光電子學導論

(8) Epitaxy of Optoelectronic Semiconductor Devices

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Growth of AlGaInP and InGaN LEDs

- **Metal-Organic Chemical Vapor Deposition (MOCVD, also called Metal-Organic Vapor Phase Epitaxy, MOVPE) is commonly used to grow AlGaInP and InGaN LEDs due to the relatively high speed in crystal growth.**
- **Molecular Beam Epitaxy (MBE) may have excellent crystalline quality in growing AlGaInP and InGaN LEDs but is relatively slow in crystal growth.**

Liquid-Phase Epitaxy, LPE

- The liquid-phase epitaxy (LPE) technique was first demonstrated in 1963. Since then, it has been successfully utilized to fabricate various types of III-V compound semiconductor devices.
- In LPE a supersaturated solution of the material to be grown is brought into contact with the substrate for a desired period of time.
- If the substrate is a single crystal and the material to be grown has nearly the same lattice constant as the substrate, some of the material precipitates on the substrate while maintaining the crystal quality. The precipitated material forms a lattice-matched epitaxial layer on the surface of the substrate.

Vertical LPE & Multibin-boat LPE Apparatus

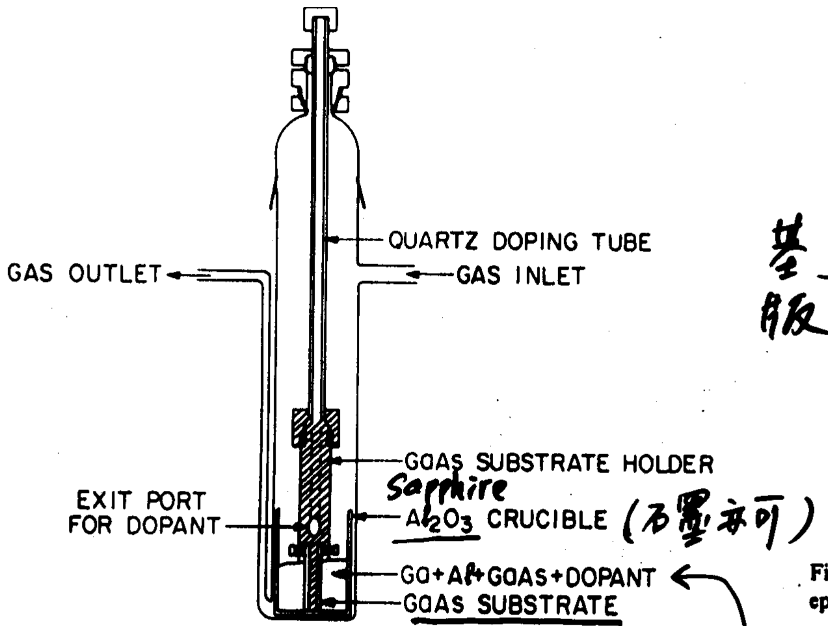

Fig. 4.2 Schematic illustration of a vertical LPE apparatus. (After Ref. 2)

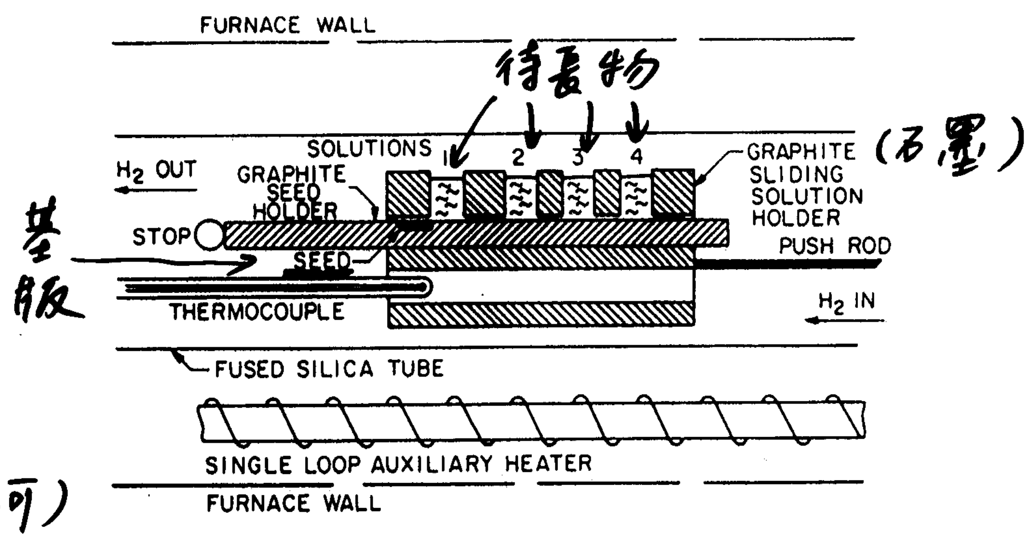

Fig. 4.3 Schematic illustration of a multibin-boat LPE apparatus used for growing several epitaxial layers. (After Ref. 4)

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Notes. 1) growth temperature ≈ 650 °C for InGaAsP/InP.

