Lesson 12 (Week 12)

3.4: Types of Physical Vapor Deposition Techniques

Some important physical vapor deposition techniques are as follows.

- ❖ Pulsed Laser Deposition (PLD)
- ❖ Electron Beam Physical Papor Deposition (EBPVD
- ❖ Molecular Beam Epitaxy (MBE)
- ❖ Sputter Deposition or Sputtering

3.5: Pulsed laser deposition (PLD)

Introduction

Pulsed laser deposition (PLD) is a thin film deposition (specifically a physical vapour deposition) technique where a high power pulsed laser beam is focused inside a vacuum chamber to strike a target of the desired composition. Material is then vapourised from the target and deposited as a thin film on a substrate, such as a silicon wafer facing the target. This process can occur in ultra high vacuum (UHV) or in the presence of a background gas, such as oxygen which is commonly used when depositing oxides to fully oxygenate the deposited films.

PLD is for instance a common technique for the fabrication of high-temperature superconductors. On the reverse, PLD is rarely used for the epitaxy of metals. Some specificities arise with respect to molecular beam epitaxy, some with advantages, some with drawbacks.

PLD is very simple technique and produces films with the same composition as the target. It is fast and cost effective. The advantages of pulsed laser ablation are its flexibility, fast response, congruent evaporation and energetic evaporants. The main drawback of PLD is the formation of droplets in thin film growth, specially when using high fluence. While the basic setup is simple relative to many other deposition techniques, the physical phenomena of laser-target interaction and film growth are quite complex.

Construction & Working Mechanism

A typical pulsed Quantel Nd-YAG or other laser with a pulse duration of few nanoseconds (e.g. 10 ns), repetition frequency ~ 10Hz and an instantaneous laser power of ~ 10MW, is sufficient to melt or evaporate the surface of any light absorbing material. The laser beam is focused by a convex lense placed in between target and laser source outside evaporation chamber. The focused laser beam is enter into evaporation chamber from a transparent quartz window into the chamber walls.

The evaporation chamber contains a rotatable substrate holder with a heating filament, a 10-20 keV electron gun coupled to a fluorescent screen equipped with a CCD camera for reflection high energy electron diffraction (RHEED) measurements to monitor in situ thin film growth, a multitarget holder, a quartz microbalance for estimating the speed of deposition and a moveable mask for varying the thickness of deposits. In general, ultra high vacuum

(UHV) of the order of a 10^{-10} or 10^{-11} Torr is used in evaporation chamber to grow ultra pure metallic thin films. Secondary vacuum of the order of 10^{-6} or 10^{-8} is also used to grow oxide thin films.

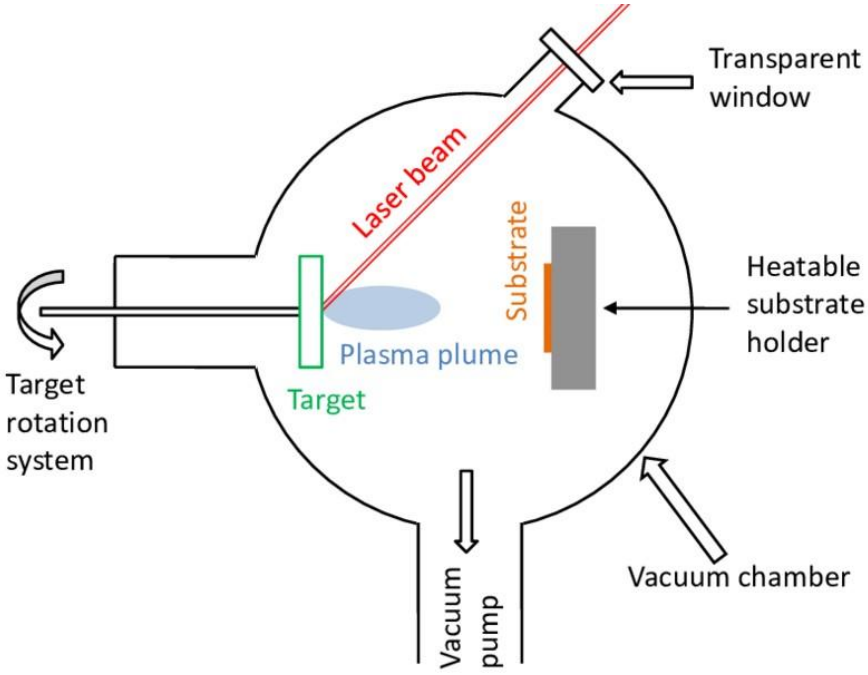

Figure 3.5: Schematic view of pulsed laser deposition (PLD) setup.

