Lecture 8 - Epitaxy cont.; Device Processing - Outline

- **Epitaxy techniques** (concluding discussion from Lecture 6)
  - Liquid phase epitaxy
  - Gas phase epitaxy
    - 1. Vapor phase epitaxy; 2. Metallorganic chemical vapor deposition
  - Molecular beam epitaxy
    - 1. Solid source; 2. Gas source; 3. Metalloganic; 4. Chemical beam
- **Device processing**
  - Etching technology
    - 1. Wet etches
      - a. Selective etches; b. Anisotropic etches; c. Isotropic etches
    - 2. Dry etching
  - Doping technology
    - 1. Diffusion
    - 2. Ion implantation
  - Device isolation
  - Ohmic contacts

Mismatched epitaxy - letting layers relax

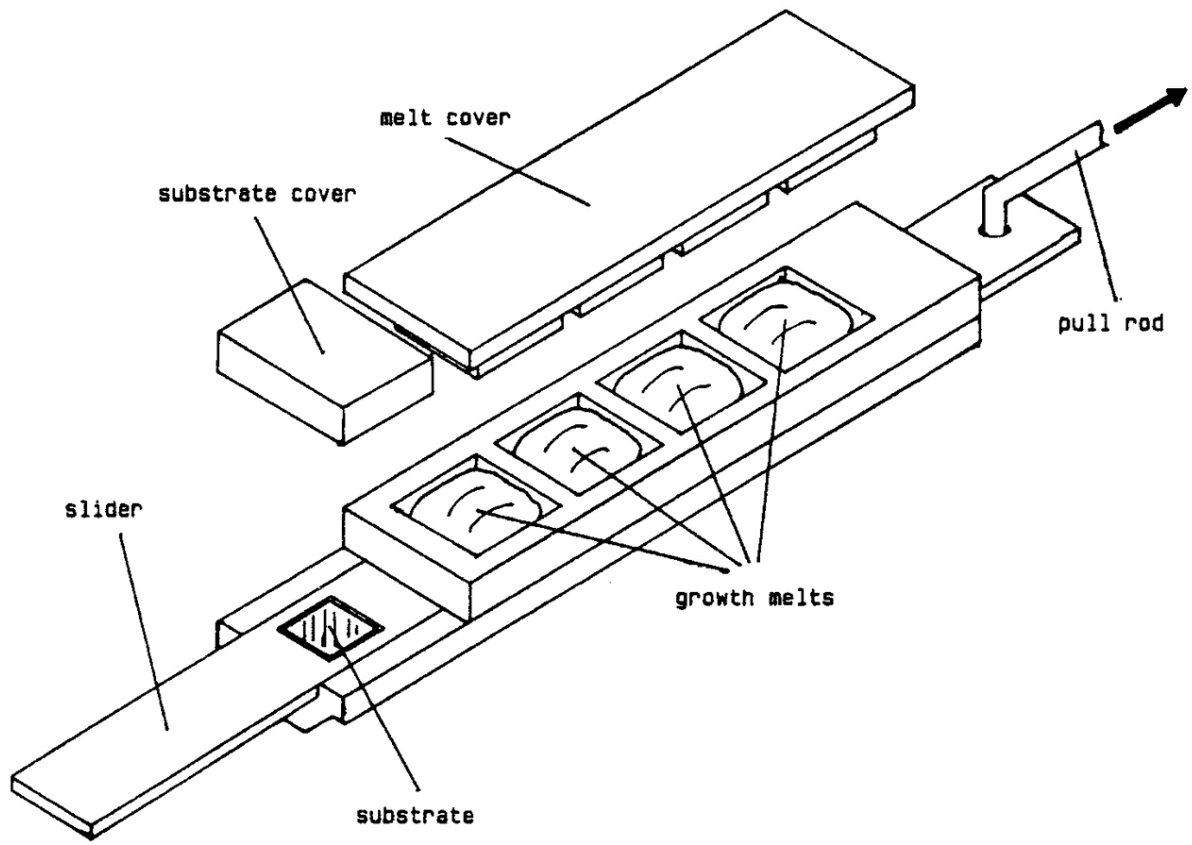
Graded lattice constant structures

Linear grading **Step grading**

- **There is no general agreement on which approach is superior and the choice often one of convenience and/or practicality.**
- **Because the last layer is often not fully relaxed, it is common to grade to a certain level and then step back, as seen in the structure on the left. In this way a fully relaxed top structure can be realized.**

