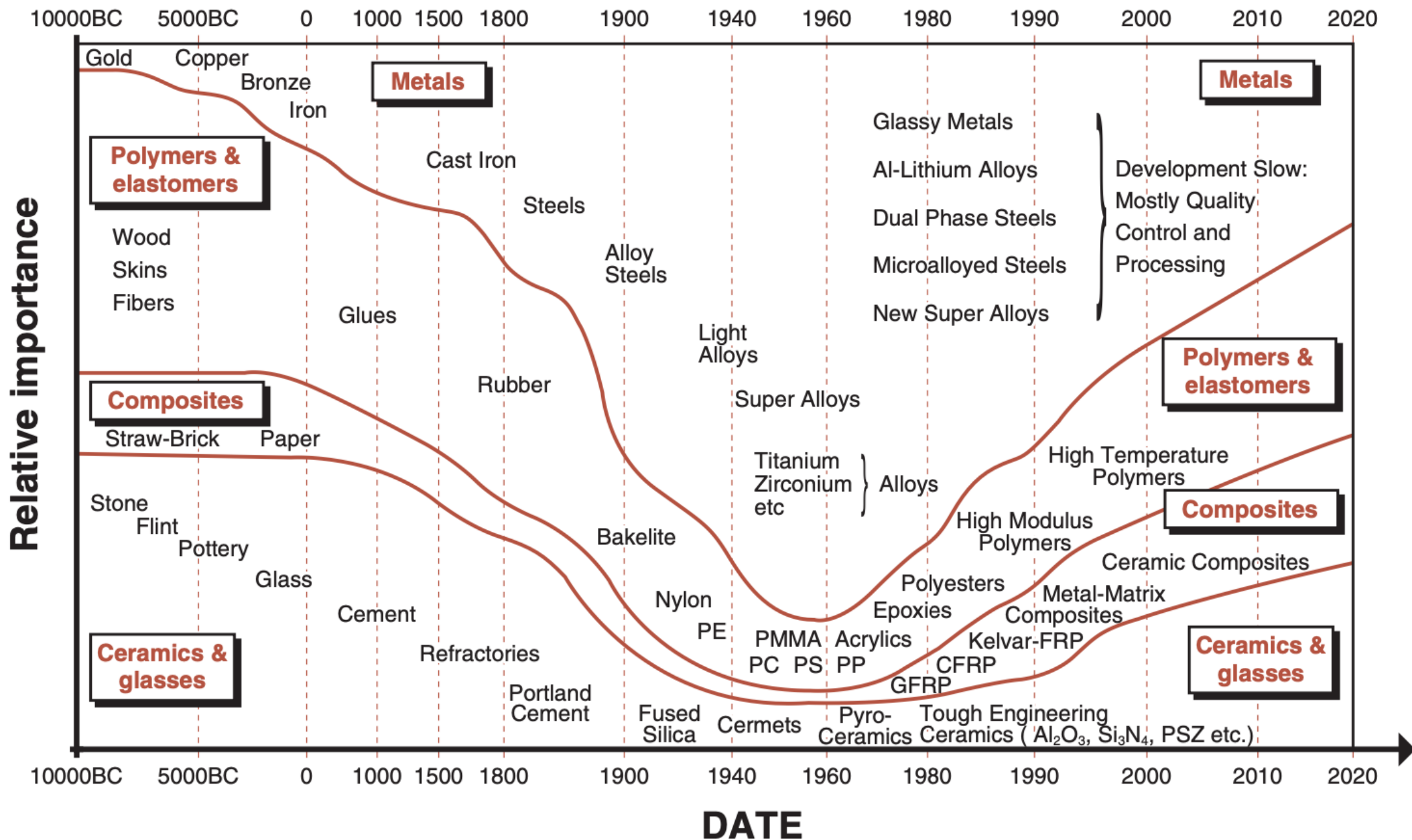
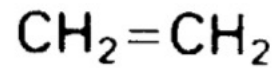


Non-metal material synthesis



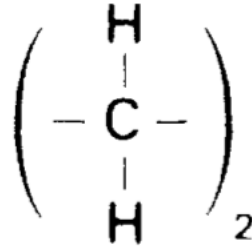
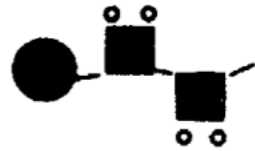
Polymer processing

Lets take ethylene

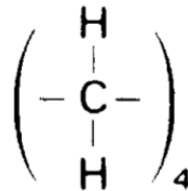
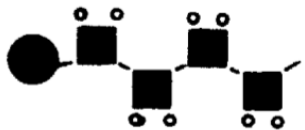


Monomer

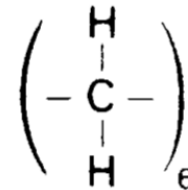
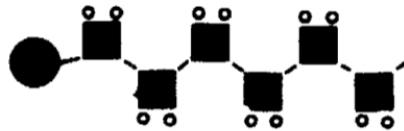
Monomer activation



When we join a few numbers of them, we get



Dimer



Polymer

A polymer should either be terminated by a terminator (eg: OH) or another monomers

Long linear chains of polymers can crystalize

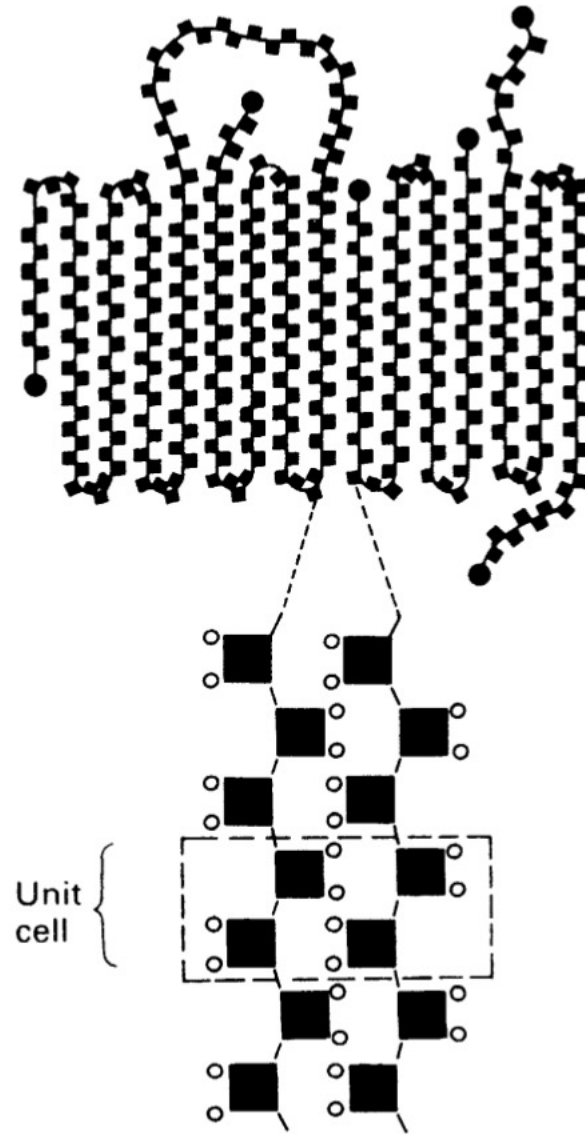
Eg: Polyethylene

Remember, **activated ethylene has no side bonds**.

When packed in high-density, hydrogen interactions make them to align and crystallize.

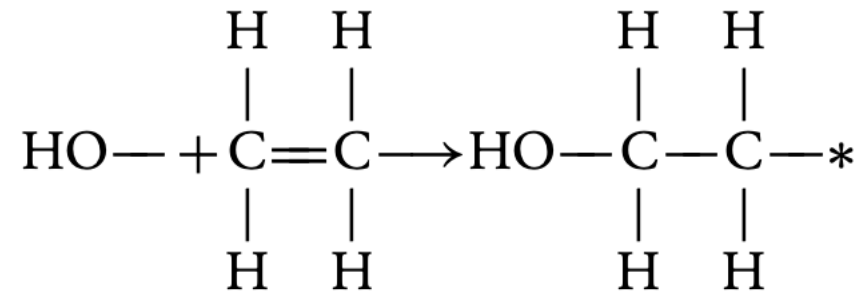
Even the most crystalline polymer is only **about 80 %** crystalline.

However, this is still good enough to give you X-Ray diffraction.



