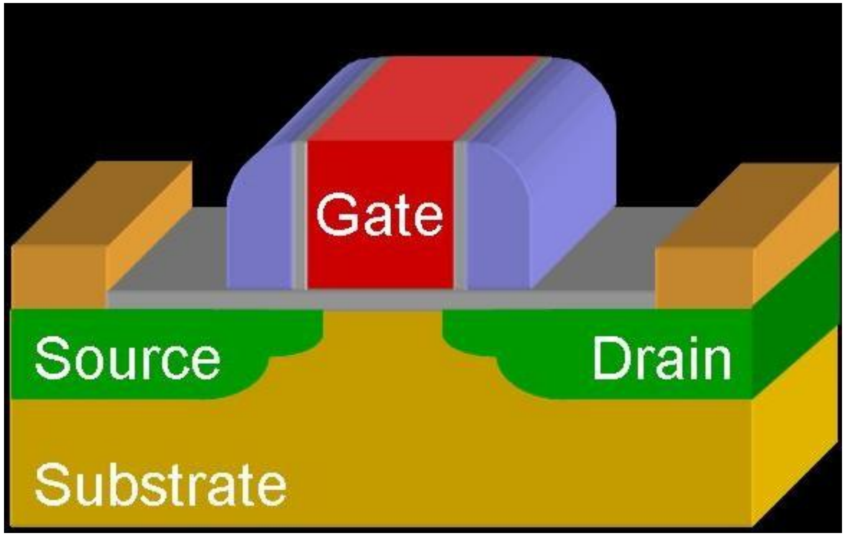
Bulk crystal growth

The progress of solid state device technology has depended not only on the development of device concepts but also on the improvement of materials.

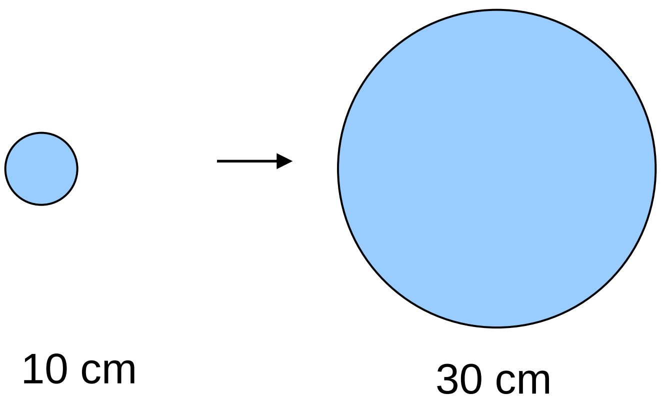
A reduction in Lg will increase g_m and f_{oper} but with some costs …

- Short-Channel Effects
- Subthreshold Conduction
- Channel Length Modulation
- Mobility Variation v_{drift} / E [$cm^2/V \cdot s$]
- Vth instabilities …



Bulk crystal growth

The purity of device-grade semiconductor crystals must be controlled within extremely close limits. For example, Si crystals now being used in devices are grown with concentrations of most impurities of less than 1pptb.



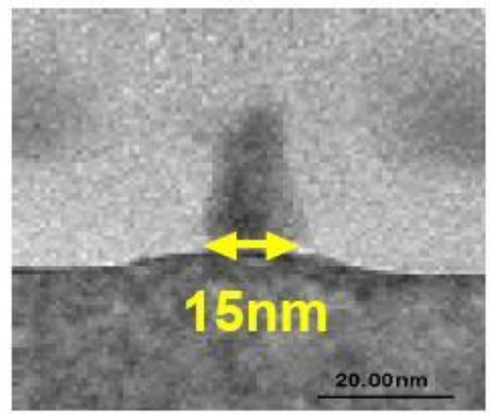


Figure : TeraHertz transistor with 15nm gate

45nm (07)

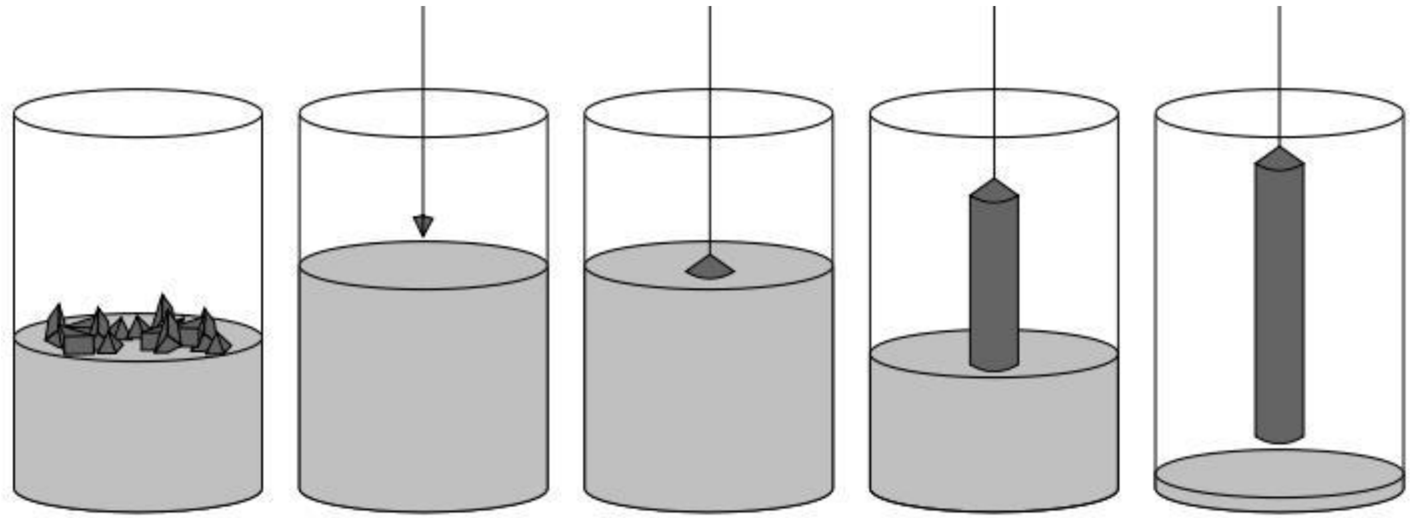
250nm (97)

Pentium

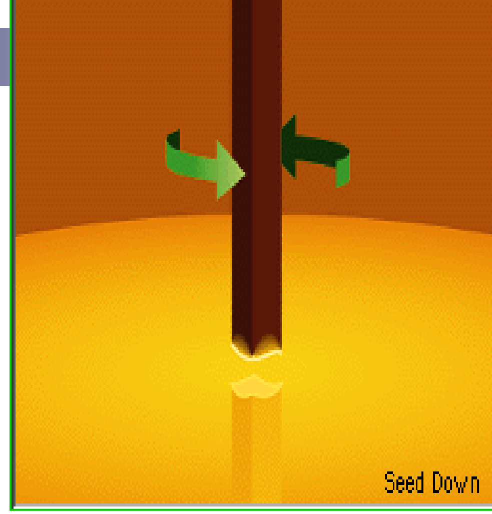
800nm (93)

