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# Crystal Growth

- *Manufacturing Single Crystal ingots*

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# Raw material for Chip Design

- **Silicon Wafer** : Obtained from Single Crystal Ingots.
- **Single Crystal** : All the basic units (atoms/ molecules) are arranged in a uniform manner throughout the material.

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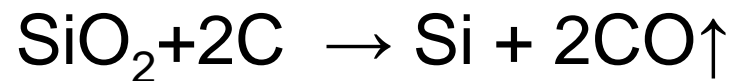
# Ways of Forming Single Crystal...

- **Natural crystal:** Diamond, Jade, Ruby etc... formed by millions of years under the earth pressure and temperature.
- **Man made crystal:** Si, Ge and many other technologically important materials as well as engineered quantum structures.

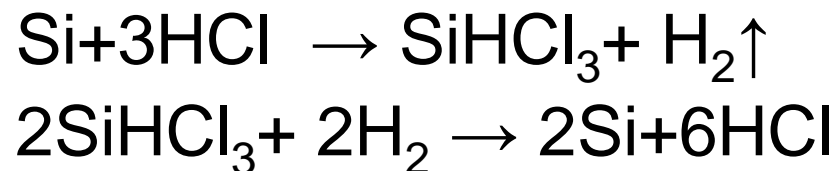
Making of such man-made crystal is called *Crystal growth*.

# The Starting Material...

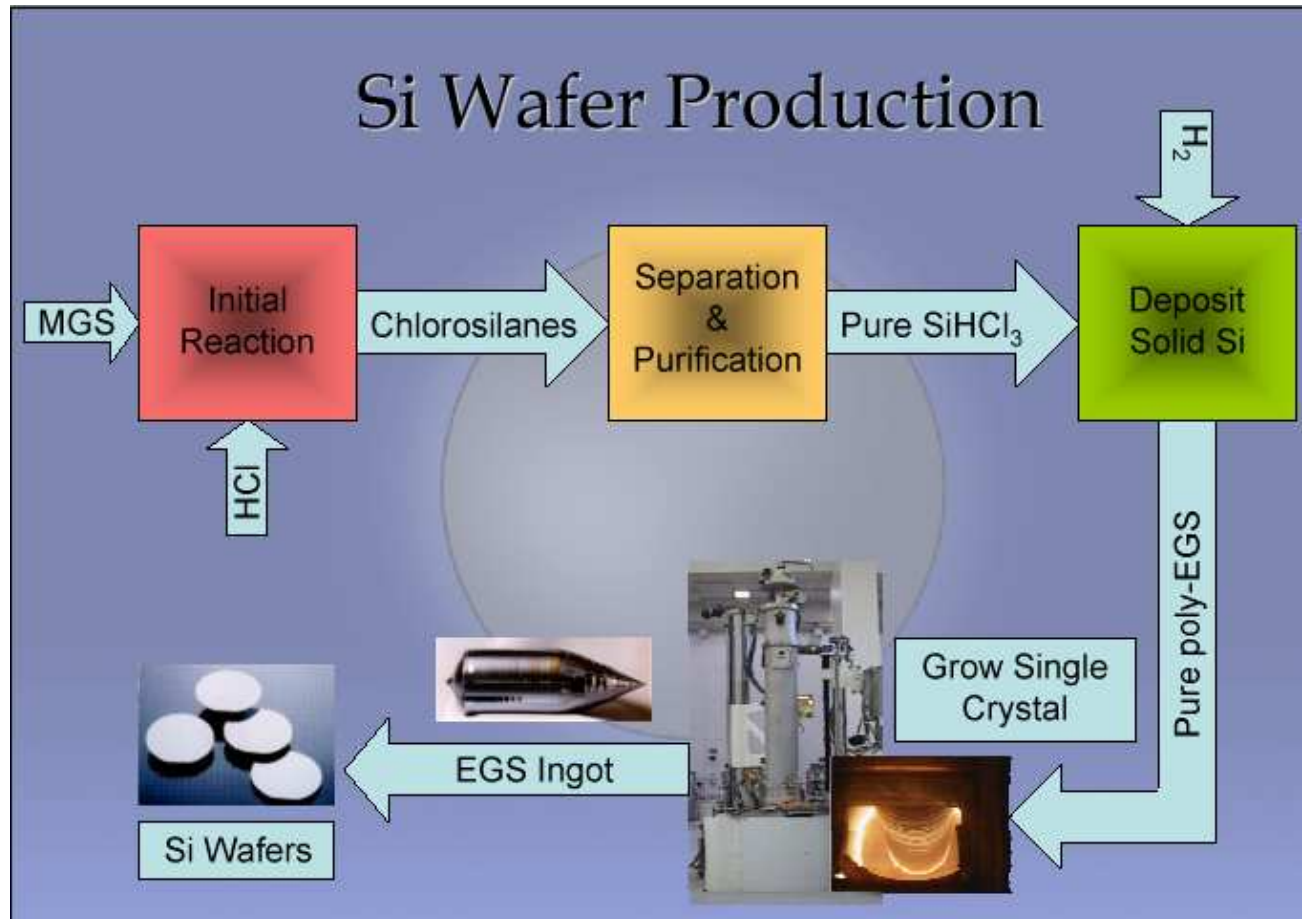
- SiO<sub>2</sub> react with C (coke) at about 1800°C to form *Metallurgical grade Si (MGS)* with impurities like Fe, Al.