Relaxed, mismatched layers are termed "metamorphic"

Liquid Phase Epitaxy -
Explode view of an LPE "boat"

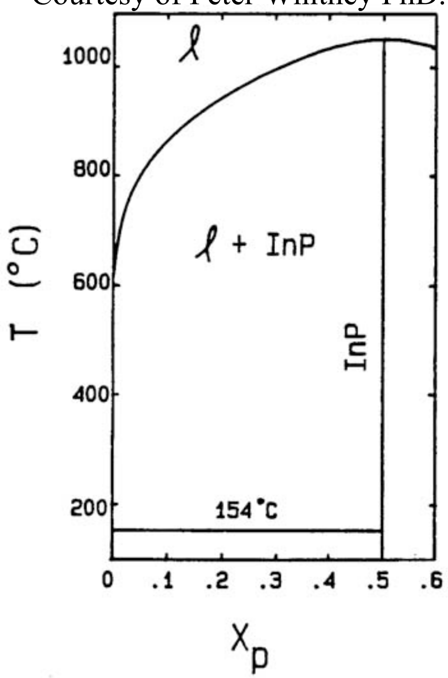


Material: Machined pyrolytic graphite

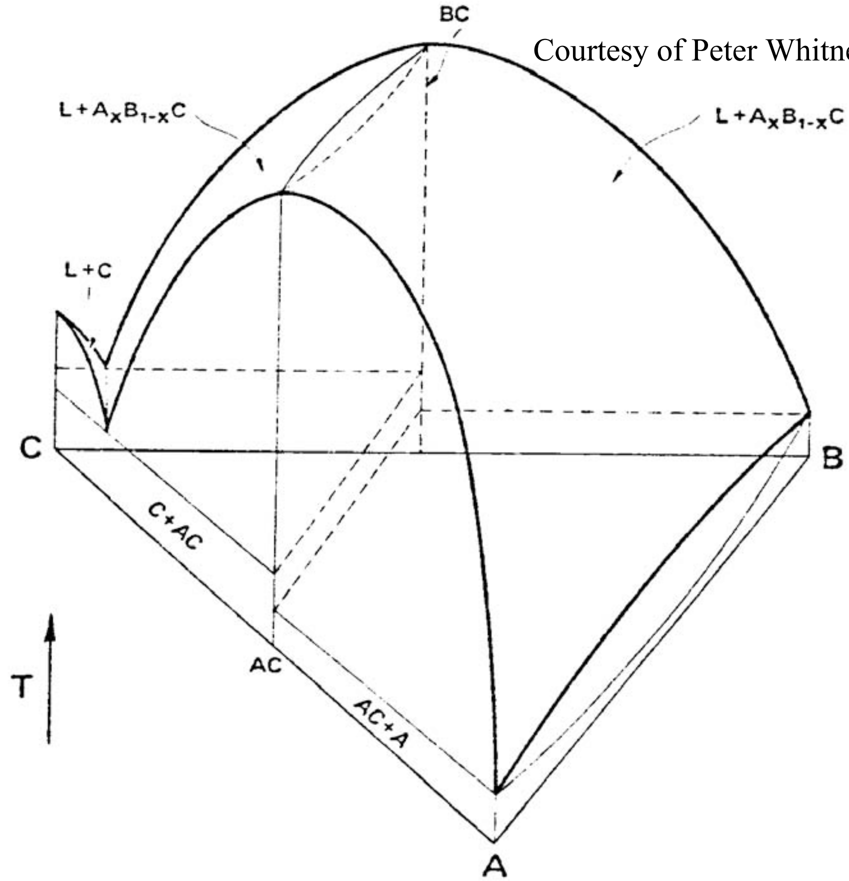
Growth ambient: Purified hydrogen at atmospheric pressure
Within a quartz tube in a resistance heated furnace

Liquid Phase Epitaxy - Melt

Courtesy of Peter Whitney PhD.



