Lecture 3

Microfabrication
– Wafer-Level Processes (Ⅰ)

- Overviews
- Wafer-Level Processes
  - Substrates
    - Silicon Wafers
      - Planes of Silicon
      - Cubic Unit Cell of Silicon
      - Czochralski Method and Float Zone
      - Quality of Silicon Crystals
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Overview

Microfabrication

- Based on planar technologies: constructing the electronic devices and MEMS components on substrates that are in the form of initially flat wafers.
- The microelectronics industry has made huge investments to develop wafer-based process technologies, there is a correspondingly huge advantage for MEMS designers to exploit these same process steps, or variants based on those steps.

Microfabrication methods

- Wafer-level processes including wafer bonding.
- Pattern transfer including isotropic and anisotropic etching.

Surface micromachining and Bulk micromachining

Substrates

- **Planar substrates :**

  Single-crystal silicon, single-crystal quartz, glass, and fused (amorphous) quartz.
- Gallium arsenide wafer for optoelectronic devices.

- It is not uncommon for a few 25-wafers runs of 100 mm wafers to supply a full year's production of a single product.
- Less pressure to go to larger wafer sizes.

Silicon Wafers

- 마이크로머시닝 연구나 생산하는 많은 그룹은 100 mm(4인치)나 150 mm(6인치) 실리콘 웨이퍼를 사용한다.
- 100 mm 웨이퍼의 두께는 대개 500 ㎛ 정도이다.
- "flats" : 결정면의 방향을 나타내는 표식.
- 웨이퍼의 크기 (또는 III-V 족 웨이퍼)에 따라 flats이 다른 의미를 갖는다.

Notation for Miller indices:

(i j k)	a specific crystal plane or face
{i j k}	a family of equivalent planes
[i j k]	a specific direction of a unit vector
<i j k>	a family of equivalent directions

Table showing standard notation for Miller indices.

Planes on Cube

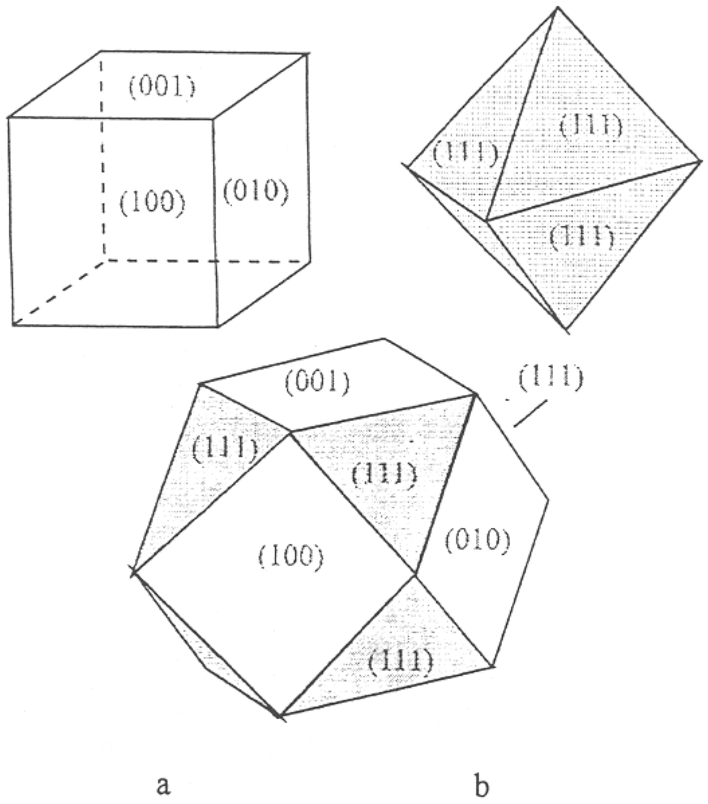


Fig. II.3.5. Crystals dominated by:
a. {001} faces
b. {111} faces
c. {111} and {001} faces

