MCT321: Introduction to Nano-Mechatronics

Lecture #4: MEMS Bulk Micromachining

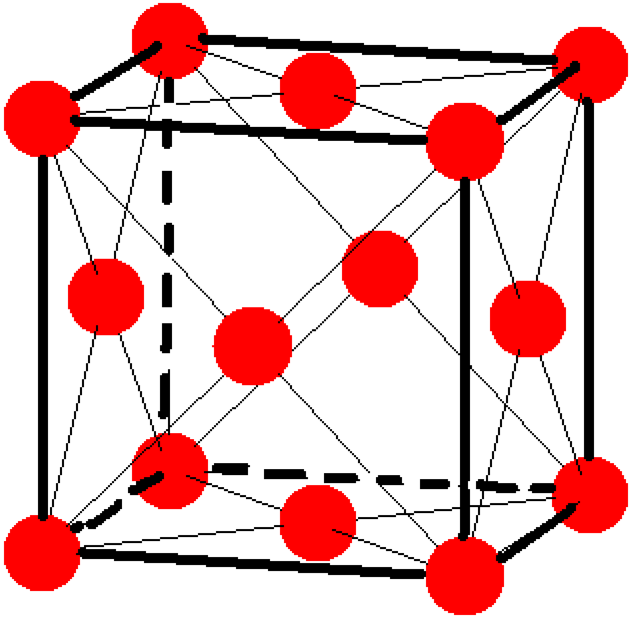
Mostafa Soliman, Ph.D.

Outline

- Wet etching
  - Anisotropic Si etching
    - Silicon Crystalline Structure
    - Miller indices
- Bulk micromachining of Si

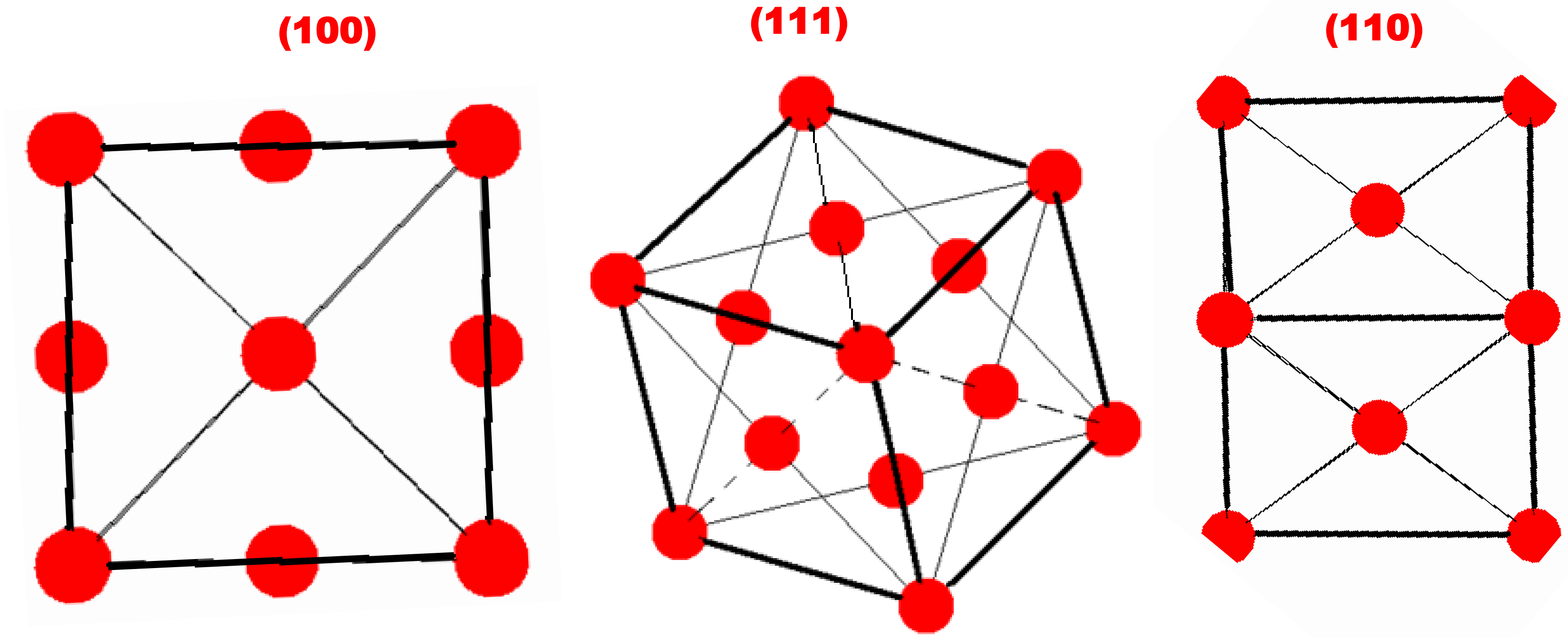
Silicon Crystal Structure

- Silicon has a cubic diamond lattice structure.
- The unit cell of the lattice is Face Centered Cubic (FCC).