Courtesy of Peter Whitney PhD.



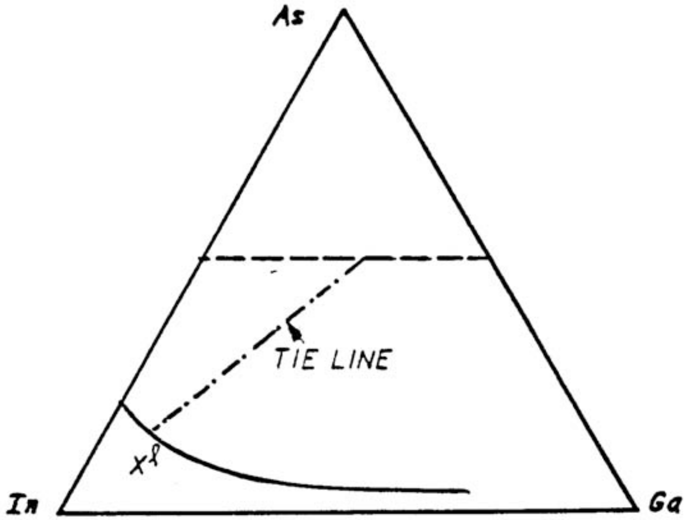
Binary phase diagram, In-P **d**

As T is reduced the binary (or ternary) solidifies from the melt:

- **In the case of the binary shown on the left the liquid is $In_{1-x}P_x$, and the solid is InP.**
- **In the case of the ternary shown on the right, the situation is more complicated. The liquid is $A_yB_zC_{1-y-z}$ and the solid is $A_xB_{1-x}C$, but the relationship between the liquid composition and x is not shown in the diagram.** **(cont. next foil)**

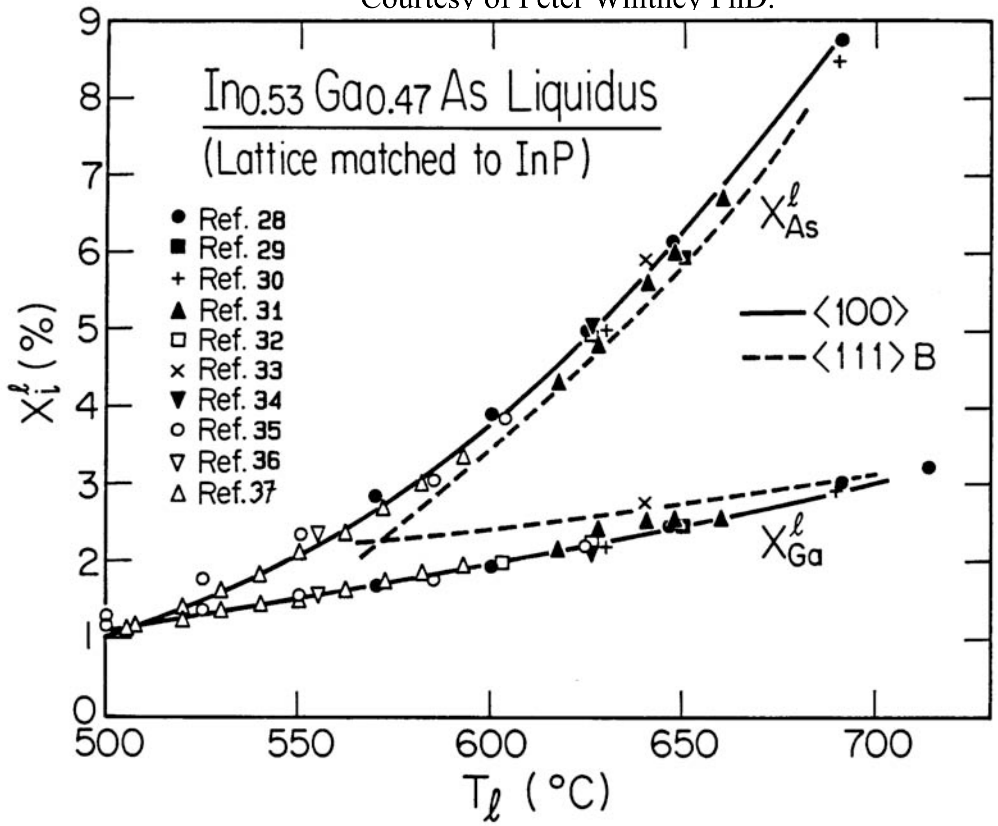
Liquid Phase Epitaxy -
Melt calculation, cont.