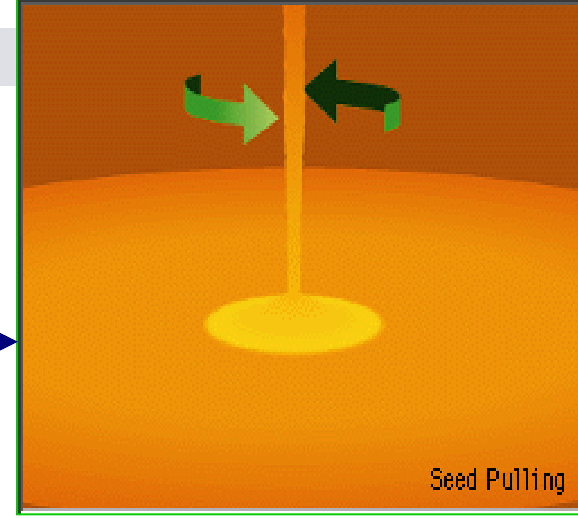
Czochralski method

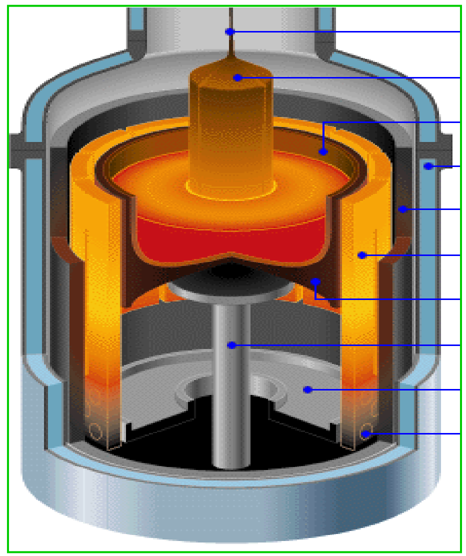
The grow of single-crystal materials is generally done by a process called the *Czochralski* method.

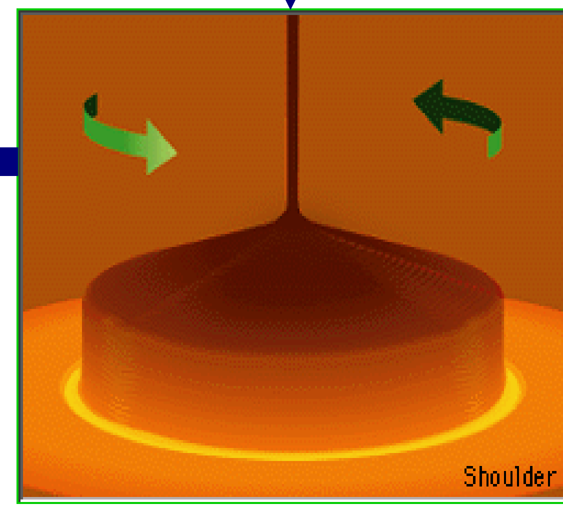


In order to grow single-crystal material, its necessary to have a seed crystal which can provide a template for growth. We melt the EGS in a quartz-lined graphite crucible by resistively heating it to the melting point of Si (1412° C).


Seed Down


Seed Pulling




Shoulder

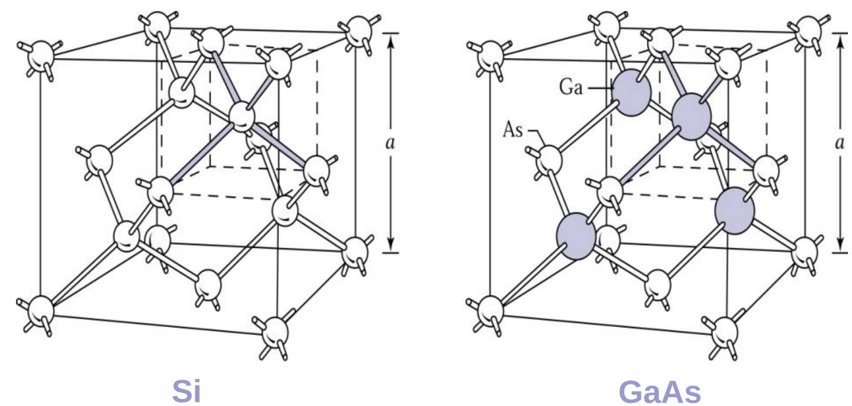
Epitaxial growth

One of the most important and versatile methods of crystal growth for device applications is the growth of a thin crystal layer on a wafer of a compatible crystal.

The substrate crystal may be a wafer of the same material as the grown layer or a different material with a *similar lattice structure*.

The growing crystal layer maintains the crystal structure and orientation of the substrate.

EG can be performed at temperatures considerable *below the melting point* of the substrate crystal.

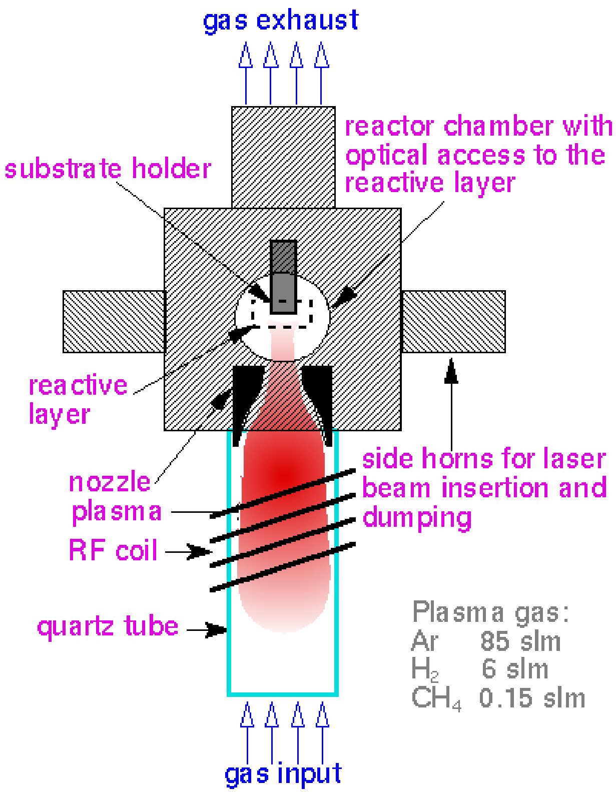


The technique of growing an oriented single-crystal layer on a substrate wafer is called *epitaxial growth*, or *epitaxy*.