- This MGS is refined further to obtain the *Electronic grade Si (EGS)* as per following two reactions.



# Getting the Si Wafer...



Photograph taken from <http://www.seas.upenn.edu/>

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# Crystal Growth Techniques...

There are many crystal growth techniques. Here are a few widely used techniques:

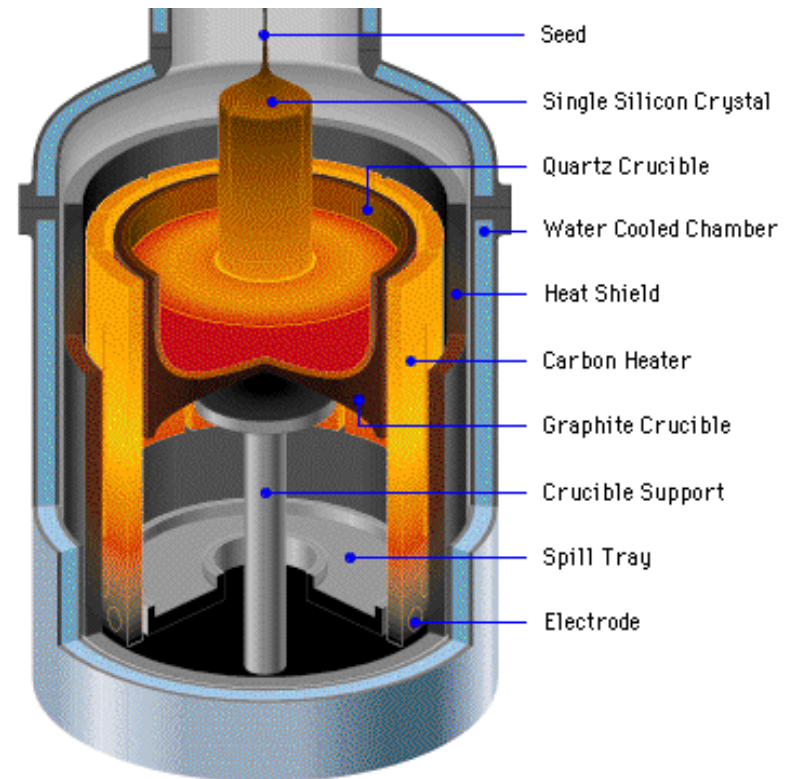
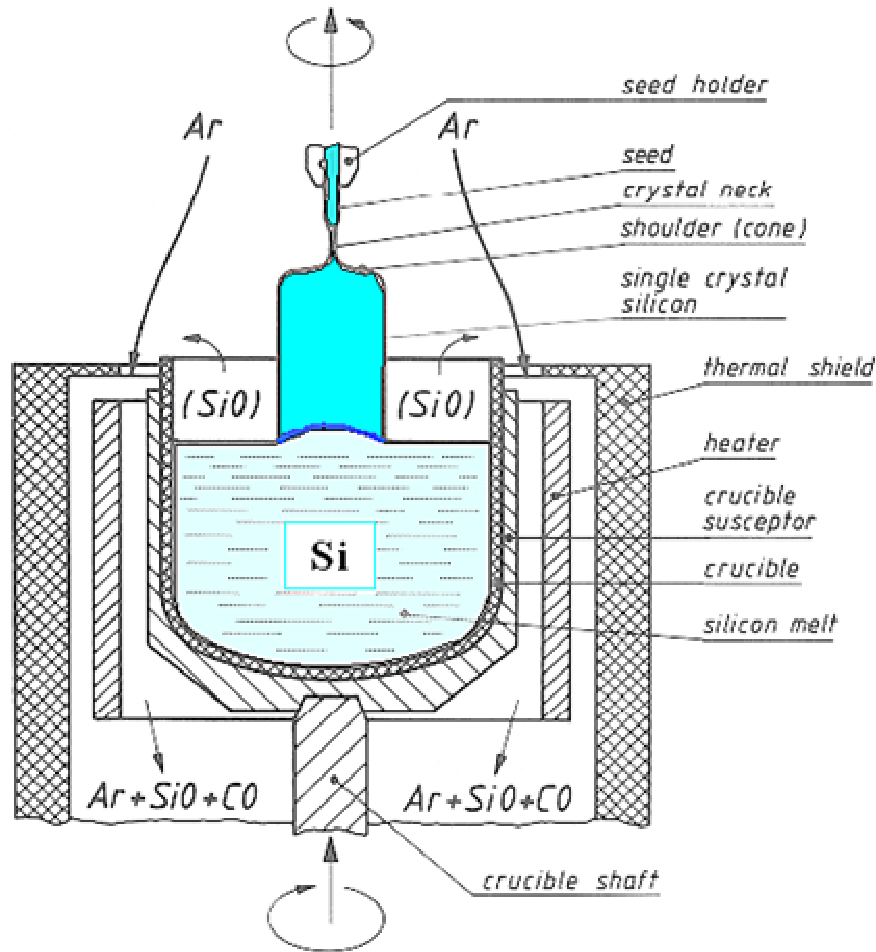
- **Verneuil method**
- **Bridgman method**
  - Horizontal Bridgman growth
  - Vertical gradient freeze technique
- **Czochralski Method** (Commonly used)
- **CVT:** Chemical Vapor Transport (basic technique used in labs)
- **MBE:** Molecular Beam Epitaxy (mainly used in labs)
- **MOCVD:** Metallo Organic Chemical Vapor Deposition