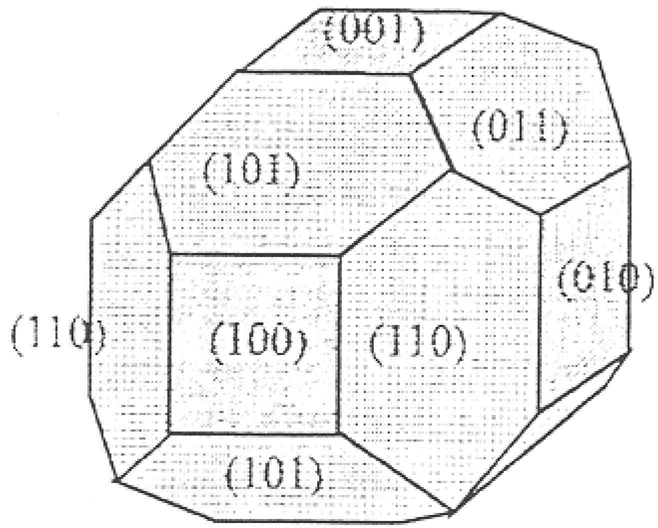


Fig. II.3.6. {100} and {110} faces on the cube

Planes of Silicon

$\mathbf{A}\cdot\mathbf{B}=|\mathbf{A}||\mathbf{B}|\cos\phi$

E.g. the angle between (111) and (001) is

$$\arccos\left\{\frac{(111).(001)}{|(111)|\times|(001)|}\right\} = \arccos\left(\frac{1}{\sqrt{3}\times 1}\right) = 54.74°$$

arccos{(111)·(001)/|(111)|x|(001)|} = arccos{1/Ö3x1} = 54.74°.

