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THIN FILM DEPOSITION TECHNIQUE: REVIEW

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Abstract: **Deposition tools may well be observed as the most important key to the advent of devices. Electronic and optical tools were primarily foundation on sample phases produced with the aid of thin-film deposition. For production of tools have incessantly required materials of enhanced nature and superiority in crystal structure, needful a fast advancement in preparation methods. Instrument producers have become successful works to complete necessities in enhanced as well as inexpensive preparation techniques and for such methods different parameters maintain sample factors. An additional significant cause for the hasty development of deposition techniques is the enhanced consideration of the chemistry and physics of samples, exteriors, boundary, as well as structures make viable through extraordinary progress in characterizations at some stage in the beyond 20 years.**

Keywords: *Chemical vapor deposition, Physical vapor deposition, Surface coating, Thin film*

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I INTRODUCTION

The material construction techniques in semiconducting tools generation as well as in another regions of digital gadgets production were significantly depending on sample preparations methods. Numerous deposition technologies for substance development are available. Because anxiety right is with thin sample preparation techniques to generating coating in width variety of some 10-9 to 10-6 meters, challenge of categorizing technology is make less difficult via proscribing the wide variety of technology to be measured. The assortment of a selected method for preparation of samples may be primarily relying on an expansion of determinations. Huge number of samples of diverse substances may prepared for a greater range of purposes; as a result, no universal procedure may be described of what the majority appropriate preparation process need to be. In deciding on a correct preparation process for a precise purpose, some standards need to be measured. The importance significance of preparation method is manufacture of semiconducting tools, a production which was definitely depending on creation of materials of a multiplicity of substances via synthesis as of liquid, solid and gaseous level. Several techniques were developed for preparation of preferred thin sample. Thin film preparation techniques are mostly divided into physical as well as chemical.

Surface engineered materials have augmented and improved performance, added functionality, reduced cost, improved material usage efficiency and provided performance which would not be possible with bulk materials [1-2].

Surface coating is a division of science that focuses on techniques for attaining desired surface finishing and near-surface region properties for thin film components to make them suitable in a desirable way for various applications in service [1, 3, 4].

It is also probable for advanced materials to be coated with a film (e.g., met glass, polymers, superlattices, photocatalysts), graded deposits, metamaterials and multicomponent deposits [2, 5–7].

In an overlay process sometimes referred to as hard facing, a protective material with superior physical and chemical properties is deposited on the surface of the substrate and the underlying material (substrate) is covered and not noticeable on the surface resulting into a thick and solid film [8].

Laser cladding, laser additive manufacturing, and weld overlays are methods used for overlaying process [9–11].

The surface coating technique requires the deposition of thin film layers on the surface, thereby altering the properties of the surface. Examples of surface coating techniques are vapor phase processes deposition (physical and chemical vapor deposition), solution state processes and fusion process. This process can be achieved via the deposition of a thin film process, plasma enhancement, ion bombardment, self-assembly, nano machining, chemical treatment to mention a few [14–19].

The term thin film is usually applied to surface deposition layers which are 2-dimensional and have the thickness range below 1 micron (10−6 meters) and thicker layers above the range of 1 micron are referred to as coating or sometimes called thick film. The resulting thin film can range from single crystal to amorphous, fully dense to less than fully dense, pure to impure and thin to thick. Thin films offer enormous potential due to the following [5,20,21]

- Conservation of scarce materials,
- Production of nanostructured coatings and nanocomposites,
- Ecological considerations—a reduction of effluent output and power consumption,
- Improved functionality of existing products,
- Solution to previously unsolved engineering problems and,
- Creation of entirely new and revolutionary products. The area of review interest is on the thin film deposition; therefore, this review has been carefully selected to focus more on the surface coating techniques used for deposition and grow of the thin film below the thickness of ten micrometers.

II DEPOSITION TECHNIQUES

A deposition technique is considered as the integral key for the creation of thin film new materials to meet the ever-increasing demand from industries for versatile and multi-dynamics materials. The deposition techniques determine virtually all the properties of the thin film and can also be used to modify the existing properties. Proper consideration needs to be given to the deposition techniques depending on the area of application because not all the deposition techniques result into the identical properties such as microstructure, surface morphology, tribological, electrical, biocompatibility, optical, corrosion and hardness [7,25].

Most deposition techniques follow these three major sequences:

1. Synthesis of the deposition species,
2. Conveyance from source to substrate,
3. Deposition and adhesion of the source onto the substrate and subsequent film growth

The prominent subsets of deposition techniques are physical vapour deposition (PVD) and chemical vapour deposition (CVD). The distinguishing feature between PVD and CVD is in the vapour. In PVD, the vapour is made up of atoms and molecules that simply condense on the substrate, and for CVD, the vapour undergoes a chemical reaction on the substrate which resulted into a thin film [26–30].