Silicon Crystal Structure

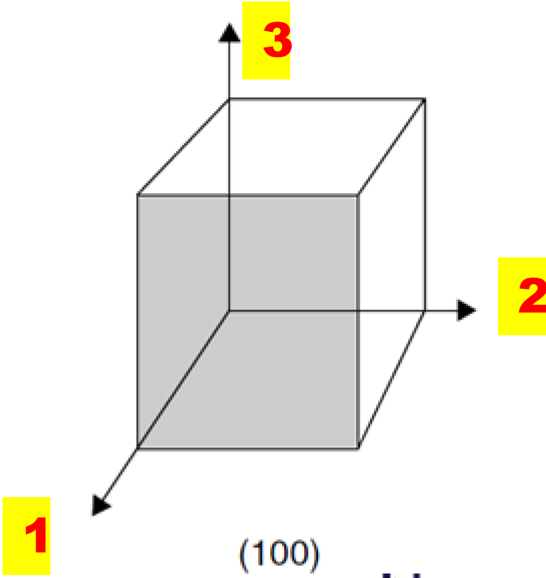
- The density of atoms is dependent on the angle the crystal is viewed from.



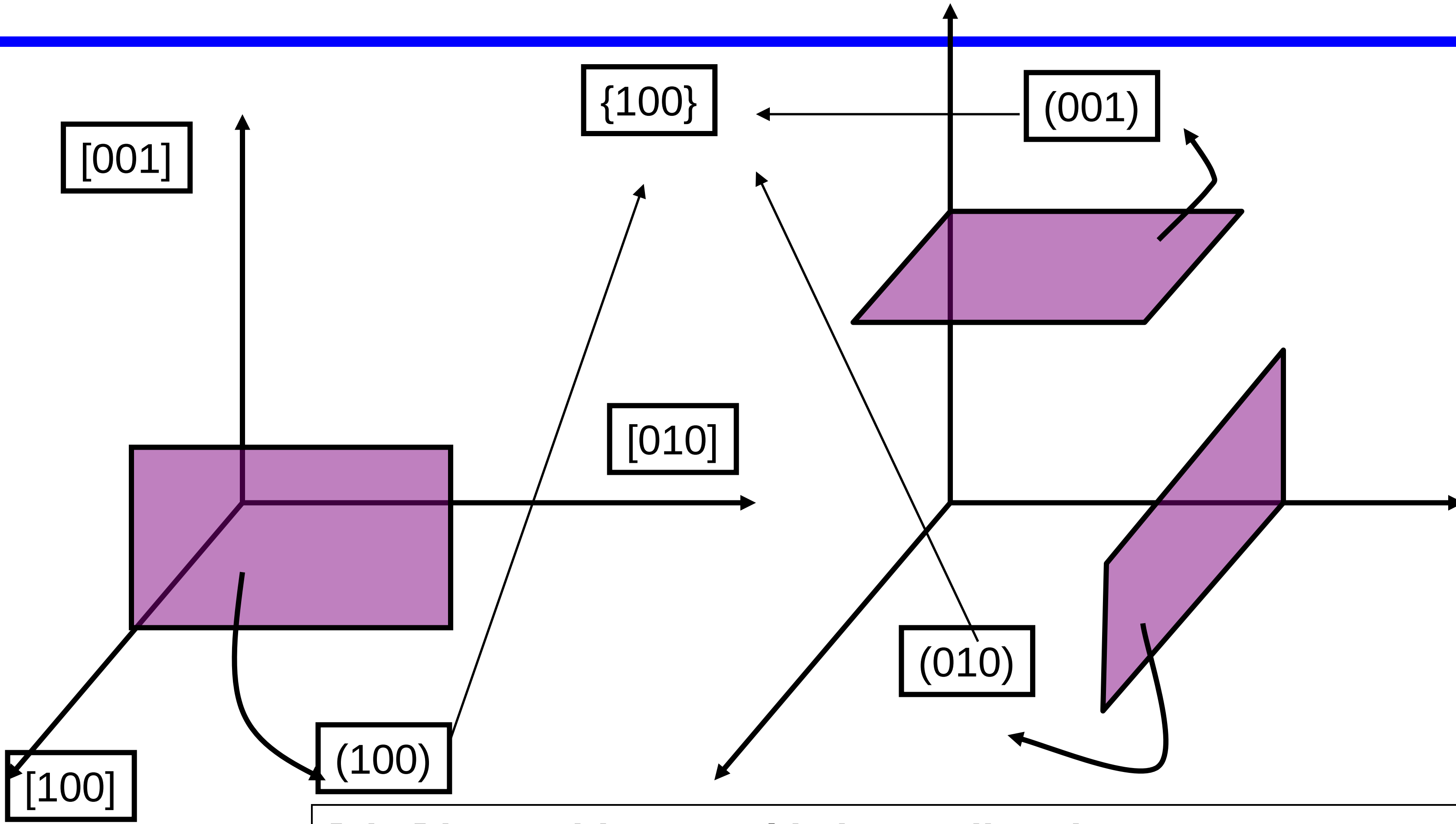
- Miller indices are used to define the different planes of the crystal.

Miller indices

- The plane that defines the faces of the cube intersects axes 1, 2, and 3 at (1, ∞, ∞).
- The miller indices of this plane is give by the reciprocal of theses intersects, that is (1,0,0), or (100).
- Silicon crystal has 6 face planes.
- Those 6 face planes are called "{100} planes family".