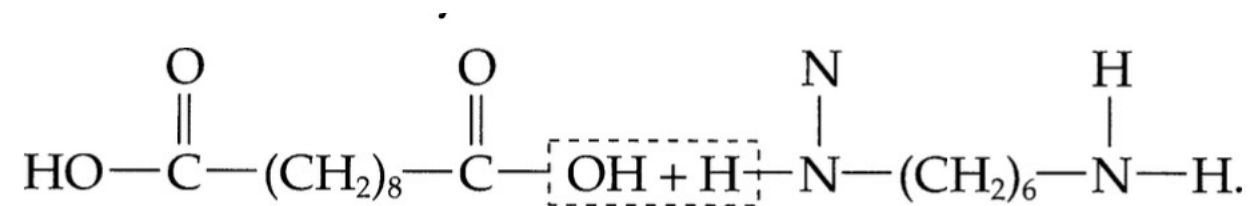
Polyethylene preparation

You need an initiator

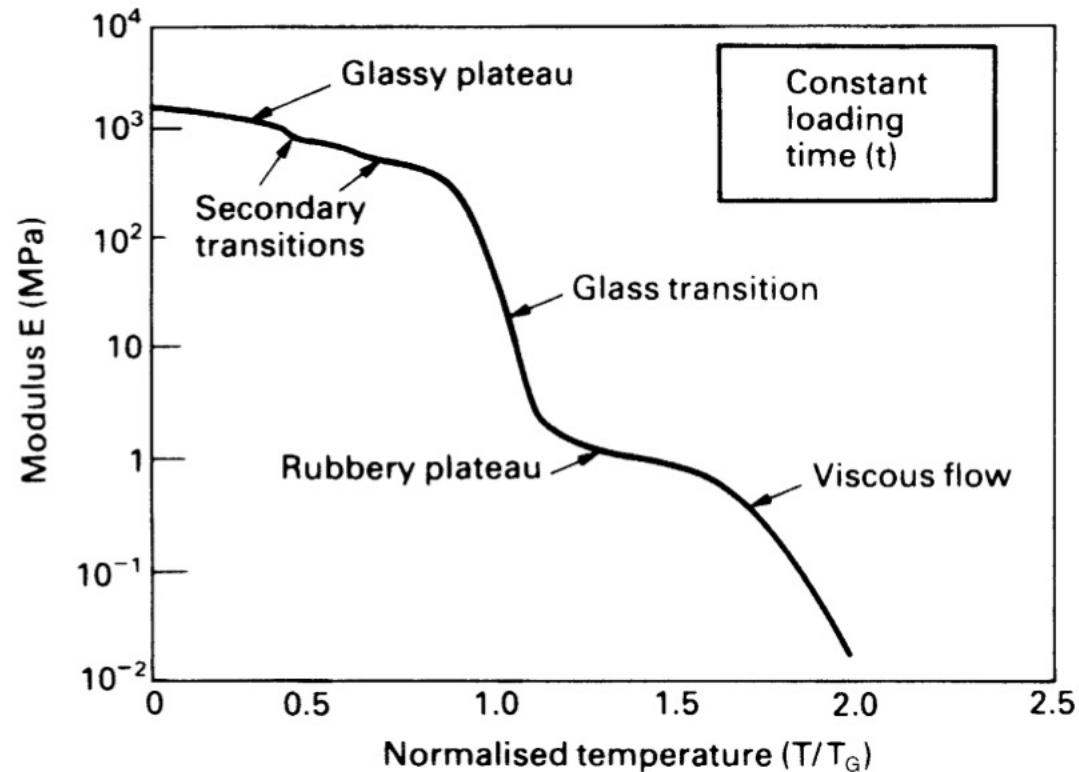


When we use hydrogen peroxide, the OH group breaks the double bond and terminates one end. Other end is now very reactive

Nylon condensation



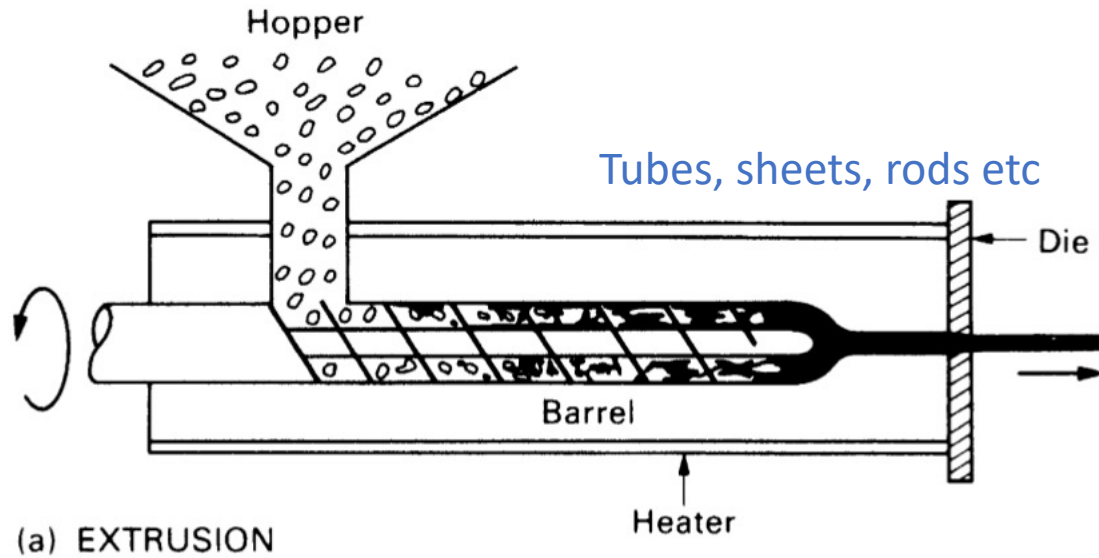
Processing criteria



Elastic modulus and stiffness to deformation can change by factor of 1000 when temperature is changed

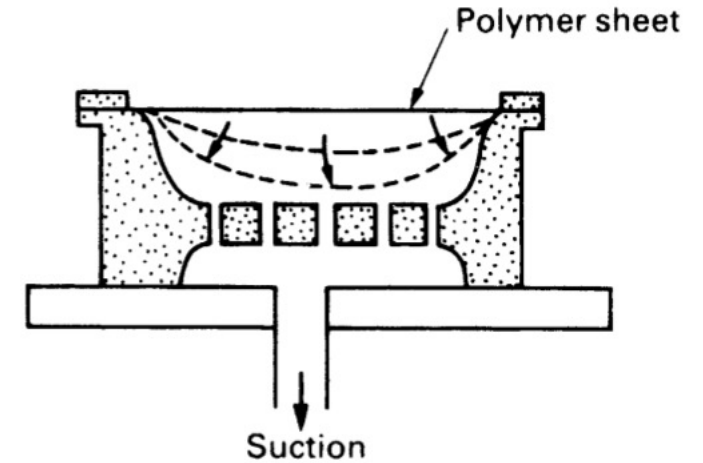
Linear linked polymers, called thermoplastics, tend to show a behavior has shown in the figure.

Common synthesis methods

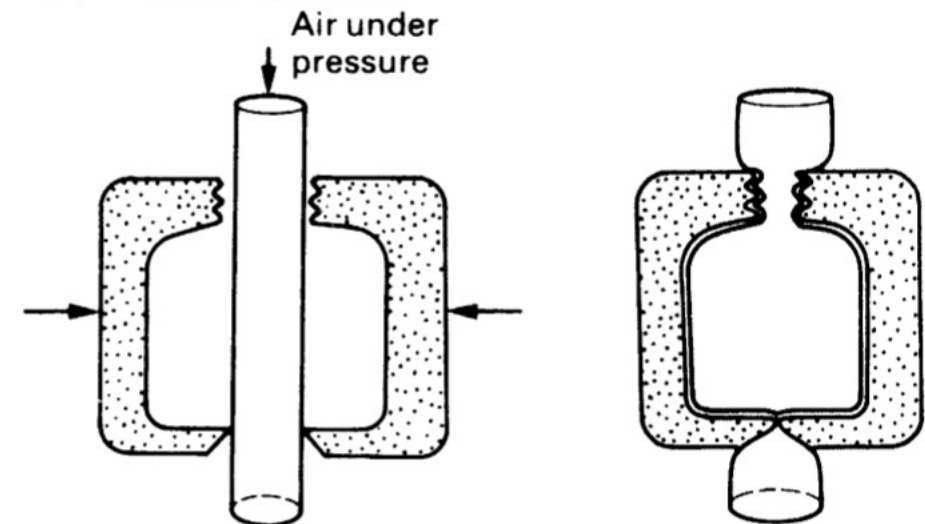


After extrusion, forming steps:

(a) VACUUM FORMING



(b) BLOW MOULDING



Ceramics

Ceramic	Cost (UK£ (US\$) tonne ⁻¹)	Density (Mg m ⁻³)	Young's modulus (GPa)	Compressive strength (MPa)	Modulus of rupture (MPa)	Weibull exponent <i>m</i>	Time exponent <i>n</i>	Fracture toughness (MPa m ^{1/2})	Melting (softening) temperature (K)	Specific heat (J kg ⁻¹ K ⁻¹)	Thermal conductivity (W m ⁻¹ /K ⁻¹)	Thermal expansion coefficient (MK ⁻¹ J)	Thermal shock resistance (K)
Glasses													
Soda glass	700 (1000)	2.48	74	1000	50	Assume 10 in design	10	0.7	(1000)	990	1	8.5	84
Borosilicate glass	1000 (1400)	2.23	65	1200	55		10	0.8	(1100)	800	1	4.0	280
Pottery, etc. Porcelain	260–1000 (360–1400)	2.3–2.5	70	350	45		–	1.0	(1400)	800	1	3	220
High-performance engineering ceramics													
Diamond	4 × 10 ⁸ (6 × 10 ⁸)	3.52	1050	5000	–	–	–	–	–	510	70	1.2	1000
Dense alumina	Expensive at	3.9	380	3000	300–400	10	10	3–5	2323 (1470)	795	25.6	8.5	150
Silicon carbide	present.	3.2	410	2000	200–500	10	40	–	3110 –	1422	84	4.3	300
Silicon nitride	Potentially	3.2	310	1200	300–850	–	40	4	2173 –	627	17	3.2	500
Zirconia	350–1000	5.6	200	2000	200–500	10–21	10	4–12	2843 –	670	1.5	8	500
Sialons	(490–1400)	3.2	300	2000	500–830	15	10	5	– –	710	20–25	3.2	510
Cement, etc.													
Cement	52 (73)	2.4–2.5	20–30	50	7	12	40	0.2	–	–	1.8	10–14	<50
Concrete	26 (36)	2.4	30–50	50	7	12	40	0.2	–	–	2	10–14	
Rocks and ice													
Limestone	Cost of mining	2.7	63	30–80	20	–	–	0.9	–	–	–	8	≈ 100
Granite	and transport	2.6	60–80	65–150	23	–	–	–	–	–	–	8	
Ice		0.92	9.1	6	1.7	–	–	0.12	273 (250)	–	–	–	

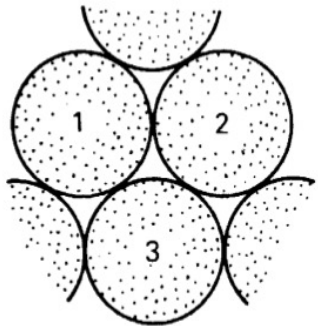
Basic processes:

Example of alumina

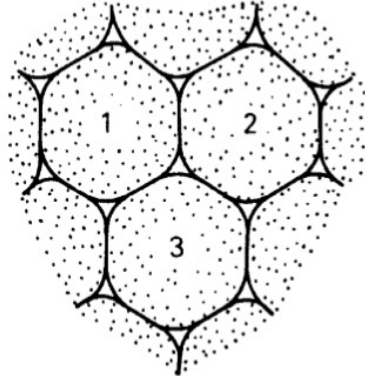


Bauxite is heated to 1150 C to dehydrate

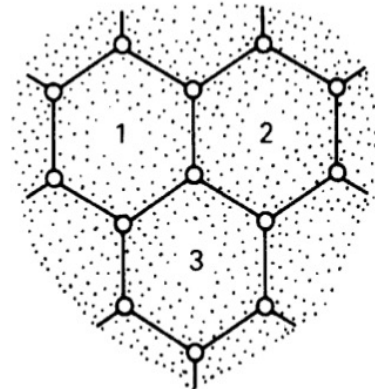
Sintering:



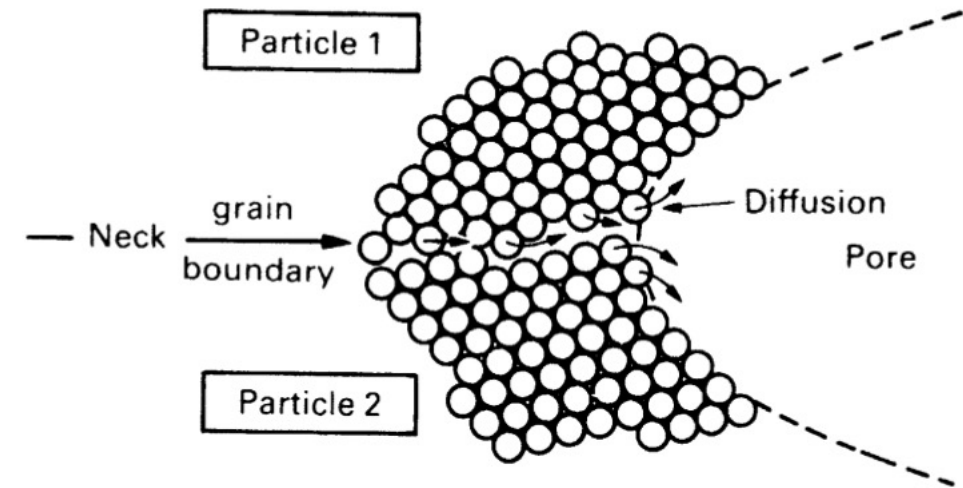
(a)



(b)



(c)



