Crystal Growth and Wafer Fabrication

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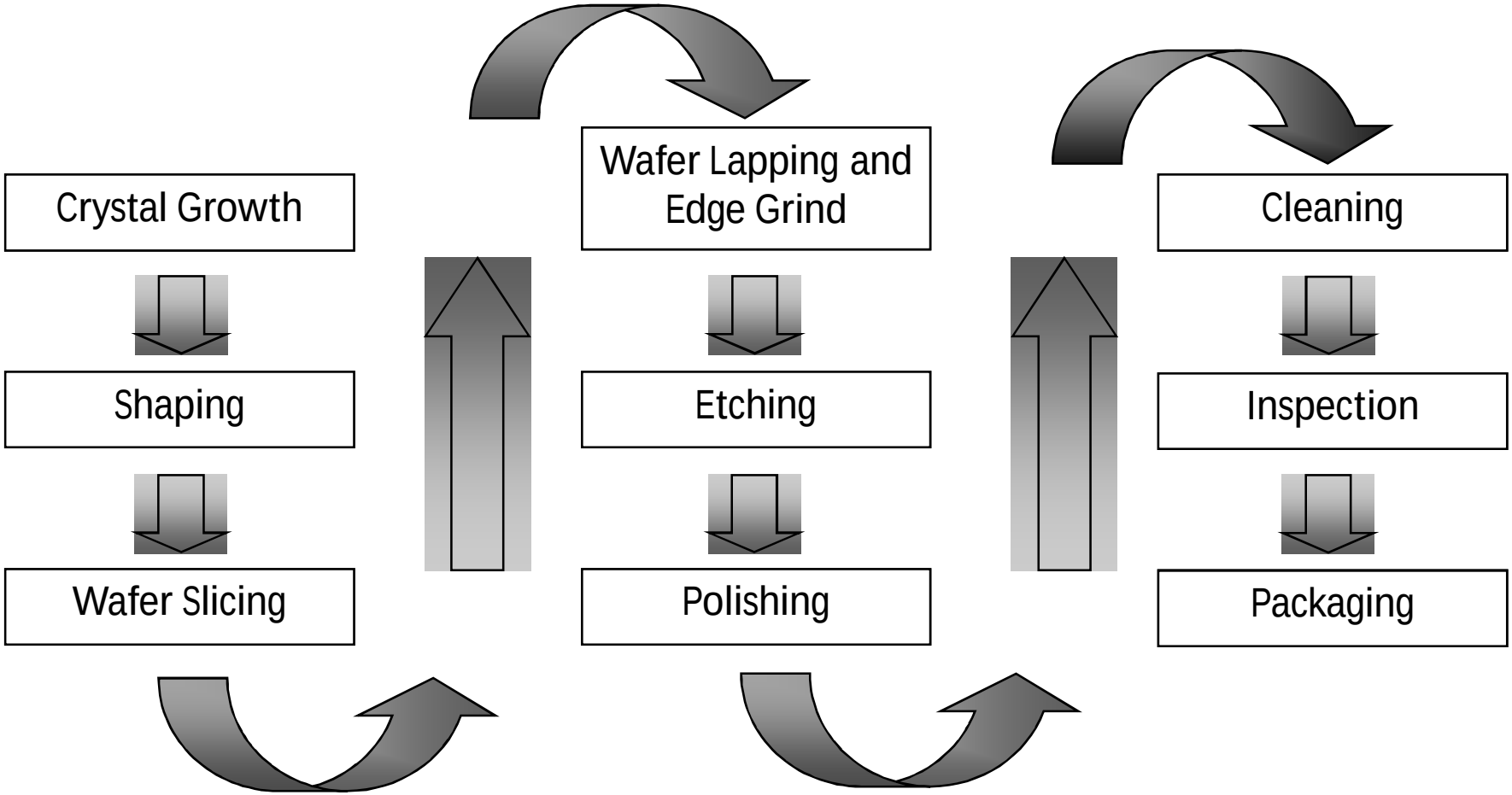
VIT

- Crystal growth
  - Obtaining sand
  - Raw Polysilicon
  - Czochralski Process (growing single crystal ingots)
  - Ingot size and Characterization
- Wafer Fabrication
  - Slicing Ingots
  - Primary and Secondary Flats (Orientation)
  - Wafer Lapping
  - Wafer Etching
  - Wafer Polishing
  - Wafer Cleaning

Basic Process Steps for Wafer Preparation



Obtaining the Sand

- The sand used to grow the wafers has to be a very clean and good form of silicon.
- For this reason not just any sand scraped off the beach will do.
- Most of the sand used for these processes is shipped from the beaches of Australia.

Preparation of MGS from Quartz Sand

- Put pure quartz sand and carbon into high- temperature furnace.
- Carbon can be in form of coal, coke or even piece of wood.
- At high temperature, carbon starts react with silicon di oxide to form carbon oxide.
- This process generates polycrystalline silicon with about 98% to 99% purity called crude or Metallurgical-grade silicon.
- The chemical reaction as follows

$$SiO_2 + 2C \rightarrow Si + 2CO$$

Silicon Purification

- Crude silicon is ground into fine powder.
- Then silicon powder is introduced into reactor to react with HCL(vapor), forming (TCS,$SiHCl_3$) vapor at about 300C.

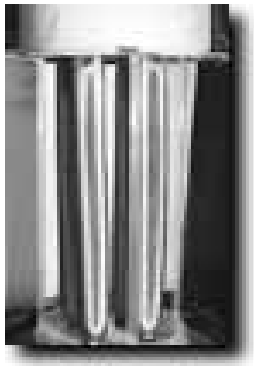
The chemical reaction as follows

$$Si + 3HCl \rightarrow SiHCl_3 + H_2$$

TCS vapor then goes through series of filters, condensers, and purifiers to get ultra high-purity liquid TCS, with purity higher than 99.99999999%.

