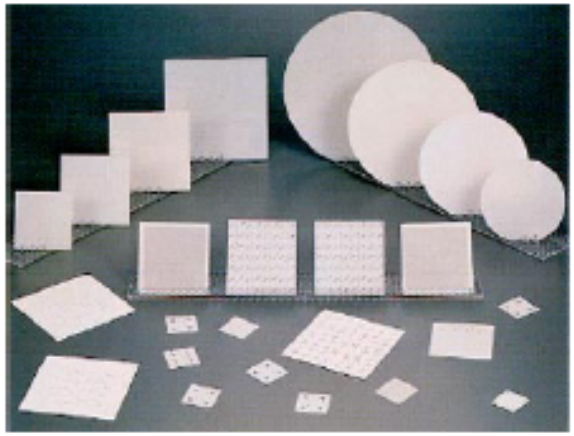
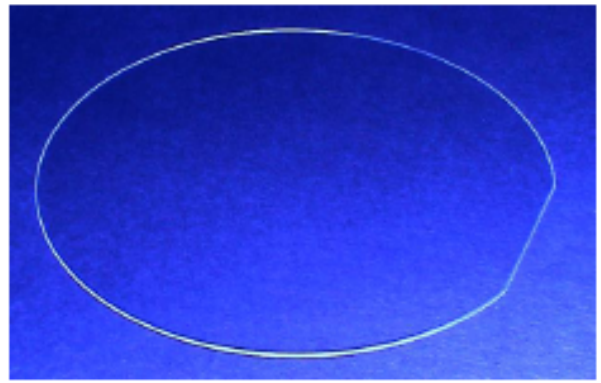
MEMS常用材料(1)

- Substrates
  - Si, Ge, GaAs, InP, glasses, metals, ceramics, polymers
  - Si → dominant material (Why? Possible to integrate circuits with MEMS devices)





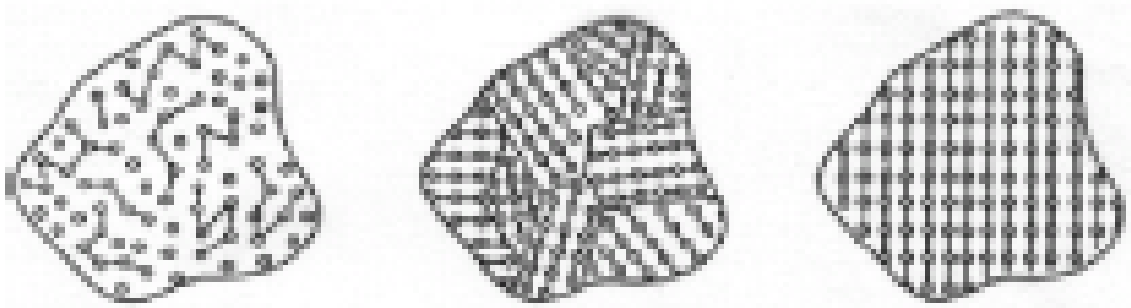
- Film materials
  - Si, poly-Si, a-Si, SiN, doped SiO_2(PSG, BPSG), undoped SiO_2, SiC, ...
  - Elemental metals and metal alloys (Ni, Cu, Au, Ag, NiFe, NiCo, NiTi, ...)
  - Polymers (PR, epoxy, polyimide, PDMS, Paralyne, PTFE, PC, COC, ...)
  - Ceramics (Al_2O_3, PZT, ...)

MEMS常用材料(2)

- Ranges of materials
  - Single crystal silicon, Polysilicon, Silicon Dioxide, Silicon Nitride, Metal, Silicon Carbide, Germanium-based materials, Piezoelectric materials, Diamond, III-V Materials.
- Fabrication Methods
  - Crystallization
  - Oxidation
  - Film Deposition
    - Physical Vapor Deposition (PVD)
    - Chemical Vapor Deposition (CVD)
    - Liquid Phase Deposition

矽晶體結構

- Crystal Structure
  - Amorphous（非晶體）: No recognizable lump range order
  - Polycrystalline（多晶體）: Completely ordered in grains
  - Crystalline（晶體）: Entire solid is made up of atoms in an orderly array

