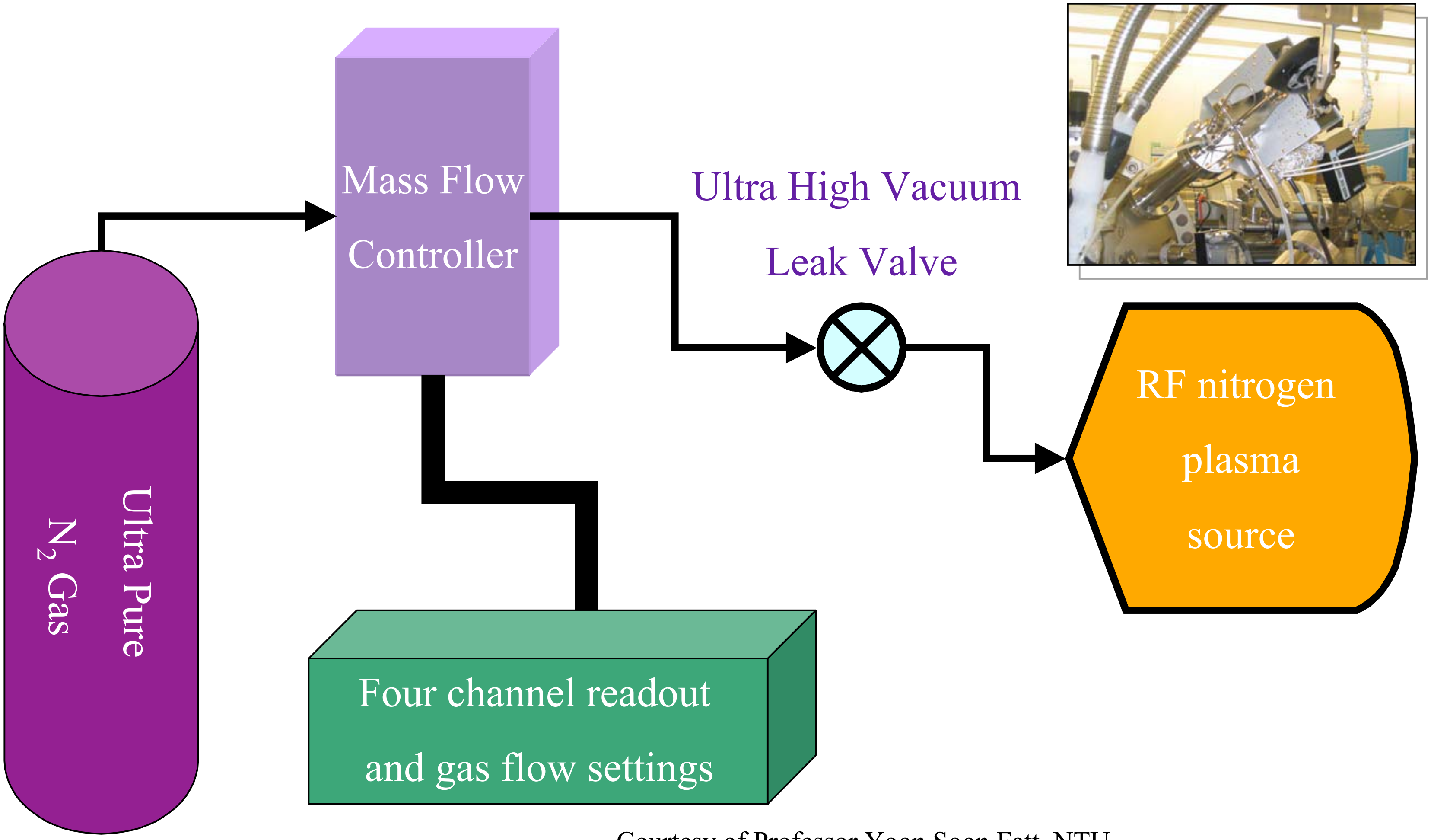
Control of r. f. nitrogen plasma source in solid source MBE

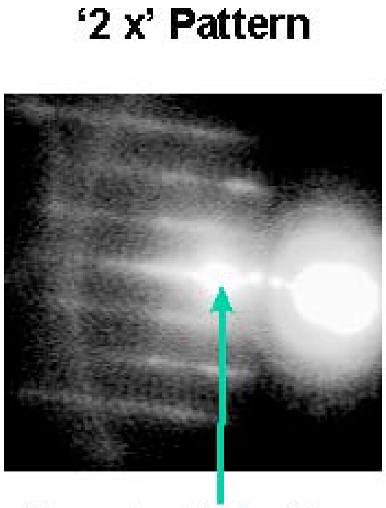
Courtesy of Yoon Soon Fatt. Used with permission.