2) 高溫下長晶, 品質較佳.

Schematic Illustration of a VPE Reactor

In vapor-phase epitaxy (VPE), the source chemicals from which the epitaxial layers are grown are gaseous.

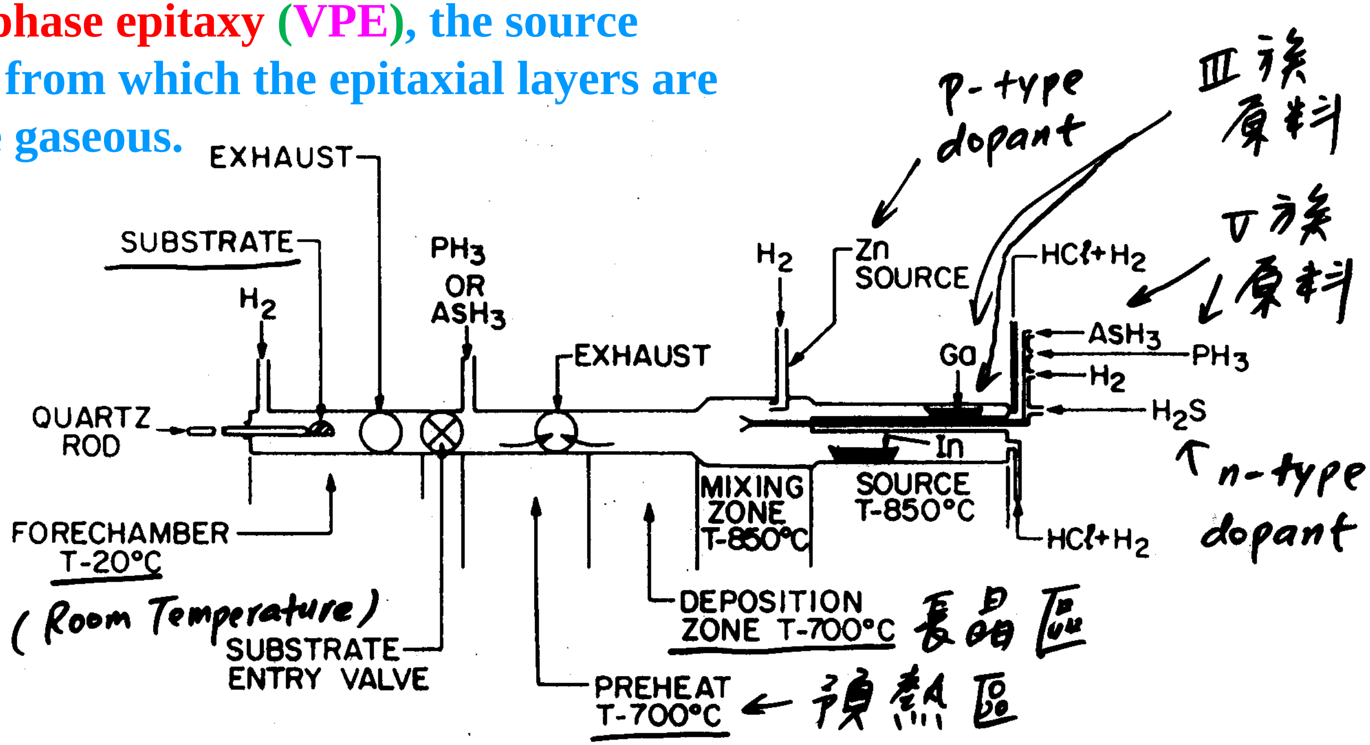


Fig. 4.9 Schematic illustration of a vapor-phase epitaxy (VPE) reactor. (After Ref. 33)

