3.7: Electron beam physical vapor deposition

Introduction

Electron Beam Physical Vapor Deposition (EBPVD) is a form of physical vapor deposition in which a target anode is bombarded with an electron beam given off by a charged tungsten filament under high vacuum. The electron beam causes atoms from the target to transform into the gaseous phase. These atoms then precipitate into solid form, coating everything in the vacuum chamber (within line of sight) with a thin layer of the anode material.

The PVD process can be carried out at lower deposition temperatures and without corrosive products, but deposition rates are typically lower. Electron beam physical vapor deposition, however, yields a high deposition rate from few nm/min to 100 nm / min at relatively low substrate temperatures, with very high material utilization efficiency.

Construction & Working Mechanism

In this technque A target (set as anode) is bombarded with an accelerated electron beam given off by a charged tungsten filament (set as cathode) under high vacuum of at least $< 10^{-4}$ Torr (secondary vacuum) to allow passage of electrons from the electron gun to the target material as shown in Fig. 3.7. Accelerating voltages can be between 3 kV – 40 kV.

When the accelerating voltage is between 20 kV – 25 kV and the beam current is a few amperes, 85% of the electron's kinetic energy can be converted into thermal energy very rapidly. The thermal energy that is produced heats up the evaporation material causing it to melt or sublimate and resulting vapors can then be used to coat surfaces.

Some of the incident electron energy is lost through the production of X-rays and secondary electron emission.

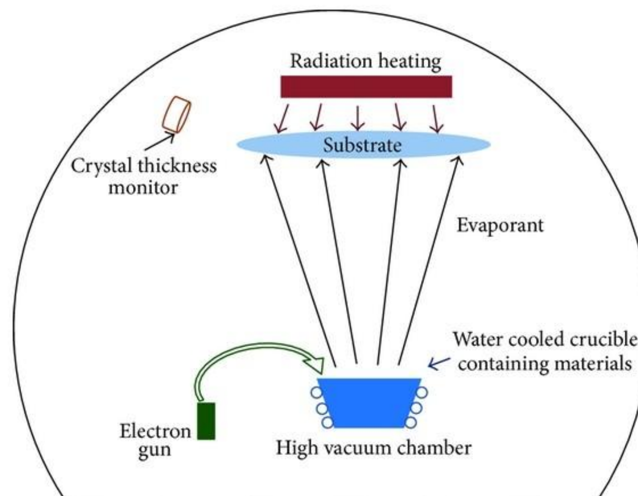

Fig.3.7 Electron beam physical vapor deposition setup

Advantages of EBPVD

- ❖ The deposition rate in this process can be as low as 1 nm per minute to as high as few micrometers per minute. Due to the very high deposition rate, this process has potential industrial application for wear resistant and thermal barrier coatings in aerospace industries, hard coatings for cutting and tool industries, and electronic and optical films for semiconductor industries and thin film solar applications.

- ❖ The material utilization efficiency is high relative to other methods and the process offers structural and morphological control of films.

Disadvantages of EBPVD

- ❖ First drawback of EBPVD is that, its a line of sight deposition process like other physical vapor deposition techniques, especially when performed at a low enough pressure (roughly $<10^{-4}$ Torr). However, when vapor deposition is performed at pressures of roughly 10^{-4} Torr or higher, significant scattering of the vapor cloud takes place such that surfaces not in sight of the source can be coated.

- ❖ The translational and rotational motion of the shaft holding objected to be coated helps for coating the outer surface of complex geometries, but this process cannot be used to coat the inner surface of complex geometries. But strictly speaking, the slow transition from line of sight to scattered deposition is determined not only by pressure (or mean free path) but also by source to substrate distance.

- ❖ Another potential problem is that filament degradation in the electron gun results in a nonuniform evaporation rate.

3.8: Molecular beam epitaxy

Introduction

Molecular beam epitaxy (MBE) is one of several methods of depositing single crystals. It was invented in the late 1960s at Bell Telephone Laboratories by J. R. Arthur and Alfred Y. Cho. MBE is widely used in the manufacture of semiconductor devices, including transistors for cellular phones and WiFi.