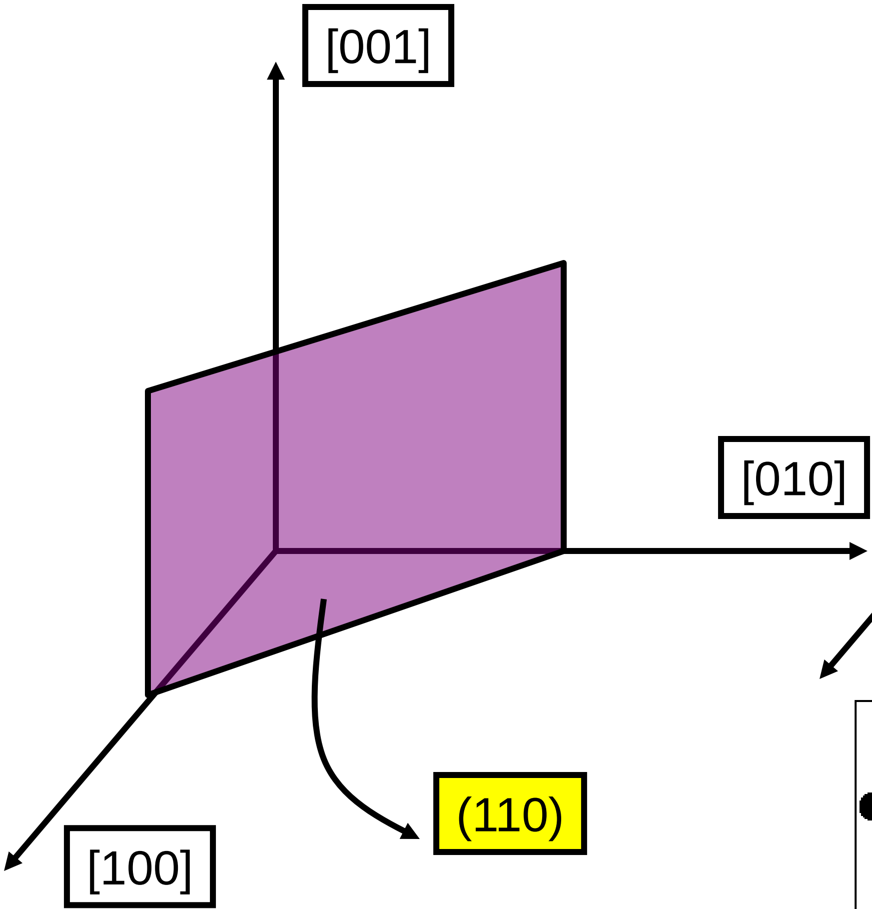


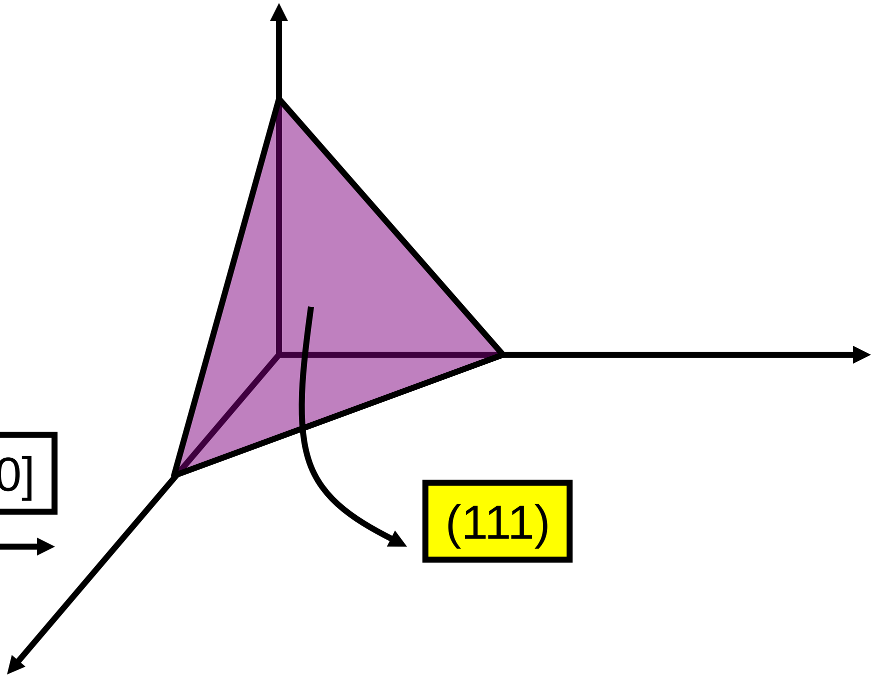
Miller indices

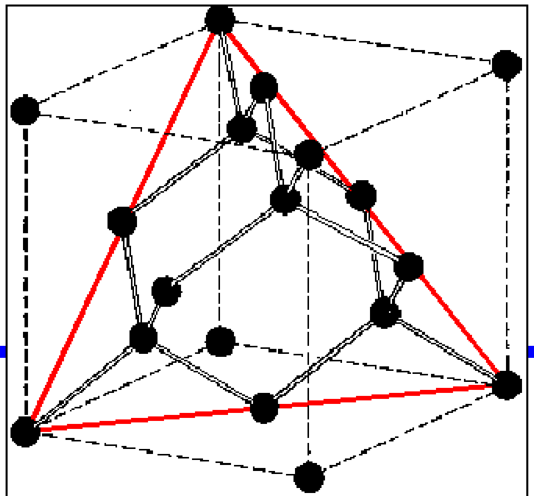


[abc] in a cubic crystal is just a direction vector
(abc) is any plane perpendicular to the [abc] vector
{…}/<…> indicate equivalent planes/direction