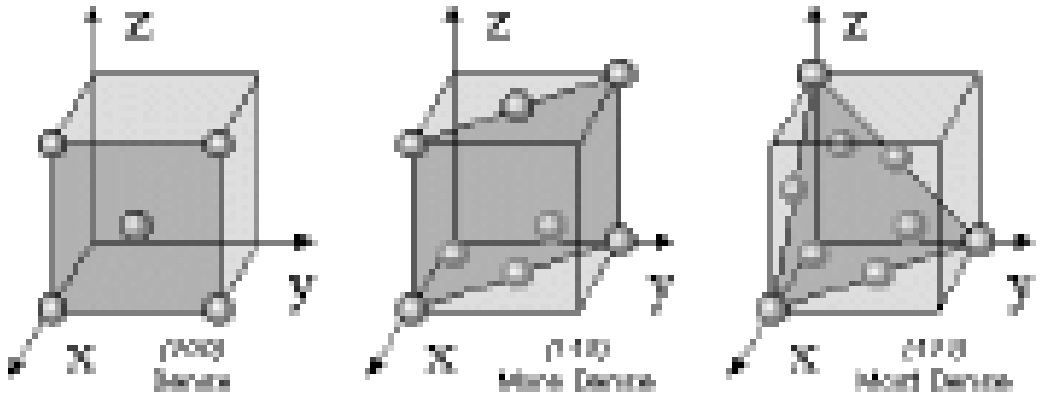


(a) Amorphous (b) Polycrystalline (c) Crystalline

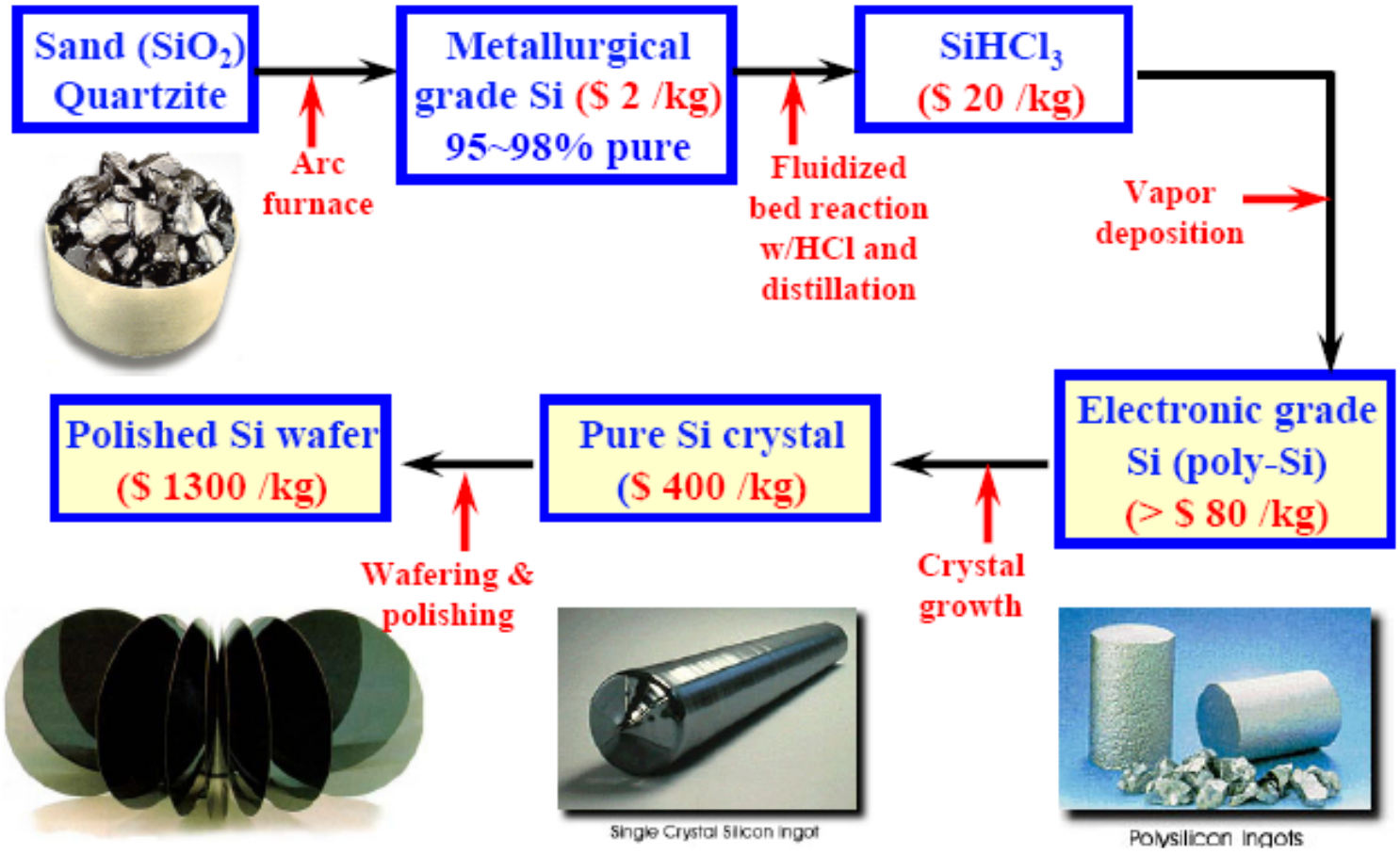
密勒指標(Miller Index)