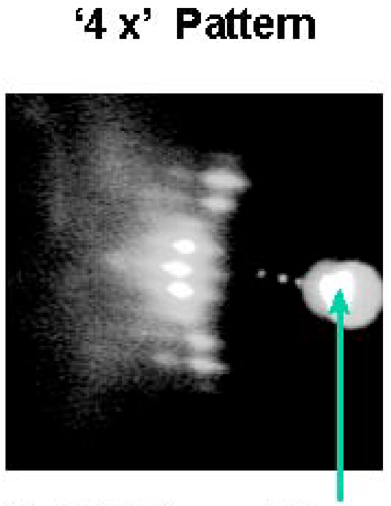
Courtesy of Professor Yoon Soon Fatt, NTU.

Courtesy Prof. Yoon Soon Fatt, NTU.

In-situ monitoring of monolayer growth



Courtesy of Professor Yoon Soon Fatt, NTU.



Courtesy of Professor Yoon Soon Fatt, NTU.

Courtesy of Yoon Soon Fatt, NTU.

Reflection high energy electron diffraction (RHEED) pattern of a GaAs surface observed during epitaxial growth at As overpressure condition.

Courtesy Prof. Yoon Soon Fatt, NTU.

Insert 1 - MBE surface reconstruction and RHEED

MBE surface action

1. Growth mechanism
2. Surface reconstruction
3. RHEED system overview
4. Origins of RHEED oscillations
5. Control panel w. RHEED display
6. RHEED oscillation plot

Variations on the MBE theme

Solid Source MBE - all elemental sources

- Advantages: no toxic gases
- Disadvantages: large heat load; phosphides require cracker or sublimation source

Gas Source MBE - column V hydrides; elemental group III's

- Advantages: easy access to phosphides; no As or P cells to recharge
- Disadvantages: large heat load; toxic gases; additional pump load

Metalorganic MBE - column III metalorganics; elemental V's

- Advantages: reduced heat load
- Disadvantages: phosphides difficult; MO purity an issue; carbon contamination a concern; additional pumping load; little advantage over SSMBE; more complex chemistry

Chemical Beam Epitaxy - MOCVC in high vacuum, beam limit

- Advantages: small heat load; phosphides easy; selective area growth possible
- Disadvantages: additional pumping load; carbon contamination possible; MO purity an issue; toxic gases

Critiquing the Epitaxy Techniques

Liquid Phase Epitaxy

Advantages: inexpensive; equilibrium growth; excellent layer quality; low toxicity

Disadvantages: complicated to do multiple layers; poor thickness control; materials and combinations limited; uniformity an issue; hard to scale up

Vapor Phase Epitaxy [chloride and hydride transport]

Advantages: high purity; low toxicity

Disadvantages: complex, messy; memory effects; poor thickness control; unifomity an issue

Metalorganic Chemical Vapor Deposition [esp. low P]

Advantages: excellent control; fast response; versatile; many materials; selective area growth possible

Disadvantages: toxic gases; uniformity and issue

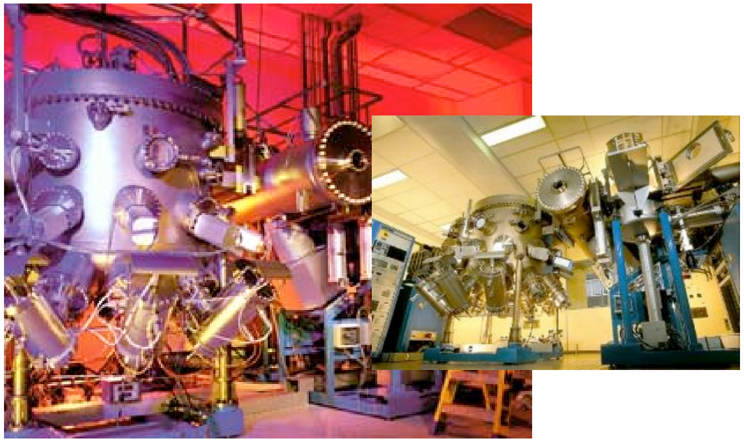
Molecular beam epitaxy

Advantages: beam technique; insitu monitoring; monolayer control

Disadvantages: slow; expensive; maintenance of UHV required

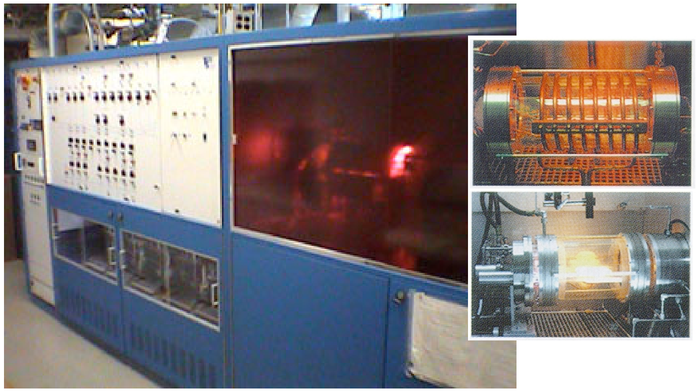
Epitaxial growth techniques

- **Molecular Beam Epitaxy (MBE)**
  – Ultra high vacuum condition
  - Solid source MBE – Elemental sources of In, Ga, Al, As and P
  - Gas source MBE – Combination of elemental source (for group III) and gas source (for group V)