III PHYSICAL VAPOUR DEPOSITION (PVD) PROCESS

Physical vapour deposition (PVD) is a generic term used to quantify thin film deposition processes that require condensation of the vaporized solid material on top of the surface of the solid material under a partial vacuum condition [31,32]. PVD is an atomistic deposition process in which there is a physical discharge of atoms or molecules and condensation and nucleation of these atoms onto a substrate through a vacuum or low pressure gaseous or plasma environment. Plasma or ions are usually the constituents of the vapour phase. Sometimes, the reactive gas can be introduced to the vapour during the deposition process and this is called reactive deposition. The atoms or molecules are conveyed in the form of a vapour via a vacuum or low pressure gaseous or plasma environment to the surface of the substrate for condensation to take place. Commonly, PVD processes are used to deposit thin films with thickness in the range of a few nanometres to a thousandth of nanometres. They can also be applied for multilayer deposition coating, graded composition deposits, very thick deposits, free-standing structure and in hybrid form with other deposition techniques [7,33]. Every PVD process can be attributed to three basic step which they all obeyed [1,7,21,34]. Creation of vapor-phase species. This requires conversion of materials to be deposited from a solid state to a vapour phase by evaporation, sputtering or ion bombardment. Movement or transportation from source to the substrate. The ejected atoms or molecules from the target will be transported through molecular flow conditions and thermal scattering processes. Also, if the partial pressure of the metal vapour or gas species in the vapour state is high enough for some of these species to be ionized, there will be a large number of collisions in the vapour phase during movement to the substrate. Film growth on the surface. The transported atom or molecule will start to nucleate around the substrate and grow by a number of processes. . The composition and microstructure of the thin film can be altered by bombardment of the growing film by ions from the vapour phase, resulting in sputtering, re-condensation, and nucleation of the film atoms and enhanced surface movement of the atoms around the surface of the film.

The major variants of PVD are listed in Figure 1 below, but the three basic processes of PVD are vacuum or thermal evaporation, ion plating and sputtering.

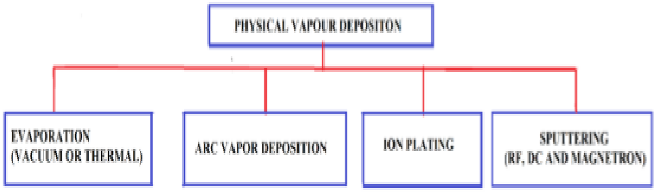

Figure 1. Variants of Physical Vapour Deposition.

During the evaporation process, thermal effect causes ejection of atoms from the source, whereas, for ion plating process, the growing film is exposed to concurrent ion bombardment. During sputtering, the atoms are ejected from the surface of the solid target by the impact of gaseous ions and then deposited on the surface of the substrate [35,36].

3.1. Thermal (or vacuum) evaporation

Thermal (or vacuum) evaporation is an old deposition process used for the formation and growth of the thin film on the surface of solid materials. The process is still beneficial in a contemporary environment and extensively applicable in the laboratory and industries for deposition of the thin film. The vapour is created from subjecting the target material to very high temperature by subliming or boiling, The ejected vapour from the target material is transported to the substrate through a vacuum, Condensation of the vapour takes place to form a solid thin film on the surface of the substrate, and further repeatability of the deposition cycles result in thin film growth and nucleation. During the thermal evaporation process, the target material vaporized from the thermal process sources gets to the substrate material with minimal interference. The process is often carried out at a high vacuum pressure (HV), and the trajectory of the movement of the target material to the substrate is a straight path trajectory termed line of sight [13]. Vapour flux is created by heating the surface of source material to a sufficiently elevated temperature in a vacuum. The flux can then condense to the surface of the substrate material to form a thin film. The vacuum environment creates a safe zone to reduce gaseous contaminants in the deposition process to an acceptable and minimal level and allows the evaporated atoms to undergo essentially collisionless transport from the source onto the substrate. The gas pressure range is usually between 0.0013 Pa to 1.3 × 10−9 Pa depending on the degree of the contamination in the deposition system, with the mean free path (MFP, the average distance between collisions occurring between species) no smaller than 5 mm. The thermal vaporization rate might be very high compared to other PVD processes [13,27]. Tungsten wire coils are commonly used as the source of the thermal heat or by using high energy electron beam for heating the target material to an elevated temperature.

Evaporation process has been reported to be performed using different configurations. These are Molecular beam epitaxy, reactive evaporation and activate reactive evaporation. Molecular beam epitaxy (MBE) was discovered by J.R Arthur and Alfred Y. Cho at Bell telephone laboratories around 1960. MBE is used for growing epitaxy through the active interaction of distinct or numerous atomic or molecular beams on the surface of a heated crystalline substrate material. The evaporation occurs at an ultra-high vacuum for deposition of the controlled composition of uniform thickness of the thin film from specific deposition rate. This process has been applied in the manufacturing of semiconductor devices like cellular phone, transistor conductors and Wi-Fi [37–40]. Reactive Evaporation involves the evaporation of atoms of metal from a target material in a chamber with the presence of reactive gas at a partial pressure. During the evaporation process, the atoms react with the gas chemically to form a compound thin film on the surface of the substrate. Reactive evaporation can form stoichiometric oxides, alloys [41,42]. Another variant of evaporation technique is Activated Reactive Evaporation (ARE). ARE takes place by evaporation of atom from the surface of the target material in the presence of plasma and react this with the reactive gas within the chamber to form compounds with faster deposition rate and improved adhesion property. The plasma improves the rate of reaction between the target and the substrate, ionization of both coatings of metals and gas atom in the vapour phase and higher conversion of the neutral atoms into ions or energetic neutrals thus enhancing reaction probabilities and rates to deposit refractory compounds. If ARE process substrate is held at a negative bias voltage, it becomes biased activated reactive evaporation [43–45].