Preparation of EGS form TCS

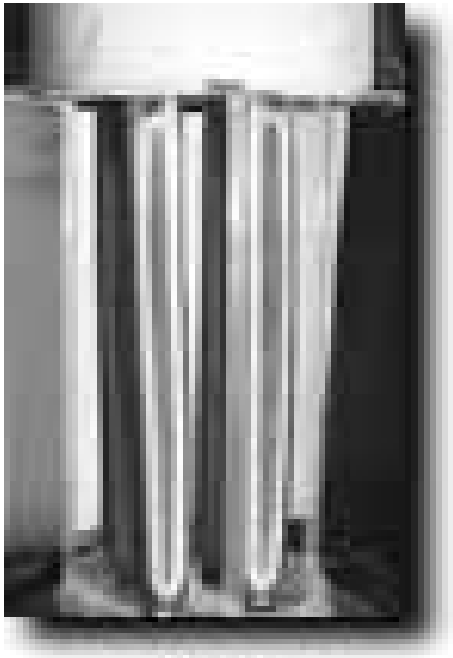
- High purity TCS is one of the most commonly used silicon source precursors for silicon deposition.
- At high temperature , TCS can react with hydrogen and deposit high purity polysilicon.
- The reaction as follows
- $SiHCl_3 + H_2 \rightarrow Si + 3HCl$
- The high purity polysilicon crystalline silicon is called electron grade silicon or EGS.



Raw Polycrystal Silicon Rods

Polysilicon Ingots

Raw Polysilicon



Raw Polycrystal Silicon Rods

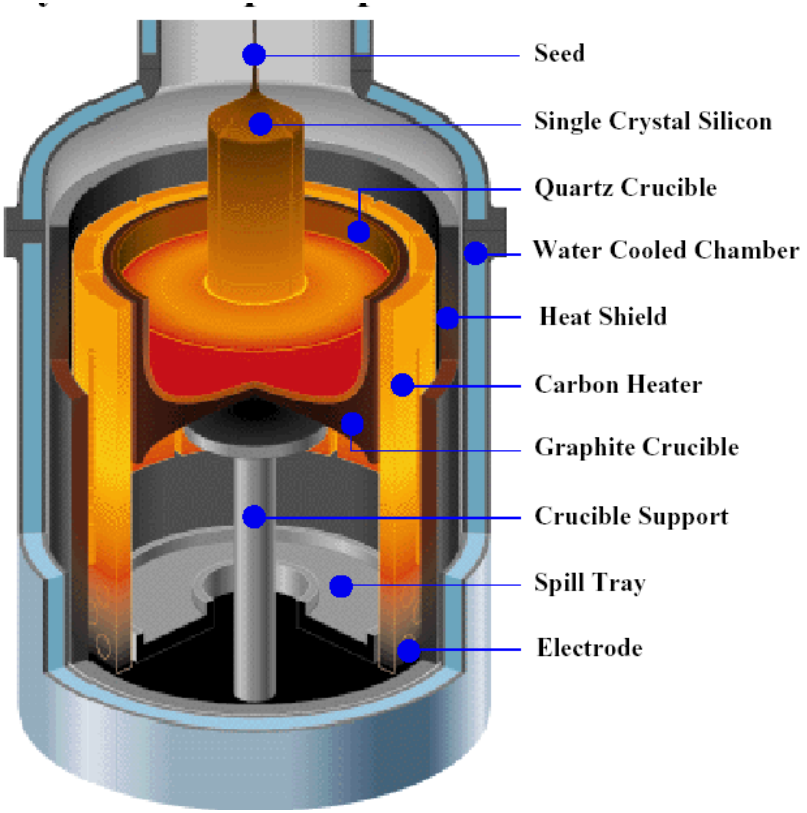
- Raw polycrystalline silicon produced by mixing refined trichlorosilane with hydrogen gas in a reaction furnace.
- The poly-crystalline silicon is allowed to grow on the surface of electrically heated tantalum hollow metal wicks

Polysilicon Ingots

Polysilicon Ingots

- The polycrystalline silicon tubes refined by dissolving in hydrofluoric acid producing polysilicon ingots.
- Polycrystalline silicon has randomly oriented crystallites, electrical characteristics not ready for device fabrication.
- Must be transformed into single crystal silicon using crystal pulling