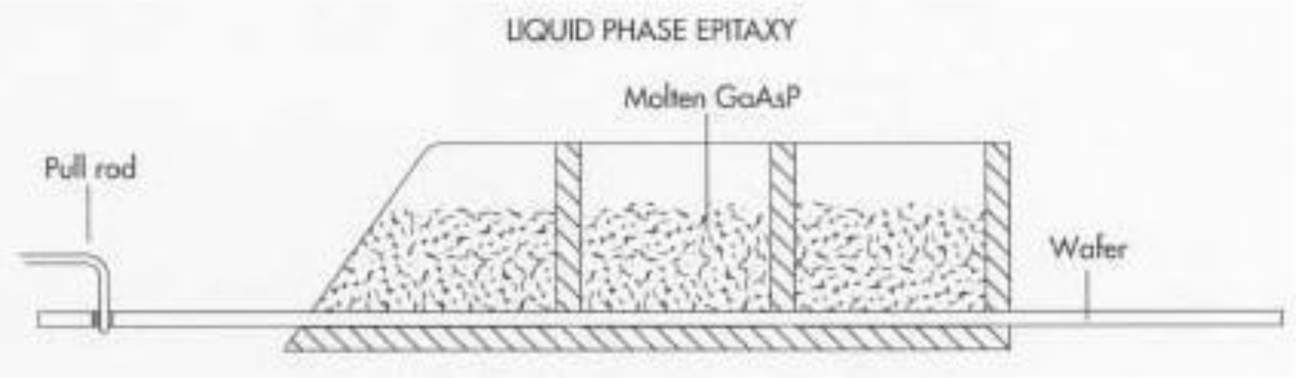
A variety of methods are used to provide the appropriate atoms to the surface of the growing layer.

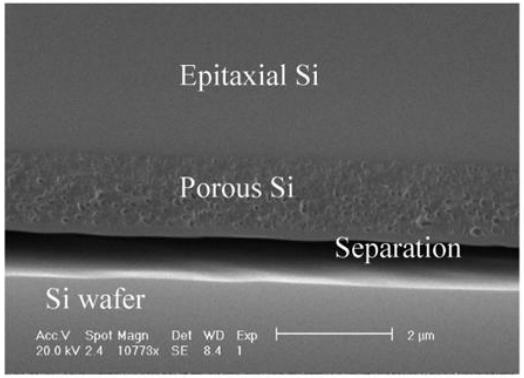
Chemical vapor deposition (CVD): is a chemical process used to produce high-purity, high-performance solid materials. The process is often used in the semiconductor industry to produce thin films.

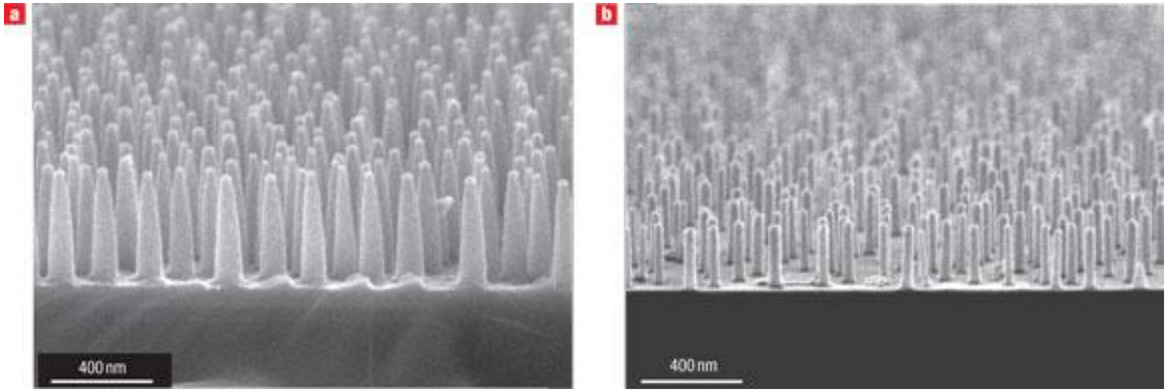
- CVD processes are typically realized by allowing hot reactant gas to contact with a cooled solid substrate.
- The gas cools rapidly in a thin layer at close proximity of the substrate, leading to deposit formation on the substrate through chemical reactions both in gas phase and substrate surface.



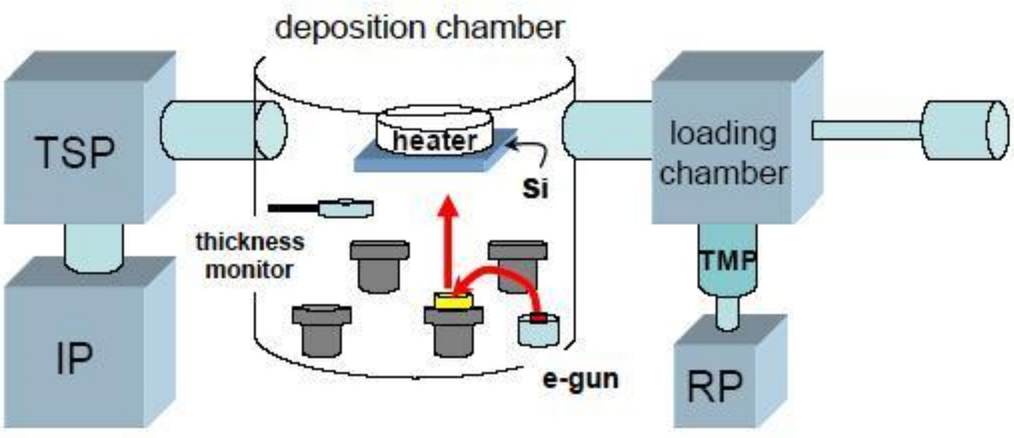
Liquid-phase epitaxy (LPE): growing of semiconductor crystal layers from its melt on solid substrates. This happens at temperatures well below the melting point of the deposited semiconductor. This method is mainly used for the growth of compound semiconductors. Very thin, uniform and high quality layers can be produced.