Miller indices

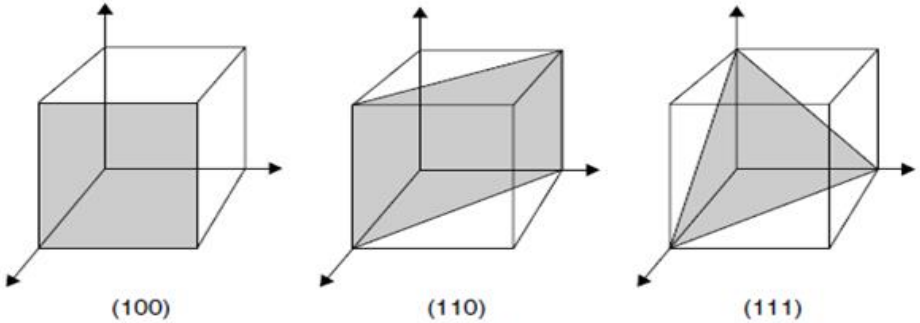




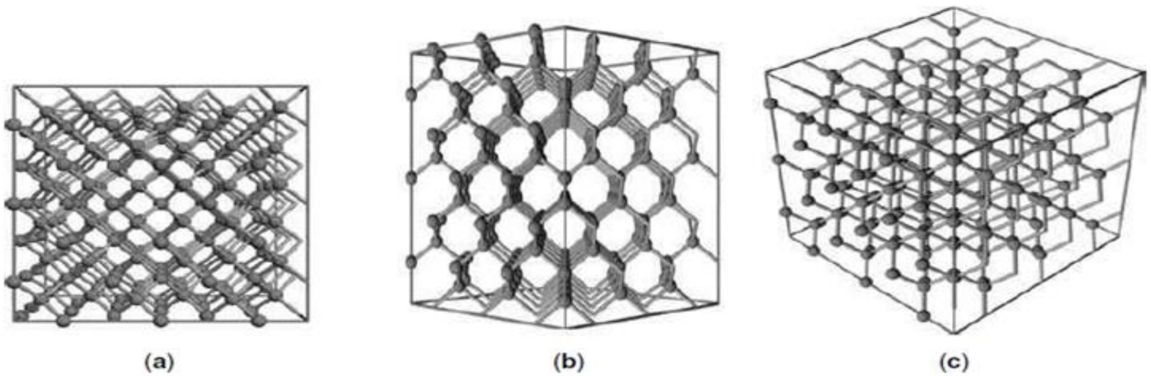


Miller indices

- Planes {100} are called face planes (6 planes).
- Planes {110} are called edge planes (12 planes). (lowest atomic density)
- Planes {111} are called diagonal planes (8 planes). (highest atomic density)

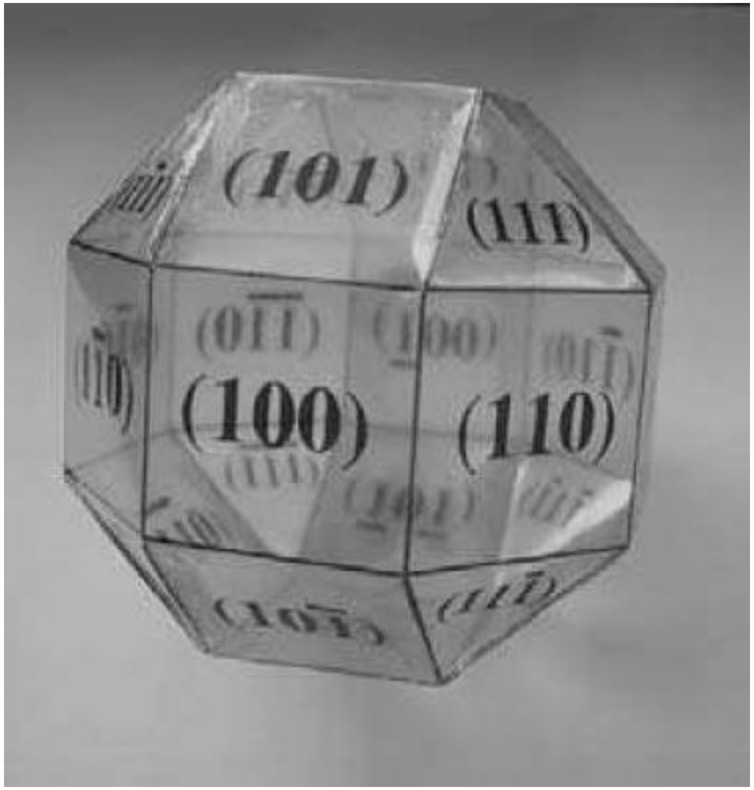


Some important silicon crystal planes with their Miller indices



Silicon crystal viewed from different angles: (a) face view (100); (b) edge view (110); (c) vertex view (111).