Rates of densification

$$\frac{d\rho}{dt} = \frac{C}{a^n} \exp(-Q/RT).$$

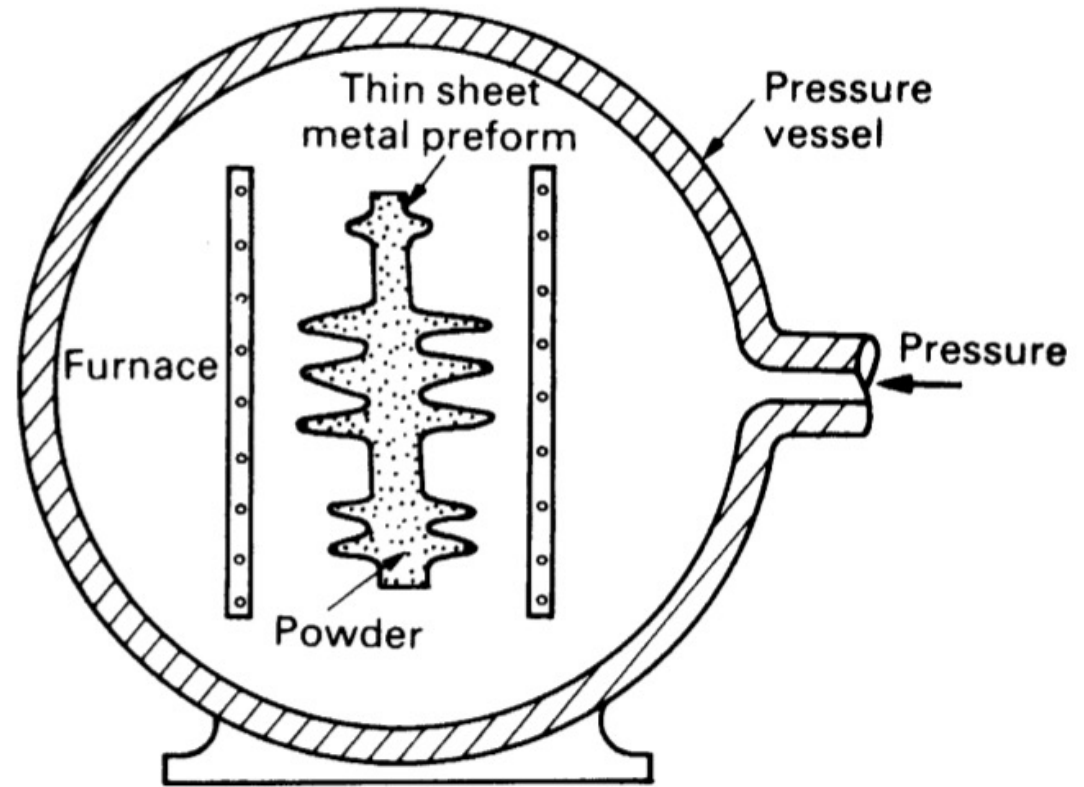
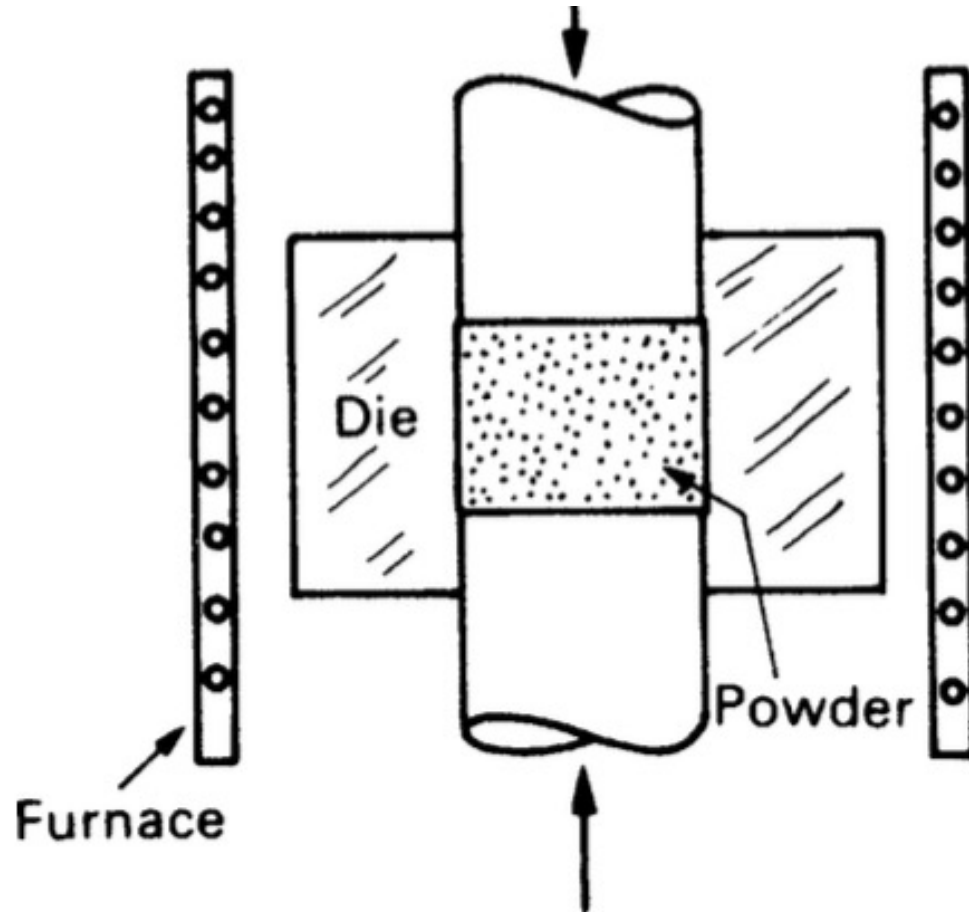
ρ - density

a - particle size

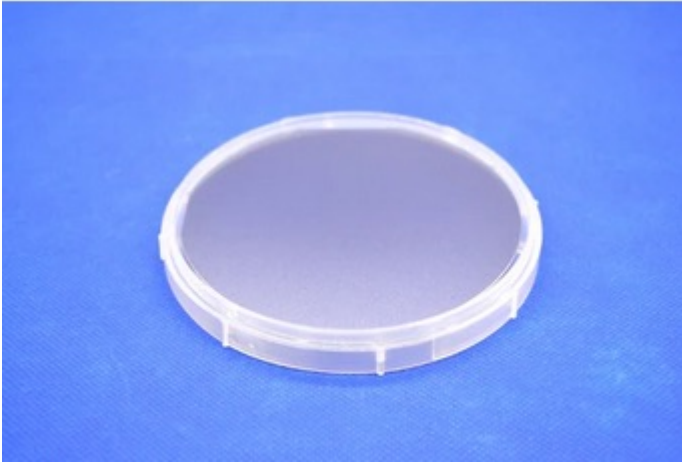
$n \sim 3$,

Q – activation energy for diffusion (typically grain boundary migration)

Commonly used techniques



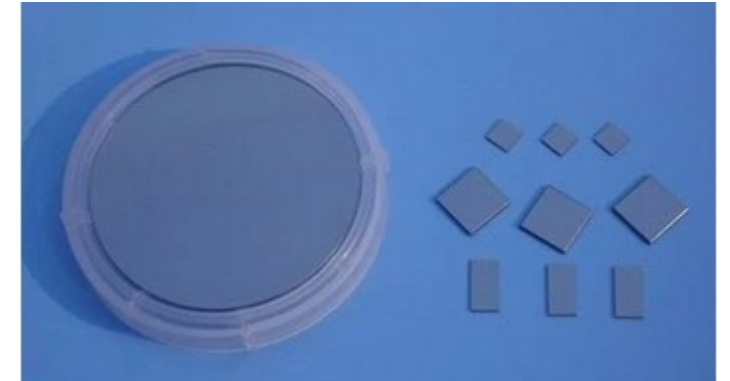
Semiconducting crystals



Si Single crystals
MSE supplies – 2" – 29\$



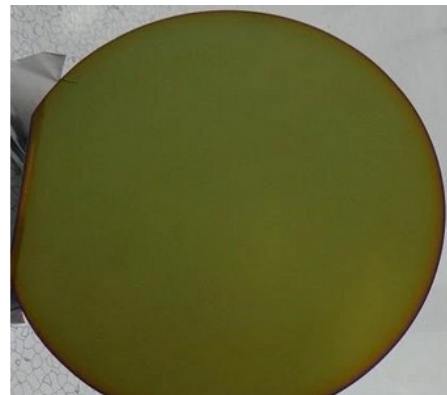
GaN single crystal
(MSE supplies – 2" wafer 2500\$)



GaAs single crystal
(MSE supplies – 2" wafer 58\$)



1"x 1" graphene
(MSE supplies – 2" wafer 300\$)

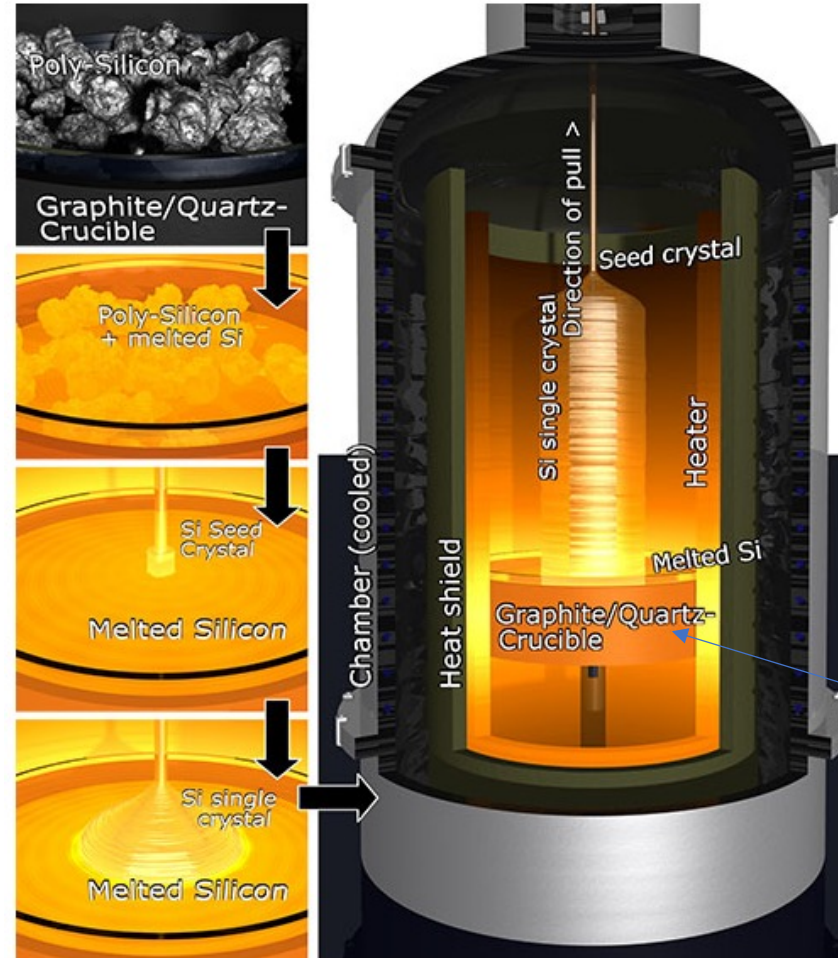
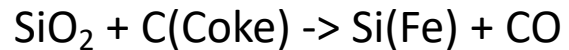


