Semiconductor Optical Communication Components and Devices

Lecture 10: Epitaxial growth - III (MBE Techniques)

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Atoms arriving at the substrate surface may undergo absorption to the surface, surface migration, incorporation into the crystal lattice, and thermal desorption. Which of the competing pathways dominates the growth will depend strongly on the temperature of the substrate. At a low temperature, atoms will stick where they land without arranging properly - leading to poor crystal quality. At a high temperature, atoms will desorb (re-evaporate) from the surface too readily - leading to low growth rates and poor crystal quality. In the appropriate intermediate temperature range, the atoms will have sufficient energy to move to the proper position on the surface and be incorporated into the growing crystal.
Molecular Beam Epitaxy

Most of the MBE growth of GaAs, $\text{Al}_x\text{Ga}_{1-x}\text{As}$, and other III-V compounds has been performed on (100)-oriented ($\pm 0.5\text{Deg.}$) substrates, 200-500$\mu$m thick.

Purities of sources $= 99.9999\%$
Molecular Beam Epitaxy In-situ Characterization

The substrate is placed in a high vacuum on which is incident a beam consisting of the material to be grown. At the low pressures used the mean free path of collision is larger than the chamber dimensions. Thin layers with interfaces less than an atomic layer can be grown. Closing off the shutter in front of the effusion cell shuts off the growth with that species.

**MBE Chamber**
- **ABES**
  - Substrate temperature
- **RHEED**
  - Surface structure
  - Morphology
  - Monolayer thickness
- **REMS**
  - Desorbed and scattered flux
- **PEO**
  - Morphology
  - Monolayer thickness

**STM Chamber**

**Effusion Cells**
- In, Ga, Al evaporators
- Valsed As, Sb crackers

**Background Pressure**: $10^{-11}$ to $10^{-12}$ Torr.

**Operating Pressure**: $10^{-4}$ to $10^{-6}$ Torr.
MBE SYSTEM

Loading Wafers to the Load Lock Chamber

LN$_2$ chamber cooling

Shutters

Heating Element

Source Material

Heat Shields

Effusion Cells

Thermocouple

Baffle

Heat Shields
Be has been used as dopant for GaAs but is avoided due to its toxic nature. Recently, carbon has been identified as a new p-type dopant because of relatively small ionization energy (20 meV), high solid solubility (~ $10^{20}$ cm$^{-3}$) and extremely low diffusion constant ($2 \times 10^{16}$ cm$^2$/s$^{-1}$ at 800°C) in GaAs.

Si is amphothetric but for the growth temperatures used it has been successfully used as n-type dopant.

Period of the RHEED oscillation gives the no. of the layers that is grown & the intensity indicates the quality and type of layer that is being grown.

In-Situ layer characterization in MBE system

- Effusion Cell
- Arsenic Valve
- Indium Flux
- Heater Power Supply
- Temperature Controller
- Period Controller

Period Detector
- Least Squares (moving windows)
- Low-Pass Filter
- Peak Detection
RHEED signal to estimate the surface roughness and composition of the layer.

\[ \theta = 0, 0.25, 0.5, 0.75, 1 \]

\[ \text{Intensity} \]

\[ \text{Time} \]

0 = number of monolayers deposited
Effusion cells should be baked at ~1600°C

Growth interruption smoothens the surface by allowing surface migration. Very important for QWs. However, in this process impurities also gets incorporated. Hence one needs to make a judicious choice. Below is shown the RHEED intensity as a function of time.

Increase in effusion cell temperature increases the Group-III flux, thus increasing growth rate, but also encourages more defects due to poor migration.

![Graph showing the relationship between GaAs growth rate, Ga source temperature, and RHEED intensity as a function of time.](image)
## MBE Substrate temperatures

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Factor Description (Abbreviation)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tsub for oxide removal (TOX)</td>
<td>580 – 650°C</td>
</tr>
<tr>
<td>2</td>
<td>Time for oxide removal (TI-OX)</td>
<td>30 - 300 sec</td>
</tr>
<tr>
<td>3</td>
<td>Tsub for AlGaAs growth (TAL)</td>
<td>580 - 630°C</td>
</tr>
<tr>
<td>4</td>
<td>Tsub for InGaAs growth (TIN)</td>
<td>450 - 520°C</td>
</tr>
<tr>
<td>5</td>
<td>Interrupt time (INT-TIME)</td>
<td>30 -90 sec</td>
</tr>
<tr>
<td>6</td>
<td>As source temperature (P\textsubscript{As})</td>
<td>180-300°C</td>
</tr>
</tbody>
</table>

x=0.2 In in In\textsubscript{x}Ga\textsubscript{1-x}As, T\textsubscript{In}=771.6°C, P\textsubscript{Ga}=1.2x10\textsuperscript{-6} torr, for a growth rate of 1.8µm/hr, then T\textsubscript{Ga}=998.9°C