Miller indices



Silicon crystal as viewed from different angles

Miller indices

- Angles between the different planes can be calculated from the scalar (dot) product of their normal vectors.

$$a \cdot b = |a||b|\cos\theta$$

- Angle between (100) and (110) planes can be calculated as follows:

$$(100)\cdot(110) = |1|\left|\sqrt{2}\right|\cos\theta$$

$$\therefore 1+0+0 = \sqrt{2}\cos\theta$$

$$\theta = \pm 45^\circ$$

- Angle between (100) and (111) planes can be calculated as follows:

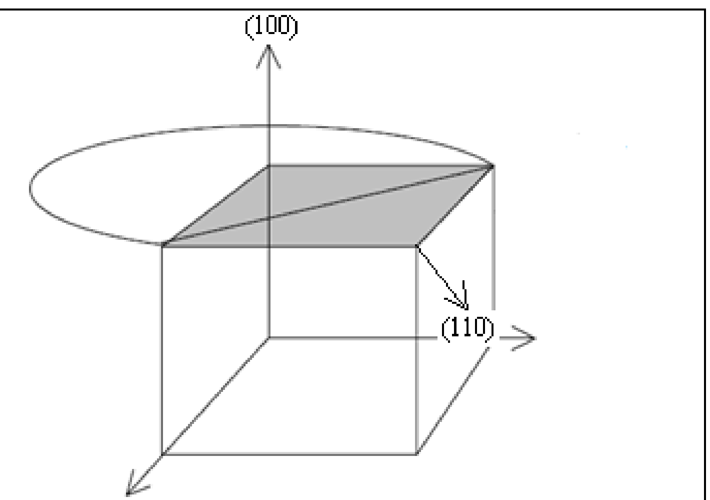
$$(100)\cdot(111) = |1|\left|\sqrt{3}\right|\cos\theta$$

$$\therefore 1+0+0 = \sqrt{3}\cos\theta$$

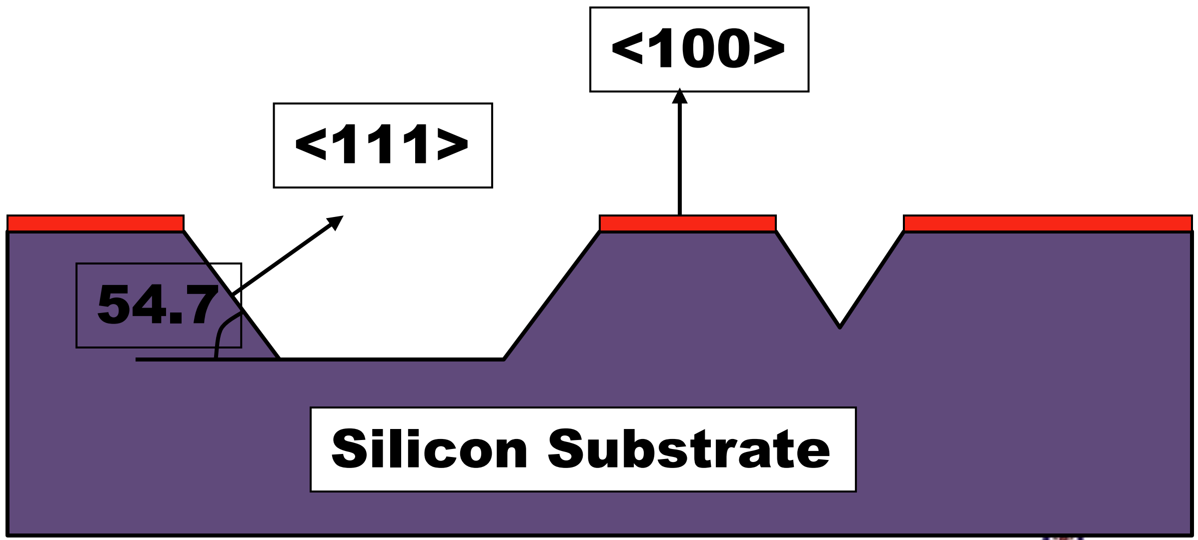
$$\theta = \pm 54.74^\circ$$

Anistropic Silicon Etching

- Anisotropic etchants have “direction dependent etch rates” in crystals
- Typically the etch rates are slower perpendicularly to the crystalline planes with the highest density, i.e. (111)
- Commonly used anisotropic etchants in silicon include Potasium Hydroxide (KOH), Tetramethyl Ammonium Hydroxide (TMAH), and Ethylene Diamine Pyrochatecol (EDP)



A <100> silicon wafer is cut so that one of the (100) planes defines the wafer surface, the vector normal to the surface is in the direction [100] and the flat is along direction [110]



Anistropic Silicon Etching

- Etch rate in different directions, (100) (110) or (111), depends on:
  - The chemical used for etching (etchant)
  - Temperature of the etchant.
  - Concentration of the etchant.