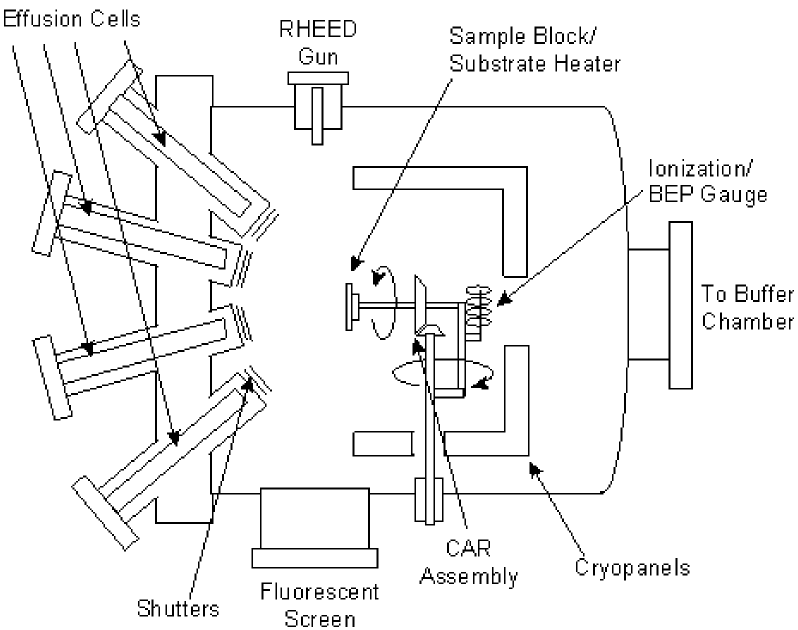




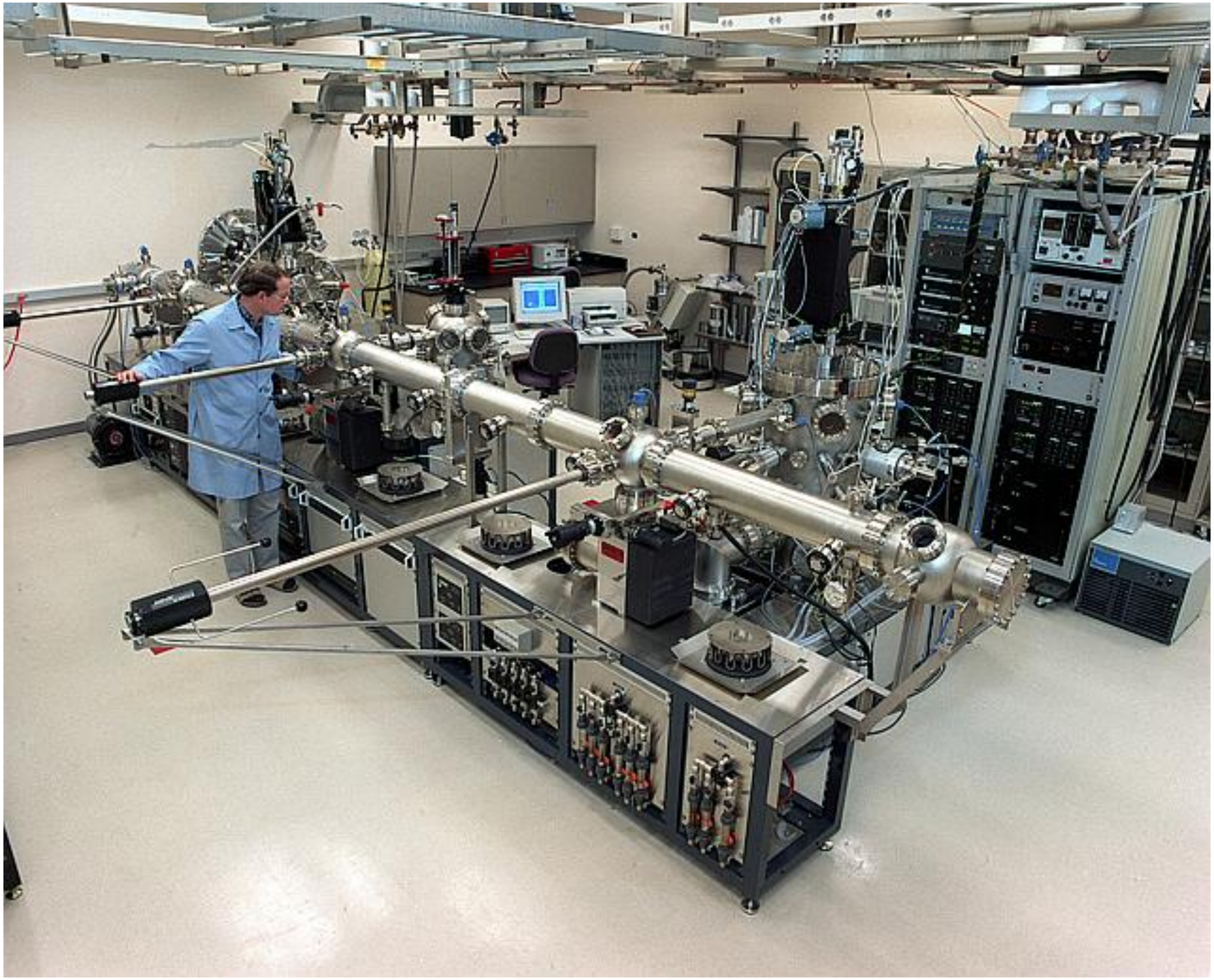


Molecular beam epitaxy (MBE): a source material is heated to produce an evaporated beam of particles. These particles travel through a very high vacuum (10^{-8} Pa; practically free space) to the substrate, where they condense. MBE has lower throughput than other forms of epitaxy.



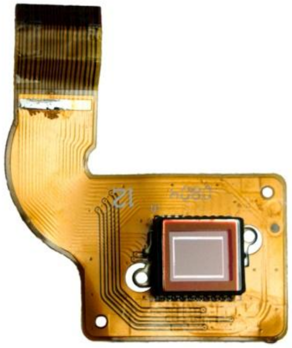


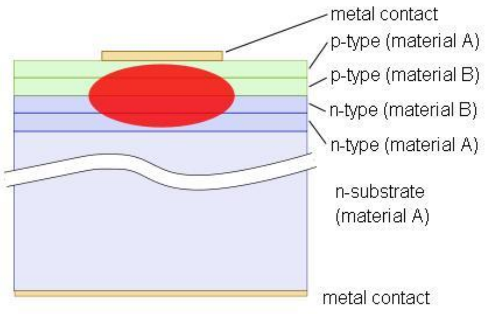
MBE system at research facility (Texas A&M U.)

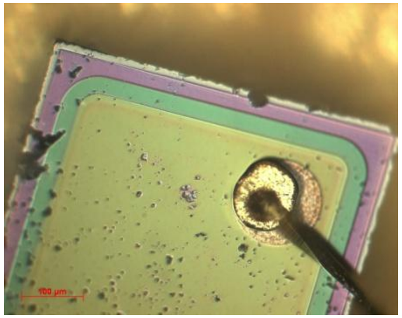


With this wide range of epitaxial growth techniques, it is possible to grow a variety of crystals for device applications, having properties specifically designed for the electronic or optoelectronic device being made.