3.2. Sputtering

Sputtering is a vital and prominent procedure among the PVD processes. It’s a non-thermal vaporization process whereby individual atom escapes from the target surface due to atomic collision cascades by suitable high energy ion bombardment. Unlike evaporation, the source is no longer created by thermal but by ion impact on the target. Also, the target to substrate distance is shorter and, in many cases, it has outperformed other PVD processes with more functionality and performance like improved adhesion and thicker film. During the sputtering process, atoms are removed from the surface of the target material by transfer of sustainable momentum from an atomic-sized energetic bombarding particle usually gaseous ion accelerated from a plasma. Sputtering deposition can be achieved in a vacuum at low pressure plasma of <0.67 Pa where the sputtered particles is in line of sight and can also be done at higher plasma pressure of 0.67 to 4 Pa, where energetic particles sputtered or reflected from the sputtering target are thermalized by gas phase collision before they reach the substrate surface. Sputtering is also being used as an etchant for cleaning the surface of solid materials and for pattern delineation because of its potential to eject atoms from an electrode surface [27,46,47]. The sputtering deposition has become a generic name for a variety of sputtering processes. These processes are named based on their source and the orientation of the process. Variants of sputtering are diode sputtering (cathode or radio frequency), reactive sputtering, bias sputtering, magnetron sputtering and ion-beam sputtering [25,48].

Sputtering deposition technique employs various sources for power, and the working pressure varies depending on the power configuration. DC sputtering is made up of a pair of planar electrodes (referred to as the cold cathode and anode). The target material to be deposited is placed on the cathode, and the substrate is positioned at the anode. The working gas inside the deposition chamber is usually argon gas due to the larger mass compared to neon and helium because higher mass correlates to more energetic collision with the target material and lower cost when compared to xenon and krypton. DC voltage is supplied between the cathode (target material) and anode (substrate) to sustain the glow discharge. The gaseous ions resulted from the sustained glow discharges are accelerated towards the target material, and sputtering takes place resulting in deposition of a thin film on the surface of the substrate material. In the DC sputtering system, the target is composed of conducting material usually metal since the glow discharge (current flow) is maintained between the metallic electrodes [49–51]. Radio Frequency (RF) Sputtering is another variant of sputtering which involves alternating the electrical potential of the current in the vacuum environment at radio frequencies to avoid charge building up on certain types of sputtering target materials. In RF sputtering, the cathode (the target) which is to become the thin film coating and an anode is connected in series with a blocking capacitor in between. The capacitor is part of an impedance-matching network that provides the power transfer from the RF source to the plasma discharge. The cathode is bombarded by high voltage in a vacuum chamber leading to high energy ions sputtering off atoms as a thin film covering the substrate to be coated at a fixed frequency of 13.56 MHz. The essence of the capacitor is to develop DC self-bias and increase the optimization of power transfer for the target material to the plasma generated. RF sputtering offers numerous advantages like possibility of deposition on insulating materials, ability to sustain plasma at low pressure of 0.13 to 2 Pa, diffusion of RF plasma throughout the entire chamber, reduction of the creation of race track erosion on the surface of the target and ability to clean up the target materials after each cycle from building up charge to reduce arcing effect [52–54]. During sputtering process, secondary electrons are usually emitted from the target surface as a result of ion bombardment and magnetron sputtering makes use of the magnetic field to restrict the movement of the secondary electron to the vicinity of the target material. The configuration and strength of the magnetic field array determine the rate of the ionization efficiency current delivers to the target material resulting in higher deposition rate at the substrate. The increased ionization efficiency noticed during magnetron sputtering allows running of the sputtering process at a lower pressure of 100 Pa and lower voltage of −500 V compare to 10 Pa and −2 kV to 3 kV for the conventional sputtering process. The two major configurations for magnetron sputtering are conventional (balanced) and unbalanced magnetron sputtering. In balanced configuration, the plasma is confined to the target region while for unbalanced configuration, not all the magnetic field lines are closed but some are directed towards the substrate while some follow the closed field path. Further reading on this can be found in [55]. Conductive materials can be deposited using a direct current (DC) power supply and insulators can be deposited by using a radio frequency (RF) power supply. Magnetic arrays in magnetron sputtering configuration can be varied in situ without tempering with the electromagnet [31,56–60].