Courtesy of Peter Whitney PhD.



Projected isotherm and tie line for In-Ga-As system

Courtesy of Peter Whitney PhD.



Equilibrium liquidus for InGaAs lattice-matched to InP

The relationship between the ternary liquid composition and the ternary solid composition is displayed by a tie line between a projected isotherm and ternary solid line, as shown on the left,

Or by a plot of liquid composition verses temperature for a specific solid composition of interest, as shown on the right.

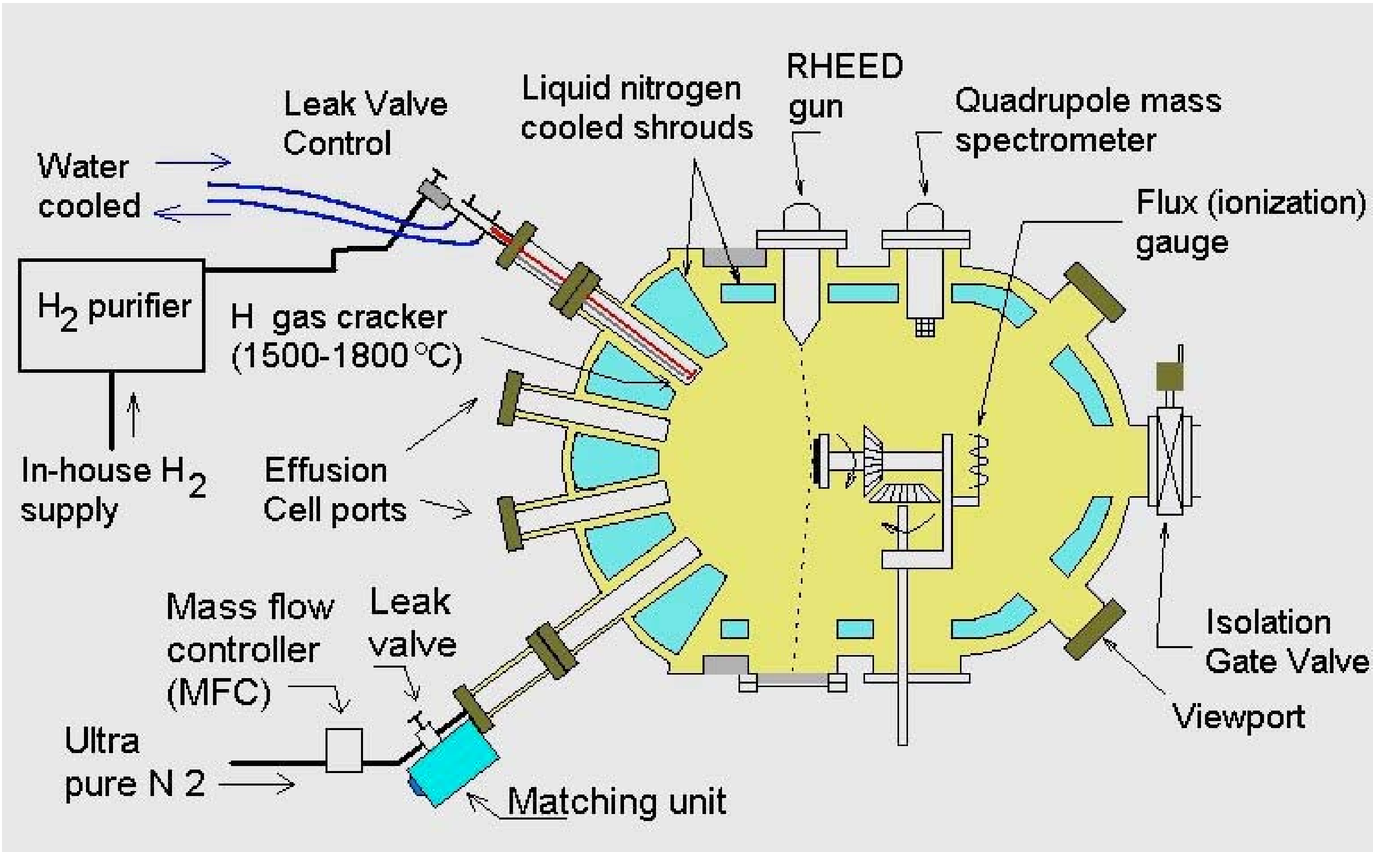
Ref: P. Whitney, Ph.D. Thesis, DMSE, MIT, 1986