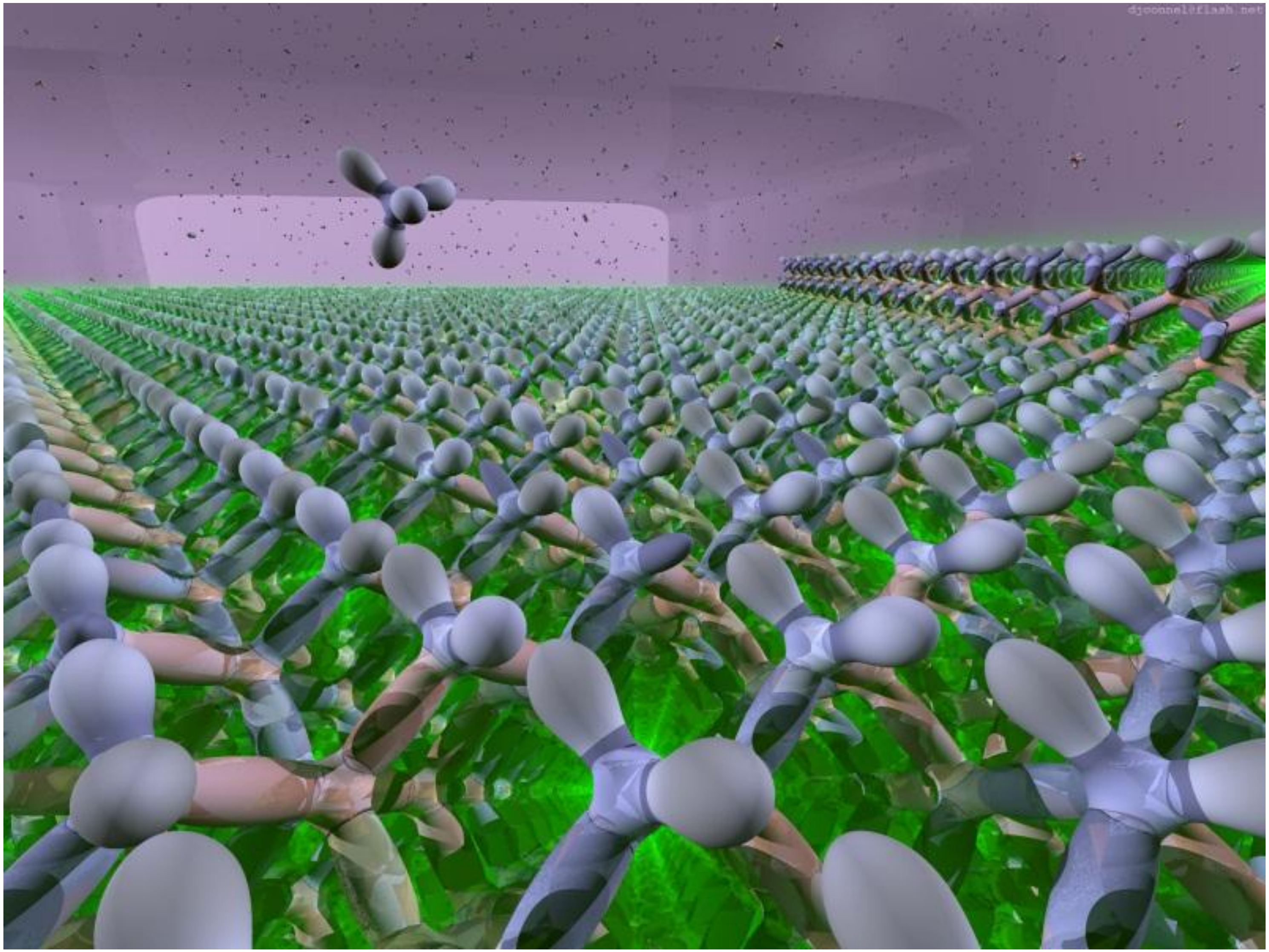
- Photodiodes and phototransistors
- Image sensors
- Laser diodes
- Night vision devices