Reactive Sputter Deposition is used for creating the compound thin film. During sputtering, a reactive gas such as nitrogen or oxygen is introduced to the deposition chamber and gas react with the target material to form a compound thin film on the surface of the substrate. This process is referred to as reactive sputtering. An increase in reactive gas causes the topmost layer of the target material to transform from single phase to compound phase, which often results in changes in the properties such as the conductivity, e.g., conductive surfaces become non-conductive, and vice versa. The inert gas usually used for this process is Argon and its possible to combine the inert gas with ionized non-inert gas (reactive gas) or introduced the ionized non-inert gas (reactive gas) alone in the chamber. The percentage of reactive gas added to the chamber is controllable to produce a specific stoichiometric ratio of the compound. Argon is in most cases the main gas and the amount of a reactive gas introduced into a process chamber is controlled to either achieve a certain amount of doping or produce a fully reacted compound. The resulting deposited thin film is different from the target [61,62]. Of recent, another variant of magnetron sputtering was invented called Pulsed Magnetron Sputtering PMS regarded as an emerging technology. The technique provides a solution to the challenging problems with other magnetron techniques like low deposition rate experience with RF magnetron sputtering and target poisoning and arc event associated with reactive magnetron sputtering. PMS concept is based on short or intermittent pulsing the medium frequency range between 10–200 kHz of the magnetron discharge for tens of microseconds at a low duty circle. The two modes for operating PMS are unipolar PMs where the voltage of the target material is pulsed between the ground and standard operating voltage and bipolar pulsed sputtering where the voltage of the target material is being reversed and turns to positive during the pulse-off duration. The pulsing process leads to the creation of super-dense plasma with exquisite properties which result in the creation of more uniform thin film and the possibility of achieving a smooth surface coating with complex and irregular shaped substrate materials [63–66]. Due to the limitation of the sputtering process, a new method of sputtering deposition is now being used called duplex sputtering where two or more deposition techniques are used to produce a functionally graded material with broad areas of application and improved properties [55].

3.3. Ion plating

Mattox [27] was the first to report Ion plating technique in 1960. It uses continuous or intermittent bombardment in an inert gas discharge system for the deposition of a film by atomic sized energetic particles to amend and regulate the properties of the depositing film. The plasma is created in a hollow cathode discharge source. The substrate material is subjected to bombardment by a high energy flux ions adequate to cause substantial sputtering on the surface of the substrate before and during thin film growth [67–69]. The deposition material may be vaporized by other physical vapor deposition techniques like evaporation, sputtering, arc erosion or by decomposition of a chemical vapour precursor but the evaporated atoms pass through the gaseous glow discharge on their way to the substrate which causes some of the vaporized atoms to be ionized [70,71]. The ions bombardment during film growth helps to create denser films with the densities closer to that of the bulk material and thus make it suitable for depositing a hard-thin film on compound materials. The gas pressure for ion plating process is between the ranges of 1 to 0.1 Pa. This pressure is enough to sustain glow discharge as well as scatter the vapour particles in all direction through numerous collisions to improve the overall coating of the substrate during film growth. A reactive gas can be added to form a compound surface coating, and the process is known as reactive ion plating.

3.4. Arc Vapour deposition

Arc vapour deposition is a deposition process that uses electric arc at high current and low voltage to vaporize a cathodic electrode (cathodic arc) or anodic electrode (anodic arc) and deposit the vaporized material on a substrate. The substrate is usually biased so as to fast-track the film ions to the surface and also, the vaporized material are highly ionized. Flux is generated by creating an arc that travels across the surface of the target [25]. The arc strikes lead to ejection of atoms from the target materials and condense on the substrate as a thin film coating. A substantial proportion of the metal atoms become ionized and makes it distinguished from vacuum or thermal evaporation. This substantial proportion of ionized atom makes it reliable for the formation of a thick coating and can be used for hard decorative surface-coating operations.

IV CHEMICAL VAPOUR DEPOSITION (CVD) PROCESS

Such method is applied to supply superior quality, high-performance, solid substances. The system is frequently applied in the materials manufacturing to provide thin coatings. In this method, the material holder is treated with at least one or more volatile precursors that combine and decay on template exterior to manufacture preferred deposit. Regularly, low boiling compounds were too formed, that can be detached by gas flow in the reaction vessel. In this method, a fluid or solid material is becomegassy via volatilization then permitted to run either via a pressure variation or through a gaseous material to templates. The chemical process is commenced thru an exterior parameter to manufacture a film.

In PVD, thin film formation is caused by condensation of atoms or molecules on the surface of the substrate due to evaporation, ion bombardment, or sputtering [18,72–74]. On the other hand, CVD is a thermodynamically complex process involving chemical reactions under specific conditions such as temperature, pressure, reaction rates, and momentum, mass, and energy transport. Several process factors and chemical reaction between the reactant and substrate are responsible for the quality of films produced during CVD and the quality of the film can be controlled and modified by using the appropriate combination of process parameter like flow rates, pressure, temperature, concentration of chemical species, reactor geometry, etc. [75,76].

In addition, CVD has the ability to deposit materials which are problematic to evaporate with low porosity property on a substrate of complicated shapes which are difficult to produce by other deposition techniques [18,48].

The chemical reaction taking place depends on the reactant (precursor) gas and the by-products. In addition, the reaction has to be thermodynamically predicted, i.e., there is a need for availability of adequate energy for the reaction to take place and the Gibbs free energy (total available energy) has to decrease in order to allow the temperature and pressure of the reaction to be altered [5,14,18,77].