- 若將密勒指標配合不同括號使用，則代表不同的集合
  - (hkl)：小括號代表單一晶面，$(\bar{1}00)$代表與X軸截距為負的平面
  - {hkl}：代表具相等對稱平面的集合{100}代表以下六平面的集合
    (100),(010),(001),$(\bar{1}00)$,$(0\bar{1}0)$,$(00\bar{1})$
  - [hkl]：代表(hkl)平面的法向量，如[100]垂直於(100)平面
  - <hkl>：代表等效方向的集合

Miller indices identify crystal planes from the unit cell:

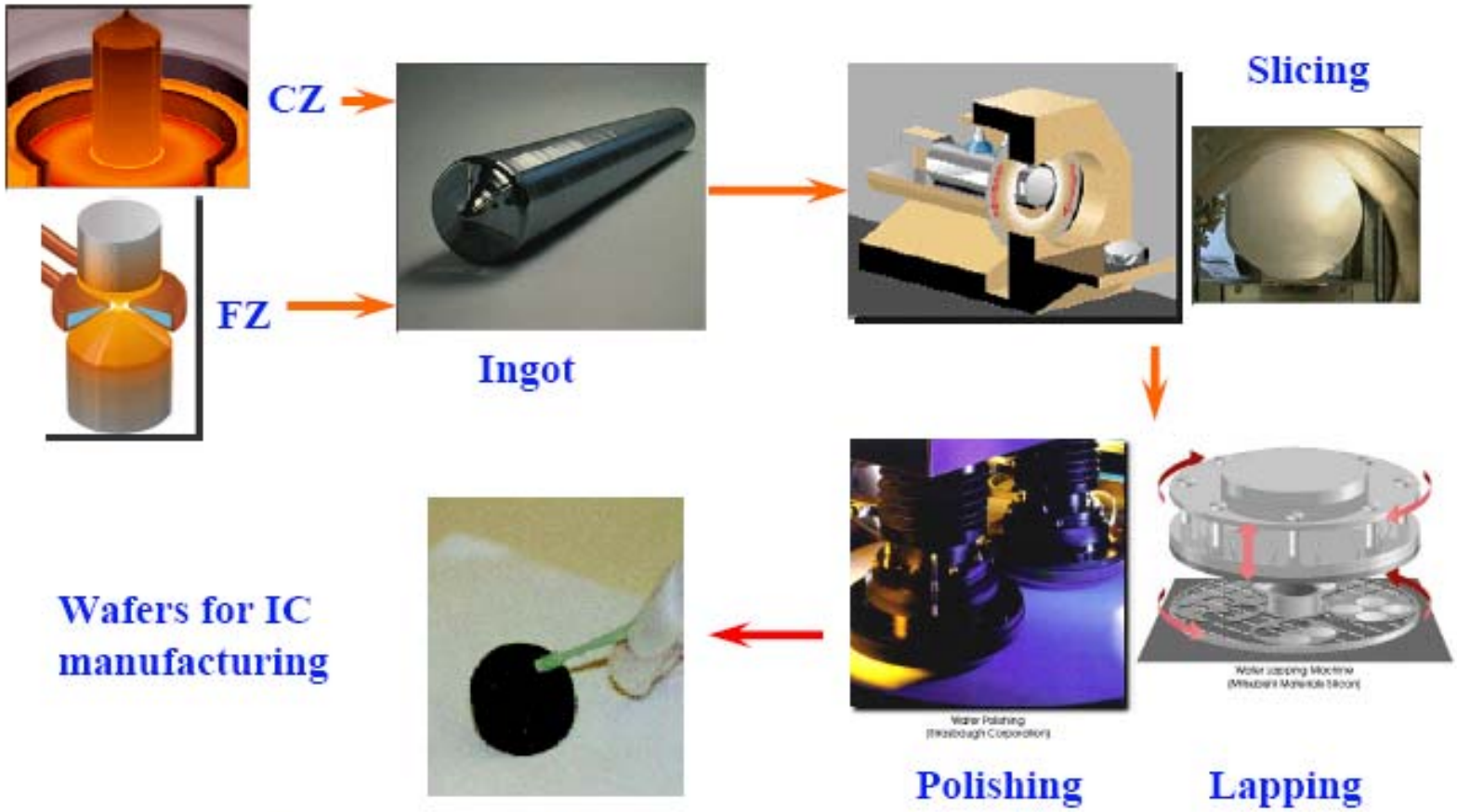


矽晶圓（Silicon Wafer)製程(1)



Source: http://www.fullman.com/semiconductors/semiconductors.html

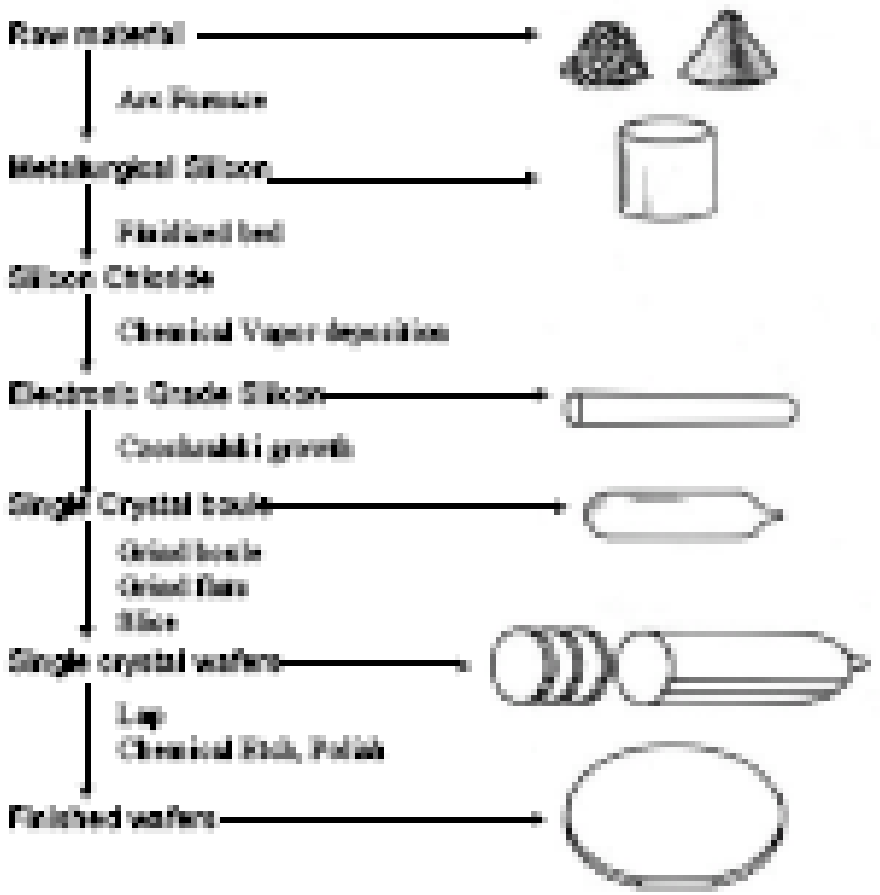
矽晶圓（Silicon Wafer)製程(2)



