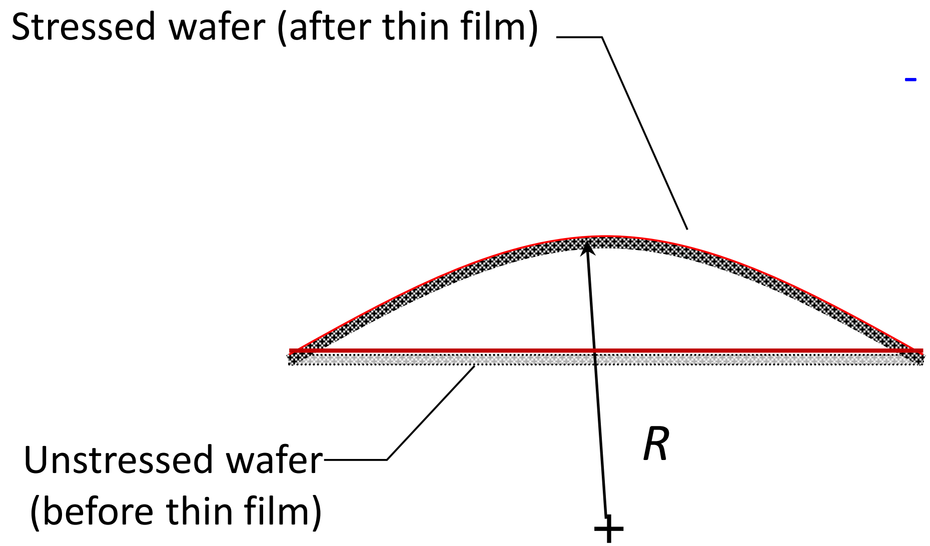
B


- Once released, the wide suspended strip (W_1) pulls on the thinner necks (W_2), resulting in a deflection δ from its original mask position toward the right to its final position.

- For structures where the strain is small enough to be molded with linear elastic behavior, the deflection δ can be related to the strain as follows:

$$\varepsilon = \frac{\sigma}{E} = \frac{\delta\left(\frac{W_1}{L_1} + \frac{W_2}{L_2}\right)}{W_1 - W_2}$$

2) Disk Method



- The disk method is based on a measurement of the deflection in the center of the disk substrate before and after processing.

$$\sigma = \frac{E}{1-\nu} \cdot \frac{T^2}{6Rt}$$

Biaxial modulus of the wafer

strain at wafer /film interface

R = radius of curvature,

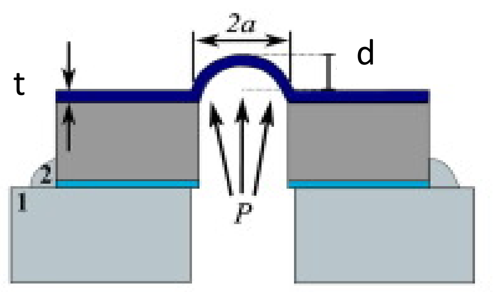
T = wafer thickness,

t = thin film thickness.

3) Suspended Membrane Methods

- By pressurizing one side of the membrane and measuring the deflection, one can extract both the residual stress and the Young's modulus of the membrane.

- Pressure to the suspended film can be applied by a gas or by a point-load application.



$$p = C_1 \frac{\sigma t d}{a^2} + C_2 \left(\frac{E}{1-\nu} \right) \frac{d^3}{a^4}$$

p : pressure difference across the film

d : center deflection

a : initial radius

t : thickness of membrane

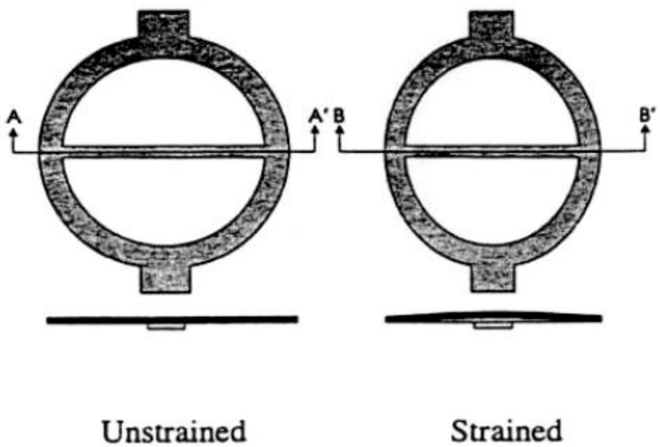
σ : initial film stress

Thin Films: Stress-Measuring Technique (4)

Etching (2): Surface Micromachining

- **4) Ring Crossbar Structures (Guckel Rings)**

- The tensile strain in the ring places the spanning beam in compression; the critical buckling length of the beam can be related to the average strain.