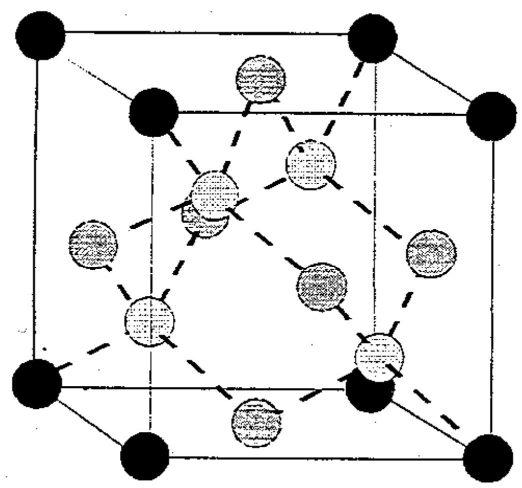


Fig.II.3.1. Unit cell of the diamond lattice (from [5],

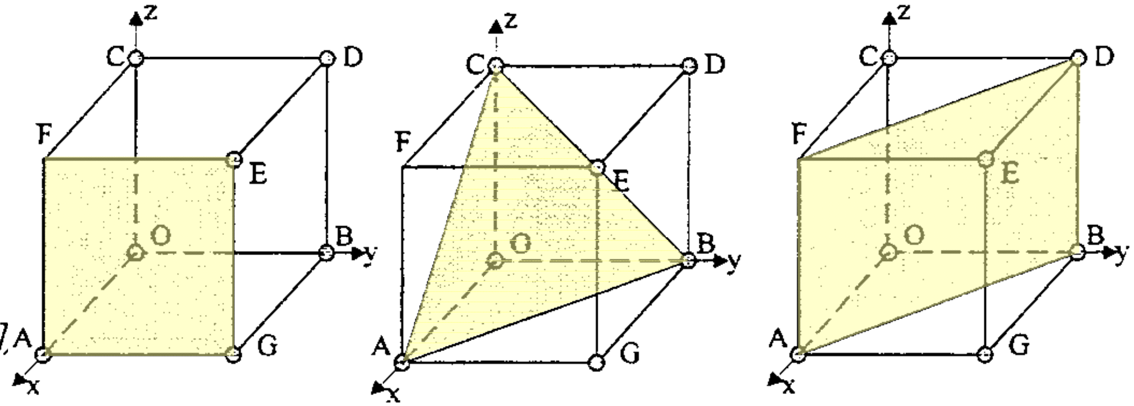
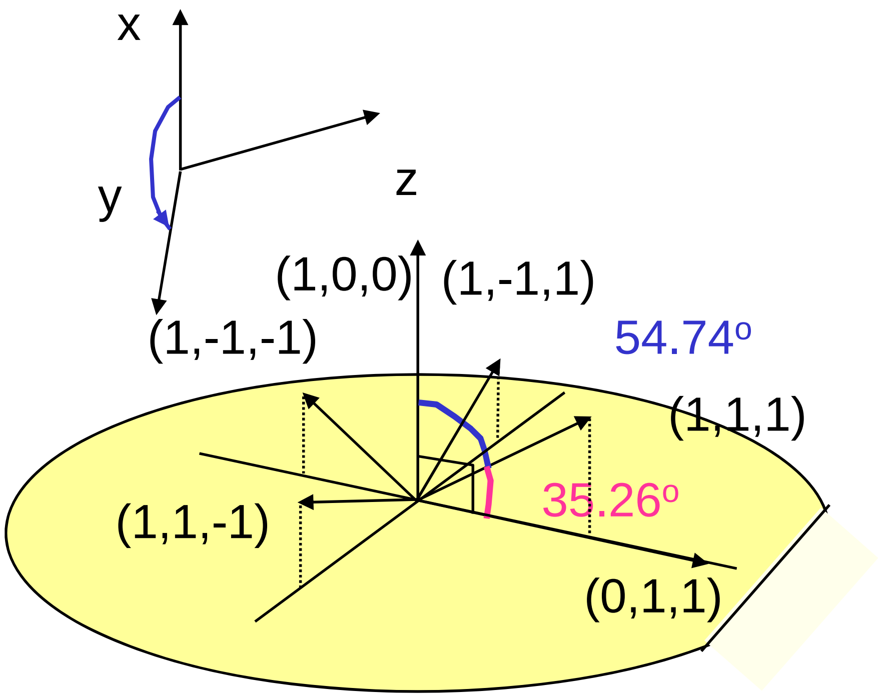
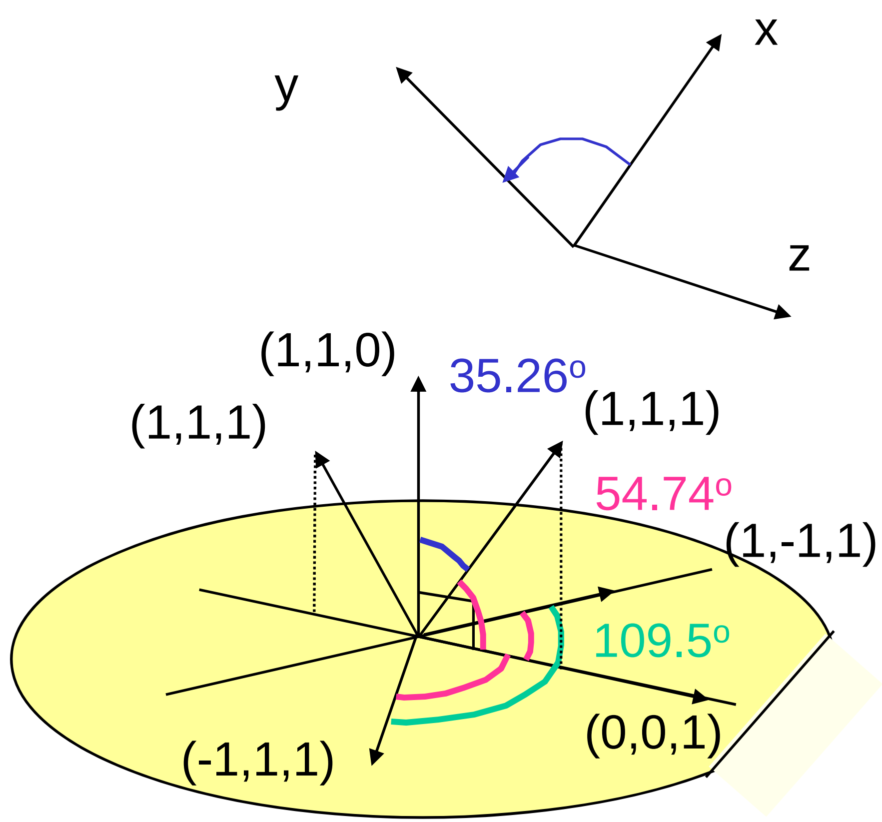