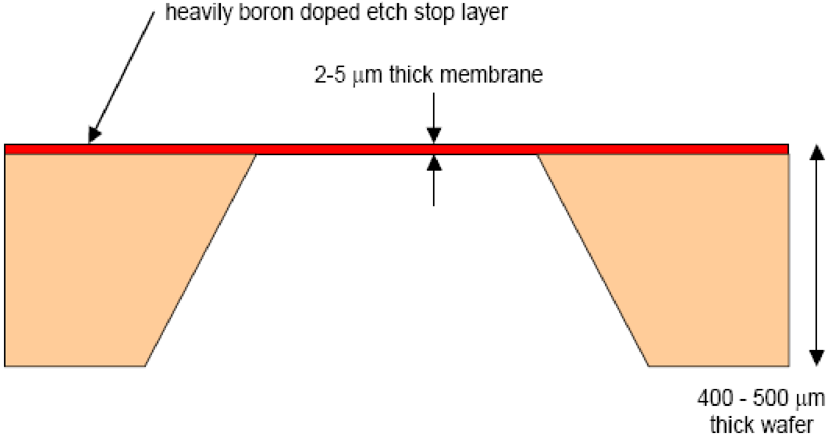
Alkaline anisotropic etchants: some main features of etchants

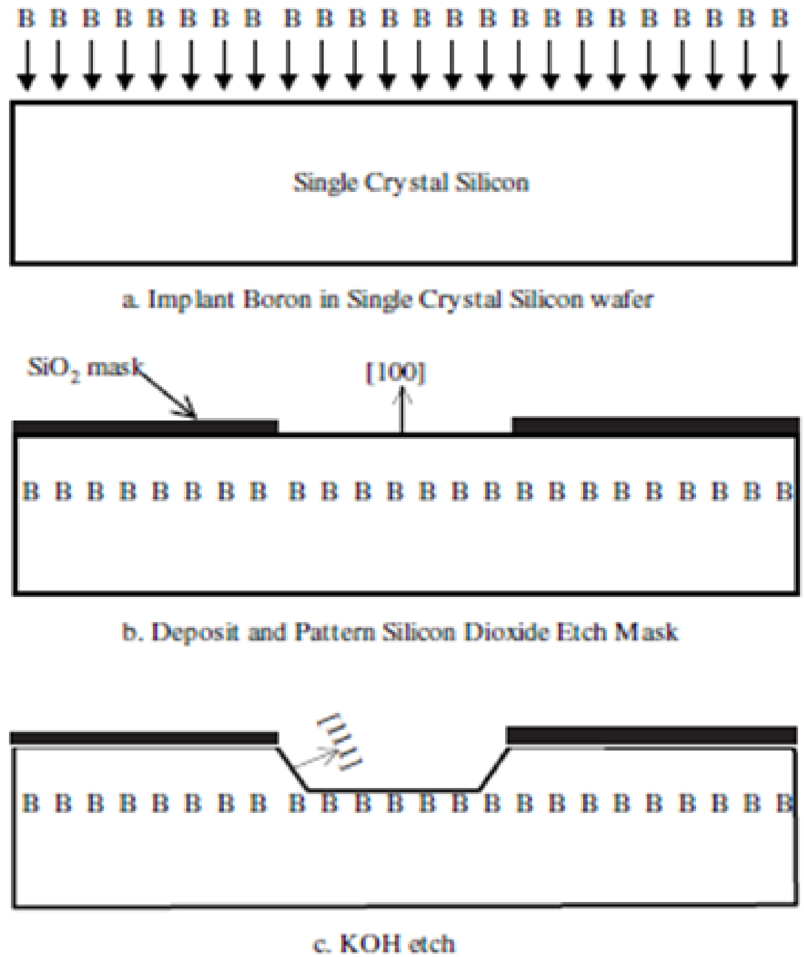
Etchant	KOH	TMAH	EDP
Rate (at 80 °C) µm/min	1	0.5	1 (at 115 °C)
Typical concentration	40%	25%	80%
Selectivity (100):(111)	200:1	30:1	35:1
Selectivity Si:SiO_2	200:1	2000:1	10 000:1
Selectivity Si:Si_3N_4	2000:1	2000:1	10 000:1

Good mask

Anistropic Etching Stop

- Wet etching can be stopped by:
  - Time controlled etch process
  - Inserting etch stop layer