Note: 1) growth rate ≃ 0.1 – 1 μm/min for InGaAsP / InP

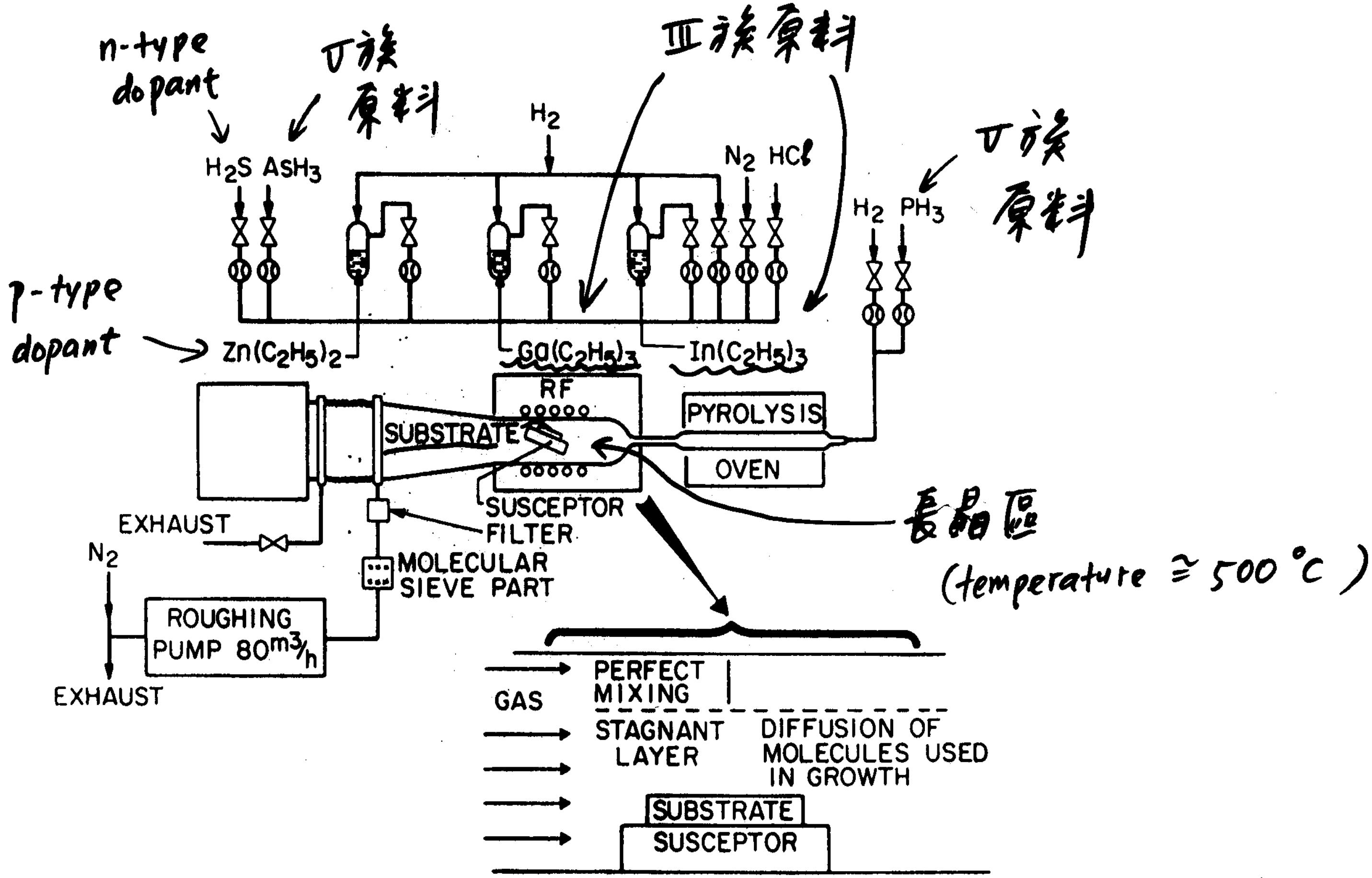
⇒ too high to grow thin layers (e.g., QWs)

2) highest growth temperature ≥ 900 °C.

Metal-Organic Chemical Vapor Deposition , MOCVD

- **Metal-organic chemical vapor deposition (MOCVD), also known as metal-organic vapor-phase epitaxy (MOVPE), is a variant of the VPE technique that uses metal alkyls (烷基) as sources from which the epitaxial layers form.**
- **For growth of InGaAsP, group III alkyls [($Ga(C_2H_5)_3$ and $In(C_2H_5)_3$] and group V hydrides (氫化物) [AsH_3 and PH_3] are introduced into a quartz reaction chamber that contains a substrate placed on a radio-frequency (RF) heated (~ 500 °C) carbon reactor.**
- **Gas molecules diffuse to the hot surface of the substrate. At the hot surface the metal alkyls and the hydrides decompose, producing elemental In, Ga, P and As. The elemental species deposit on the substrate, forming an epitaxial layer. $Zn(C_2H_5)_3$ and H_2S are used as sources for p-type and n-type doping respectively.**

Schematic Illustration of a Low-Pressure MOCVD System



Growth Rate ≅ 2-4 μm/hr
⇒ good enough for growth of quantum wells.