Fig. II.3.2. The family of planes AFEG (100), ABC (111) and ABDF (110) in cubic lattices

Planes of Wafers



(111) planes in the (100) oriented wafer



(111) planes in the (110) oriented wafer

Typical Silicon Wafer Types

- MOS technologies: (100) wafers because of the low defect density that can be achieved at the interface between silicon and silicon dioxide.
- Bipolar-transistor technologies: historically (111) wafers, now (100) wafers.
- Selective-etching applications: (110) wafers

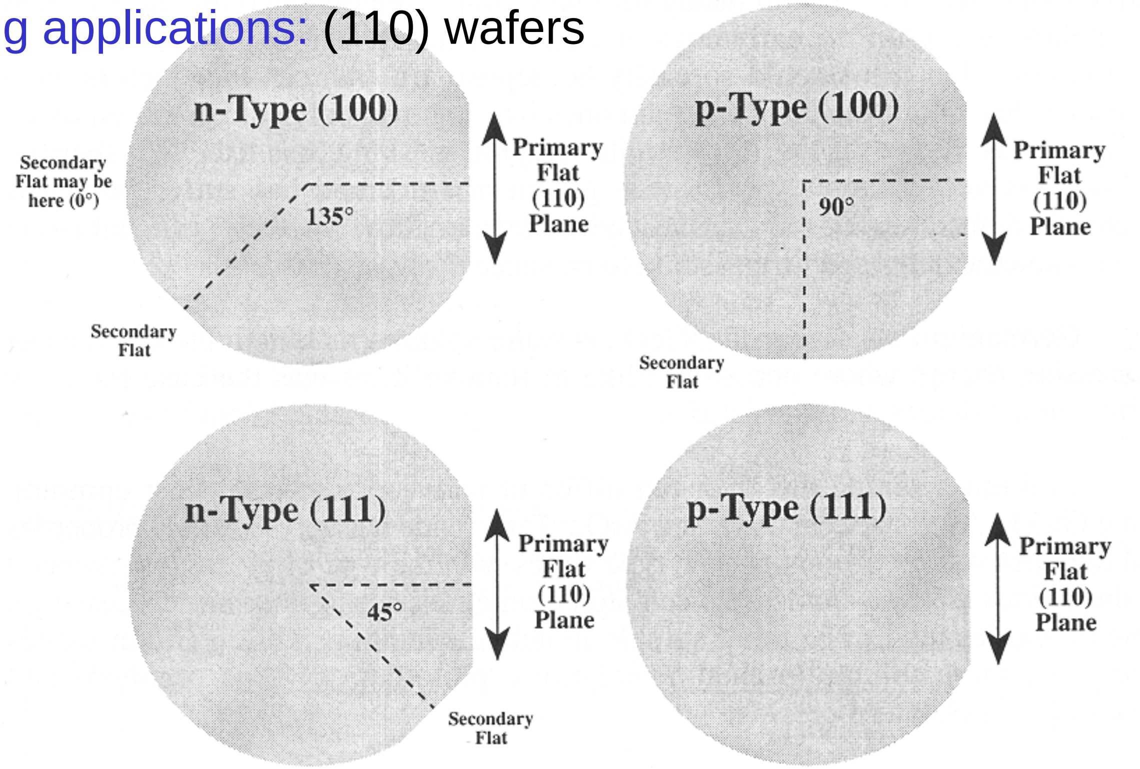
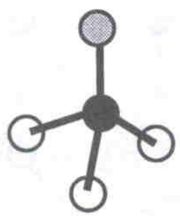