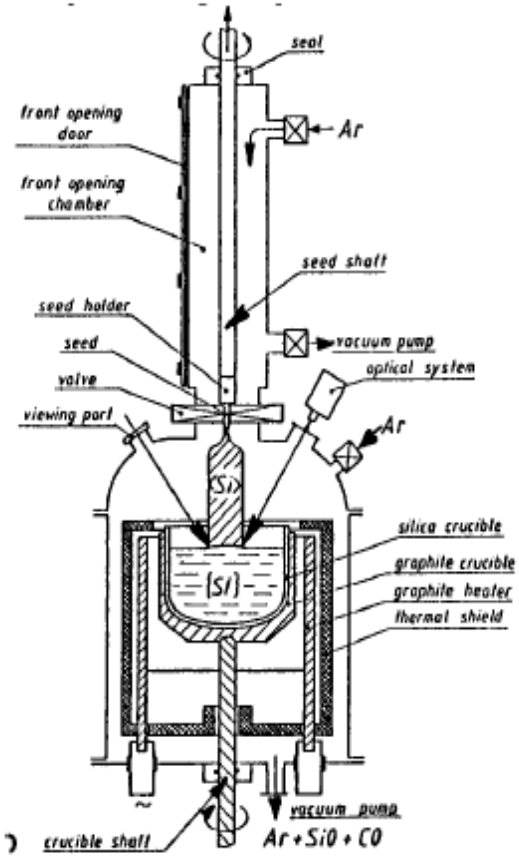
Sources: http://www.fullman.com/semiconductors/semiconductors.html
http://www.msil.ab.psiweb.com/english/msilhist0-e.html

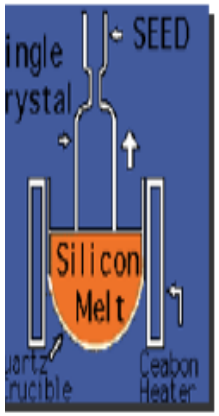
矽晶圓（Silicon Wafer)製程(3)

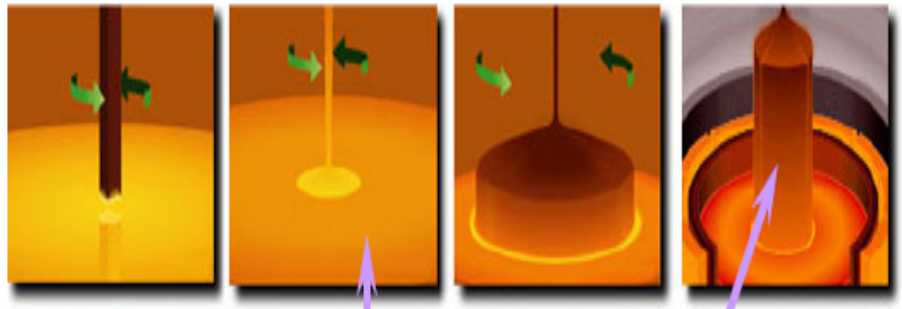
- 矽礦冶煉
- 精純
- 拉晶
- 切邊、切片
- 研拋



柴可斯基拉晶法(CZ法)