GaN epitaxial stacks
(MSE supplies – 2" wafer 535\$ and above)

Example 1: 3D Crystal Growth from Seed:



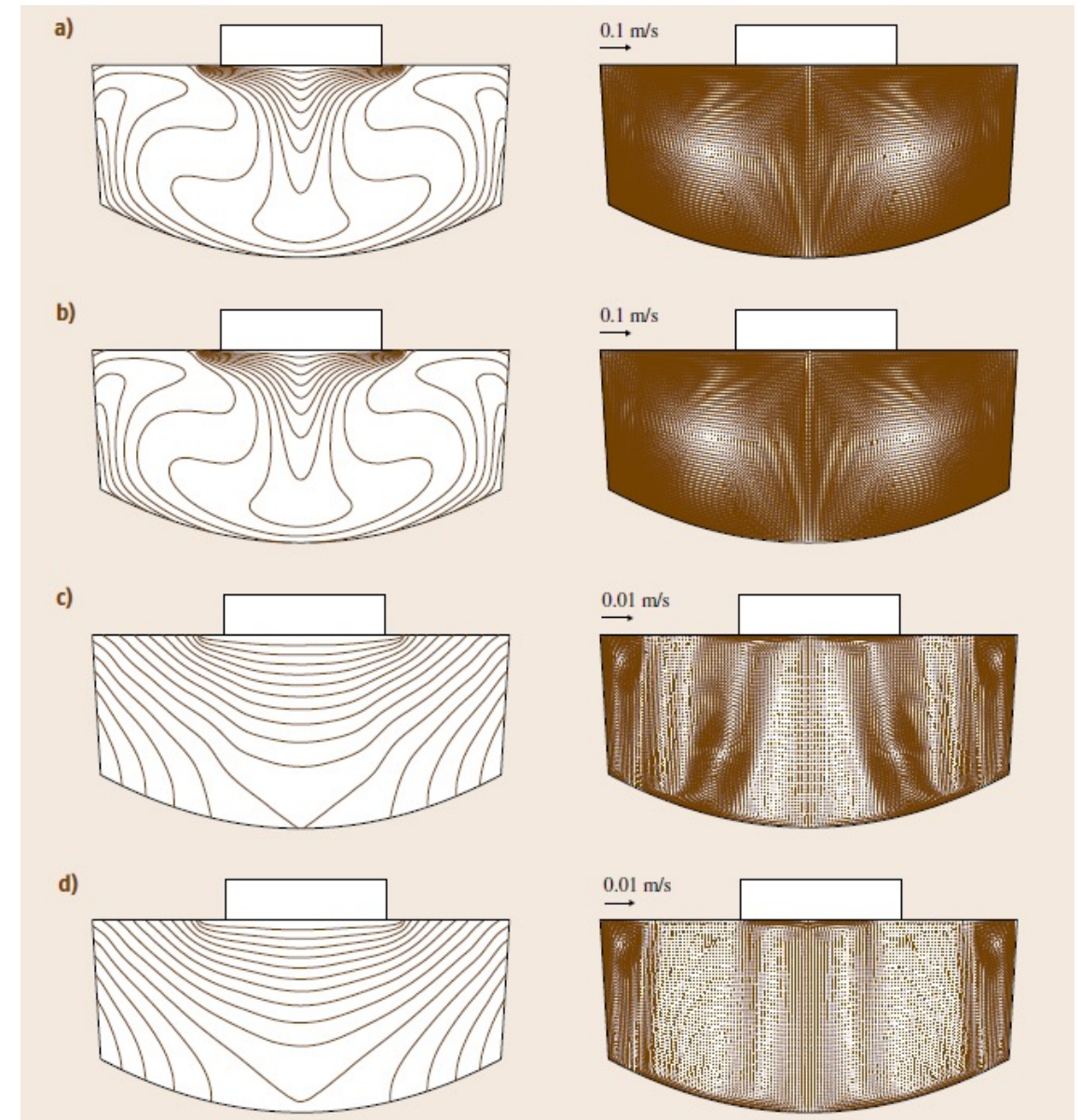
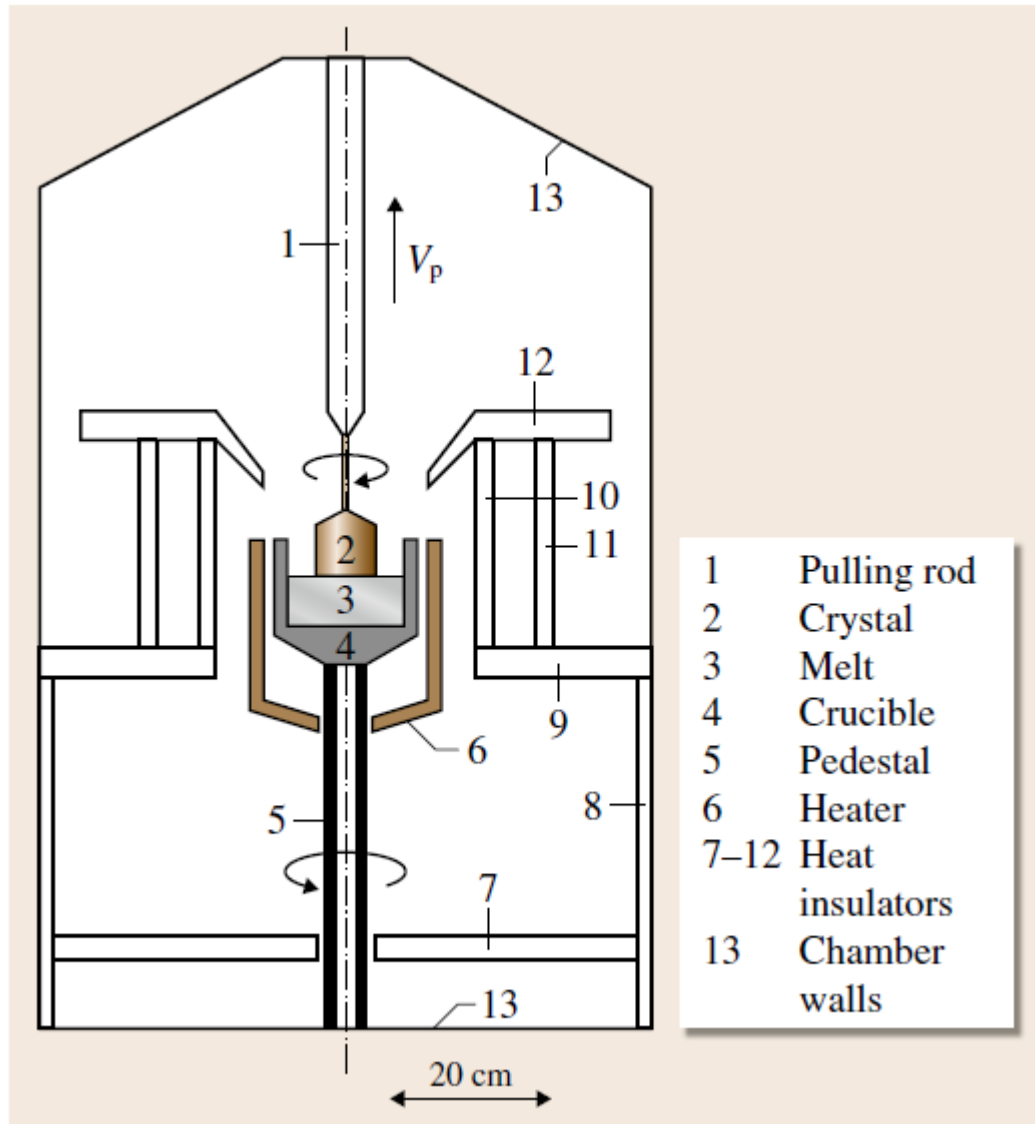
They say sand, but to get electronic grade Si, you need 99.999999999% pure Si powder



Si in the liquid phase gets attracted to the seed crystal
Due to surface tension.