Riber Production MBE6000 (Courtesy of MBE Technology (S) Pte Ltd)

- **Metalorganic Chemical Vapor Deposition (MOCVD)**
  – Low vacuum condition
  - Gas sources such as TMG, TMI, TMA, AsH_3 and PH_3 are used.



Insert 2 - Comparison of MOCVD and MBE results

Comparison of MOCVD and MBE

1. RTD performance
2. 2DEG mobility
3. PL spectra of AlGaAs

Growing Quantum Wires and Dots - beyond quantum wells

Grow and pattern

- Growing quantum wells and patterning them into wires and/or dots is generally not the method used. The patterns needed are too small and the dimensions are hard to control.

Direct growth

- The more common approach is to grow on a specially prepared surface so that the resulting heterostructure contains quantum wires or dots
- Quantum wires:
  - 1. Growth on stepped surfaces
  - 2. Growth on grooved surfaces

- Quantum dots:
  - Growth of thin, highly mismatched layers

Growing Quantum Wires -

MOCVD on V-grooves

(Image deleted)

See M. Walther et al, Appl. Phys. Lett. 60 (1992) 521-3.

(Image deleted)

See X-L Wang et al, Appl. Phys. Lett. 71 (1997) 2130-2.

TEM

Growth objective

(Image deleted)

See M. Walther et al, Appl. Phys. Lett. 60 (1992) 521-3.

(Image deleted)

See X-L Wang et al, Appl. Phys. Lett. 71 (1997) 2130-2.

TEM

Calculated wavefunctions

Growing Quantum Dots - dots = boxes □

Stranski Krastanov strain-driven growth of dots: □

Layer sequence □

(Images deleted)

See M. H. Son et al, Appl. Phys. Lett. 82 (2003) 1230-3.

Cross-section TEM of stacked dots

(termed self-assembled quantum dots, SAQDs)

After somewhat more than a monolayer of InAs has been deposited, dots form. Empirically it is found that 1.8 monolayers per dot layer is an "optimum" amount.

The dots in subsequent layers tend to form over the underlying dots, resulting in ordered stacking (self-assembly).

III-V Processing - General Comments/Overview

General Picture

III-V device processing is in general more complex than silicon processing in that

1. there are no native oxides comparable to SiO_2
2. many of the constituent elements in the III-V semiconductors have high vapor pressures and are subject to decomposition unless encapsulated or under pressure

On the other hand, with the III-Vs

1. one has the availability of complex heterostructures
2. there are very selective etches available to differentiate between heterostructure components

III-V Processing - General Comments, cont.

Doping

diffusion: open tube (a la Si) not practical

sealed ampoule - to provide As or P overpres.

from spin-on glasses and doped metals

ion implantation: standard process

RTA activation

Device isolation

mesa etching

proton (H^+) bombardment: makes many wider bandgap III-V's like GaAs, InP high resistance

Passivation, encapsulation

no native oxides; oxidation not viable - sulfidation maybe

deposited SiO_2 and Si_3N_4 widely used - Ga diffuses thru SiO_2, but not Si_3N_4

III-V Processing - General Comments, cont.

Ohmic contacts

deposition and alloy of doped metals - e.g. Au-Zn

narrow bandgap ohmic contact layer - e.g. InGaAs

heavily doped layer contact layer - Si standard too.

Wet etching

there are highly selective etches for III-V heterostructures that can be used to advantage in device processing:

- Etchants that differentiate between AlGaAs and AlAs, or between GaAs and AlGaAs for selected AlGaAs aluminum fraction ranges
- Similar etchants in the InGaAlAs system
- Etchants that differentiate between InGaAlAs and InP

Dry etching

widely employed: see following foils

Insert 3 - III-V processing

Etching, doping, and contacting the III-Vs
(22 foils from Prof. Chua Soo Jin, NUS)

Final comments - What's hot in epi today...

AlGaInN on whatever: substrates are the problem
Sapphire (Al_20_3), Silicon Carbide (SiC)
Gallium Nitride - if available
Si - <111> best

InGaAs on GaAs and GaInAsN on GaAs: getting longer wavelength, higher mobilities on an inexpensive substrate (rather than on InP)

GaAs and InP on Si: dealing with 1. lattice mismatch, 2. antiphase domains, and 3. thermal expansion coefficients