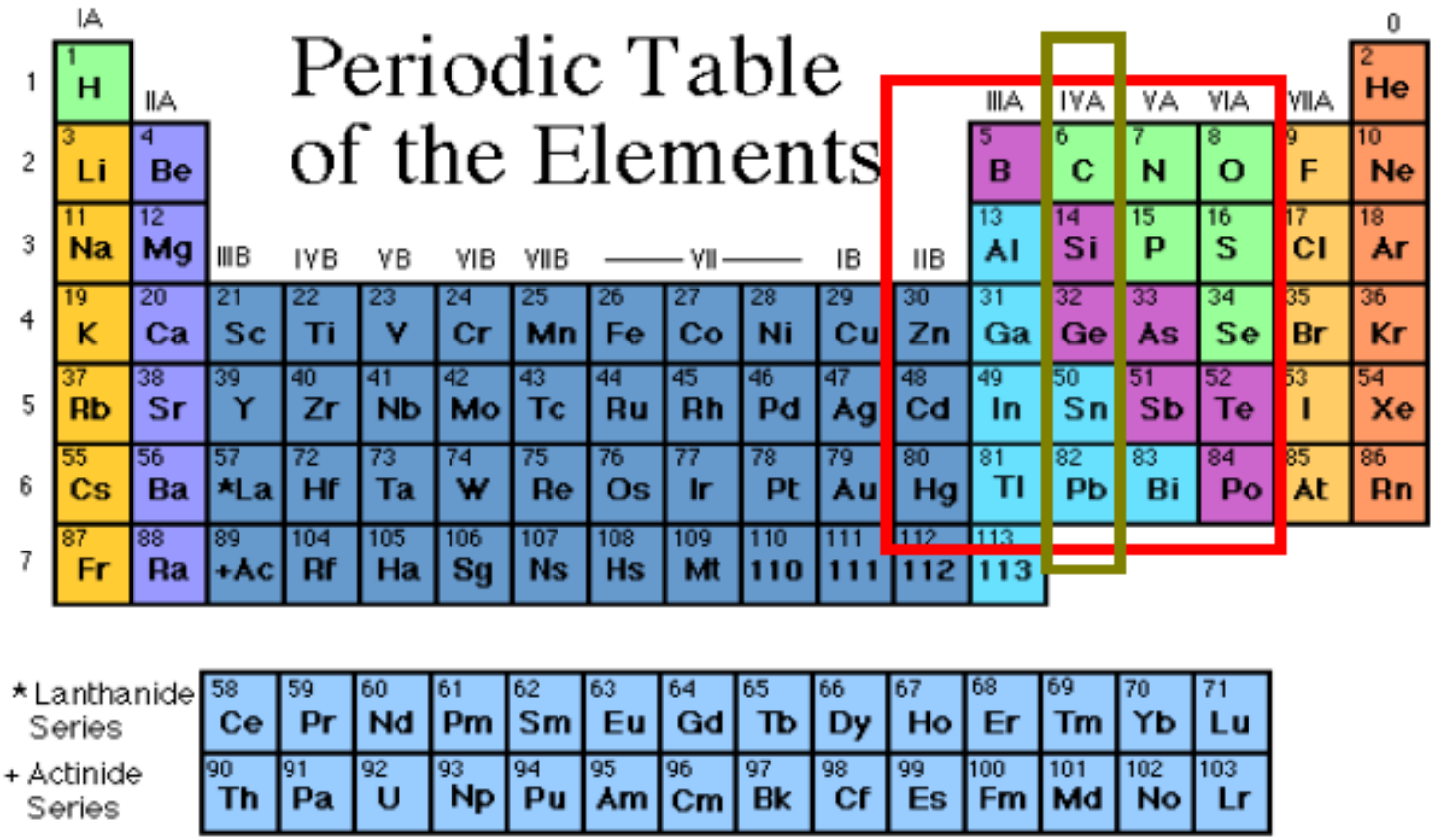
CZ

Poly-Si

Single crystal Si

Sources: http://www.fullman.com/semiconductors/semiconductors.html
http://www.msil.ab.psiweb.com/english/msilhist0-e.html

化學週期表



Source: http://www.pmel.org/HandBook/PeriodicTable/periodic.htm

單晶矽材料特性(1)

- General material properties of Si
  - Crystal structure: Diamond
  - Number of atoms in 1 cm^3: 5 x 10^{22}
  - Density: 2.329 g/cm^3
  - Lattice constant: 5.431 Å
  - Atomic weight: 28.09
- Electrical properties
  - Dielectric constant: 11.9
  - Electron affinity: 4.05 eV
  - Energy band gap: 1.12 eV
  - Intrinsic carrier concentration: 1.45 x 10^{10} cm^{-3}
  - Electron mobility ≈ 1,500 cm^2/V-s.
  - Hole mobility ≈ 450 cm^2/V-s.
- Optical properties
  - Index of refraction: 3.42
- Thermal properties
  - Melting point: 1415 °C
  - Thermal conductivity: 157 W/m-K
  - Thermal expansion coefficient: 2.33 ppm/K
- Mechanical properties
  - Young's modulus in {111}: 190 GPa
  - Young's modulus in {100}: 130 GPa
  - Poisson ratio in {100}: 0.28
  - Yield strength: 7 GPa

Si has no fatigue below 800°C ➔ good for high thermal cyclic loads applications
Si is very brittle.

單晶矽材料特性(2)

原子序	14	密度	2.33 克／毫升
原子量	28.09	比熱	0.181 卡／克・℃
單位體積原子數	5×10^{22}	熔化熱	9450 卡／克分子
顏色	銀白色	氣化熱	44086 卡／克分子（25℃）
晶體結構	金剛石晶格	熱導率	0.20 卡／秒・厘米・℃（25℃）
硬度	莫氏硬度 6.25	延展性	脆
折射率	3.87	電容率	12
熔點	1412℃	沸點	2600℃