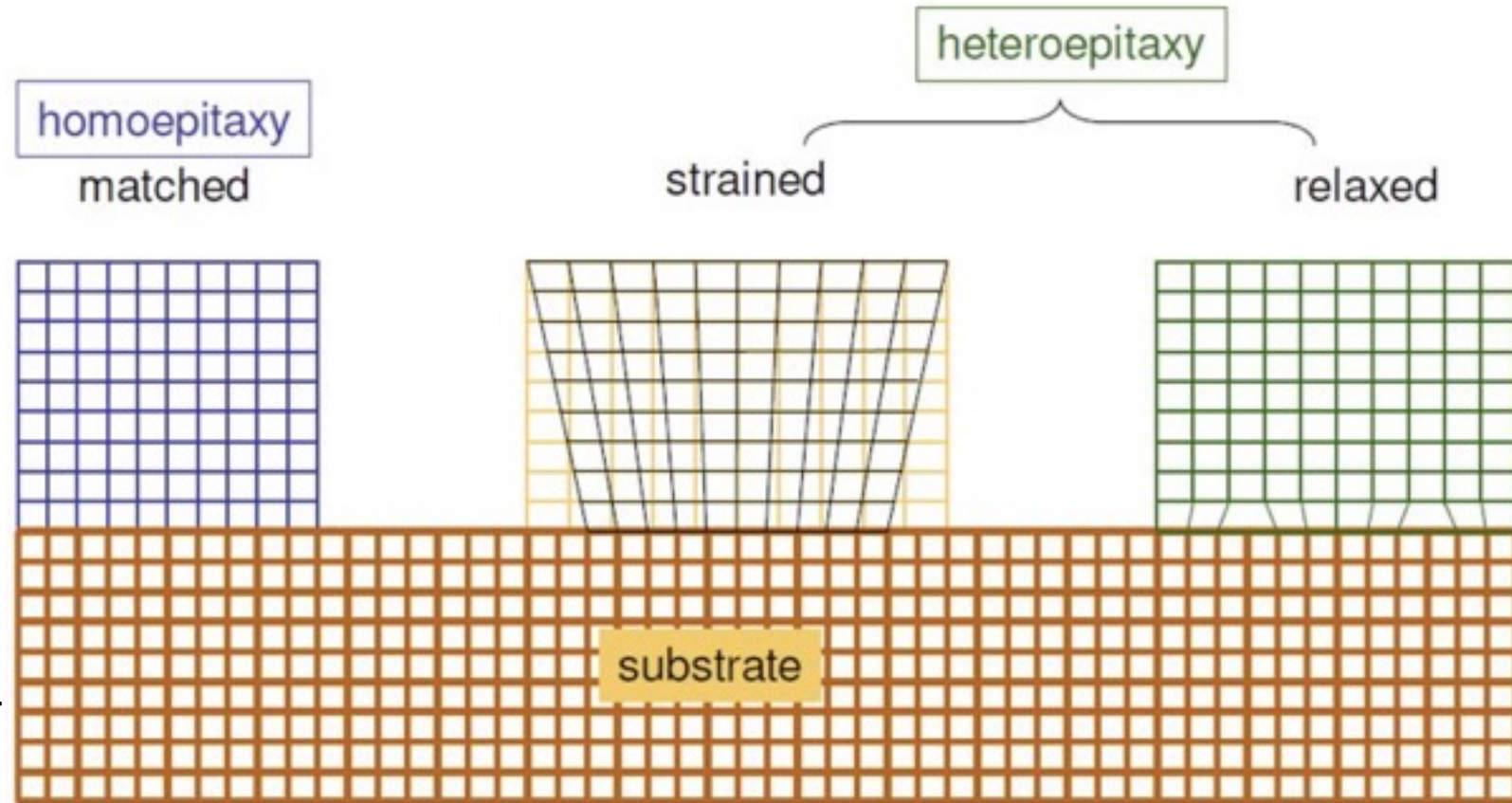
1500 C crucible

Czochralski process



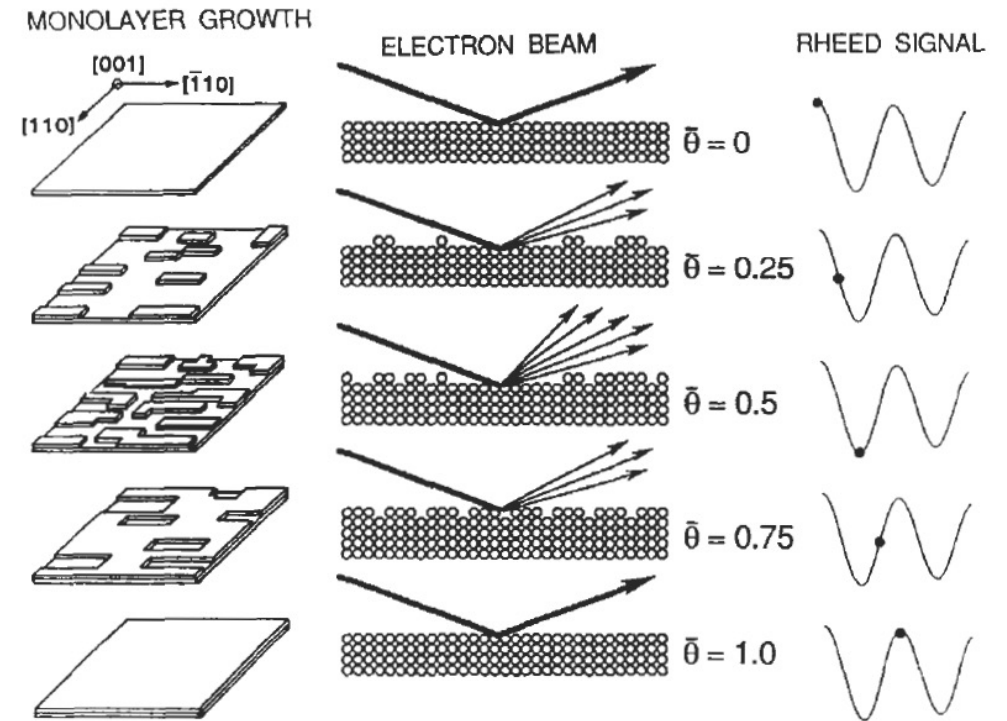
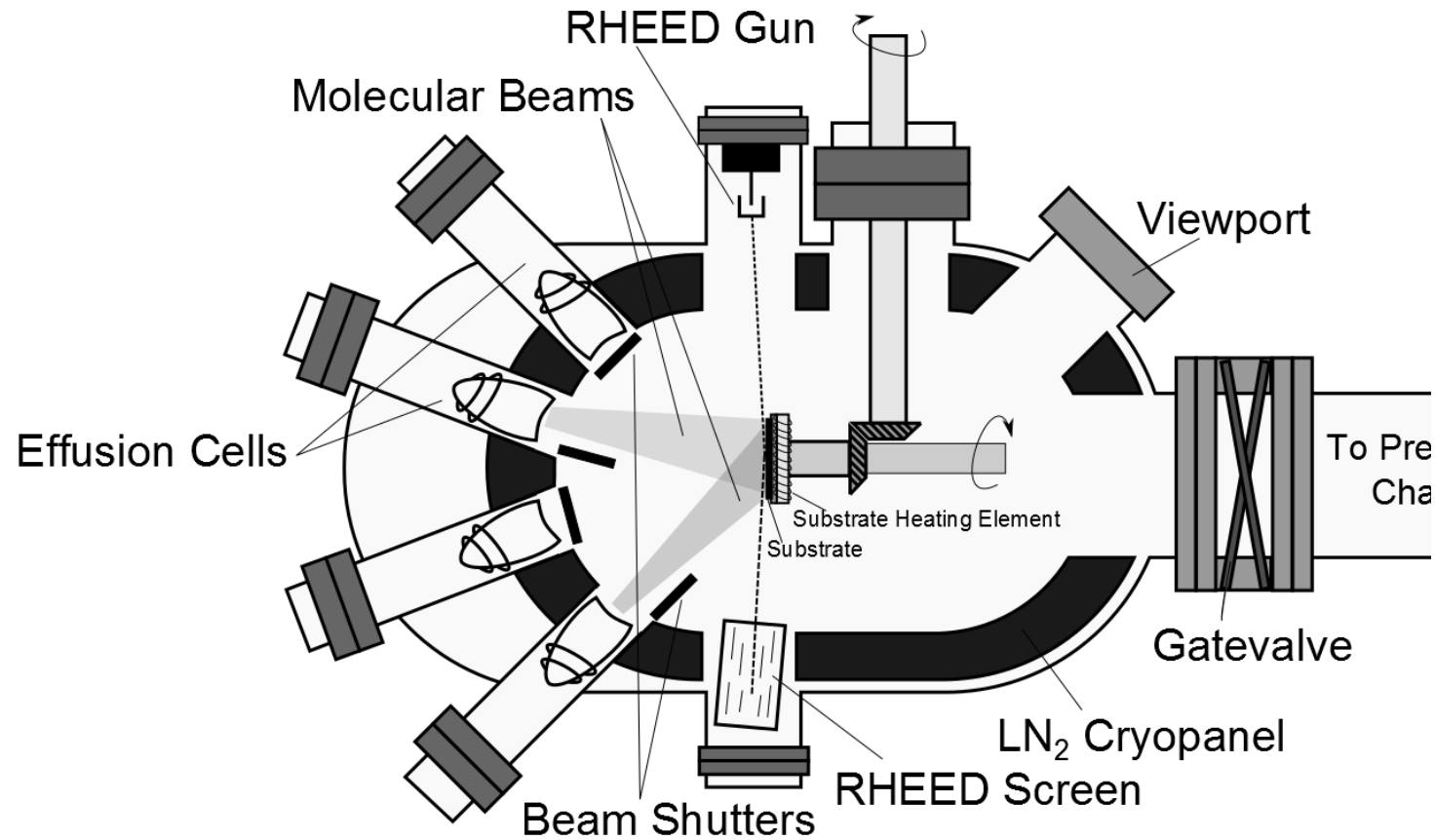
Epitaxy