Metalorganic Chemical Vapor Deposition - MOCVD

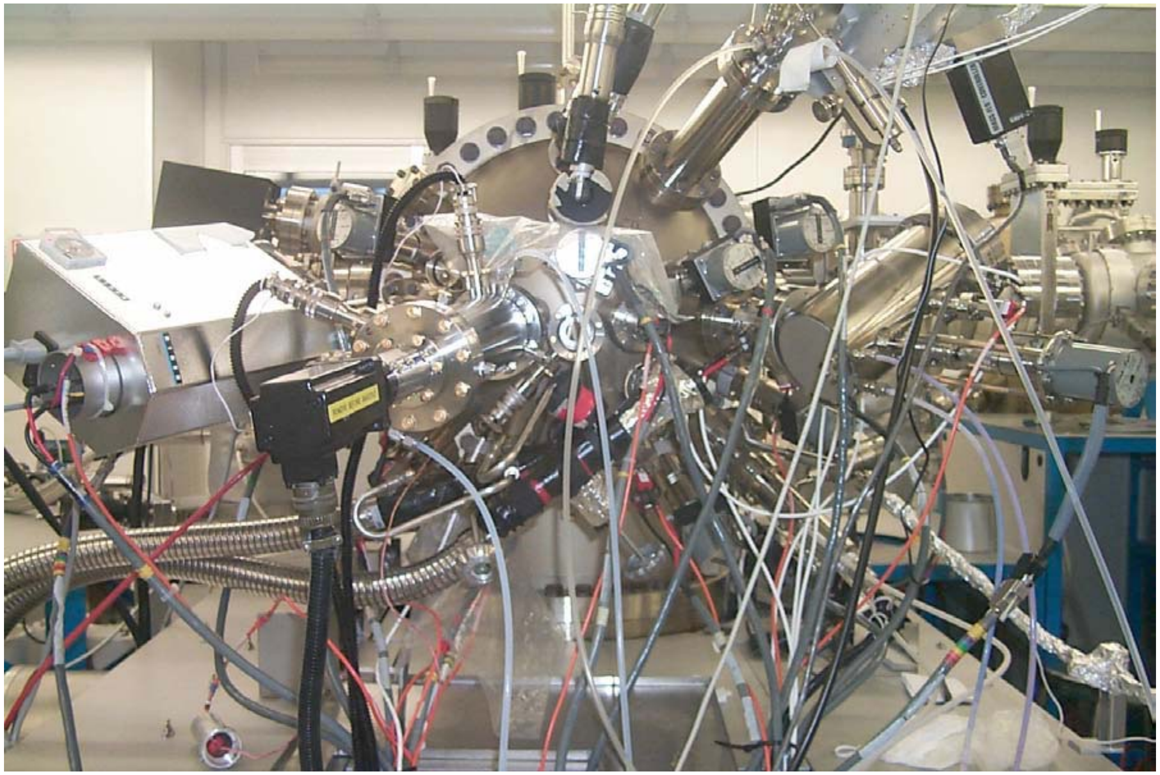
A group III precursor bubbler:

Operation:
- Bubbler held in constant-temperature bath
- Hydrogen "carrier" saturated with precursor (group III metalorganic) at fixed T
- Precursor transported through heated lines as a "gas"
- Flow controlled by mass flow meters

Schematic diagram of solid source molecular beam epitaxy



Solid source molecular beam epitaxy system (NTU)



Courtesy of Yoon Soon Fatt, NTU.