When the laser pulse is absorbed by the target, energy is first converted to electronic excitations and then into thermal, chemical and mechanical energy resulting in evaporation and plasma formation. The ejected species expand into the surrounding vacuum in the form of a so called plume containing many energetic species including atoms, molecules, electrons, ions, clusters, before depositing on the typically hot substrate.

The process of PLD can schematically be divided into four stages:

- ❖ Laser ablation of the target material and creation of a plasma
- ❖ Dynamic of the plasma under vacuum (expansion, cooling)
- ❖ Deposition of the ablated material on the substrate
- ❖ Nucleation and growth of the film on the substrate surface

Each of these steps is crucial for the crystallinity, uniformity and stoichiometry of the resulting film.

Factors effecting deposition rate

It is important to know and control the speed of deposition or deposition rate to control the thickness of the material deposited. Furthermore, the growth of material will be different according to the speed at which we deposit. The deposition rate can be adjusted by modifying any of the following two parameters.

1) **The power of the laser beam in J/pulse.**

   If we change the power of laser beam it changes the fluence (energy per unit surface area called the fluence) while the surface of evaporation is kept constant (laser spot diameter or focusing of laser is fixed). The rate of evaporation versus fluence displays a threshold above which the rate of evaporation increases sharply with laser power or fluence. This is achieved by varying the time delay between the oscillator and amplificatory stages of the laser.

2) **By focusing or defocusing laser on target**

   It is achieved by moving the converging lense placed between target and laser source towards or away from the target. Before entering the deposition chamber the beam has a diameter of about 0.5 cm^2. The beam is then focused on a target by a converging lens. The target is placed between f/5 and f/3 focal point. By playing with the focus, it adjusts power (or energy per unit surface area called the fluence). Moving towards focus increases the fluence and thus the rate of evaporation per unit area, however the total area of evaporation is reduced because spot size of laser decreases due to focusing.

Determination of thin film thickness

A quartz balance in evaporation chamber is used for this purpose. It is a quartz plate whose shear resonance frequency varies depending on rigidity and inertia. The inertia is proportional to quantity of material deposited. Thus, the frequency evolution of the resonance inform us about the quantity of material deposited in terms of thickness deposited per second e.g, nanometer per second (nm/s).

Before each deposition, the quartz is placed in front of the target at the position of substrate. The laser beam is sent on target to evaporate and plasma is deposited on quartz plate to check the deposition rate. If we know the deposition rate then thickness can be easily calculated by multiplaying the deposition rate with time during which we have done deposition.

3 .6 : Sputter Deposition Techniques

There are in general two types of sputtering process

- ❖ DC Diode Sputtering
- ❖ AC or RF Sputtering

Both DC diode and AC sputtering each have one more derivative

- ❖ DC Diode Magnetron Sputtering
- ❖ AC or RF Magnetron Sputtering

Below we will describe in detail each of above four types of sputtering process.

3.6.1: DC Diode sputtering

If a high negative potential difference (~1000V) is applied between the target and the substrate in a rarefied Argon environment, electrons released from the target collide with Argon atoms and ionise them, giving them a positive charge. These are then accelerated towards the target and strike it at high energy, releasing target material. However, diode sputtering requires a relatively high process pressure because the electrons follow a short, direct route to the anode (the substrate) so the probability of any given electron striking a given Argon atom (the collisional cross section) is relatively low, and many gas atoms are needed to increase this. This in turn means that sputtered material goes through many collisions with gas atoms, greatly reducing the amount actually reaching the substrate deposition rates are low and much of the target material coats the system rather than the substrate but coverage of uneven surfaces can be highly uniform.