- Epitaxy is growth of ordered layer over another pre-existing substrate.
- In conventional semiconductor industry, it is used to grow crystalline layers of a semiconductor over a large area wafer.
- If the second layer is the same as the first layer, it is called as homoepitaxy and if the second layer is different, it is called as heteroepitaxy.

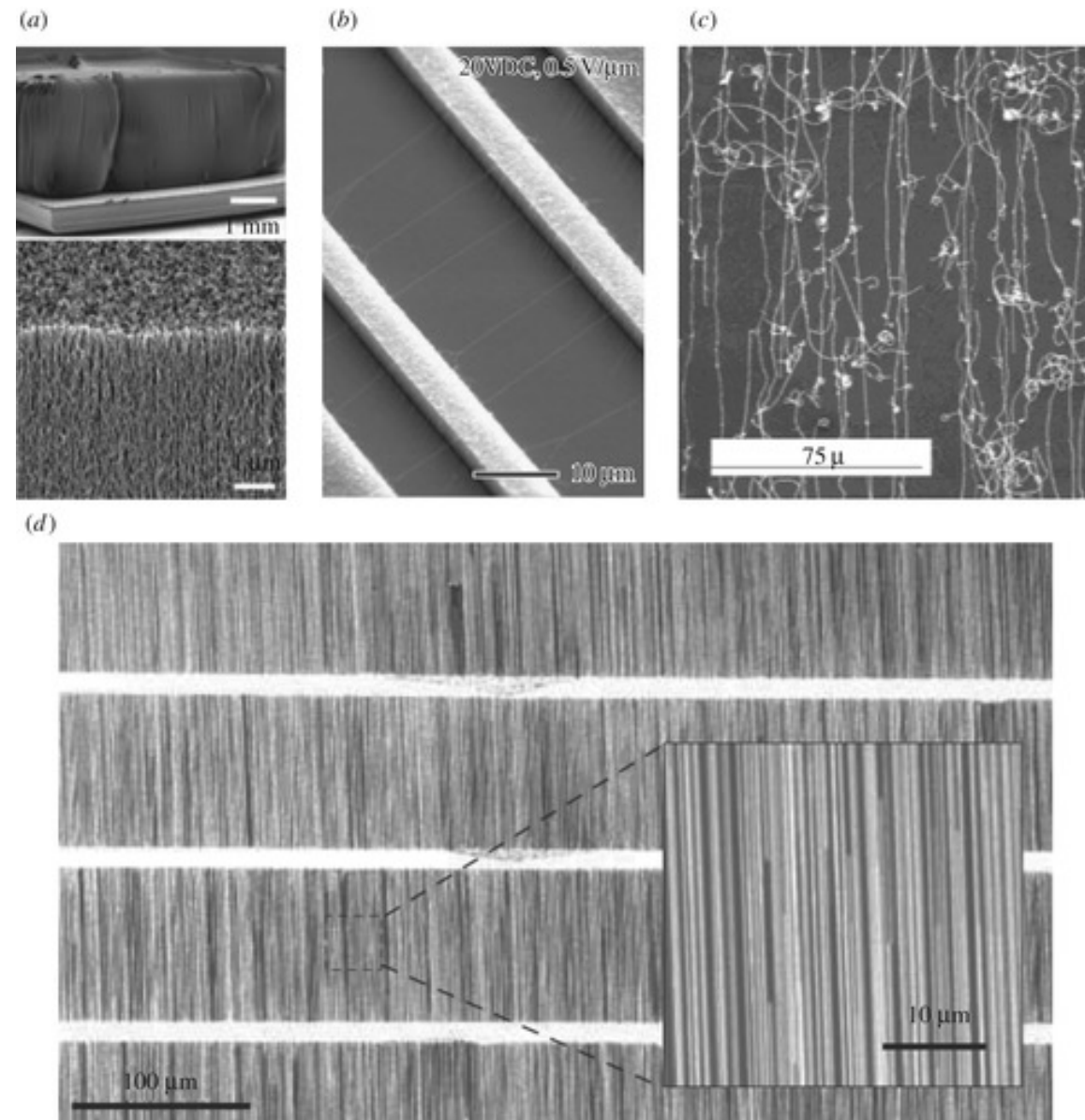
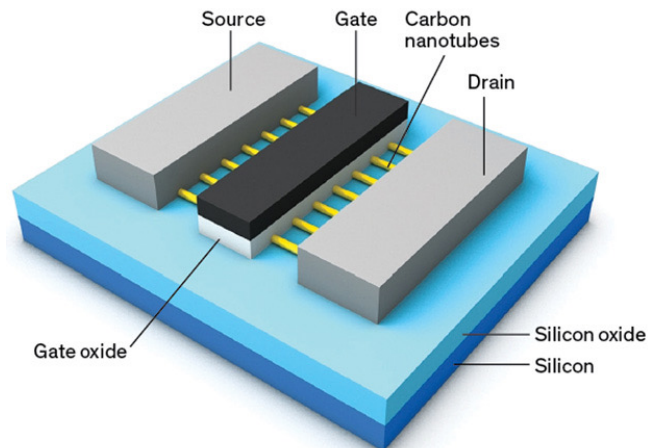
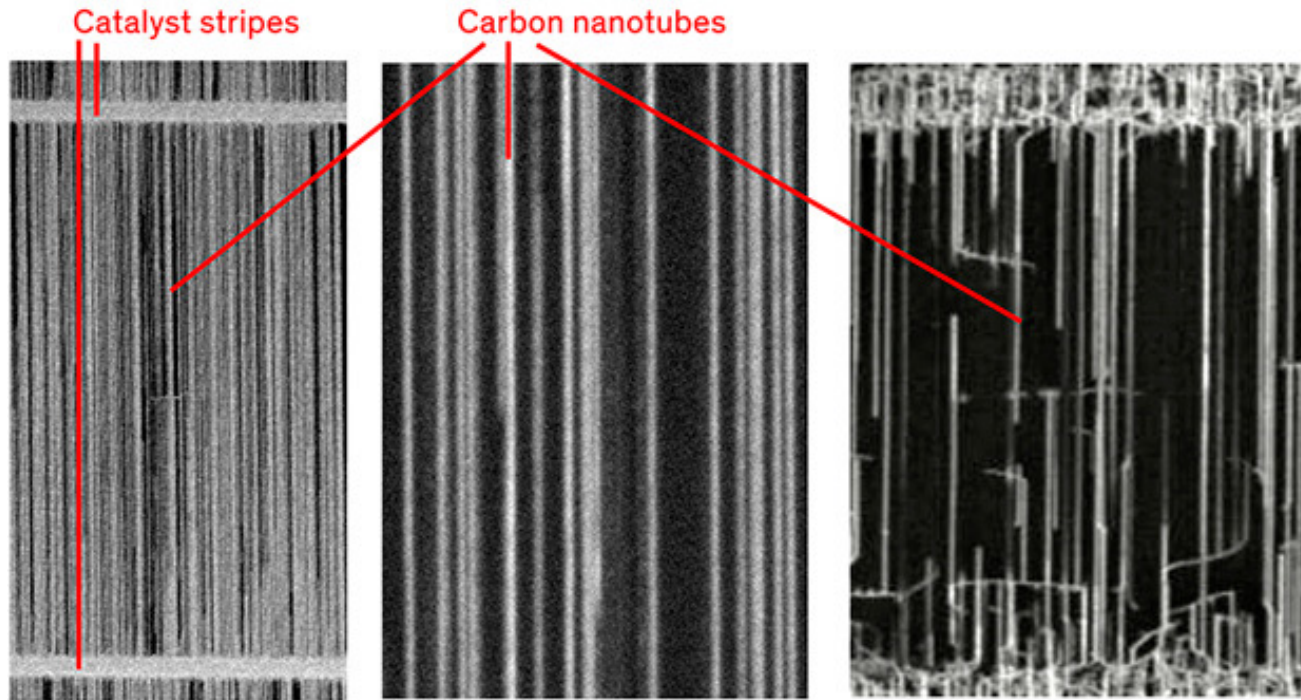