Base pressure: 10^{-11} Torr (with cryogenic cooling)

Pressure during epitaxial growth: 10^{-8} to 10^{-7} Torr

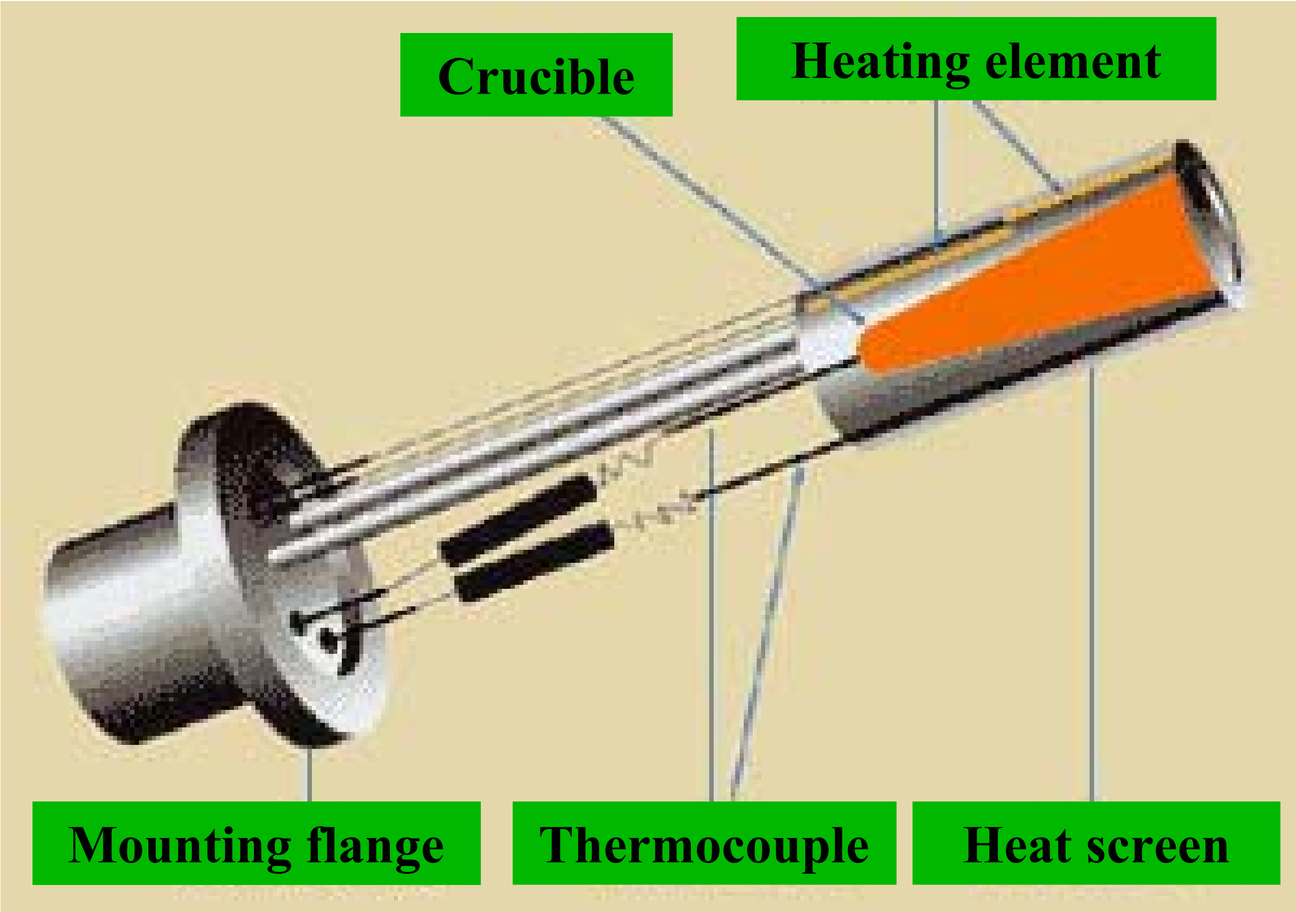
Sample loading and manipulation in the MBE system (NTU)

