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MOLECULAR BEAM EPITAXY

WITH A FOCUS ON OPTICAL TECHNIQUE TO DETERMINE SUBSTRATE TEMPERATURE :

The term "EPITAXY" comes from a Greek root EPI meaning ***above*** and TAXIS meaning in ***ordered manner*** , giving a complete meaning being arranged upon something . It refers to the method of depositing a monocrystalline film on a monocrystalline substrate. The deposited film is called the epitaxial layer and the substrate acts as the seed crystal .It can be categorized into two forms based upon the film produced and the substrate used

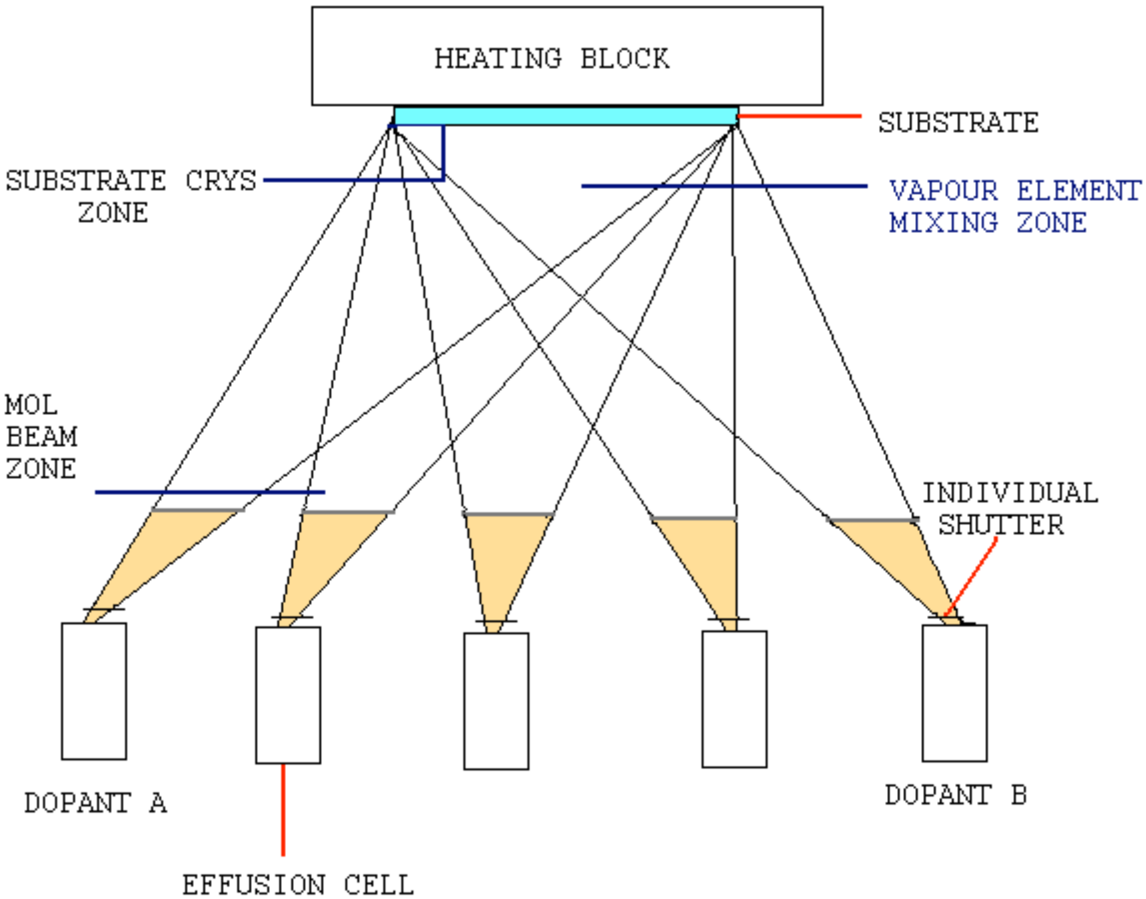
1. Autoepitaxy/Homoepitaxy/Isoepitaxy, if the film and the substrate are identical materials

2. Heteroepitaxy, if the film and the substrate are different materials

Epitaxy exists in different forms, according to the source of the atoms being arranged on the substrate. They are VAPOUR PHASE, LIQUID PHASE and SOLID PHASE. The solid phase epitaxy is also referred as MOLECULAR BEAM EPITAXY (MBE) . In MBE a source is heated to produce an evaporated beam of particles .These particles travel through a very high vacuum to the substrate where they condense and a film is formed. This method was invented by ***A.J.CHO*** and ***J.R.ARTHUR*** in 1960's in the Bell Labs.