Czochralski (CZ) crystal growing

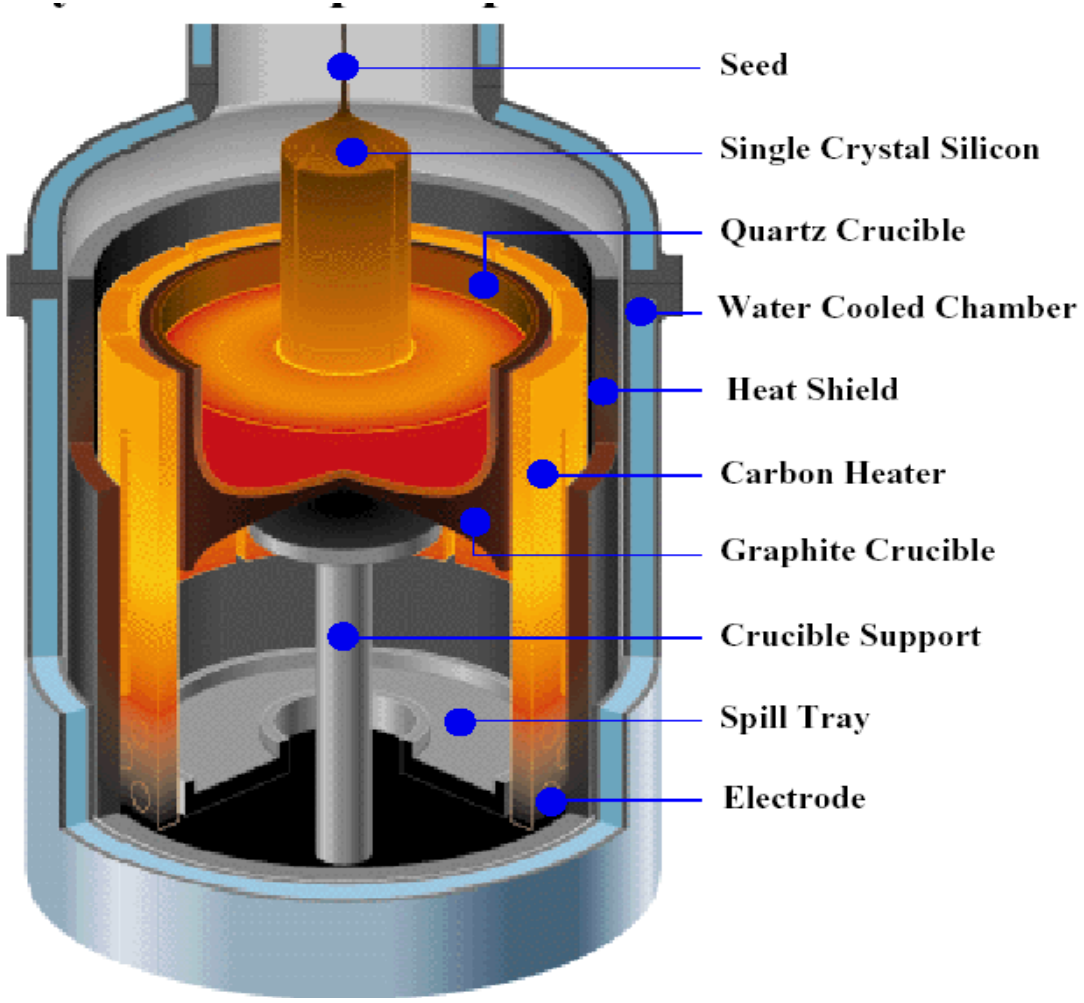


Step:1 Preparation of high purity molten silicon

Step:2 Dipping Seed crystal

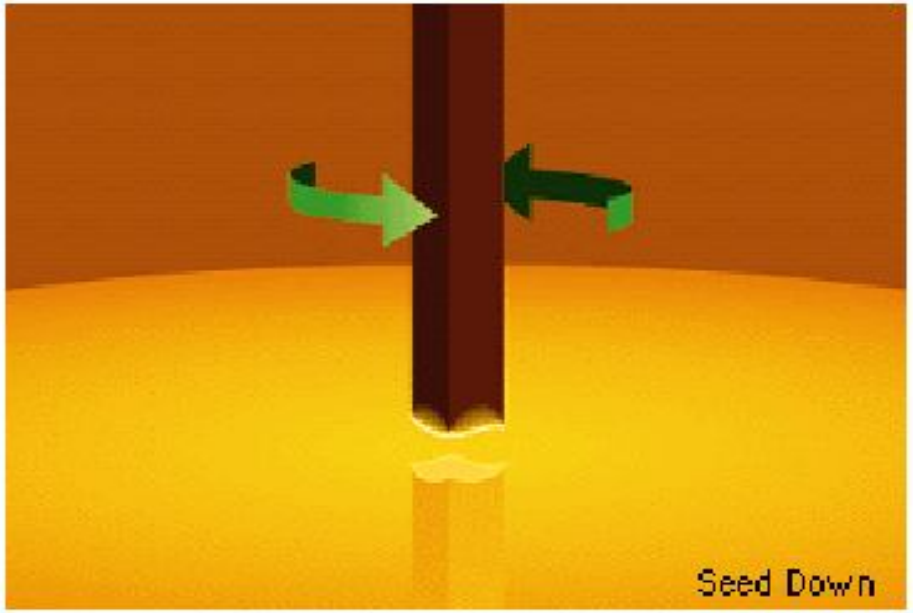
Step:3 Pulling the seed upwards

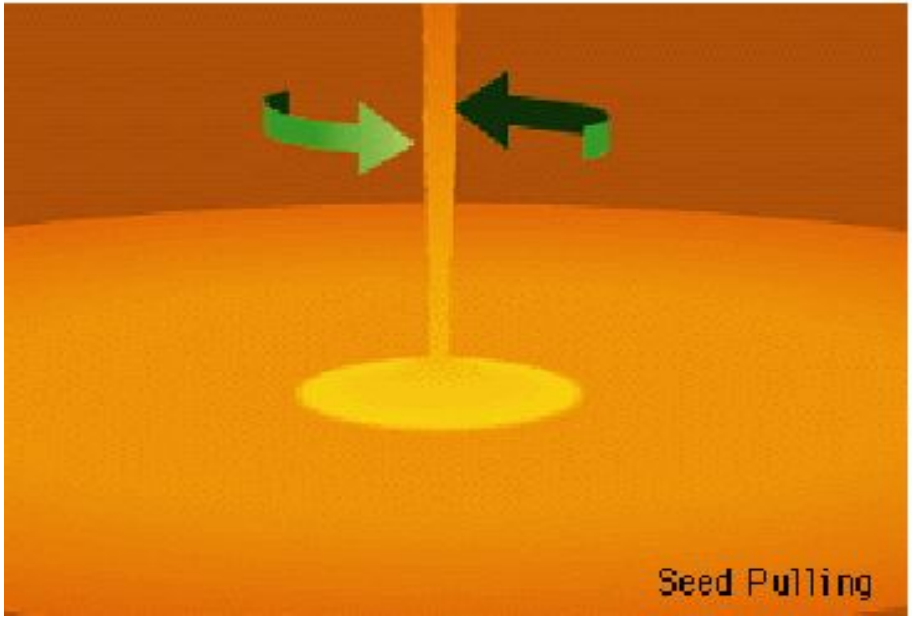
Czochralski (CZ) crystal growing

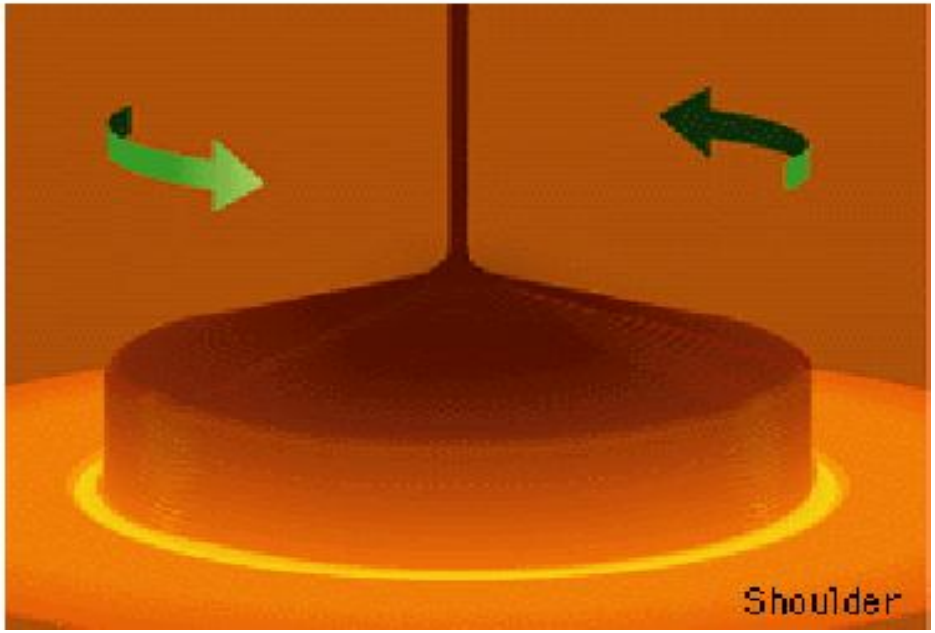


- All Si wafers come from "Czochralski" grown crystals.
  Polysilicon is melted, then held just below 1417 °C, and a single crystal seed starts the growth.
  Pull rate, melt temperature and rotation rate control the growth