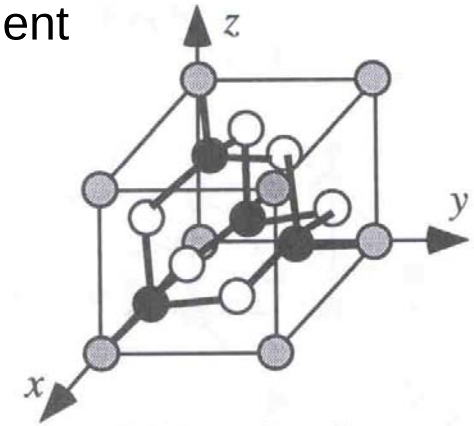
Illustration of coded "flats" as typically used on 4 in. wafers to help identify them (the configuration shown at upper left is the most common). (SEMI standard.)

Cubic Unit Cell of Silicon

- Each atom is identical, but shading is used to clarify their positions.
- Every atom is tetrahedrally bonded to four neighbors.
- The illustrations on the left shows an interior atom bound to one corner atom and three face-center atoms.
- But in fact, since every atom is identical, every atom has the exact same bonding structure and local environment



Tetrahedral bonding of silicon atoms



Cubic unit cell of silicon

The tetrahedral bonding of each atom in the silicon unit cell. For clarity, atoms at the corners of the cubic unit cell are shaded, those in the center of the faces are white, and those interior atoms that are displaced by ¼ of the body diagonal from either a face or corner atom are shaded black.

Anisotropic Etching Characteristics

- A (111) oriented surface has the highest density of atoms per unit area.
- Each atom in a (111) surface is tetrahedrally bonded to three atoms beneath the surface, leaving only one bond potentially “dangling” at the free surface.
- In contrast, atoms on (110) or (100) surfaces are tetrahedrally bonded to only two atoms beneath the surface, and have two potential “dangling” bonds.
- The fact that silicon can be etched anisotropically by certain etchants is attributed, in part, to this difference in bonding of the atoms on the different crystal surfaces.

Czochralski Method and Float Zone

- **CZ(Czochralski) method**
- A small seed crystal with a preselected orientation is inserted into a heated crucible containing a highly purified melt.
- The seed is gradually pulled out of the melt while the crucible containing the melt is rotated.
- The melt temperature and pulling speed are controlled to balance crystal growth rate with pulling rate.
- **FZ(float zone)**
- Starting with a polysilicon rod, a radio-frequency heater creates a local melted zone that is dragged from one end of the rod to the other.
- To start the growth, a seed crystal can be used at one end of the rod assembly.

Quality of Silicon Crystals

- **Quality of Silicon Crystals**
- Specified in terms of their chemical impurities and structural imperfections such as
  1. Point defects: atoms missing or out of place
  2. Dislocations: places where the crystal planes don’t fit perfectly together because of either extra planes of atoms or imperfect stacking of the planes into a screw-like assembly.

CZ and FZ Wafers

- **CZ Wafers**
- Higher amounts of residual chemical impurities, such as carbon, oxygen and heavy metals, compared to FZ wafers.
- Because the molten zone tends to carry impurities with it as it sweeps from one end of the rod to the other.
- Oxygen as an impurity has some benefit in certain microelectronic device fabrication sequences, as the presence of oxygen promotes the migration of point defects during high-temperature process steps away from the surfaces where devices fabricated.
- **FZ Wafers**
- The higher purity FZ wafers may be required in devices where heavy-metal contamination must be minimized.
- Dislocation density is also affected by high-temperature processing.
- Crystals can now be grown virtually free of the most disruptive forms of dislocations.