SCHEMATIC OF MBE SYSTEM:

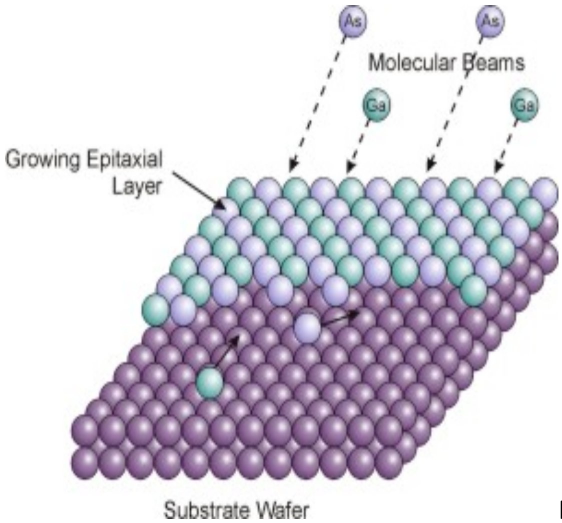
Each MBE arrangement may be divided into three different zones where different physical phenomenon take place . The first zone is the generation of molecular beams , second zone is where the beams from different sources intersect each other and the vaporized elements mix ,together creating a very special gas phase contacting the substrate area . The third zone is the area in which the crystallization process takes place . The molecular beams are generated in the first zone under UHV conditions from effusion cells whose temperatures are accurately controlled.



SCHEMATIC FOR ESSENTIAL PARTS OF MBE

Epitaxial growth in MBE is realized in the third zone , on the substrate surface , the series of processes that are involved can be summarized as the following

- ***Adsorption*** of the constituent atoms or molecules impinging on the substrate surface ,
- ***Surface migration*** and ***dissociation*** of the adsorbed molecules ,
- ***Incorporation*** of the constituent atoms into the crystal lattice of the substrate,
- ***Thermal desorption*** of the species not incorporated into the crystal lattice .



REPRESENTATION OF PROCESSES ON THE SUBSTRATE

There are some ***prerequisites*** for MBE to take place. They are as following,

- The category of vaccum in which MBE takes place is called **Ultra high vacuum (UHV)** and this is realized when the total pressure of the residual gas in the reactor is in the range $1.33 * 10^{-7}$ Pa (10^{-9} torr) or greater than that .
- Two parameters ,closely related to pressure ,are important for the characterization of the vacuum .The first is the ***mean free path of the gas molecules*** penetrating the vacuum , while the second is the ***concentration of the gas molecules*** (the number of molecules per unit volume).
- The relation for the mean free path is given by **$L= 1/\sqrt{2}\, \pi * n * d^2$**

  Where d : molecular diameter , n : concentration of the gas molecules in the vacuum

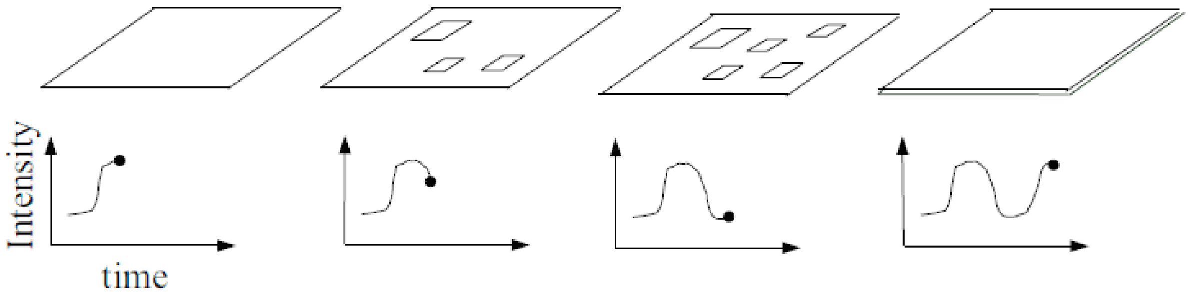
  The relation between the concentration of gas molecules , pressure p , temperature T is given by

  $n= p/kT$ where $k = 1.381 * 10^{-23}$ JK^{-1}, boltzmann constant.

Since UHV is the essential environment for MBE , the rate of gas evolution from the materials in the chamber has to be low as possible . So pyrolytic boron nitride (PBN) is chosen for the crucibles which gives low rate of gas evolution and chemical stability up to 1400^0 C, molybdenum and tantalum are widely used for the shutters, the heaters and other components, and only ultra pure materials are used as source. A cryogenic screening around the substrate minimizes spurious fluxes of atoms and molecules from the walls of the chamber.

MBE systems permit the control of composition and doping of the growing structure at monolayer level by changing the nature of the incoming beam just by opening and closing mechanical shutters. The operation time of a shutter of approximately 0.1 s is normally much shorter than the time needed to grow one monolayer (typically 1-5 s). The UHV environment of the system is also ideal for many insitu Characterization tools, like the RHEED (reflection high energy electron diffraction).

The oscillation of the RHEED signal exactly corresponds to the time needed to grow a monolayer and the diffraction pattern on the RHEED window gives direct indication over the state of the surface. It can be understood from the figure below .



RHEED OSCILLATIONS.