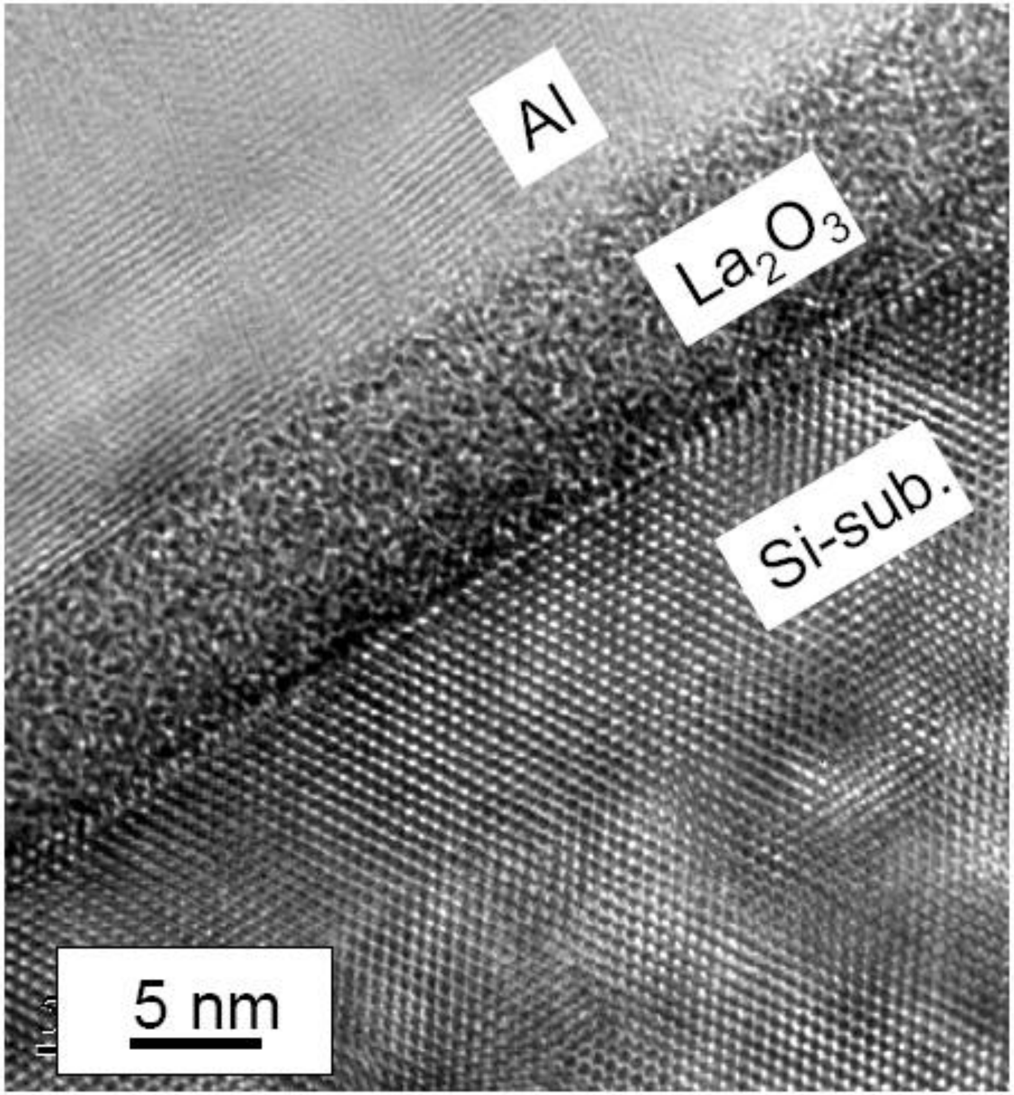




Ideal Case



TEM IMAGE FOR MIS SYSTEM

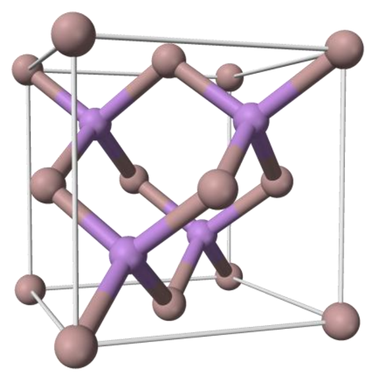


Homoepitaxy is a kind of *epitaxy performed with only one material*. In homoepitaxy, a crystalline film is grown on a substrate or film of the same material. This technology is applied to growing a more purified film than the substrate and fabricating layers with different doping levels.

Heteroepitaxy is a kind of *epitaxy performed with materials that are different from each other*. In heteroepitaxy, a crystalline film grows on a crystalline substrate or film of another material. This technology is often applied to growing crystalline films of materials of which single crystals cannot be obtained and to fabricating integrated crystalline layers of different materials. Examples include gallium nitride (GaN) on sapphire or aluminium gallium indium phosphide (AlGaInP) on gallium arsenide (GaAs).

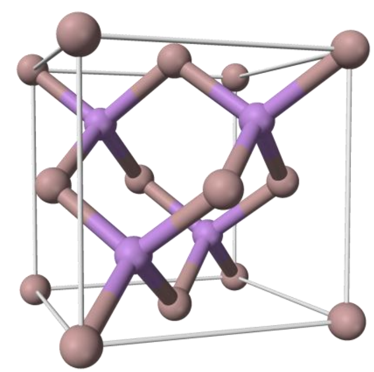
When Si epitaxial layers are grown on Si substrates, there is a natural matching of the crystal lattice, and high-quality single crystals layers result.

On the other hand, it is often desirable to obtain epitaxial layers that differ somewhat from the substrate. This can be accomplished if the *lattice structure and lattice constant match for the two materials*.



GaAs

Eg= 1.43
Lattice= Z
a= 5.65



AlAs

Eg= 2.16
Lattice= Z
a= 5.66

Lattice Matching in Epitaxial Growth

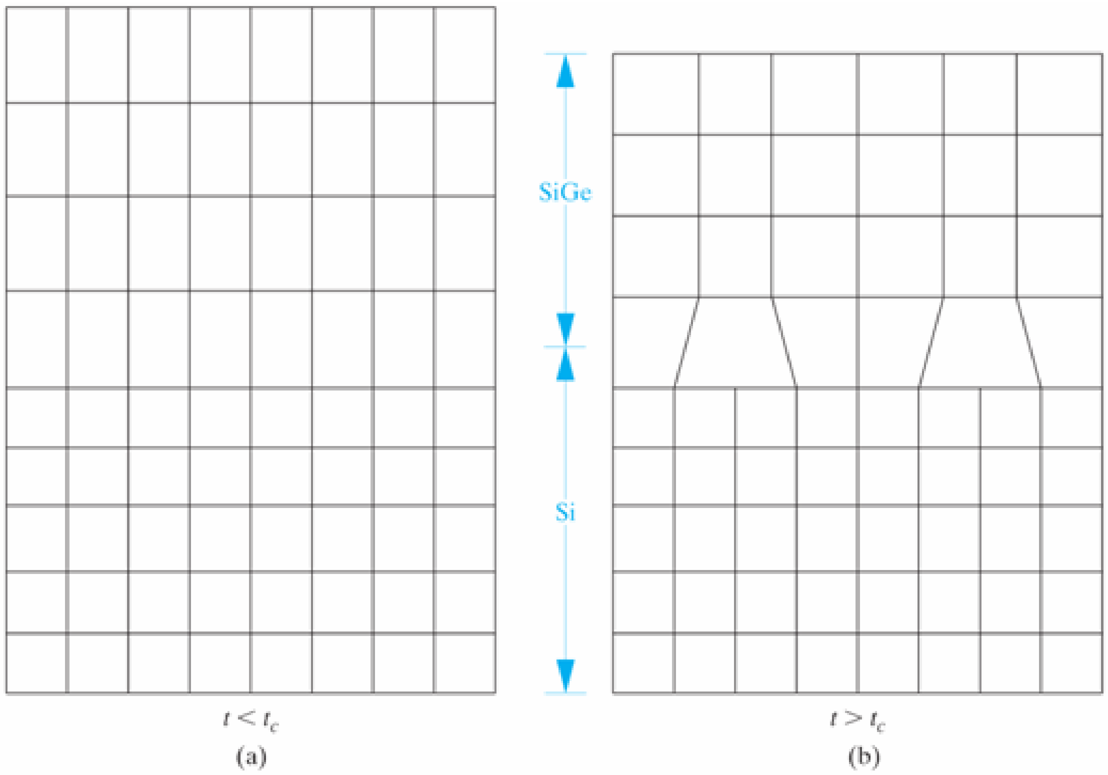


Figure 1.14

Heteroepitaxy and misfit dislocations. For example, in heteroepitaxy of a SiGe layer on Si, the lattice mismatch between SiGe and Si leads to compressive strain in the SiGe layer. The amount of strain depends on the mole fraction of Ge. (a) For layer thicknesses less than the critical layer thickness, t_c, pseudomorphic growth occurs. (b) However, above t_c, misfit dislocations form at the interface which may reduce the usefulness of the layers in device applications.

SiGe Technology:

New Research Directions and Emerging Application Opportunities

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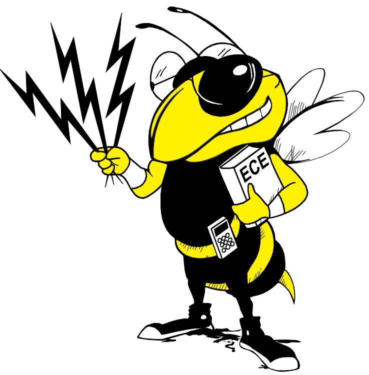