Courtesy of Yoon Soon Fatt, NTU.

Courtesy of Yoon Soon Fatt, NTU.

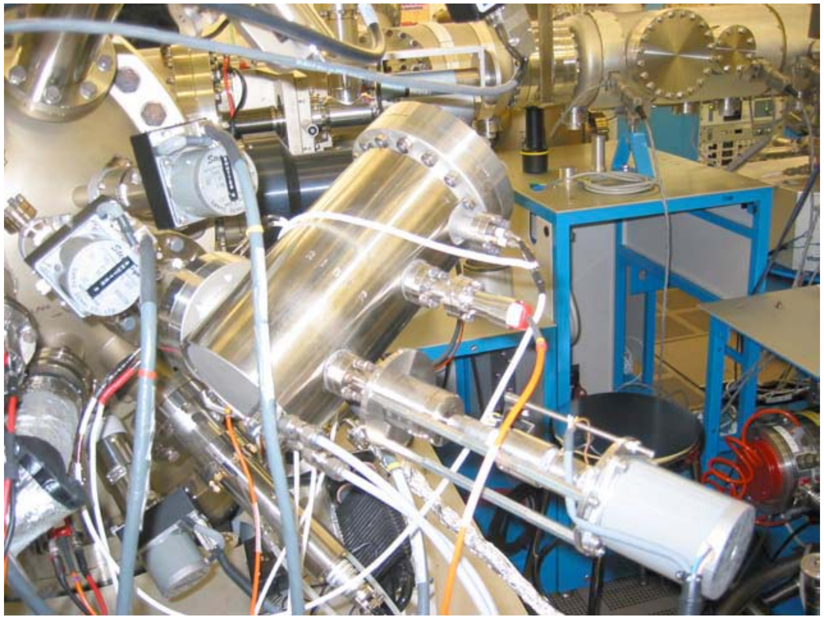
Samples are loaded and out-gassed in UHV transfer chamber prior to epitaxial growth in main chamber.

Single filament effusion cell
(In, Ga and Al)

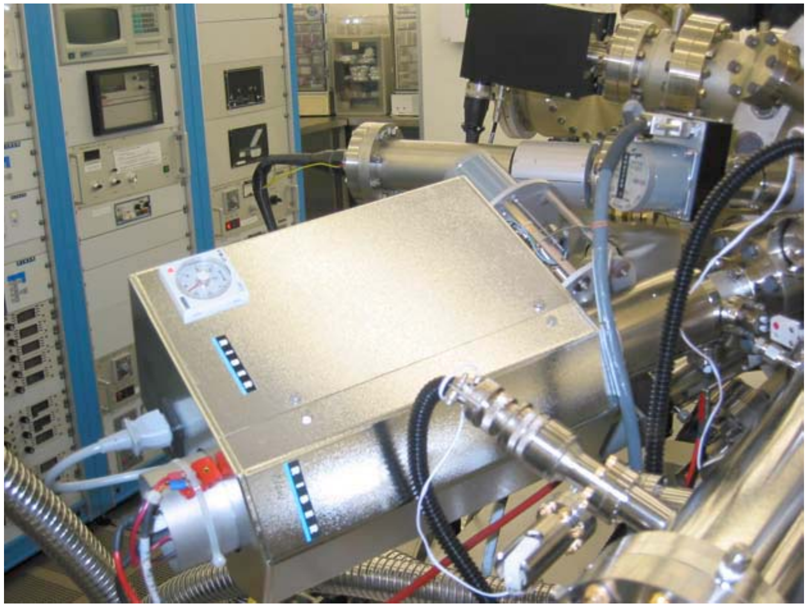


Courtesy of Yoon Soon Fatt, NTU.