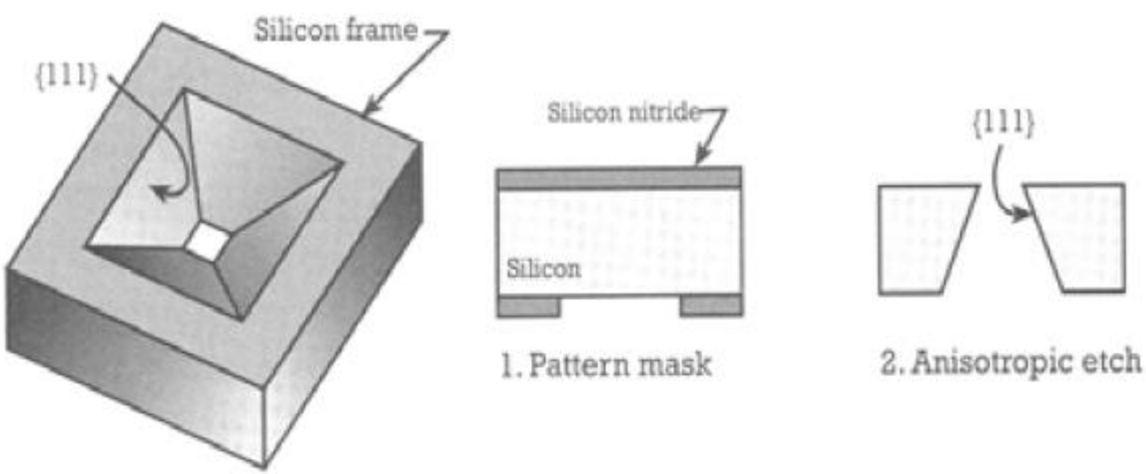


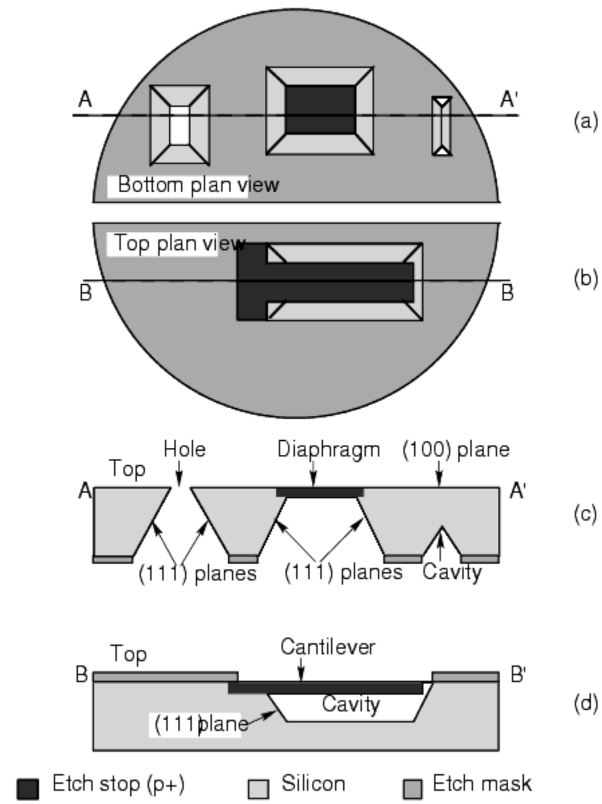


Boron-doped silicon used to form features or an etch stop.

Anistropic Etching

- Different bulk michromachined structures



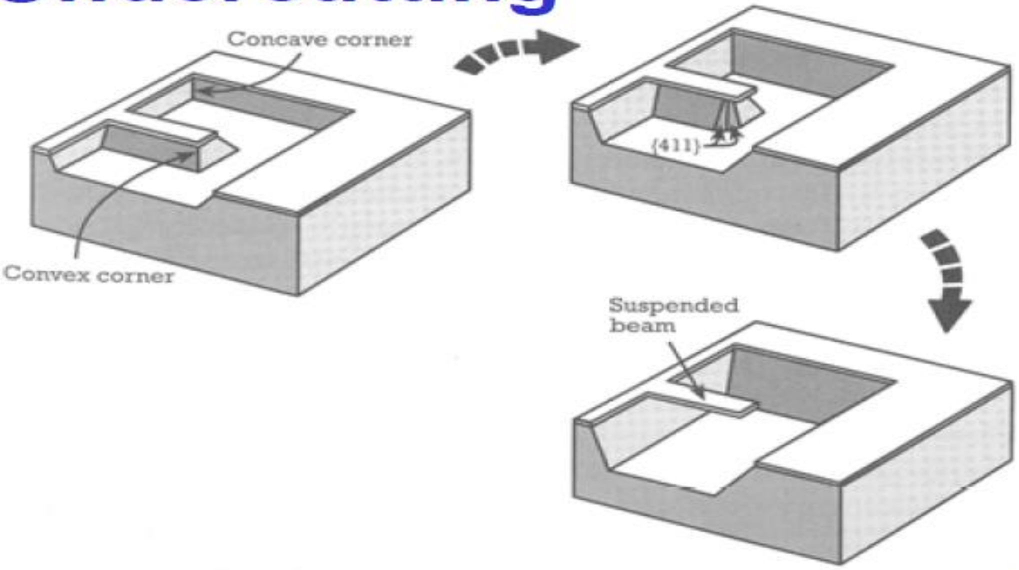


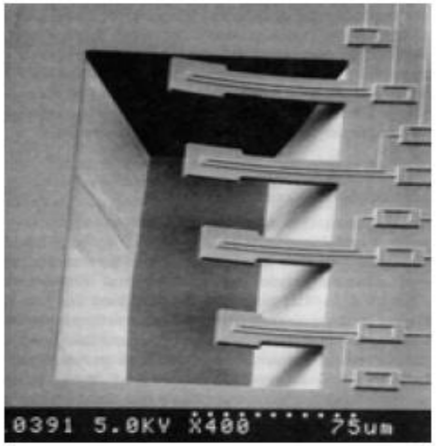
Bulk micromachined features realized by anisotropic etching of silicon. (a) Bottom plan view of etched wafer with cavities, diaphragms, and holes; (b) top plan view of an anisotropically etched wafer showing the fabrication of a cantilever beam using etch stop layer; (c) cross section, AA', showing the hole, diaphragm, and cavity of (a); and (d) cross section, BB', showing the cantilever beam of (b).