Fig. 4.11 Schematic illustration of a low-pressure MOVPE system. (After Ref. 47)

Pressure ≅ 0.1 - 0.5 atm.

Molecular Beam Epitaxy, MBE

- The lattice-matched growth of AlGaAs on GaAs substrates by molecular-beam epitaxy (MBE) was first reported in 1971.
- In the MBE technique, epitaxial layers are grown by impinging (撞擊) atomic or molecular beams on a heated substrate kept in an ultrahigh vacuum (note: the vacuum chamber is usually kept at a pressure of about 10^{-10} torr).
- The constituents of the beam "stick" to the substrate, resulting in a lattice-matched layer. The beam intensities can be separately controlled to take into consideration the difference in sticking coefficients of the various constituents of the epitaxial layers.

A MBE System for Epitaxial Growth of AlGaAs

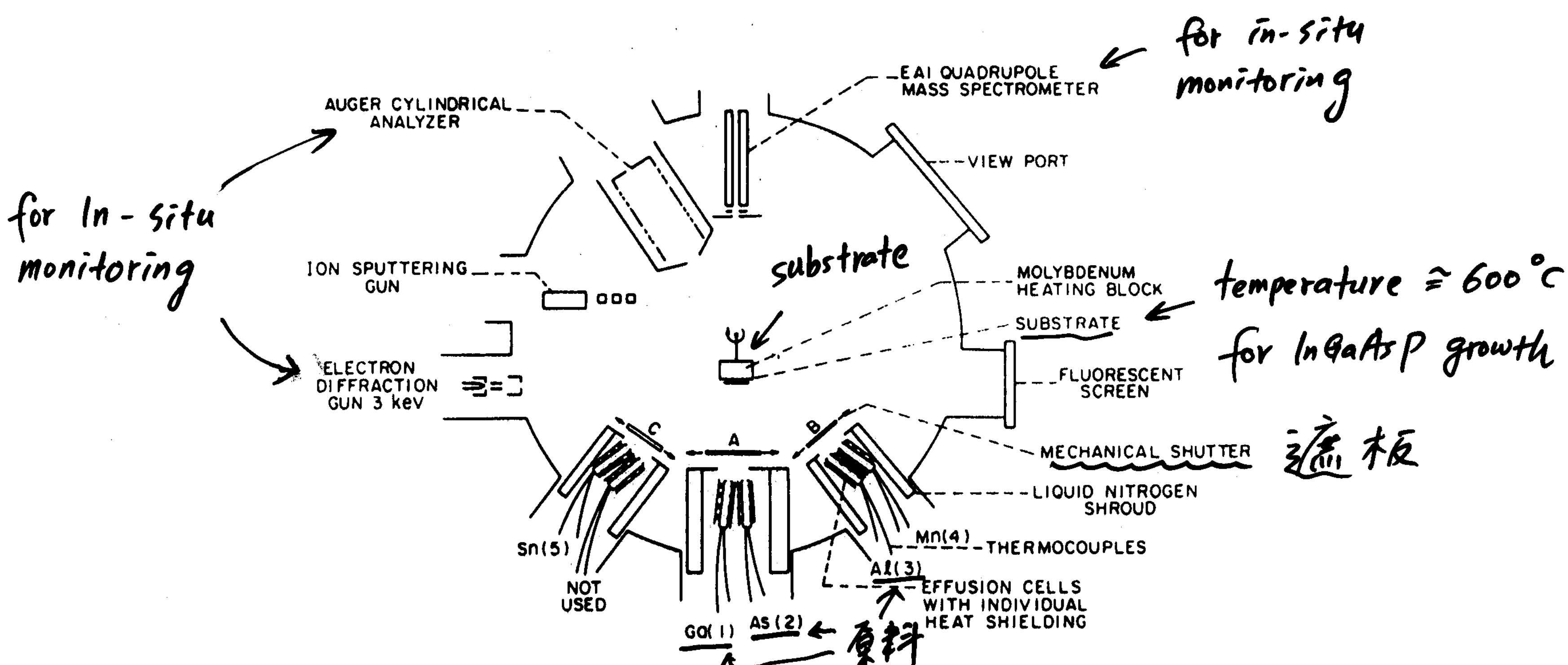