This process involves the reaction of one or more volatile precursor transported via the vapour phase to produce a non-volatile solid that deposits atomistically on a suitably placed substrate within the confinement of a reaction chamber [13,78]. The fundamental sequential steps that occur in every CVD process are stated below [79]:

- Convection or diffusion movement of reactant in a gas phase to the reaction chamber,
- Chemical and gas phase reactions leading to the formation of reactive species and by-products,
- Transport of the reactants through the boundary layer to the substrate surface,
- Chemical and physical adsorption of the reactants on the substrate surface,

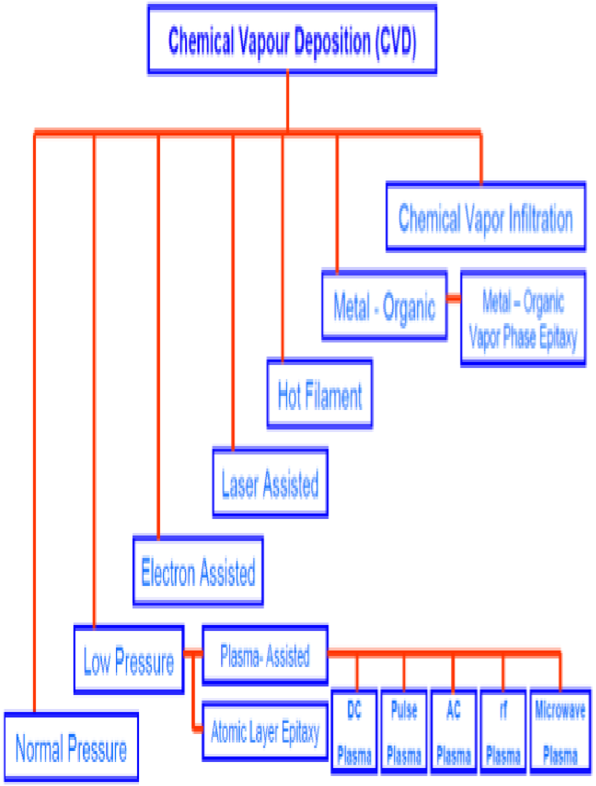

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Figure 2. Variants of Chemical Vapour Deposition.

- Heterogenous surface reactions leading to the formation of a solid film,
- Desorption of the volatile by-product to the main gas stream by diffusion through the boundary layer,
- Removal of gaseous by-products out of the reactor via convection and diffusion process. CVD process usually characterized by volatile reaction of by-products and unused precursor species. Many CVD reactions by-products are very hazardous volatile by-products such as H2, Cl2, HCl, HF or water vapour. Proper safety precaution is needed when using CVD. Venting, scrubbing of by-products and unreacted compounds are essential in CVD processes. CVD can be grouped based on energy used to drive the chemical reaction. Sources of energy can either be a photon, laser or temperature (thermal). Figure 2 illustrates the variants of the CVD process.

4.1. Thermal CVD

Thermal CVD is a CVD process for depositing a thin film on various materials. This process uses heating lamps or other methods to heat the substrate rapidly and activate the energy needed for the reaction to take place. The growing film surface is exposed to thermal energy from either the condensing atoms or substrate heater to create the thin film. This thermal surface energy is responsible for mobilizing the atoms which lead to the creation of thin film with uniform thickness and good surface coverage and finishing. Since the thermal surface energy is dependent on the working temperature, an increase in temperature also resulted in a better thin film distribution on the surface of the substrate. The surface chemistry and surface atom mobility are aided by the substrate temperature alone [80,81].

4.2. Laser CVD (LCVD)

LCVD is also a variant of CVD process. It involves exposing a focused laser beam to locally heat the substrate of one or more volatile precursors which react on the surface to produce thin film deposition. The laser which occurs because thermal energy produces a coherent, monochromatic high-energy beam of photons can be used effectively to drive CVD reactor for deposition of the thin film [82–84].

4.3. Photon CVD

Photon CVD is another type of CVD. The chemical reaction is driven by the photon usually ultraviolet (UV) radiation which has the necessary energy to break the chemical bonds among the reactant molecules for deposition of the thin film [85,86].

4.4. Plasma-enhanced CVD (PECVD)

PECVD is a variant of CVD that is used to deposit a thin film from gaseous state to a solid state on the substrate. The chemical reaction takes place after the creation of a plasma in the reactor chamber and subsequently leads to deposition of a thin film on the surface of the substrate. PECVD uses an electrical source of energy to generate plasma and sustain the reaction process rather than thermal energy for the majority of the CVD processes. The electrical energy is used to initiate homogeneous reactions for the creation of chemically active ions and radicals that can partake in heterogeneous reactions, which, in turn, lead to layer formation on the substrate. The main benefit of PECVD over thermal CVD processes is the possibility of deposition to take place at a very low temperature close to the ambient temperature and permits materials sensitive to temperature change to be worked on [87–89]. The use of plasma to activate the gas phase chemistry opens up several new reaction paths for deposition at a significantly lower temperature [90].