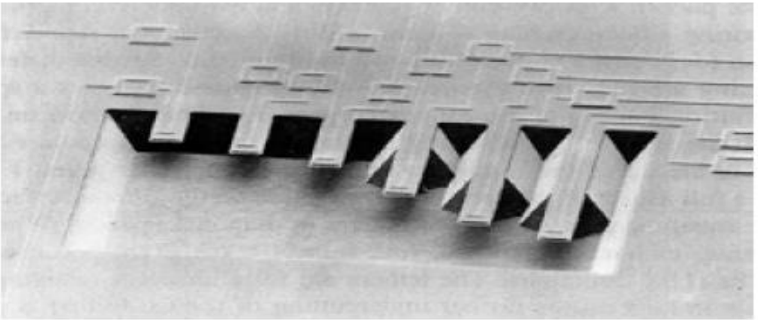
Anistropic Etching

Undercutting

- Convex corners bounded by {111} planes are attacked

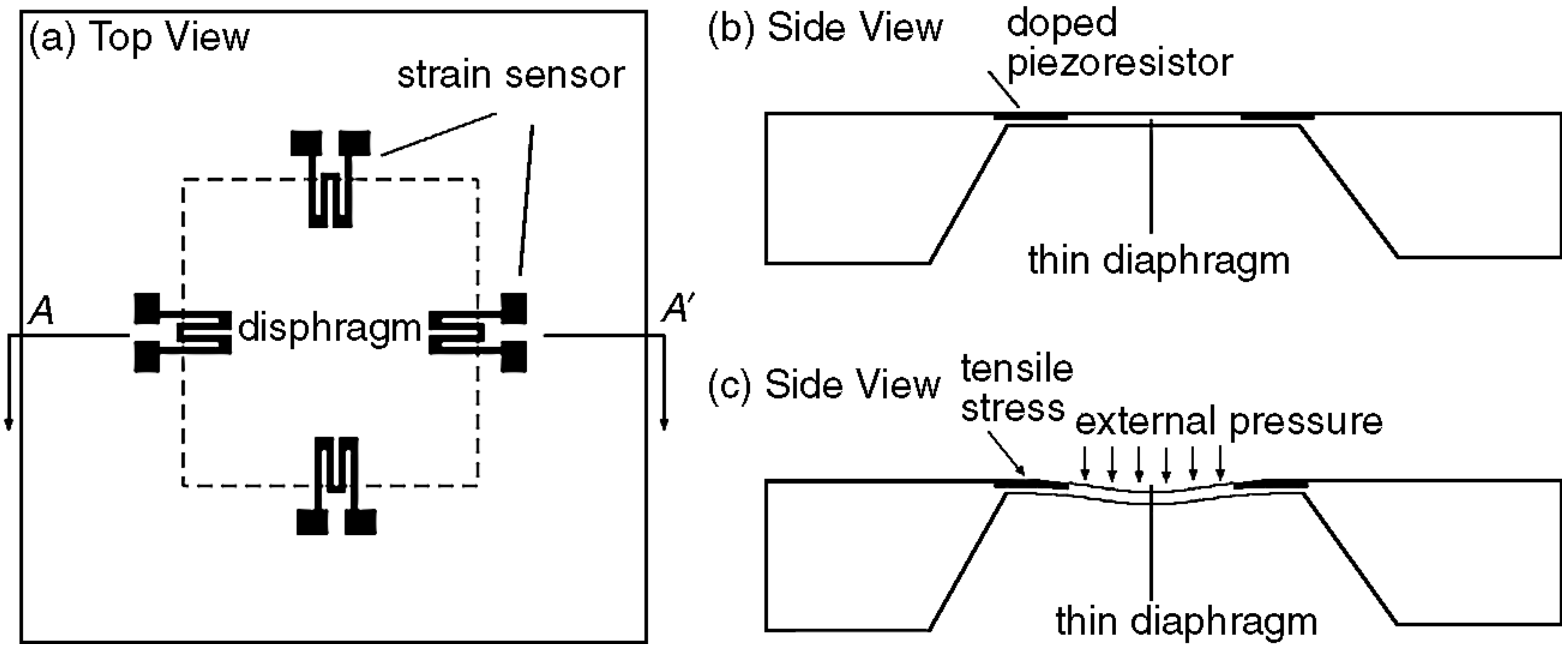






Bulk Micromachining, example

MEMS based pressure sensor:



Bulk Micromachining, example

MEMS based pressure sensor:

The fabrication process for a pressure sensor using plain silicon wafer as the substrate is shown in this figure.
In the first step, the wafer is selectively doped with boron or phosphorous atoms to create
piezoresistors on the front side (a). The wafer is then passivated with a thermally grown silicon dioxide thin film (b). In the ensuing step, the silicon dioxide film on the backside is patterned and selectively etched to expose the silicon (c). The exposed silicon material will be etched when the wafer is immersed in an anisotropic silicon etchant (d). In order to form the silicon diaphragm with desired thickness,