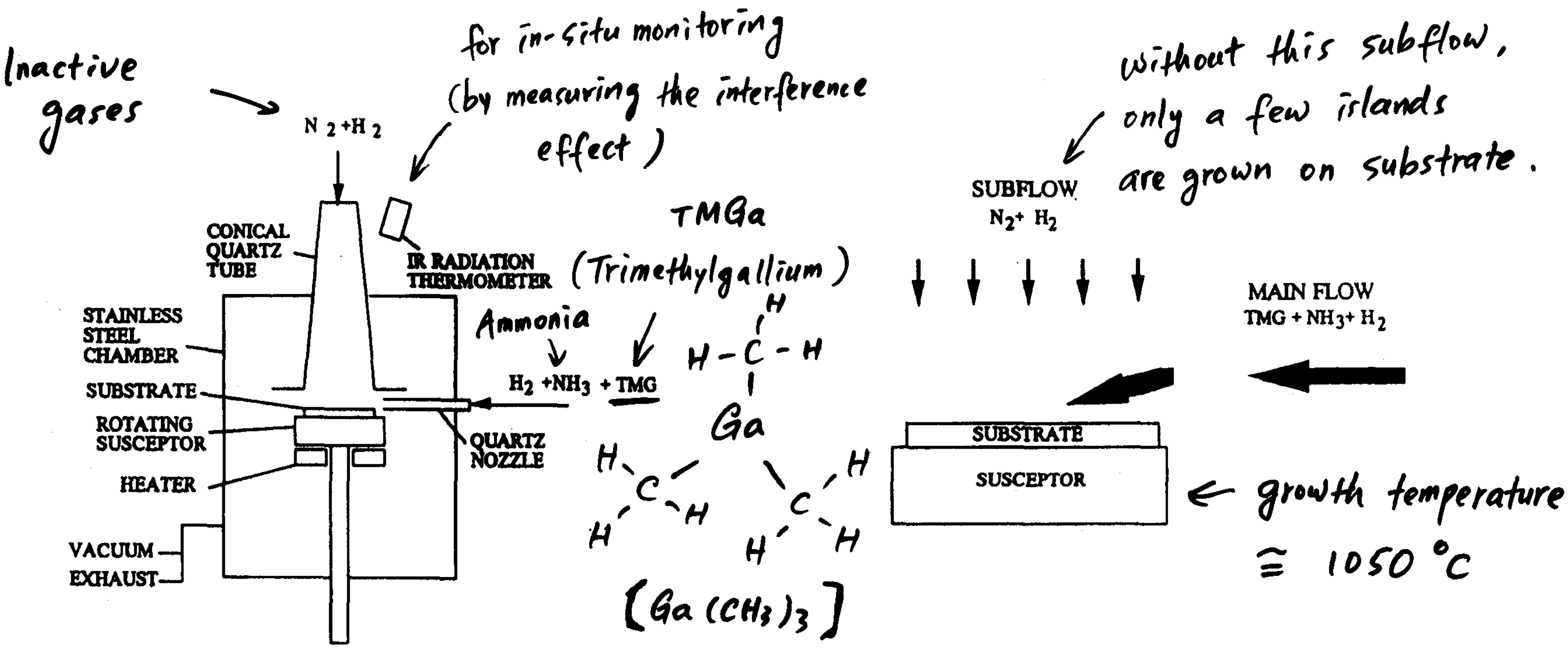
Fig. 4.12 Schematic illustration of a molecular-beam-epitaxy (MBE) system for epitaxial growth of AlGaAs. (After Ref. 59)

Note : 1) for Group III materials (e.g., Al, Ga)
⇒ sticking coefficient ≈ 1.0 (100 %)
2) for Group V : varies.

Difficulty of Growing InGaN LEDs and LDs

- There is **no lattice-matched substrate** for InGaN semiconductor materials. InGaN LEDs and laser diodes are usually grown on lattice-mismatched sapphire substrate. Hence, a large amount of **crystal defects** may be expected.
- InGaN grown on sapphire **can not be cleaved** to form **laser mirrors**. **Reactive-Ion Etching** (RIE) is usually used to fabricate the laser mirrors. It is **more expensive** to fabricate laser mirrors with RIE. Moreover, the quality of the mirrors is poor when compared to that of cleaved ones.