Specifications of CZ Silicon Wafers

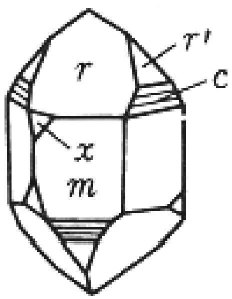
Property	Value
Diameter	up to 300mm
Thickness	500 μm *for* 100 mm, 675 μm *for* 150 mm
Wafer bow	$\leq 25\,\mu m$
Wafer taper	$\leq 15\,\mu m$
Oxygen	5 – 25 ppm
Carbon	1 - 5 ppm
Heavy metals	$\leq$ 1 ppb

Quartz Wafers

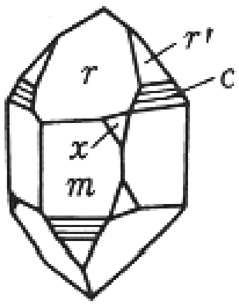
- Hexagonal material, with the z-axis conventionally identified as the hexagonal axis.
- Piezoelectric properties.
- Some of the basic orientations (or “cuts”), such as X-cut and Z-cut quartz, refer to the crystalline axes normal to the plane of the wafer.
- But others, such as AT-cut quartz, refers to off-axis orientations that are selected for specific temperature insensitivities of their piezoelectric or mechanical properties.

Quartz Crystal

- Quartz(Single-crystal SiO_2) : hexagonal lattice
- 선광성(旋光性), 결정형의 차이에 따라 左水晶, 右水晶으로 나뉜다.
- 573 °C에서 α-quartz에서 β-quartz로 변환한다.
- 압전성, 절연성이 좋다.



左水晶



右水晶

Table 1. Some properties of quartz.

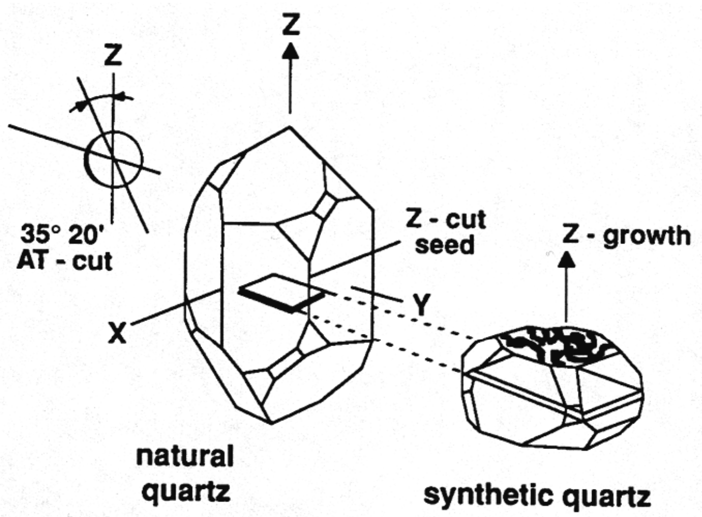
Physical property	Value $\parallel Z$	Value $\perp Z$
Thermal conductivity (cal cm^{-1} s^{-1} $°C^{-1}$)	29×10^{-3}	16×10^{-3}
Dielectric constant	4.6	4.5
Thermal expansion coefficient ($°C^{-1}$)	7.1×10^{-6}	13.2×10^{-6}
Electrical resistivity (Ω cm)	$0.1 \times 10^{+15}$ (ionic)	$20 \times 10^{+15}$ (electronic)
Young's modulus (N m^{-2})	$9.7 \times 10^{+10}$	$7.6 \times 10^{+10}$
Density	2.65	