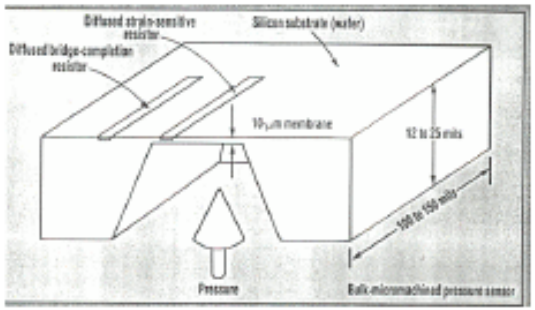
單晶矽材料與其他材料特性比較

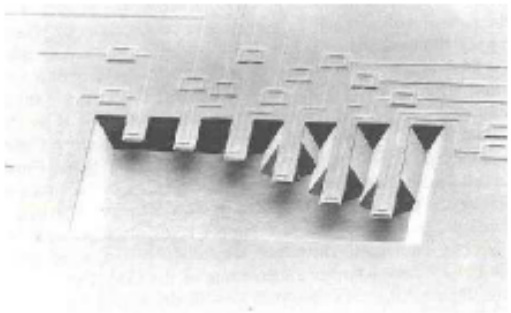
Material	Yield Strength (10^9 N/m^2)	Knoop Hardness (kg/mm^2)	Young's Modulus (GPa)	Density (g/cm^3)	Thermal Conductivity (W/cm•K)	Thermal Expansion Coefficient (10^6/K)
*Diamond	53	7,000	1,035	3.5	20	1
*SiC	21	2,480	700	3.2	3.5	3.3
*TiC	20	2,470	497	4.9	3.3	6.4
*Al_2O_3	15.4	2,100	530	4	0.5	5.4
*Si_3N_4	14	3,486	385	3.1	0.19	0.8
*Iron	12.6	400	196	7.8	0.803	12
SiO_2 (fibers)	8.4	820	73	2.5	0.014	0.55
*Si	7	850	190	2.3	1.57	2.33
Steel (max strength)	4.2	1,500	210	7.9	0.97	12
W	4	485	410	19.3	1.78	4.5
Stainless Steel	2.1	660	200	7.9	0.329	17.3
Mo	2.1	275	343	10.3	1.38	5
Al	0.17	130	70	2.7	2.36	25

基板(Substrate)的特性

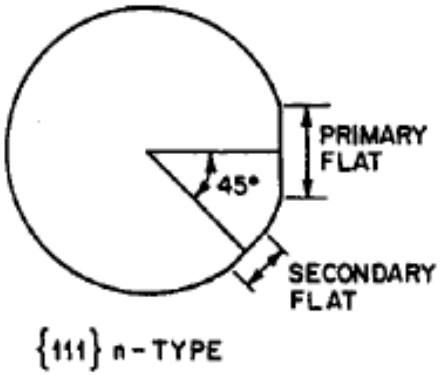
Substrate	Cost	Metallization	Machinability
Ceramic	Med.	Fair	Poor
Plastic	Low	Poor	Fair
Silicon	High	Good	Very good
Glass	Low	Good	Poor

- Si is expensive, but the cost can be offset by the small feature size.
- Vast majority of bulk micromachining was done in single crystal Si.