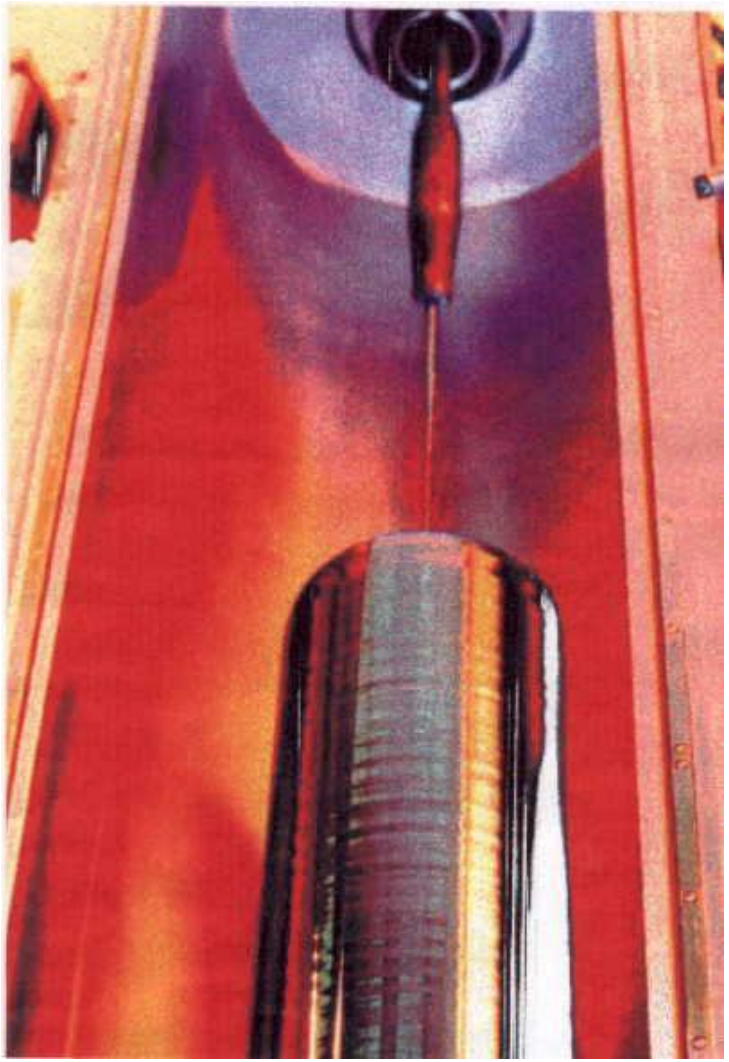
- It contains < 1 ppb impurities. Pulled crystals contain O (~10^{18} cm^{-3}) and C (~10^{16} cm^{-3}), plus dopants placed in the melt.