Table Mechanical properties of quartz and silicon

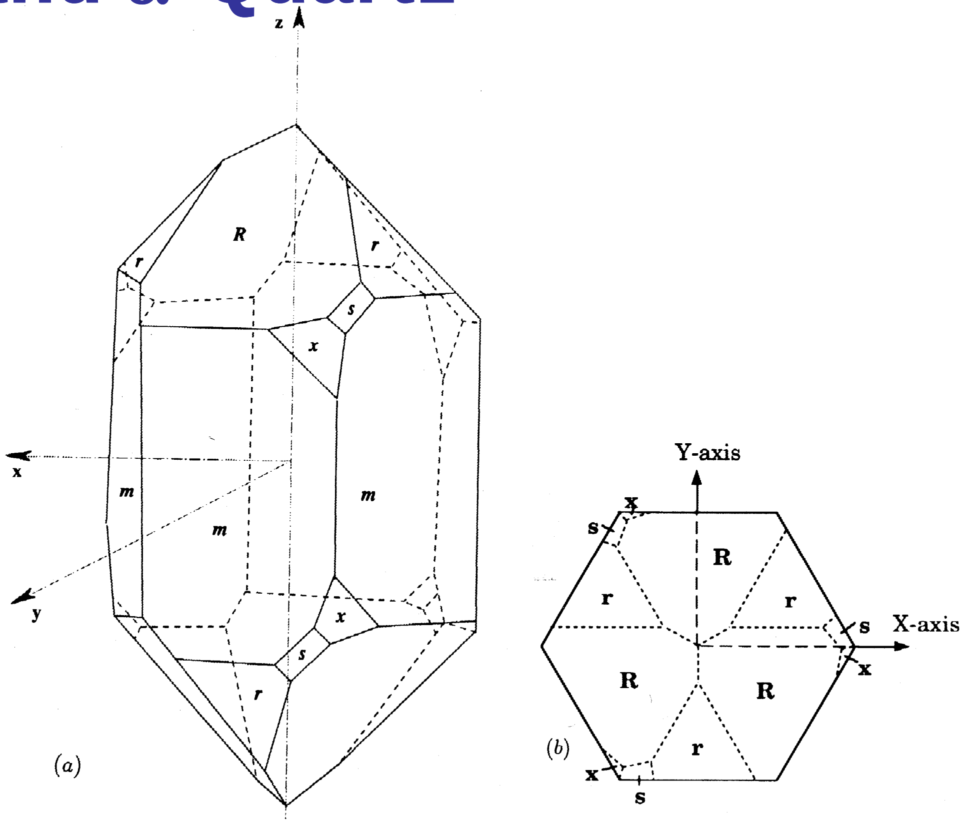
Property	Quartz	Silicon
Density	2.65	2.32
Young's modulus(10^{10} Pa)	(001) : 10 ⊥(001) : 8	(100) : 13 (110) : 17 (111) : 19
Bending mechanical strength (10^7 Pa)	9	7-20

Right-Hand α-Quartz

- Z축 : 3중 대칭.
- X축 : 2중 대칭 (electrical axis), 3개.
- Z축 식각 속도가 빠르기 때문에
  Z-cut wafer를 많이 씀.



Quartz axes defined X : electrical axis : Y : mechanical axis.



Right-hand α-quartz (a) and its projection on the XY plane (b) The crystal structure of α-quartz has a trigonal unit cell with dimensions a = 4.904 and c = 5.394 Å. Only one of the three possible X and Y axes is shown in the figures. On a Z-cut wafer (XY surface), one of the m planes is aligned with an edge of the quadratic quartz wafer.

Wafer Cleaning – RCA Cleans

1. Removal of all organic coatings in a strong oxidant, such as a 7:3 mixture of concentrated sulfuric acid and hydrogen peroxide (“pirhana”).
2. Organic residues are removed in a 5:1:1 mixture of water, hydrogen peroxide, and ammonium hydroxide.
   - Because this step can grow a thin oxide on silicon, it is necessary to insert a dilute hydrofluoric acid etch remove this oxide when cleaning a bare silicon.
   - The HF dip is omitted when cleaning wafers that have intentional oxide on them.
3. Finally, ionic contaminants are removed with 6:1:1 mixture of water, hydrofluoric acid, and hydrogen peroxide.

- Note that the cleaning solutions do not have metallic positively charged ions.
- These RCA cleans must be performed before every high-temperature step (oxidation, diffusion, or chemical vapor deposition).