Molecular Beam Epitaxy

1. High vacuum technique – 10^{-11} torr
2. Approximately 1 monolayer per sec.
3. Several monitoring tools.
4. Walls cooled by liquid N_2
5. One or more molecular beams are directed towards the substrate
6. Extreme material purity, doping control and thickness of layers

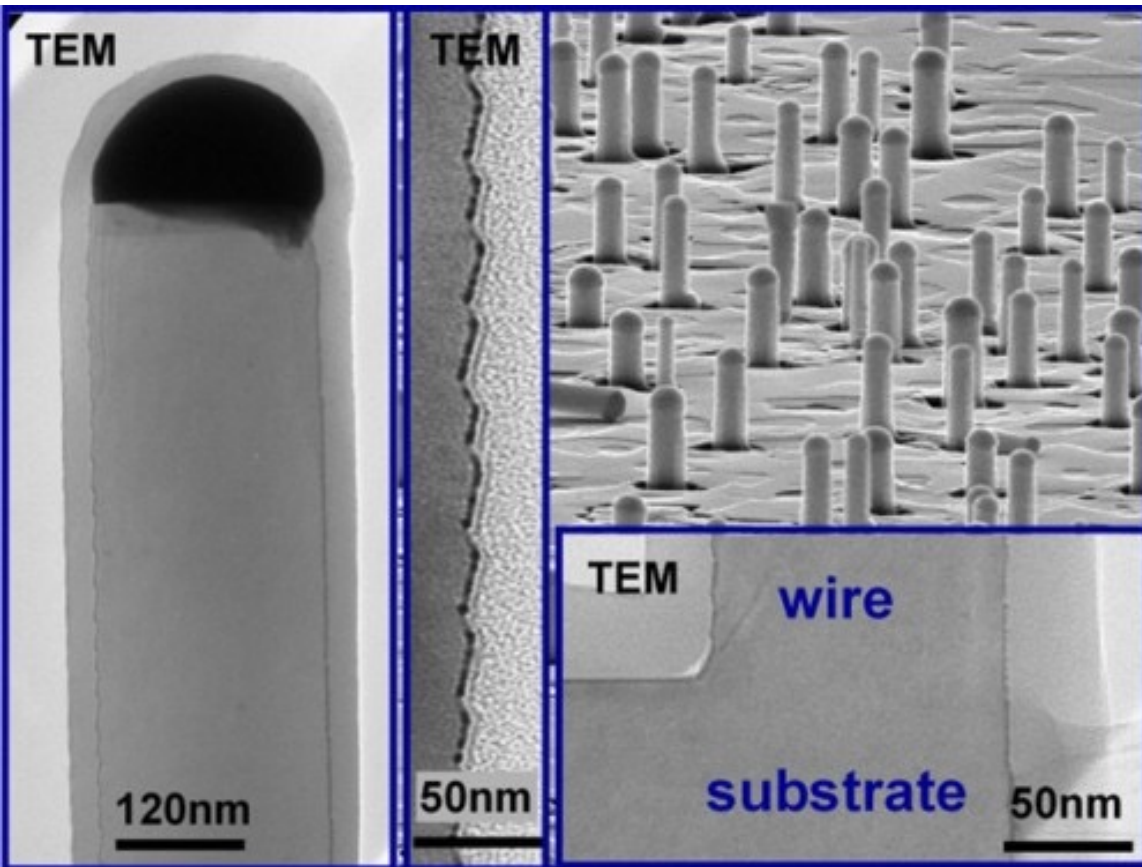


1D nanostructures

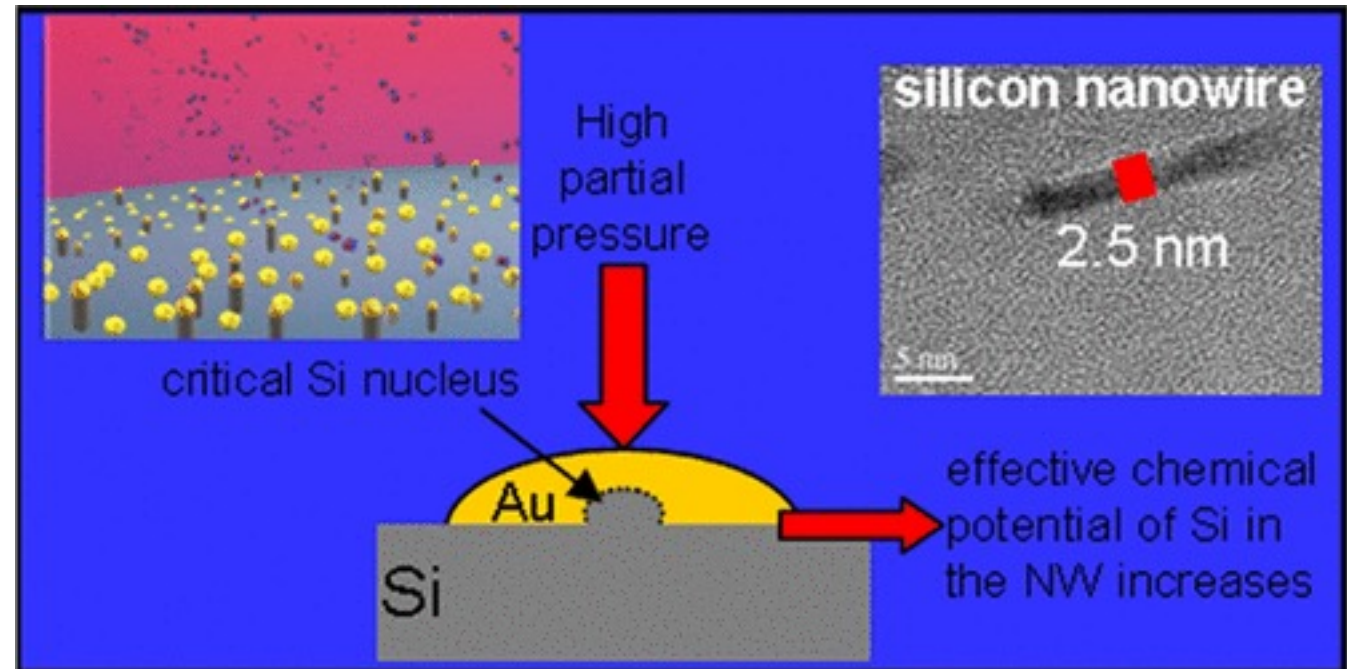


Growth by epitaxial CVD

Si Nanowires



Vapor – Liquid – Solid Method



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