Seed Down


Seed Pulling

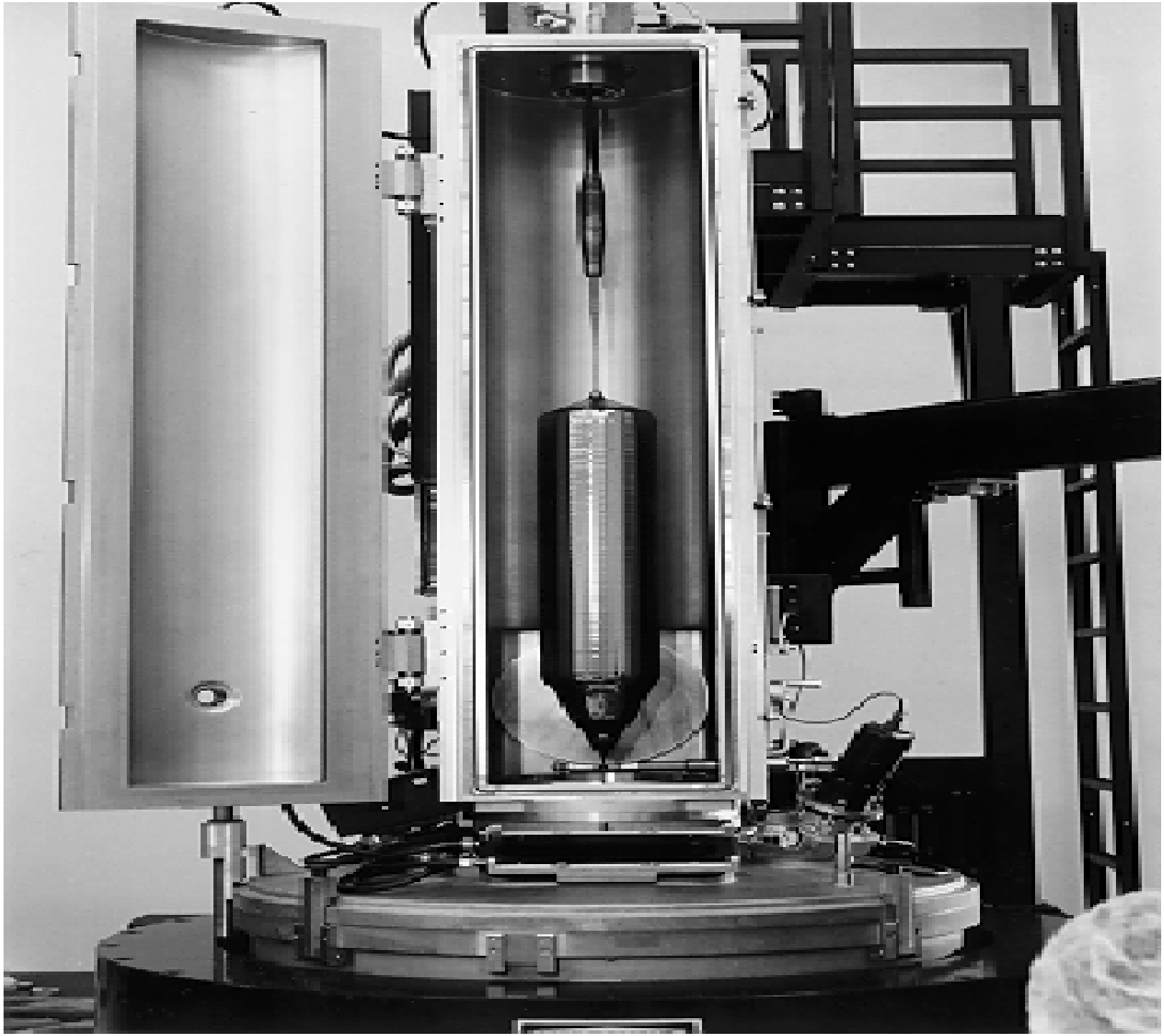

Shoulder

Silicon Ingot Grown by CZ Method



Photograph courtesy of Kayex Corp., 300 mm Si ingot

Photo 4.1



Examples of completed ingots

Ingot Sizes

Single Crystal Silicon Ingot

- Most ingots produced today are 150mm (6") and 200mm (8") diameter,
- For the most current technology 300mm (12") and 400mm (16") diameter ingots are being developed.

Ingot Characterization

- Single Crystal Silicon ingots are characterized by the orientation of their silicon crystals. Before the ingot is cut into wafers, one or two "flats" are ground into the diameter of the ingot to mark this orientation.

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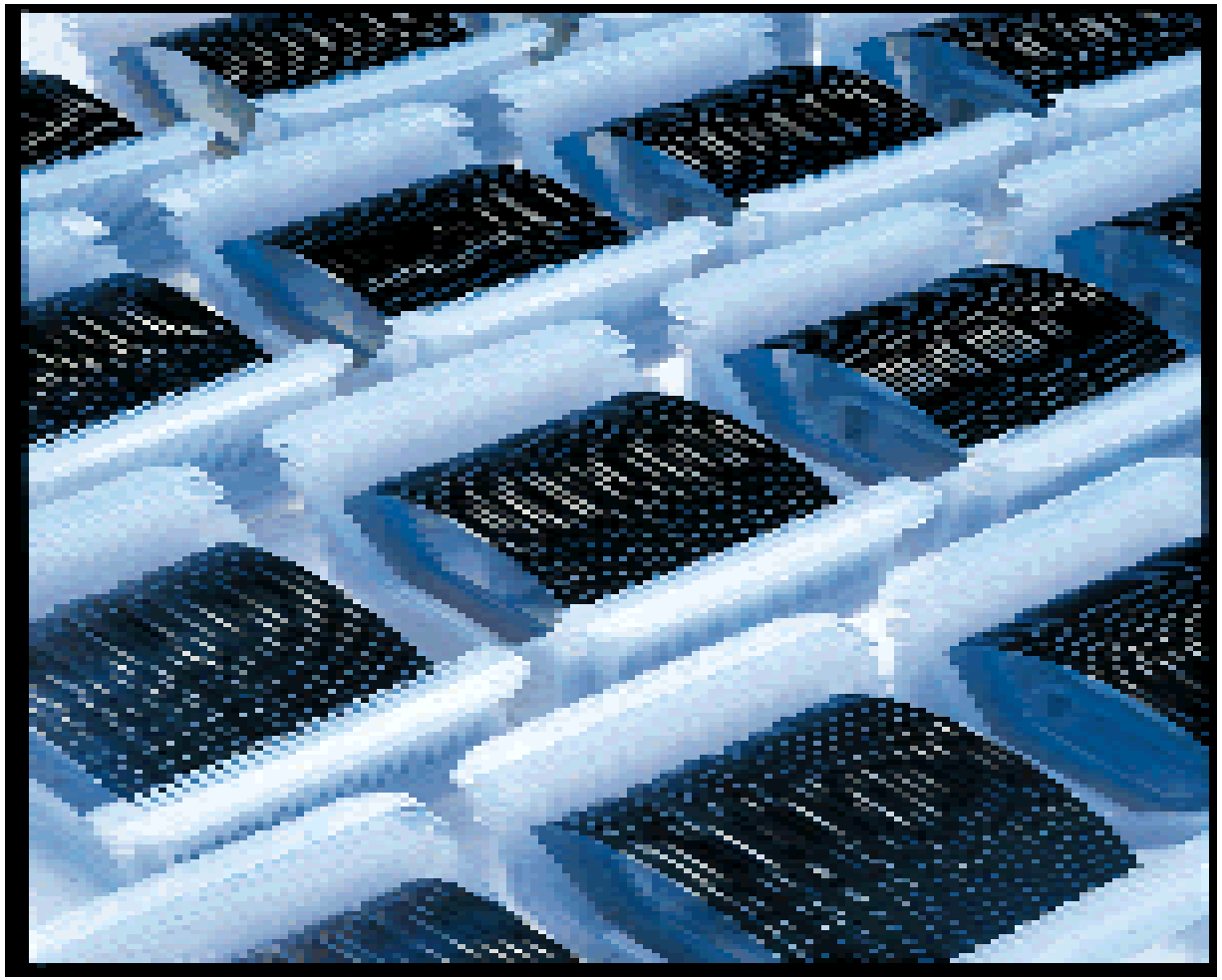
Slicing Ingots

- The ingot is ground into the correct diameter for the wafers.
- Then it is sliced into very thin wafers.
- This is usually done with a diamond saw.