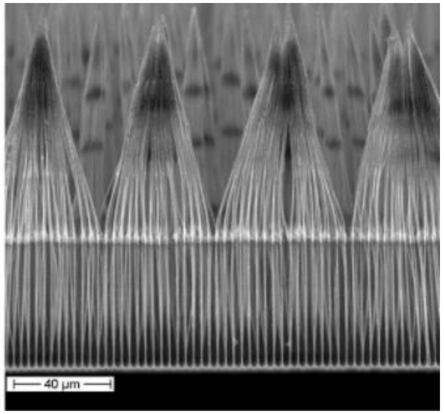
Tensile Residual Stress

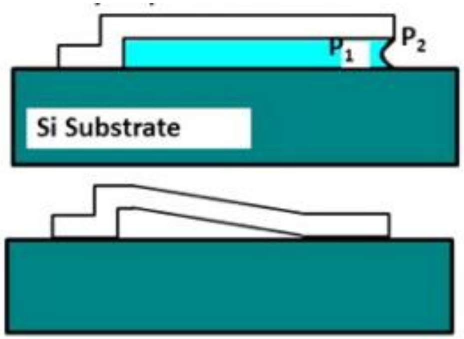
$$\sigma_r = \frac{\pi^2 h^2 E}{12 g(R) R^2}$$

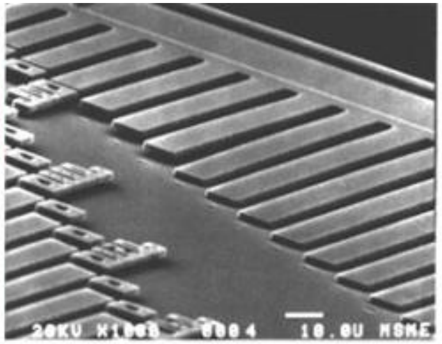
E: Young's modulus
h: wafer thickness
R: radius of ring
g(R): function of inner and outer ring diameter <0.918

- **Stiction**

  - As the structure dries, the surface tension of the process solution pulls the delicate microstructure to the others where a combination of forces, van der Waals forces and hydrogen bonding, keeps it firmly attached.

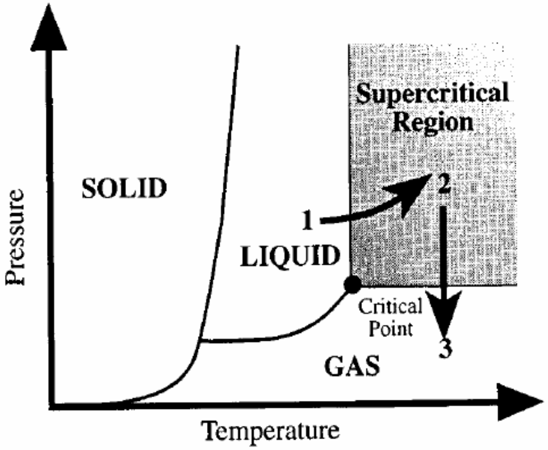






Methods to reduce stiction :

a. stand-off bumps (dimples) on the underside of a structure
b. use of sacrificial supporting polymer column
d. HF vapor
e. supercritical drying



Comparison of bulk and surface micromachining

Bulk Micromachining	Surface Micromachining
Large features with substantial mass and thickness	Small features with low thickness and mass
Utilizes both sides of the wafer	Multiple deposition and etching required to build up structures
Vertical dimensions: one or more wafer thicknesses	Vertical dimensions are limited to the thickness of the deposited layers (~2 μm) leading to compliant suspended structures with the tendency to stick to the support
Generally involves laminating Si wafer to Si or glass	Surface micromachined device has its built-in support and is more cost effective
Piezoresistive or capacitive sensing	Capacitive and resonant sensing mechanisms
Wafers may be fragile near the end of the production	Cleanliness critical near end of process
Sawing, packaging, testing is difficult	Sawing, packaging, testing is difficult
Some mature products and producers	No mature products or producers
Not very compatible with IC technology	Natural but complicated integration with circuitry; integration is often required due to the tiny capacitive signals

Source: Adapted from H. Jerman, 1994.[1]