**As stabilized source temperatures**

For Al\textsubscript{x}Ga\textsubscript{1-x}As at a growth rate of 1.8mm/hr,

P\textsubscript{Ga}=5.9x10\textsuperscript{-7} torr, T\textsubscript{Ga}=960°C

(at x=0.24), P\textsubscript{Al}=9.5x10\textsuperscript{-7} torr, T\textsubscript{Al}=1104.2°C

For In\textsubscript{x}Ga\textsubscript{1-x}As (x=0.1), P\textsubscript{In}=1.2x10\textsuperscript{-7} torr, at a growth rate of 2mm/hr,

T\textsubscript{In}=733.9°C

P\textsubscript{In}=4.3x10\textsuperscript{-7} torr, at a growth rate of 2.3mm/hr, however the fraction x is not only the flux ratio.
MBE Growth rates and source temperatures

For \( \text{Al}_x\text{Ga}_{1-x}\text{As} \) at a growth rate of 1.8mm/hr,

\[
P_{\text{Ga}} = 5.9 \times 10^{-7} \text{ torr}, \quad T_{\text{Ga}} = 960\,^\circ\text{C}
\]
(at \( x=0.24 \)), \( P_{\text{Al}} = 9.5 \times 10^{-7} \text{ torr}, \quad T_{\text{Al}} = 1104.2\,^\circ\text{C}\)

For \( \text{In}_x\text{Ga}_{1-x}\text{As} \) (\( x=0.1 \)), \( P_{\text{In}} = 1.2 \times 10^{-7} \text{ torr}, \) at a growth rate of 2mm/hr, \( T_{\text{In}} = 733.9\,^\circ\text{C}\)

\( P_{\text{In}} = 4.3 \times 10^{-7} \text{ torr}, \) at a growth rate of 2.3mm/hr, however the fraction \( x \) is not only the flux ratio.

\[
x = \frac{P_{\text{In}}}{(P_{\text{In}} + R \cdot P_{\text{In}})}, \quad R = \frac{R_{\text{In}}}{R_{\text{Ga}}}, \text{ where } R \text{ is the relative incorporation rate.}
\]

Usually \( T_{\text{As}}(2.7 \times 10^{-5} \text{ torr}) = 213.4\,^\circ\text{C}, \quad T_{\text{SubsClear}} = 583\,^\circ\text{C}, \)

DOPING

\( T_{\text{Si}}(\text{n+}, 1 \times 10^{18}) = 1110\,^\circ\text{C}, \quad T_{\text{Si}}(\text{n}, 3.5 \times 10^{17}) = 1060\,^\circ\text{C} \)

\( T_{\text{Si}}(\text{n-}, 1 \times 10^{15}) = 857\,^\circ\text{C}, \quad T_{\text{Be}}(\text{p+}, 5 \times 10^{18}) = 750\,^\circ\text{C}, \)

\( T_{\text{Subs}} = 480\,^\circ\text{C}, \)

II-VI (\( \text{Cd}_x\text{Zn}_{1-x}\text{Te} \)) Epitaxial layers on GaAs grown typically at a rate of 0.2mm/hr.

\( T_{\text{sub}} = 320\,^\circ\text{C}, \quad T_{\text{Cd}} = 160\,^\circ\text{C}, \quad T_{\text{Zn}} = 250\,^\circ\text{C}, \quad T_{\text{Te}} = 320\,^\circ\text{C}. \)
MOMBE/CBE

**Methods**
- **ATMCVD**
  - Source: Vapour sources III, V
  - Pressure (torr): 760

- **LPCVD**
  - Source: Vapour sources III, V
  - Pressure (torr): 300

- **CBE**
  - Source: Vapour sources III, V
  - Pressure (torr): $\leq 10^{-4}$

- **MOMBE**
  - Source: Solid source V
  - Pressure (torr): $\leq 10^{-5}$

- **GSMBE**
  - Source: Solid sources III, V
  - Pressure (torr): $\leq 10^{-5}$

- **MBE**
  - Source: Solid sources III, V
  - Pressure (torr): $\leq 10^{9}$
1. A graded Al$_{0.36}$Ga$_{0.64}$As is to be grown on GaAs for a thickness of 1μm at a growth rate of 1μm/hr. in an MOCVD system using TMG, TEG, and AsH$_3$. Find the flow rates of TMG, TEG, and AsH$_3$ with time if growth is done at 750°C. The carrier gas (H$_2$) flow rate is 10 SLM (Standard Litres per minute).

2. An In$_x$Ga$_{(1-x)}$As$_y$P$_{(1-y)}$ is to be grown lattice matched to InP at a band gap of 0.8eV. Find the flow rates of TMG, TMI, AsH$_3$, and PH$_3$, if growth is to be done at 700°C. The carrier gas (H$_2$) flow rate is 15 SLM.