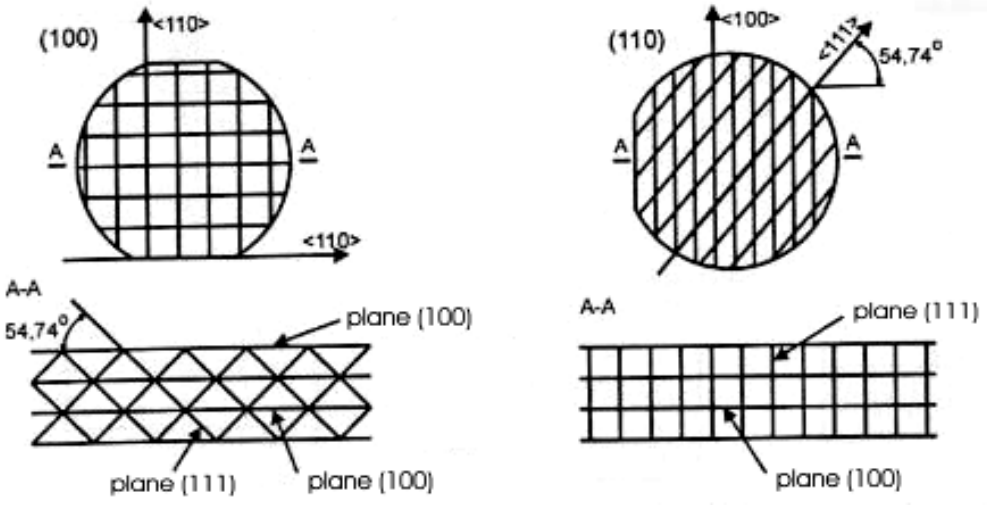
Some wafers in storage trays



Lattice Orientation

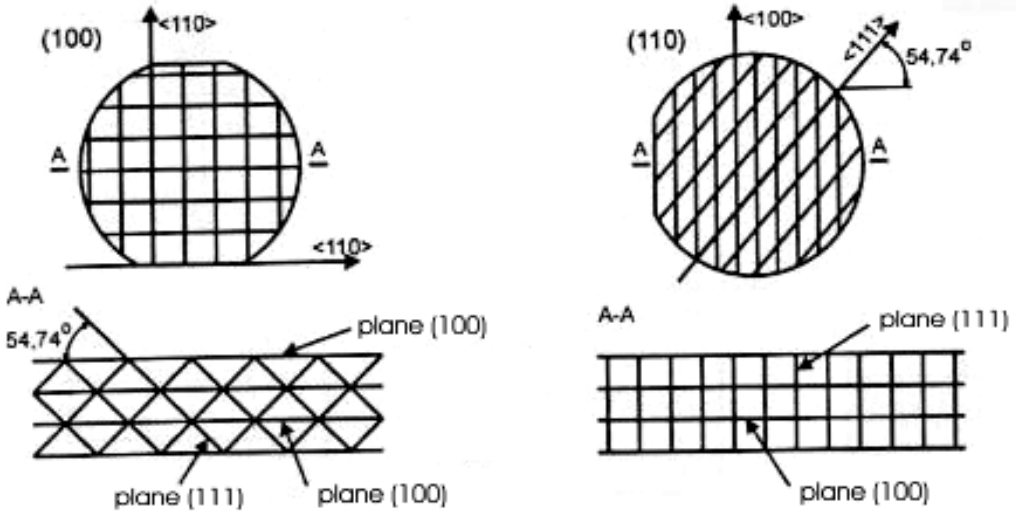
- The lattice orientation refers to the organized pattern of the silicon crystals in the wafer and their orientation to the surface.
- The orientation is obtained based on the orientation of the crystal that is placed into the molten silicon bath.
- The different orientations have different benefits and are used in different types of chips.

<100> Lattice Orientation



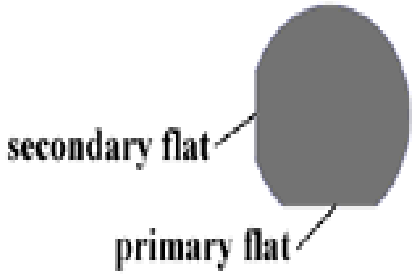
- This lattice orientation is used for MOS (metaloxide semiconductor), Bi-CMOS, & GaAs types of chips.

<111> Lattice Orientation



- This orientation is used for Bipolar types of chips

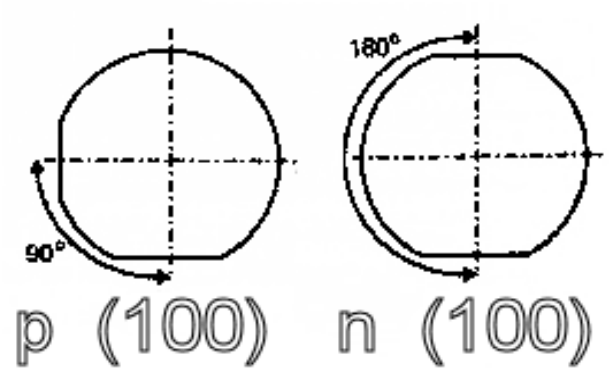
Different flats for orientation

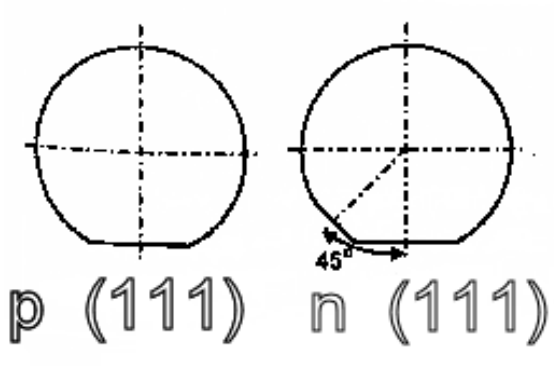


Wafer Flats **-** orientation for automatic equipment and indicate type and orientation of crystal.

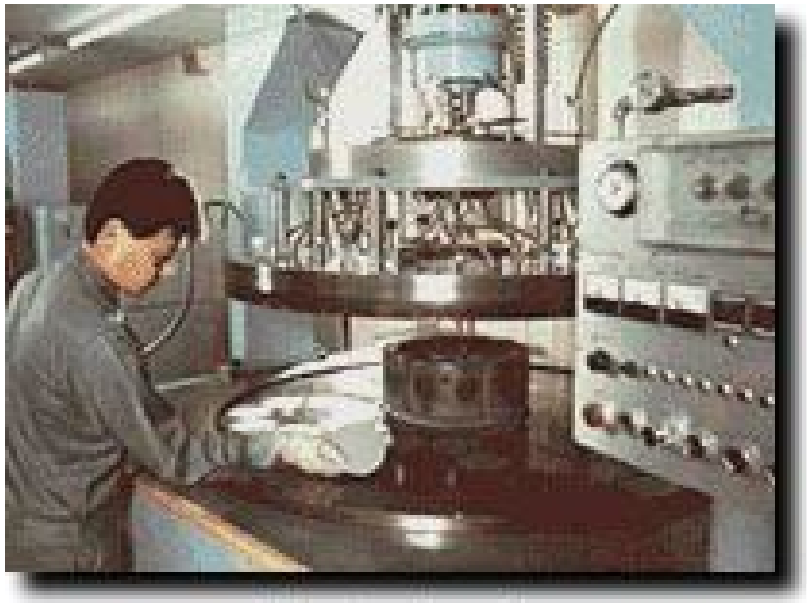
Primary flat – The flat of longest length located in the circumference of the wafer. The primary flat has a specific crystal orientation relative to the wafer surface; major flat.