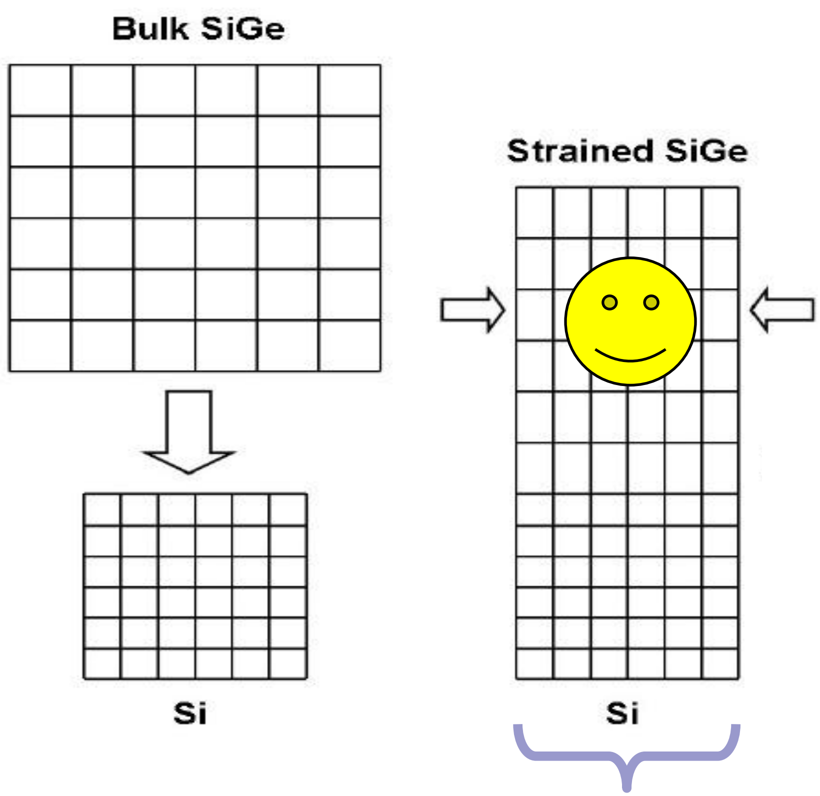
IEEE Electron Devices Society Distinguished Lecture

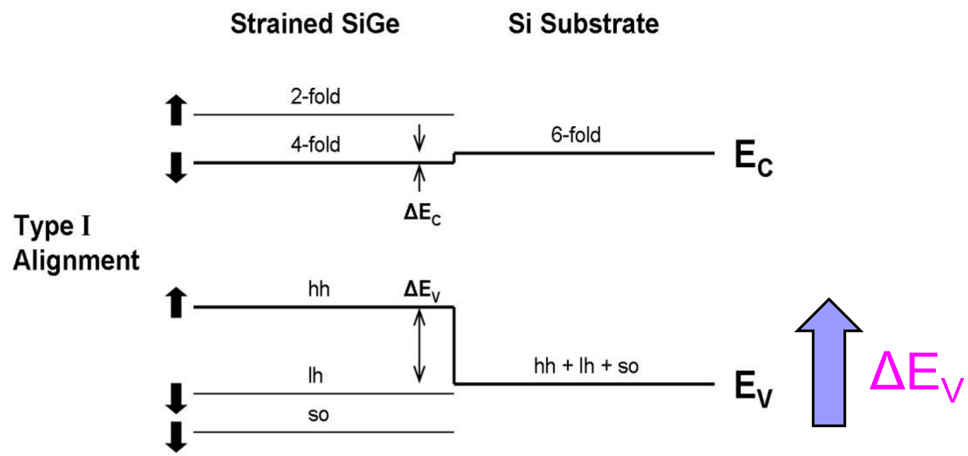
National Institute of Astrophysics, Optics and Electronics, Puebla, Mexico, May 2010