4.5. Pulsed CVD

Pulsed CVD also was known as atomic layer deposition (ALD) or atomic layer epitaxy (ALE). Its origins can be traced back to two different places. ALD was first developed as a promising coating technology on inorganic materials by Aleskovskii during the 1960s in Russia and was referred to as molecular layering [91]. It became a major innovation when Suntola in the 1970s developed the atomic layer epitaxy technique to deposit ZnS for electroluminescent displays [92]. ALD is based on self-limiting reactions between two gaseous precursors and allows the deposition of thin films in a layer-by-layer fashion. The ability to deposit conformal films on high aspect ratio structures, with high uniformity over large areas, at (relatively) low temperatures and moderate pressure, as well as exquisite thickness control are well beyond the reach of other thin film technologies such as physical vapor deposition and chemical vapor deposition and has made ALD a technique of choice for the preparation of ultrathin films [91,93]. It uses only surface chemical reactions to build up ultrathin films with the ability to achieve a very precise control of thin film thickness down to atomic level [94,95]. ALD allows a wide range of deposition and also viewed as an alternative method for exploring more surface growth mechanisms to form new hybrid nanostructures. It has been extensively used for the nanofabrication processes for microelectronic applications. ALD became commercially important in the early 2000s when the semiconductor industry started to adopt ALD for manufacturing high-performance complementary metal–oxide– semiconductor (CMOS) transistors. Both Intel and IBM have utilized ALD to fabricate high-k dielectric layers in CMOS since 2007. Recently, Intel stated that the use of ALD was a key factor for the successful development of the high-k metal gate transistors that allowed further downscaling of the size of integrated circuit chips [96]. Nowadays, ALD has already percolated into the multitudinous application domain such as magnetic recording heads, optics, demanding protective coatings, and micro-electromechanical systems. Some more detailed information on ALD application has been summarized by Octavio [91], Hong [93] and Bo Yan [97]. Other notable mention deposition techniques that use CVD reaction principle of operation are metal organic vapour phase epitaxy, metal organic CVD, pyrolysis, reduction, oxidation, compound formation, disproportionation, and reversible transfer. Some CVD processes can also be carried out in atmospheric pressure known as Atmospheric pressure CVD or APCVD. APCVD are commonly used to form SnO2 on hot glass using SnCl4 or monobutyltn trichloride and dopants to make the coating on the surface [34,98].

V CHEMICAL DEPOSITION METHOD:

(1) Spray Pyrolysis

They include thermally inspired reaction among groups of fluid otherwise gaseous atoms of various spraying components of preferred substances onto a template preserved at larger temperature. The tiny droplets accomplishment at the warm substrates undergoes disintegration and is prepared in nature of bunches of materials. Spray pyrolysis has been used to deposit a huge sort of thin films. These films were used in a variety of tools like solar equipment, sensors, and solid oxide fuel cells. It’s far located that often the properties of obtained sample depend on the preparation parameters. A widespread evaluation of the causes of spray factors on film nature is given to express the significance of the method of optimization. The substrate material temperature is the mainly vital factor as it depends on film irregularity, cracking, crystallinity, etc.

(2) Screen-printing

This process mostly generates thick sample coating in that a preferred substance was printed via routine method onto an appropriate material. An outline is photographically described on a stainless steel screen through an emulsion coating. A paste of the substance to be screen printed is hard pressed via the screen by means of a squeegee. Crucial screen printing factors are: the thickness of the mixture, the mesh quantity of the screen, the snap-off distance among the screen and the substance, the pressure and velocity of the squeegee. Subsequent to levelling, the printed damp film is dried up. By then, the film includes unfastened conglomerates of extremely minute particles. The sintering steps consequences in dense films, wherein big particles are electronically and optically closely connected.

(3) Anodization

The method is referred to as anodizing due to the component to be considered as the anode. This process decreases conduction to deteriorationand wear, and gives improved sticking together for primers and paste than the uncovered steel plates. Such films too may be applied for a variety of superficial things, both with solid absorbent outside layer which may soak up stain or with tiny obvious coatings so as to add interferingcauses to reflected beam. In such technique,metallic component wasprepared anode in suitable electrolyte. In the coating, the most important parameter is pH.Accompanied by pH, other parameter like, applied potential difference, reactive mixture temperature, period of coating andnature metallic material were toosignificant. In such process, oxide coating was created using material. Anode combines by means of anion as of electrolyte then turns into oxidation, developing oxidecovering on semi-conductors as well as on some precise conductors, although H_2 vapors is generated at other electrode. Non-porous as well as adhere oxides may produce on different templates. Majority significant appliances were decay protecting and attractive coats having coloring on Al and their solid solution, and sheets for electrical lagging.

(4) Electrodeposition

Electrodeposition is an attractive phenomenon. That possible put a glossy coating of one metal on some other really via donating electrons to ions in a solution is splendid, and research of the procedure at an atomic stage carry on to yield astonishes. Electrodeposition is extremely flexible, and precious applications continue being invented. In electrodeposition method, the deposition of material is accomplished on electrode through electrolysis process. The chemical alteration is delivered approximately through passing electric current via electrolyte. In the course of deposition, ions attain at the individual electrode, stabilize on it, liberate their charges and undertake electrochemical deposition. Significant variables were current outcome, pH, current allocation, temperature, current density, amount of reactant, and the stirring effect. Many metals and their combinations were productively electroplated using aqueous phase. Though, the precisely the majority practical electroplated metals are rhodium, chromium, gold, copper, zinc, silver, nickel and a sequence of dual combination as well as nickel/chromium compound. Electroplating is extensively applied in manufacturing and may create coatings that vary from thin coating to extremely thick coatings.

5) Chemical Bath Deposition

On this approach, the film may be developed on any appropriate substrate via dropping in proper aqeous phase of metal compound. Positive ions chelated by means of appropriate chelating ligand are allowable to combine using group VI ions. Positive ions and group VI ions were to produce gradually via rising heat of reaction mixture. The generated cations and anions created association on templates through nucleus formation process. Development typically happened through ion creation technique.