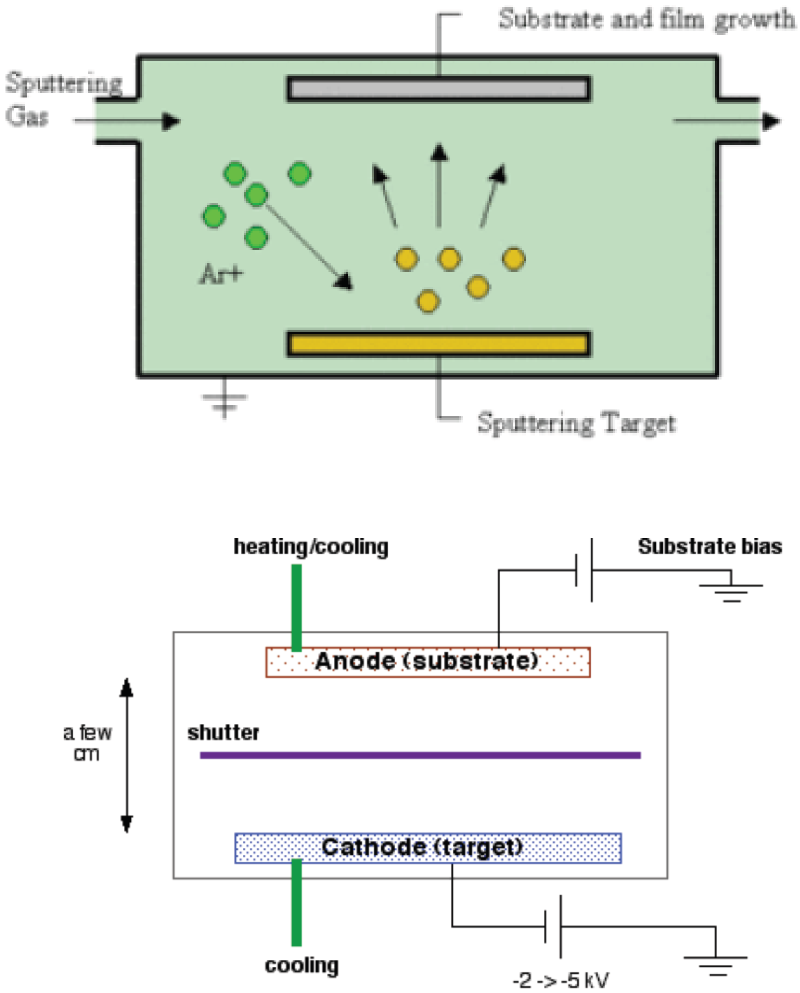

Fig. 3.6.1: Schematic Sputter deposition setup

Parameters effecting sputter deposition rate

Nature of bombarding Inert gas
Higher the mass or size of bombarding inert gas atoms (Typically Argon is used for sputtering), higher will be the sputter & hence deposition rate resulting rapid thin film coating.

Bombarding Inert gas pressure
Higher the bombarding inert gas pressure, higher will be the sputter & hence deposition rate, resulting rapid thin film coating.

Sputter voltage
Higher the sputter voltage, higher will be the sputter & hence deposition rate, resulting rapid thin film coating

Below threshold voltage no sputtering yield and above and below optimum sputter voltage sputter yield decreases.

Parameters effecting thin film quality

Substrate Temperature
Usually control with substrate heater, but also changes due to heating from energetic deposited material, which can be decreased with increasing substrate bias or voltage.

Higher or lower substrate tempreature than optimum value can result in rough thin film growth or higher crystallographic defects in film.

Sputtered Plasma Energy
Increases with increasing sputter voltage , decreases with increasing substrate bias, decreases with increasing Ar pressure

Higher or lower sputter plasma atomsor molecules energy than optimum value can result in rough thin film growth or higher crystallographic defects in film.

