Molecular Beam Epitaxy (MBE)

BY

A.AKSHAYKRANTH

JNTUH
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What is Epitaxy?

- Method of depositing a mono crystalline film i.e deposition and growth of mono crystalline layers.

- Epitaxial: Growing crystalline layers on a crystalline substrate.

- Greek root: ‘epi’ means ‘above’ and ‘taxis’ means ‘ordered’
Molecular beam Epitaxy is a technique for epitaxial growth via the Interaction of one or more molecular or atomic beams that occur on a surface of a heated crystalline substrate.
Epitaxy types:

1. **Homoepitaxy**: Substrate & material are of same kind, means same composition. (si-si)
   To fabricate layers with different doping levels.

2. **Heteroepitaxy**: Substrate & material are of different kinds, means different composition (Ga-As).
   To fabricate integrated crystalline layers of different materials.
Epitaxy Techniques

**Vapor-Phase Epitaxy (VPE)**
- Modified method of chemical vapor deposition (CVD).
- Undesired polycrystalline layers
- Growth rate: ~2 \( \mu \text{m/min} \).

**Liquid-Phase Epitaxy (LPE)**
- Hard to make thin films
- Growth rate: 0.1-1 \( \mu \text{m/min} \).

**Molecular Beam Epitaxy (MBE)**
- MBE is an ultra high vacuum (UHV) based technique for producing high quality epitaxial structures with mono layer (ML) control.
- “Beam” molecules do not collide to either chamber walls or existent gas atoms.
- We do MBE in a vacuum chamber (pressure: \( \sim 10^{-11} \) Torr).
- Growth rate: 1\( \mu \text{m/hr} \).
Why we go for MBE?

- This technique for producing epitaxial layers of metals, insulators, and superconductors as well as both at the research and industrial production level.
MBE: Working Principle

1. **MBE: process**: the term ‘beam’ means the evaporated atoms do not interact with each other or with other vacuum chamber gases until they reach the wafer.

   Ultra pure elements are heated in separate quaï-effusion cells (e.g. Ga and As) until they begin to slowly sublimate.

2. **Epitaxial growth**: Epitaxial growth takes place due to the interaction of molecular or atomic beams on a surface of a heated crystalline substrate.

   - They provide an angular distribution of atoms or molecules in a beam.
   - The substrate is heated to the necessary temperature.
   - Atoms on a clean surface are free to move until finding correct position in the crystal lattice to bond.
A commercial MBE system
MBE: Working Conditions

- The mean free path ($\lambda$) of the particles > geometrical size of the chamber.

- That is easily fulfilled if the total pressure does not exceed $10^{-5}$ torr.

- It is also the condition for growing a sufficiently clean epilayer.
Some attributes of MBE Chambers
MBE: Operation

- The vacuum system consists in a stainless-steel growth chamber.
- The pumping system usually consists of ion pumps, cryogenic pumps for the pumping of specific gas species.
- Ultra high vacuum is used to obtain sufficiently clear epilayer.
Effusion cell:

- Effusion cells are the key components of an MBE system, because they must provide excellent flux stability and uniformity and material purity.
- A collection of gas molecules moving in the same direction.
- Oven contains the material to make beam.
- Oven is connected to a vacuum system through a hole.
- The substrate is located with a line of sight to the oven aperture.

Effusion cell beam system
MBE: Control Mechanisms

- MBE systems permit the Control of composition and doping of the growing structure at monolayer by changing the nature of the incoming beam just by opening and closing mechanical shutters.

- The operation time of a shutter is approximately 0.1s, that is much shorter than the time needed to grow one mono layer (typically 1-5s).

- Molybdenum and tantalum are widely used for shutters.

- what is RHEED

RHEED (Reflection High Energy Electron Diffraction) for monitoring the growth of the crystal layers.

![Graph showing RHEED oscillations]
Benefits and Drawbacks of MBE

Benefits

- Clean surfaces, free of an oxide layer.
- *good control of layer thickness and composition.*
- Low growth rate (1μm/h), so we get high material purity.
- Precisely controllable thermal evaporation.
- Seperate evaporation of each component takes place.
- Substrate temperature is not high.

Draw backs

- Expensive (10^6 $ per MBE chamber)
  - Very complicated system
- Epitaxial growth under ultra-high vacuum conditions
Applications

- Hetero junction bipolar transistors (HBT’s) used in satellite communications.
- Electronic and optoelectronic devices (LED’s for laser printers, CD and DVD players).
- Used in the construction of quantum wells, dots and wires for use in lasers.
- To build a solar cell by depositing a Thin film of a photo voltaic material
- Low temperature Super conductor.
Conclusions

- **Objective:** to deposit single crystal thin films
- Typically in ultra-high vacuum
- Deposition rates are very low (1µm/hr)
- Very well controlled (Shuttering: 0.1s)
- Film growth with good crystal structure

- Deposition rate is so low that substrate temperature doesn’t need to be as high.

- Expensive
VIDEOS OF MBE
ANY QUERIES

THANK YOU