Secondary flat – Indicates the crystal orientation and doping of the wafer.





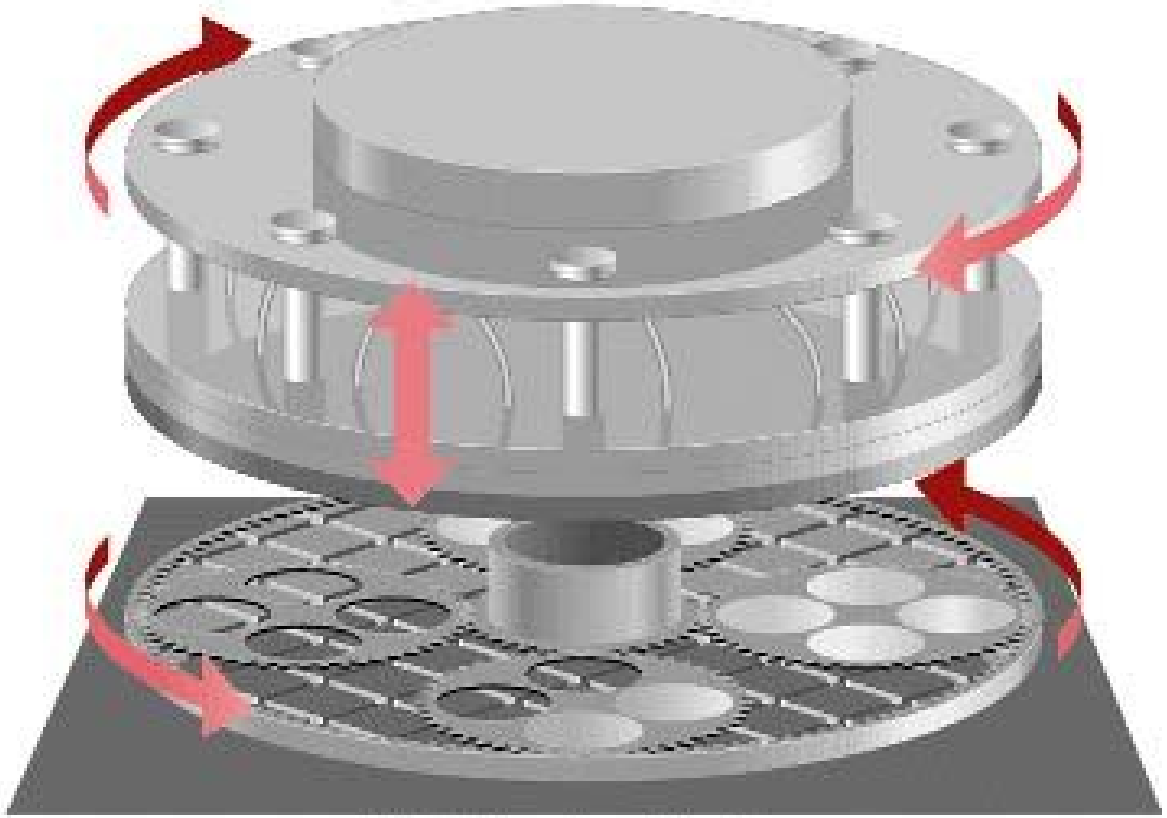
Wafer Lapping



Wafer Lapping
(Mitsubishi Materials Silicon)

- The sliced wafers are mechanically lapped using a counter-rotating lapping machine and aluminum oxide slurry. This flattens the wafer surfaces, makes them parallel and reduces mechanical defects like saw markings

Wafer Lapping Machine



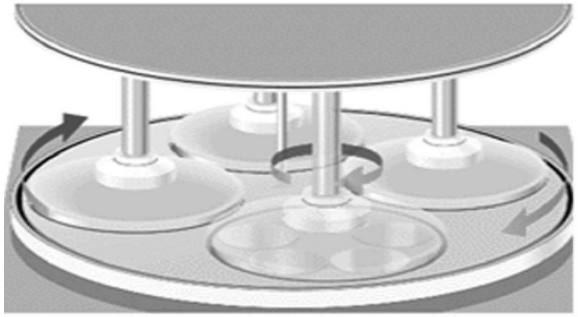
Wafer Lapping Machine
(Mitsubishi Materials Silicon)

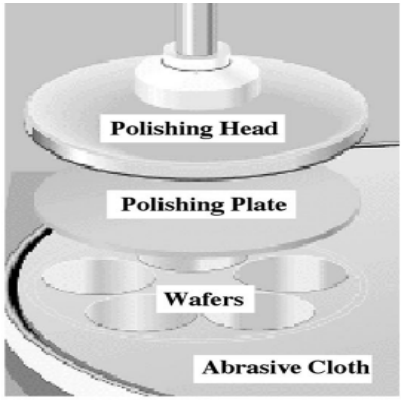
Wafer Etching

- After lapping, wafers are etched in a solution of nitric acid/ acetic acid or sodium hydroxide to remove microscopic cracks or surface damage created by the lapping process.

- The acid or caustic solution is removed by a series of high-purity RO/DI water baths

Wafer polishing





Next, the wafers are polished in a series of combination chemical and mechanical polish processes called CMP

The wafers are held in a hard ceramic chuck using either wax bond or vacuum and buffed with a slurry of silica powder, RO / DI water and sodium hydroxide

Wafer Cleaning

A . Solvent Removal

1. Immerse in boiling trichloroethylene (TCE) for 3 min.
2. Immerse in boiling acetone for 3 min.
3. Immerse in boiling methyl alcohol for 3min.
4. Wash in DI water for 3min.