Deposition Rate
Increases with Ar pressure, increases with sputter voltage or yield

Higher or lower deposition rates than optimum value can result in rough thin film growth or higher crystallographic defects in film.

Substrate Bias Voltage
Substrate is being bombarded by electrons and ions from target and plasma, so substrate bias can significantly change these parameters & hence thin film properties.

3.6.2: DC Magnetron sputtering

If a strong mangetic field is applied along with an electric field, the electrons follow a spiral path around the field lines giving them a much longer path length before being absorbed into a surface. This greatly increases their chance of striking and ionising an Argon atom and therefore gives the same ion density at a much lower pressure than for diode sputtering.

If the ends of the magnetic field lines are at the cathode then the electrons will continue to bounce back and forward almost indefinitely. This technique can be used with both DC or RF voltages.

3.6.3: AC or radiofrequency (RF) sputtering

When the Argon ion strikes the target an electron is released from the surface and combines with the ion to neutralise it, returning it to the vacuum as an Argon atom. If the target material is dielectric this process rapidly casues a charge buildup at the surface until Argon ions are no longer attracted, electrons are no longer released and the plasma extinguishes. To sputter nonconducting or insulating materials it is therefore necessary to apply AC or pulsed power to the target whereby the ion charge, which has built up on the target surface during negative cycle, is expelled during the positive cycle. Because the power supply is only negative half the time, rates are lower than for DC sputtering whilst power supplies are more complex and therefore more expensive.

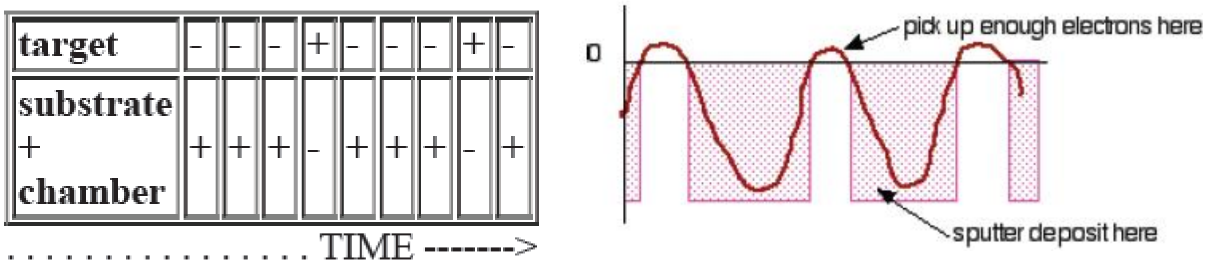

Fig. 3.6.3: Schematics AC or radio frequency sputtering

<u>Frequency of AC or RF power Supplies</u>

For Frequencies< 50 kHz

- electrons and ions in plasma are mobile
- both follow the switching of the anode and cathode
- basically DC sputtering of both surfaces

For Frequencies abov > 50 kHz

- ions (heavy) can no longer follow the switching
- electrons can neutralize positive charge build up

In AC sputtering, working at frequencies below about 50 kHz, the potential on the target is periodically reversed When potential on target is negative, the ions have enough mobility to reach cathode target before change of potential to do DC diode-like sputtering, while electrons reach the substrate which at that time is at positive potential and results in increase in temprature by depositing their energy there.

One the other hand after change of polarity on target and substrate i.e when target becomes positive, electrons will move towards target and will neutralize target on which positive charge was accumulated during negative potential at target while ions will travel towards substrate and will do sputtering of film deposited on substrate. To avoid sputtering of substrate chamber walls are used as counter electrode along with substrate, then most of sputtering will be done at chamber wall instead of substrate and we can protect substrate from sputtering.

At frequencies above 50 kHz, the ions do not have enough mobility to reach the target before change of polarity to allow establishing a dc-diode-like sputtering of target and results in stop of sputtering.

A major disadvantage of RF sputtering of dielectric targets is that most insulating materials have poor thermal conductivity and high coefficients of thermal expansion, and are usually brittle materials. Since most of the bombarding energy produces heat, this means that large thermal gradients can be generated that result in fracturing the target if high power levels are used.