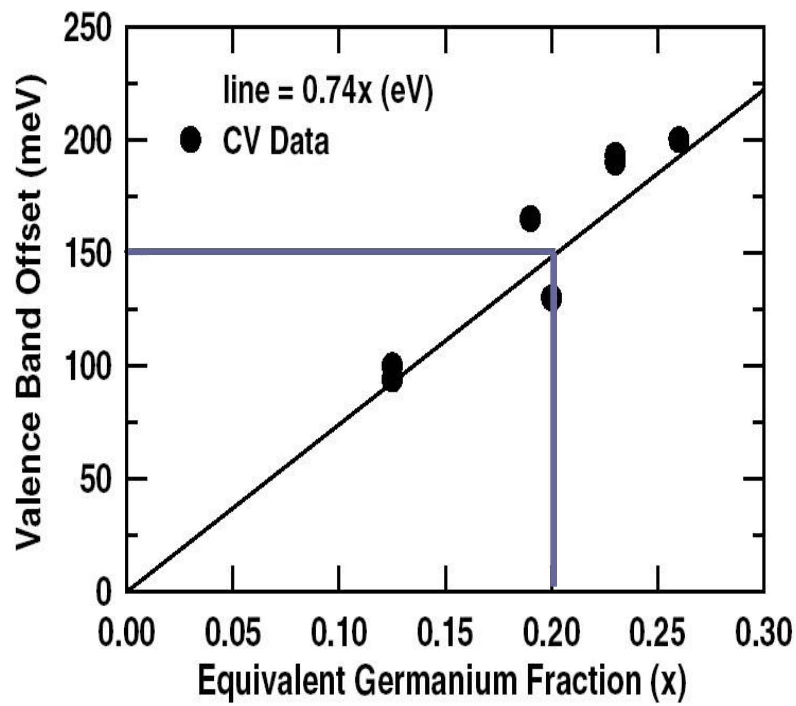
SiGe Strained Layer Epi

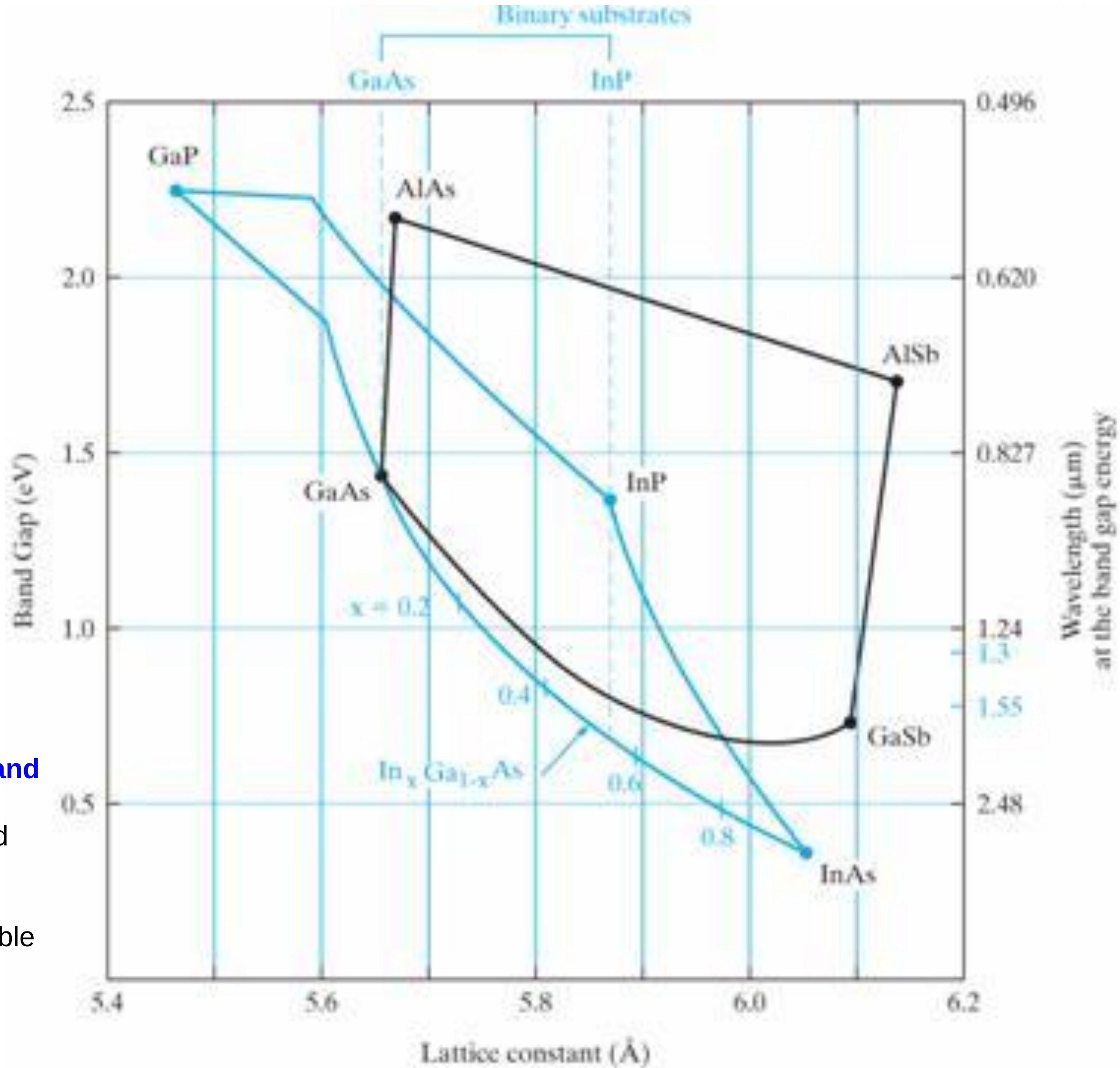
The Bright Idea!

Practice Bandgap Engineering
… but do it in Silicon!









Relationship between **band gap *Eg* and lattice constant *a*** for several III-V ternary compounds as they are varied over their composition ranges.The dashed vertical lines show the lattice constants for the commercially available binary substrates GaAs and InP.

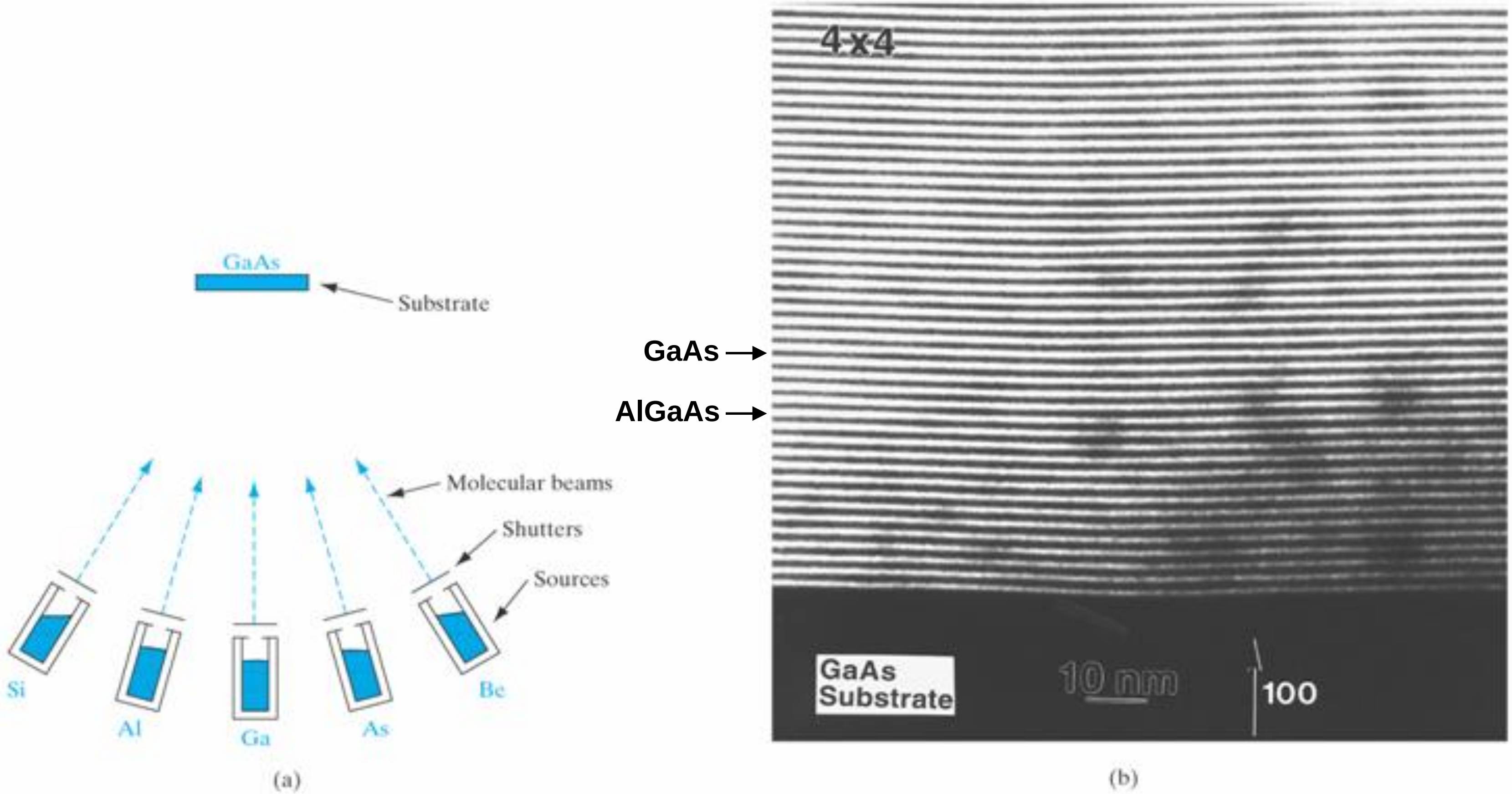


Figure 1.16

Crystal growth by molecular beam epitaxy (MBE): (a) evaporation cells inside a high-vacuum chamber directing beams of Al, Ga, As, and dopants onto a GaAs substrate; (b) scanning electron micrograph of the cross section of an MBE-grown crystal having alternating layers of GaAs (dark lines) and AlGaAs (light lines). Each layer is four monolayers ($4 \times a/2 = 11.3$ Å) thick. (Photograph courtesy of Bell Laboratories.)