Two-Flow MOCVD Used by Nichia Inc.



Notes:

1) V/III flow rate ratio >> 1000

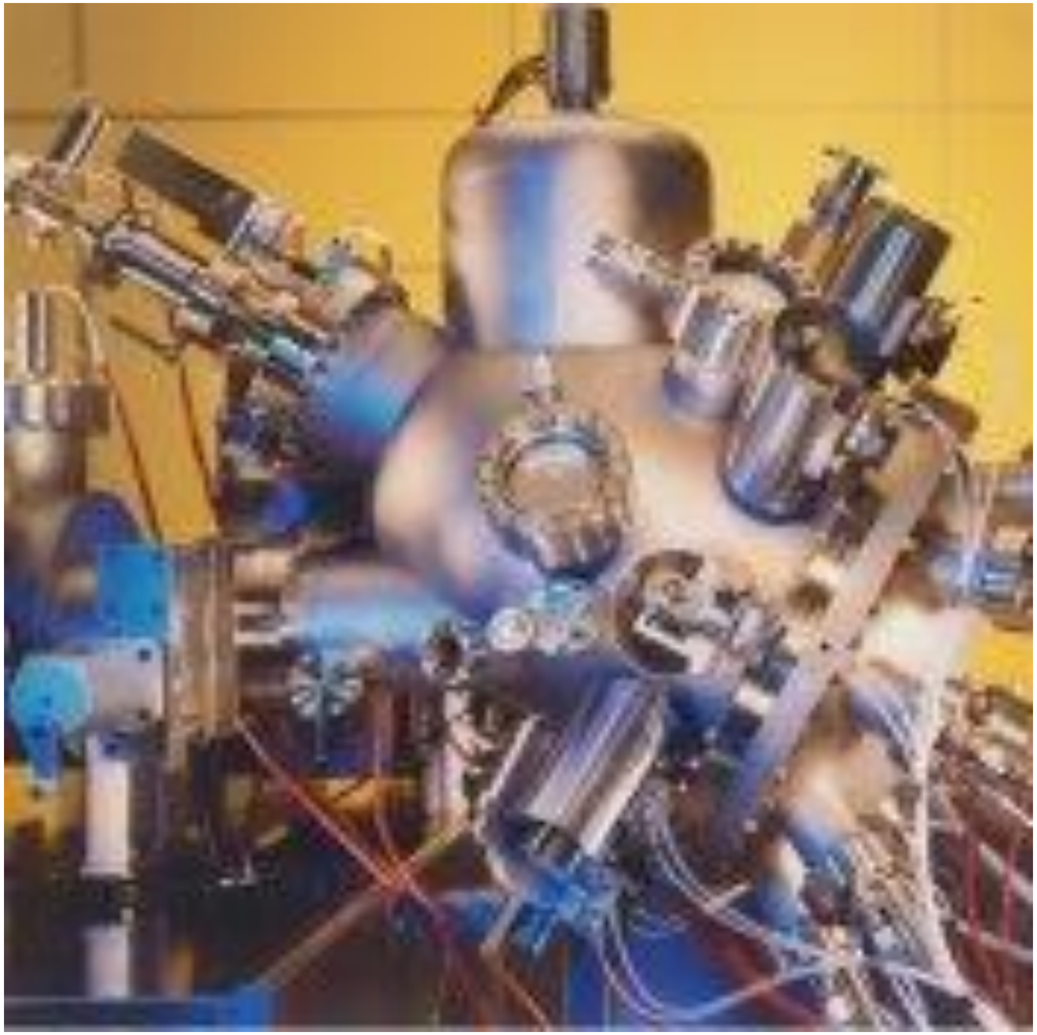
2) Melting point of GaN ≅ 1700 °C

⇒ LPE is difficult.

MOCVD Versus MBE for GaN

Comparison	MOCVD	MBE
Advantage	➤Has demonstrated good device performance ➤Commercial machine is available	➤Use much lower consumption of source materials ➤No post-growth thermal annealing is needed to activate the p-type dopant
Disadvantage	➤P-doping concentration is low and post-treatment is needed ➤Material cost per run is high	➤Device performance can't compete with the devices grown by MOCVD yet **(After Prof. Man-Fang Huang)**

Oxford VG80H MBE



Sharp Inc. used Oxford MBE system with some modifications to grow the first GaN LD using MBE in March 2004.

(After Prof. Man-Fang Huang)

Clusterlab 600 Research MBE System

國立彰化師範大學奈米科技中心於2005年6月購入乙台MBE