Valved arsenic and phosphorus cracker source (NTU)



Courtesy of Yoon Soon Fatt, NTU.



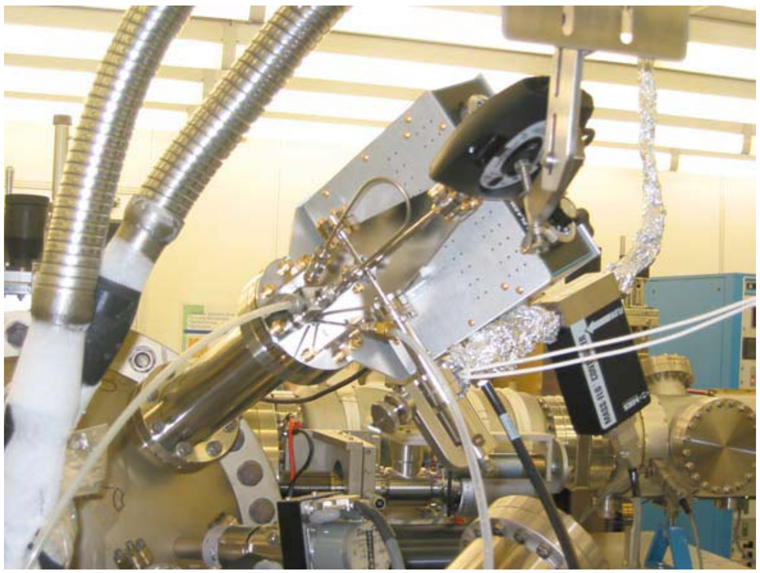
Courtesy of Yoon Soon Fatt, NTU.

Valved arsenic cracker

Valved phosphorus cracker

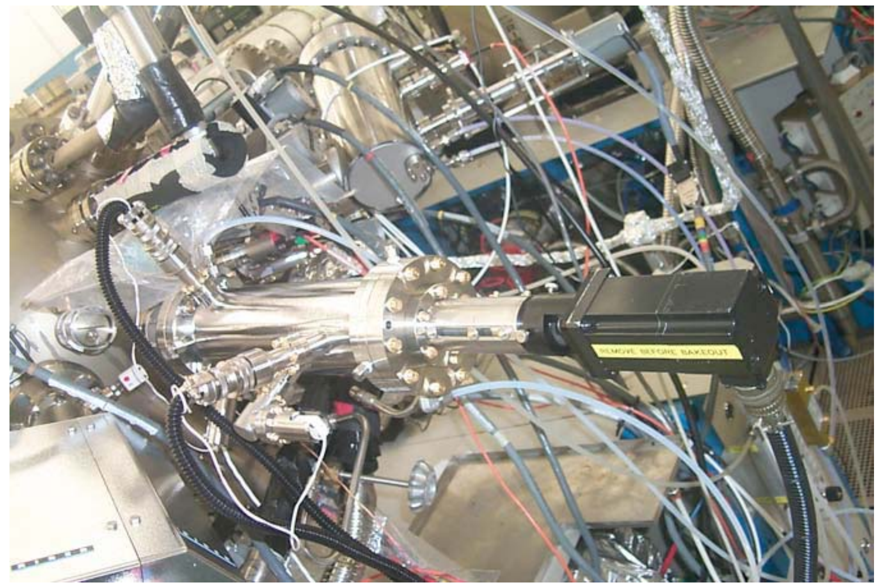
For fast interruption and abrupt change of As or P flux.

Radio frequency (r. f.) nitrogen plasma and valved antimony cracker source (NTU)



Courtesy of Yoon Soon Fatt, NTU.

Radio frequency nitrogen plasma source



Courtesy of Yoon Soon Fatt, NTU.

Valved antimony cracker source