Molecular beam epitaxy takes place in high vacuum or ultrahigh vacuum (10^{-10} Torr). The most important aspect of MBE is the very small deposition rates (typically < 1 nm per sec) allows the films to grow epitaxially. These deposition rates require proportionally better vacuum to achieve the same impurity levels as other deposition techniques. The absence of carrier gases as well as the ultra high vacuum environment result in the highest achievable purity of the grown films.

Such layers are now a critical part of many modern semiconductor devices, including semiconductor lasers and light emitting diodes. Molecular beam epitaxy is also used for the deposition of some types of organic semiconductors. In this case, molecules, rather than atoms, are evaporated and deposited onto the wafer. Lately molecular beam epitaxy has been used to deposit oxide materials for advanced electronic, magnetic and optical applications. For these purposes, MBE systems have to be modified to incorporate oxygen sources.

Construction & Working Mechanism

In solid source MBE, elements such as gallium and arsenic, in ultrapure form, are heated in separate quasi Knudsen effusion cells until they begin to slowly sublime (Fig. 3.8). The gaseous elements then condense on the wafer, where they may react with each other. In the example of gallium and arsenic, single crystal gallium arsenide is formed. The term "beam" means that evaporated atoms do not interact with each other or vacuum chamber gases until they reach the wafer, due to the long mean free paths of the atoms.

During operation, reflection high energy electron diffraction (RHEED) is often used for monitoring the growth of the crystal layers. A computer controls shutters in front of each furnace, allowing precise control of the thickness of each layer, down to a single layer of atoms. Such control has allowed the development of structures where the electrons can be confined in space, giving quantum wells or even quantum dots.

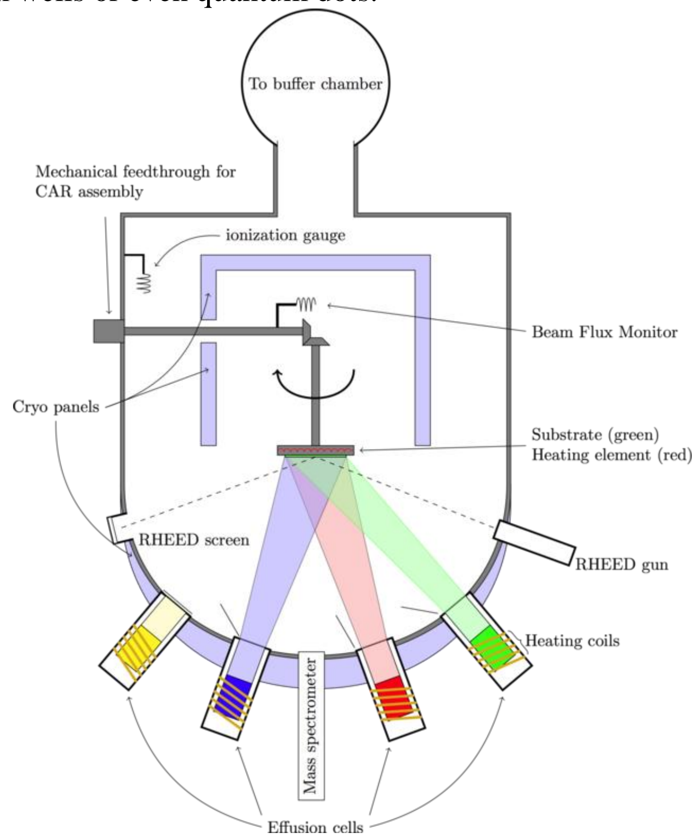

Fig.3.8: Schematic Molecular Beam Epitaxy Setup

3.9: Chemical vapor deposition

Introduction

Chemical vapor deposition (CVD) is a widely used materials-processing technology. The majority of its applications involve applying solid thin-film coatings to surfaces, but it is also used to produce high-purity bulk materials and powders, as well as fabricating composite materials via infiltration techniques. It has been used to deposit a very wide range of materials.