B. Removal of Residual Organic/Ionic Contamination

1. Immerse in a (5:1:1) solution of H_2O –NH_4OH-H_2O_2;heat solution to 75-80 °C and hold for 10min
2. Quench the solution under running DI water 1 min
3. Wash in DI Water for 5min.

C. Hydrous Oxide Removal

1. Immerse in a (1:50) solution of HF-$H2_O$ for 15 sec
2. Wash in running DI water with agitation for 30 seconds.

D. Heavy metal clean

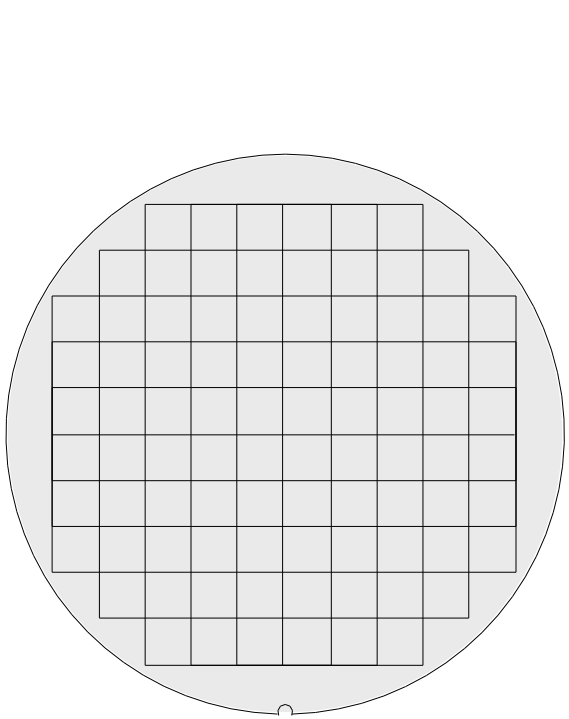
1. Immerse in a (6:1:1) solution of H_2O-HCL-H_2O_2 for 10 min at a temperature of 75-80 °C
2. Quench the solution under running DI water for 1 min.
3. Wash in running DI water for 20min.

Wafer Dimensions & Attributes

Diameter (mm)	Thickness (μm)	Area (cm^2)	Weight (grams/lbs)	Weight/25 Wafers (lbs)
150	675 ± 20	176.71	28 / 0.06	**1.5**
200	725 ± 20	314.16	53.08 / 0.12	**3**
300	775 ± 20	706.86	127.64 / 0.28	**7**
400	825 ± 20	1256.64	241.56 / 0.53	**13**

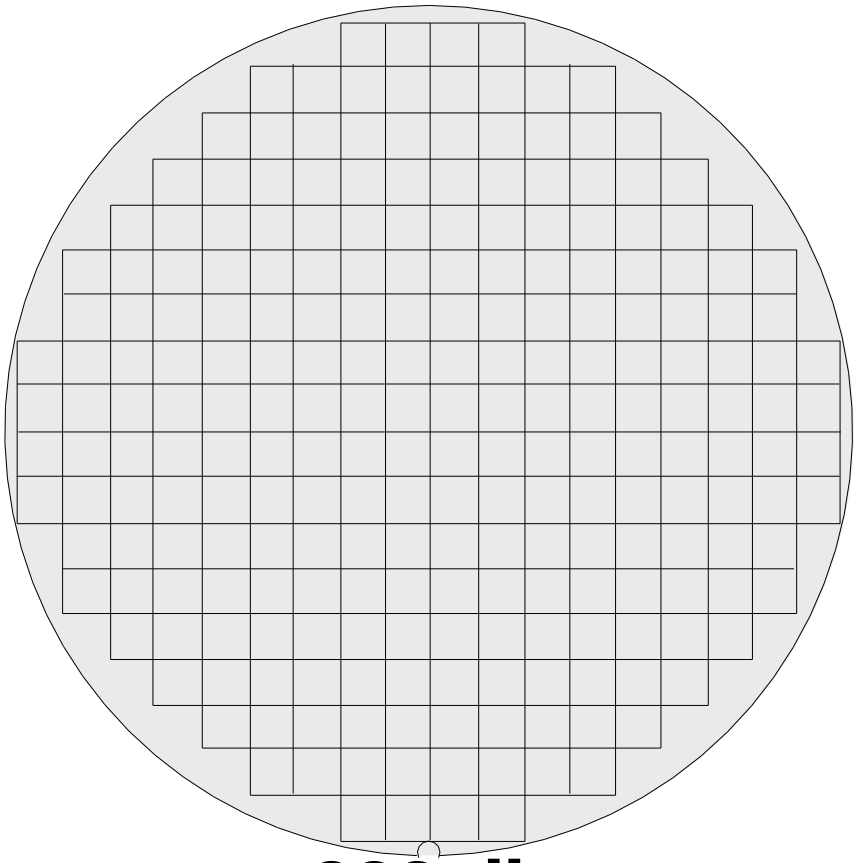
Table 4.3

Increase in Number of Chips on Larger Wafer Diameters (Assume large 1.5 x 1.5 cm microprocessors)



88 die

200-mm wafer



232 die

300-mm wafer

Figure 4.13

Developmental Specifications for 300-mm Wafer Dimensions and Orientation

Parameter	Units	Nominal	Some Typical Tolerances
Diameter	mm	300.00	± 0.20
Thickness (center point)	μm	775	± 25
Warp (max)	μm	100	
Nine-Point Thickness Variation (max)	μm	10	
Notch Depth	mm	1.00	+ 0.25, -0.00
Notch Angle	Degree	90	+5, -1
Back Surface Finish		Bright Etched/Polished	
Edge Profile Surface Finish		Polished	
FQA (Fixed Quality Area – radius permitted on the wafer surface)	mm	147	

From H. Huff, R. Foodall, R. Nilson, and S. Griffiths, "Thermal Processing Issues for 300-mm Silicon Wafers: Challenges and Opportunities," ULSI Science and Technology (New Jersey: The Electrochemical Society, 1997), p. 139.

Table 4.4

Quality Measures

- Physical dimensions
- Flatness
- Microroughness
- Oxygen content
- Crystal defects
- Particles
- Bulk resistivity