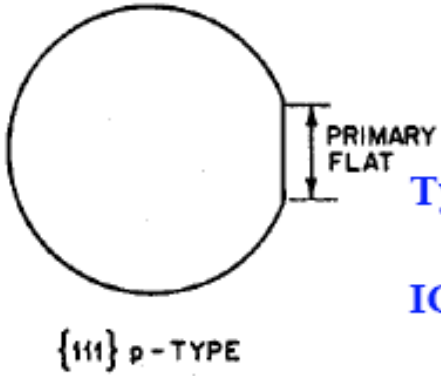




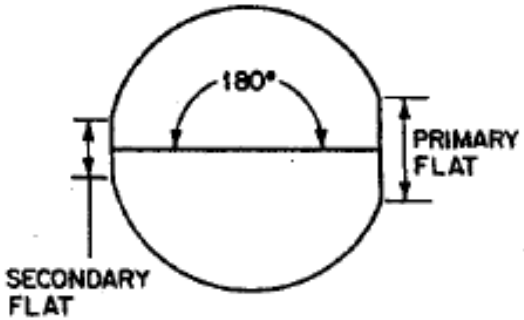
晶圓主平面與次平面



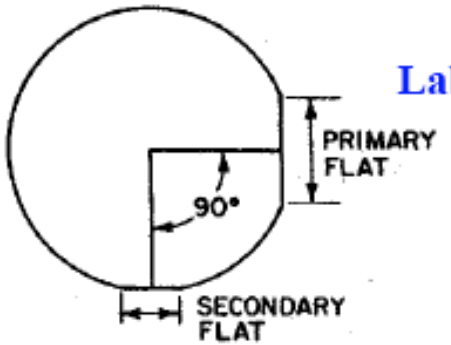
{111} n-TYPE



{111} p-TYPE



{100} n-TYPE



{100} p-TYPE

Typically used Si wafers

IC industry: 8~12" dia. {100}

MEMS industry: 4~8" dia.
{100} & {110}

Labs: 2~6" in dia.
{100} & {110}

晶圓方向

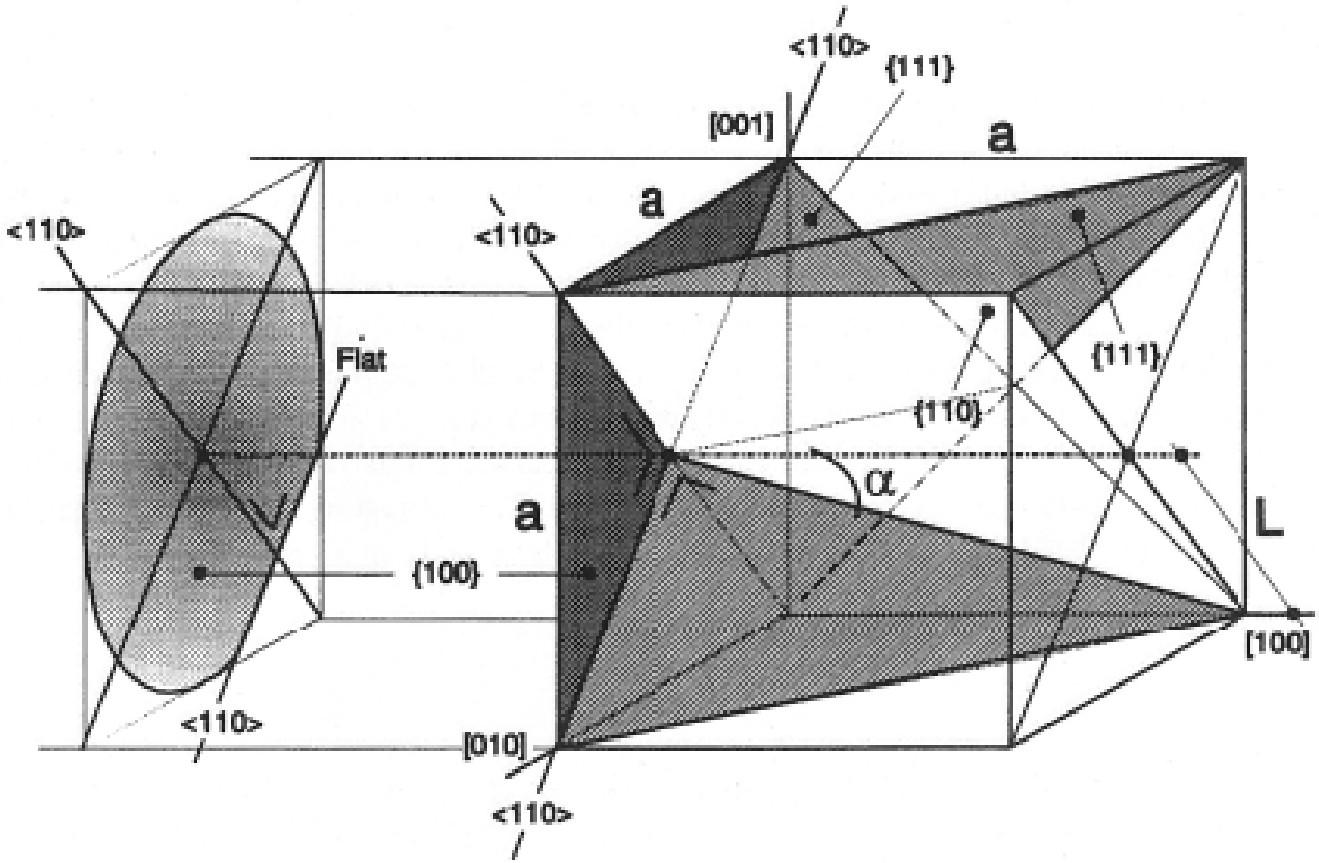


FIGURE 16.6 (100) silicon wafer with reference to the unity cube and its relevant planes. (From Peeters, E., *Process Development for 3D Silicon Microstructures with Application to Mechanical Sensor Design*, KUL, Belgium, 1994. With permission.)