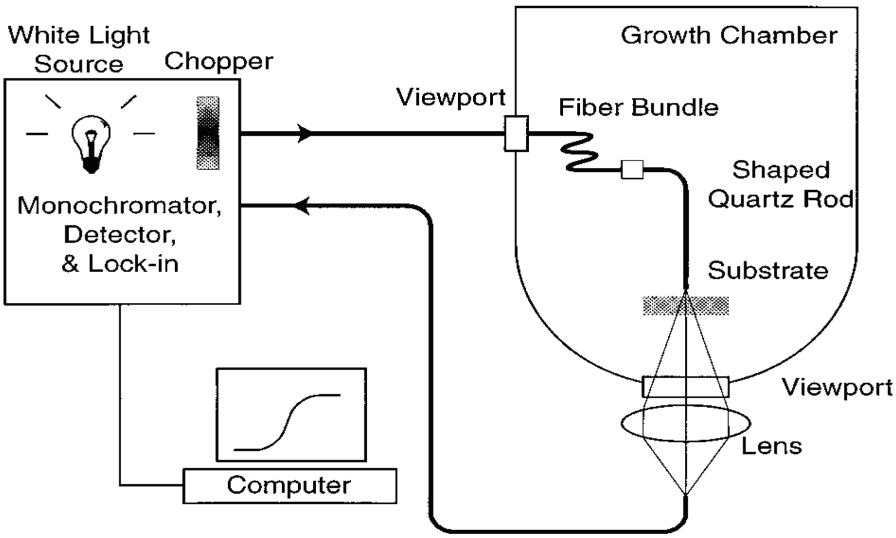
APPLICATIONS AND ADVANTAGES OF MBE:

A computer controls shutters in front , allows precise control of the thickness of each layer, down to a single layer of atoms. Intricate structures of layers of different materials may be fabricated this way. Such control has allowed the development of structures where the electrons can be confined in space, giving quantum wells or even quantum dots. Such layers are now a critical part of many modern semiconductor devices, including semiconductor lasers and light-emitting diodes. The growth rate is typically 1µm/h.

In comparison to all other epitaxial growth techniques MBE has a unique advantage. Being realized in an ultra high vacuum environment, it may be controlled in situ by surface diagnostic methods such as Reflection High – Energy Electron Diffraction (RHEED) , Auger Electron Spectroscopy (AES) , Ellipsometry , Optical Reflectance –difference and Laser intereferometric methods . These powerful facilities for control and analysis eliminate much of the guesswork in MBE, and enable the fabrication of sophisticated device structure using this growth technique .

OPTICAL TECHNIQUE FOR MEASURING SUBSTRATE TEMPERATURE :

MBE is a sophisticated process but still has some short comings which effect its overall progress . It is the lack of any means to accurately sense and control one basic parameter , SURFACE TEMPERATURE . This problem arises because the typical sensor used for temperature control is a thermocouple . It fails to be in contact with the substrate at high temperatures. This could be rectified by using optical pyrometers but upto some extent, the optical pyrometers are limited by the stray lights coming from the source ovens and the substrate heater filaments. To rectify this , we look upon a successful noncontact temperature measurement which was achieved by installing an optical pipe inside the MBE machine .This is based on using the fundamental optical properties such as band gap of a semiconductor and their temperature dependence as a vehicle for obtaining the substrate temperature . This is done as follows , the fundamental band gap of the substrate is measured from the transmission spectrum obtained after passing white light through substrate . The temperature of the substrate is determined by comparing the band gap obtained with one in the database.



SCHEMATIC OF OPTICAL DELIVERY SYSTEM FOR THERMOMETRY MEASUREMENTS

There are two primary components which are installed inside the vacuum chamber. The first one is a shaped quartz rod that guides light from a fiber bundle to the back side of the substrate, quartz is considered due to high temperature stability properties. The second one is a UHV compatible fiber bundle, which is attached to one end of the quartz rod . The individual fibers are made of borosilicate and the bundle is encased in a stainless steel monocoil, and between the fiber bundle and steel is a layer of a fiberglass material called silver flex (UHV compatible). One more key requirement is satisfied by keeping a pyrometer view port in front of the sample while in the growth position.

Outside the vacuum chamber we use commercially available hardware and software for performing the optical transmission measurements. This system uses chopped white light from a 20 W lamp order to separate our light source from stray light due to the heater, ion gauges, and cells. This light is directed to the back side of the substrate using the fiber bundle and shaped quartz rod discussed earlier. The light which is transmitted through the wafer is collected through a view port on the growth surface side of the sample. The primary loss of light collection is due to beam divergence from the quartz rod to the view port. A simple lens system collects the light and focuses it onto a fiber bundle, after which the light is piped into a fast-scan grating monochromator with a silicon-germanium detector and a lock-in amplifier. A computer reads the transmission spectra and then calculates the fundamental band gap using either a first or second derivative technique.
Thus, we can compare the obtained data to determine the substrate temperature.

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