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# Czochralski Method ...

- This process uses Czochralski Crystal Grower.
- Poly-EGS is melted in a quartz-lined crucible at about  $1412^{\circ}\text{C}$  .
- Seed crystal is introduced into the molten poly-EGS to begin crystallization.
- Seed pulled slowly, allowing the crystal to grow on to it. Simultaneously, the crystal is rotated slowly to give slight stirring of the melt to prevent inhomogeneous solidification.
- Then Ingot is cooled at a very slower rate.

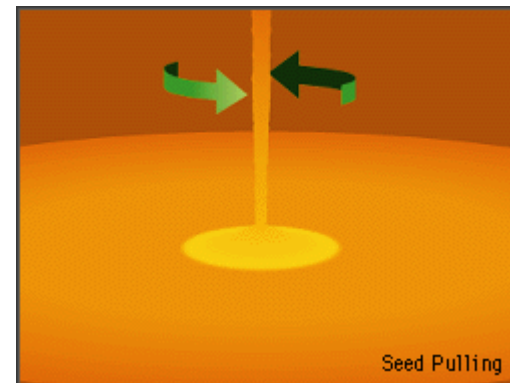
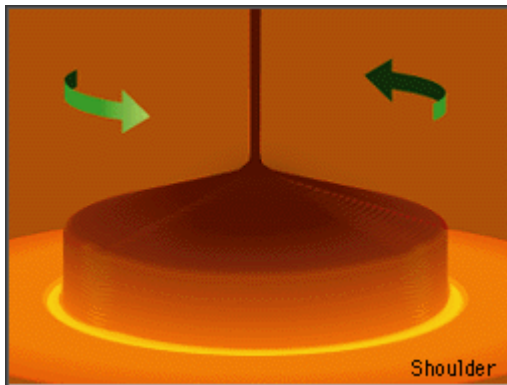
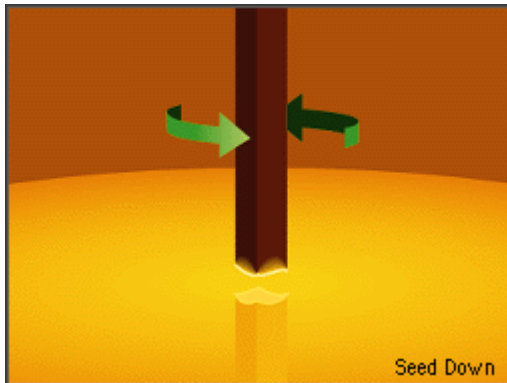
# Czochralski Crystal Grower....