Construction & Working Mechanism

In its simplest form, CVD involves flowing a precursor gas or gases into a chamber containing one or more pre heated objects to be coated (or substrates). Chemical reactions occur on and near the hot surfaces (substrates), resulting in the deposition of a thin film on the surface. This is accompanied by the production of chemical by-products that are exhausted out of the chamber along with unreacted precursor gases.

As would be expected with the large variety of materials deposited and the wide range of applications, there are many variants of CVD. It is done in hot-wall reactors and cold-wall reactors, at sub-torr total pressures to above-atmospheric pressures, with and without carrier gases, and at temperatures typically ranging from 200-1600°C. There are also a variety of enhanced CVD processes, which involve the use of plasmas, ions, photons, lasers, hot filaments, or combustion reactions to increase deposition rates and/or lower deposition temperatures.

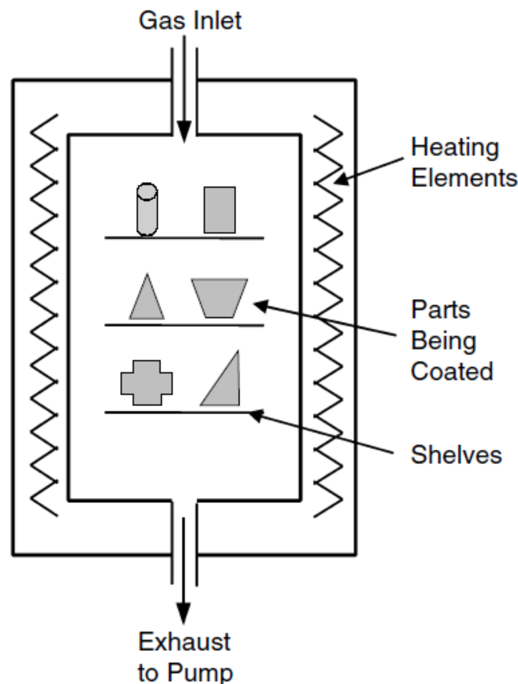

Fig. 3.8- Schematic drawing of hot wall CVD reactor used to coat multipule parts.

Types of CVD Process

There are also many derivatives of the CVD terminology, such as metal-organic chemical vapor deposition (MOCVD) or, less commonly, organo-metallic chemical vapor deposition (OMCVD), which are sometimes used to note the class of molecules used in the deposition process. Some practitioners chose to differentiate epitaxial film deposition from polycrystalline or amorphous film deposition, so they introduced a variety of terms that include "epitaxy" in the acronym. Two of the more common variants are organometallic vapor phase epitaxy (OMVPE) and metalorganic vapor phase epitaxy (MOVPE) which are often used in the compound semiconductor epitaxy literature.

Advantages of CVD Process

CVD has a number of advantages as a method for depositing thin films.

- One of the primary advantages is that CVD films are generally quite conformal, i.e., that the film thickness on the sidewalls of features is comparable to the thickness on the top. This means that films can be applied to elaborately shaped pieces, including the insides and undersides of features, and that high-aspect ratio holes and other features can be completely filled.

- Secondly, in addition to the wide variety of materials that can be deposited, they can be deposited with very high purity. This results from the relative ease with which impurities are removed from gaseous precursors using distillation techniques.

- Thirdly, CVD has relatively very high deposition rates as compared to all PVD techniques.

- Fourthly, CVD often doesn't require as high vacuum as PVD processes.

Disadvantages of CVD Process

- One of the primary disadvantages lies in theproperties of the precursors. Ideally, the precursors need to be volatile at near-room temperatures. This is non-trivial for a number of elements in the periodic table, although theuse of metal-organic precursors has eased this situation.

- CVD precursors can also be highly toxic ($Ni(CO)_4$), explosive (B_2H_6), or corrosive ($SiCl_4$). The byproducts of CVD reactions can also be hazardous (CO, H_2, or HF). Some of these precursors, especially the metal-organic precursors, can also be quite costly.

- The other major disadvantage is the fact that the films are usually deposited at elevated temperatures. This puts some restrictions on the kind of substrates that can be coated. More importantly, it leads to stresses in films deposited on materials with different thermal expansion coefficients, which can cause mechanical instabilities in the deposited films.