Photograph taken from <http://www.tf.uni-kiel.de> (left), and <http://semiconductor-nano.com/> (right)



# The Process...



Photograph taken from <http://semiconductor-nano.com/>

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## Contd... (Czochralski Method)

- This Technique is widely used in Growing Si, Ge and some compound semiconductor.
- In pulling compounds like GaAs from the melt, vaporization of volatile elements (e.g. As) is prevented.
- In one method, known as *Liquid Encapsulated Czochralski (LEC)* growth, the same can be done by using  $B_2O_3$  (Boron Trioxide) , which floats on the surface of the molten GaAs.

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## Contd... (Czochralski Method)

- Here the shape of the ingots is determined by a combination of the tendency of the cross section to assume a polygonal shape due to crystal structure and the influence of surface tension, which encourages a circular cross section.

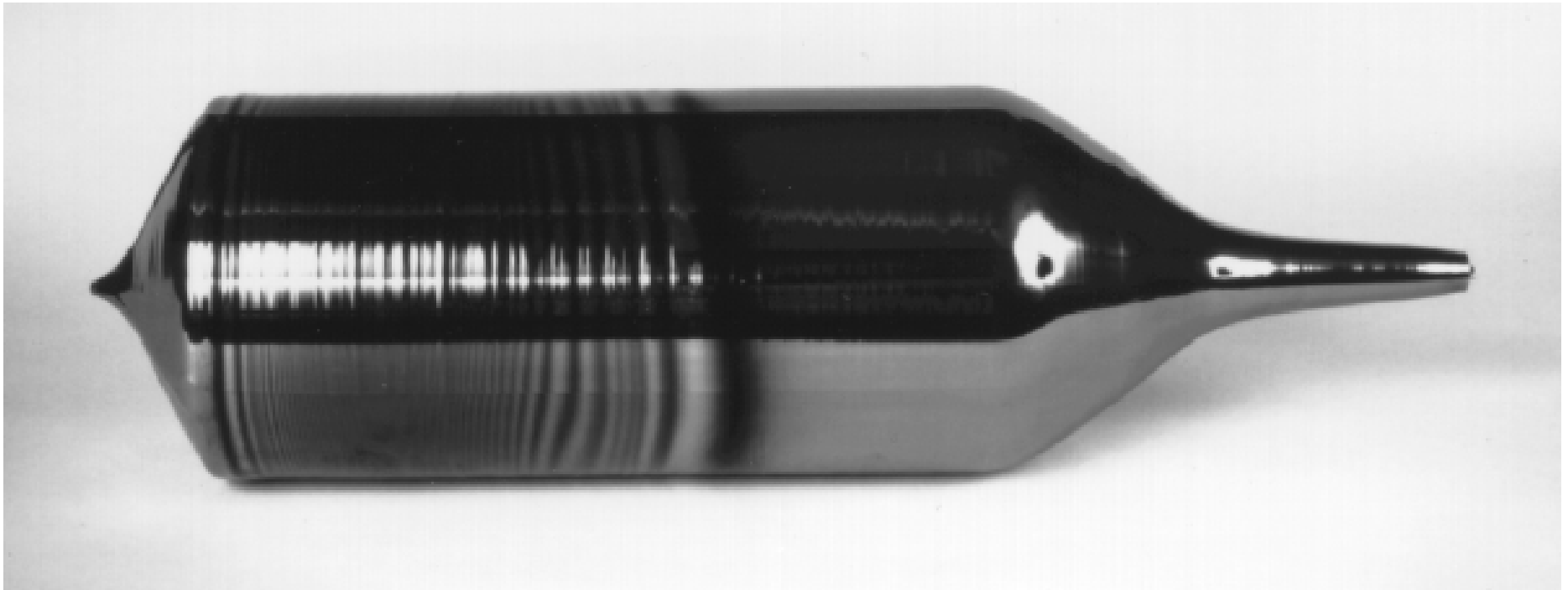
# The Finished Crystal Parts...



Photograph taken from <http://www.seas.upenn.edu/>

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# Single Crystal Ingots...



Photograph taken from <http://www.kasap3.usask.ca>

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# The Si Wafers...

- After growing the single crystal, it is first grinded to get a perfect cylinder with a precisely controlled diameter.
- Using X-ray crystallography, crystal planes in the ingots are identified.
- Most Si ingots are grown along the  $\langle 100 \rangle$  direction.
- The Si cylinder is sawed into individual wafer (about  $775\mu\text{m}$  thick) by using diamond-tipped inner-hole blade saw, or a wire saw.

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# The finished Si Wafers...



Photograph taken from <http://www.seas.upenn.edu/>

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# References...

- Solid State Electronic Device, Streetman, Banerjee.
- <http://www.tf.uni-kiel.de>
- <http://semiconductor-nano.com/>
- <http://www.seas.upenn.edu/>



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Thank U...