VI CHOICE OF METHOD OF PREPARATION

Even though there are numerous methods of synthesis of thin sample one necessity to choose suitable technique, in relation to necessities. An ultimate method of coating must have subsequent properties

(a) Ability for synthesis of materials like conductors, solid solutions, chemical composites.

(b) Capability to generate polycrystalline or non- crystalline preparation.

(c) Retaining of stoichiometric composition

(d) Proper binding to dissimilar templates

(e) Changeability of residual stress and amount of imperfection.

(f) Capability for coating above extensive range of numerous preparative factors.

(g)Capacity for dissimilarity of extensive range of crystallographic factors

(h) Respectable throwing capacity

(i) Capability to maintain sample thickness.

VII THIN FILM

The thin film can be labelled as thin materials layers ranging from a fraction of nanometers to one micron (10^{-6} meters) in thickness. The paramount distinction between thin film and thick coating depositions is the thickness of the layers deposited. Thin film deposition involves deposition of individual atoms or molecules on the surface while thick coating deals with deposition of particles. It is being used to modify the physical and chemical properties and surface morphology of materials without altering the properties of the bulk material. A thin film can be personalized as one homogeneous composition, single layer, crystalline phase composition and microstructure, or have an inhomogeneous multilayer or composite structure depending on the envisaged properties and area of applications. The structure of the multilayer can be periodic, have a set pattern or be entirely random. Almost all thin films deposition techniques have four or five basic chronological steps. The steps are unique to the overall properties of the thin film and are listed below [13,68]:

- The source of the pure material to be deposited is selected. This source of material will act as a target during the deposition process,
- The target is transported through a medium to the prepared substrate. This medium can either be a fluid or vacuum, depending on the materials and the deposition technique used,

- The target is deposited onto the substrate, forming a thin film on the substrate surface,
- The thin film may be subjected to an annealing or other heat treatment processes, depending on whether or not this is necessary to achieve the desired film properties,
- The film properties are analyzed. If necessary, the analysis results can be incorporated to modify the deposition process.

7.1. Thin film growth and nucleation

Most often, the properties of the thin film are affected by the underlying properties of the substrate and can vary drastically depending on the thickness of the film and the deposition techniques employed for deposition. There are three major steps required in thin film growth and nucleation. The first step involves the creation of the deposition species, i.e., the substrate and the target material, follow by the transportation from the target to the substrate using any deposition technique and the final stage involves the growth of the target on the substrate to form the thin film. The atoms from the target impinge on the substrate, where they can either reflect immediately from the substrate, evaporating back into the gas phase after a certain residence time, or condense on the substrate surface. This process is affected by numerous factors, including activation energy, the binding energy between the target and substrate, the adhesion coefficient, etc. The ration between the condensing atoms to the impinging atoms is called sticking coefficient. During this process, the atoms lose energy and might not immediately react with the substrate. They will have some mobility over the surface before condensation and these mobile atoms are referred to as adatom which is a portmanteau for absorbed atoms. The energy lost during condensation of the atom on the surface can either be by chemical reaction with the substrate atoms, the collision of the diffusing surface atoms, finding a preferential nucleation site or collision of the absorbed surface species. If the surface mobility is low and the atom to atom interaction is strong, each atom can serve as nucleation site for growth but when the adatom–surface interaction is feeble, the surface mobility of the condensing adatom will be high and results in condensation at preferential nucleation sites where there is stronger bonding either due to an increase in the coordination number or a change in elemental or electronic chemistry. The condensing atoms react and bond with the atoms on the surface to form atom to atom chemical bonds. The chemical bond formed may be of any of these following bonding types: electrostatic attraction (van der Waals forces) due to the polarization of atoms, metallic (homopolar) bonding where the atoms share orbital electron or electrostatic (coulombic heteropolar) where the ions are formed due to electron loss or gain. The atom is said to have undergone chemisorption if the resulting bonding from the reaction between the condensed atom and the surface atom is very strong. This adatom transformed to nuclei by a conglomeration of numerous adatoms and resulted in the continuous thin film. Due to the nature of the deposition, the resulting nuclei formed at the initial stage are often thermodynamically unstable and might desorb with time depending on the deposition parameters used. After a while, the clustered nuclei reach a critical safe size and become thermodynamically stable and the nucleation challenge is said to have been overcome. This process involving the transition from thermodynamically unstable condition to a thermodynamically stable condition where a stable, critical-sized nucleus formed is termed the nucleation stage [67–69]. As the deposition process continues, the stable critical nuclei grow in number as well as in size until a saturated nucleation density is attained. The nucleation density and the average nucleus quantity depends on number of deposition parameters such as the temperature of the substrate, working pressure, adhesion properties, binding energy between the target and the substrate, energy of the impinging species, the activation energies of adsorption, desorption, thermal diffusion, the rate of impingement, topography, and chemical nature of the substrate. A nucleus can grow in two modes named parallel and perpendicular depending on the configuration of the substrate and target, and the two scenarios can be experienced in a single deposition. Parallel growth occurs on the substrate by surface diffusion of the adsorbed atoms while perpendicular growth is because of direct impingement of the incident species. However, the rate of parallel growth sometimes called lateral growth at this stage is much higher than the perpendicular growth and the grown nuclei are called islands. In the coalescence stage, small islands start coalescing with each other on the surface of the substrate to reduce the substrate surface area and replace it with a thin film coating. This resulted in the formation of a bigger island and the process is called agglomeration. Increasing the surface mobility of the adatoms enhance the agglomeration process and growth density of the nucleation site, i.e., by increasing the temperature at the surface of the substrate. In some reactions, the formation of new nuclei may also take on areas newly exposed because of coalescence. Bigger islands grow together, leaving channels and holes of the uncovered substrate between the islands and leading to discontinuous film formation on the surface of the substrate creating a porous defect on the surface. Further growth of the larger islands causes continuous agglomeration and filling of the created channels and holes [23,67,68,99,100]. Nucleation mechanism of thin film growth has been classified into three major types depending on the interaction between the deposited atoms of the target and the surface of the substrate developed by Lewis and Anderson in their studies of evaporated films [101–104]. These are:

- Van der Merwe or island growth mechanism. This growth can be noticed when the adherence between the atom to atom is greater than the bonding between the substrate and the adatoms. Group of stable adatoms accumulate and coalesce on the surface and grow in three dimensions to form an island,
- Volmer Weber or layer mechanism. This occurs when the adhesion between the atom and the surface is greater. The film grows layer by layer on the surface of the substrate and can be used for dense coating,
- Stranski-Krastanov (S-K) mechanism. The SK mechanism combines both island and growth mechanisms. The adatoms begin to accumulate and form islands after an initial layer has grown.

There is not unique technique to fulfil entirely such necessities. Every technique has their individual benefits and drawbacks. It is necessities of use technique themselves which decides optimal of coating process. Several overall standards for such choice are

(a) Substances to be coated

(b) Essential characters of samples

(c) Templates restrictions and characteristics

(d) Templates bombardment in addition to succeeding microscopic consequence

(e) Throwing capacity and speed of coating

(f) Obtainability of essential device and

(g) Price of dissimilar objects.

VIII APPLICATION OF THIN FILM

Over time, the applications of thin films have grown exponentially and have become an integral part of both industrial and research processes. Deposition of the thin film can make a material to be versatile and be used for different applications, by improving the surface properties like wear, fatigue, corrosion, hardness, and other surface related phenomena. Applications of thin films may be grouped under the following generic areas: Electronic component and display. The production of electronic components such as semiconductors, single and multilayer metal conductor film and microelectronic integrated circuits have undoubtedly found enormous and vast applications for thin films deposition. Compound conductor films for semiconductor, dielectric and insulating material, and metal refractory silicide conductors have also benefited immensely from thin film deposition. The fabrication of electronic displays requires conductive and transparent films, luminescent or fluorescent film as well as dielectric and insulating layers [25,48]. Solid surface coating and biomedical. The tribology resistance and corrosion performance of components can be improved by coating the surface of the component with thin film coatings of carbides, silicides, nitrides, and borides respectively. These coatings are being used in tools production, an area with sliding friction like bearing and machine parts. In recent time, more attention and interest has been given to films of diamond-like carbon because of this capability to dissipate heat, hardness, electrical insulation, and respectable resistance to high-temperature and high-energy radiation. It is also used for biomedical application to enhance proper osteo integration and adhesion properties. Optical coating and optical data storage devices. Thin film coating is essential for optical coating. It is used to filter interference on solar panels and acts as antireflection purpose. Thin films with appropriate refractive index gradients are being used on optical fibers to improve refraction and absorption coefficient performance. High reflective coatings that can withstand the extremely high radiation intensities without being degraded and failed when in use are needed for laser optics and are being achieved by deposition of thin films metal reflective coating with excellent properties. Infrared reflecting coatings are applied to filament lamps to increase the luminous flux intensity. Commercial demand for thin film coating is also on the rise in the optical data storage devices like computer memory and storage disk. They serve as a protective coating on the surface to and act as a shield against temperature rise. Thin film has also been used extensively in coating window glass and mirror to prevent heat from passing through [5,69].

REFERENCES:

1. Stokes J (2003) Production of coated and free-standing engineering components using the HVOF (High Velocity Oxy-Fuel) process [PhD thesis]. Dublin City University.
2. Martin P (2010) Deposition technologies: an overview, Handbook of deposition technologies for films and coatings, 3 Eds., Oxford: Elsevier.
3. Halling J (1986) The tribology of surface coatings, particularly ceramics. P I Mech Eng C-J Mec 200: 31–40.
4. Halling J, Nuri K (1985) The elastic contact of rough surfaces and its importance in the reduction of wear. P I Mech Eng C-J Mec 199: 139–144.
5. Martin PM (2009) Handbook of deposition technologies for films and coatings: science, applications and technology, William Andrew.
6. Bräuer G (2014) Magnetron Sputtering, In: Hashmi S, Comprehensive Materials Processing.
7. Martin P (2011) Introduction to surface engineering and functionally engineered materials, John Wiley & Sons.
8. Bhushan B, Gupta BK (1991) Handbook of tribology: materials, coatings, and surface treatments.
9. Toyserkani E, Khajepour A, Corbin SF (2004) Laser cladding, CRC Press.

10. Mahamood RM, Akinlabi ET (2016) Laser Additive Manufacturing, In: Akinlabi ET, Mahamood RM, Akinlabi SA, Anonymous Advanced Manufacturing Techniques Using Laser Material Processing, IGI Global, 1–23.
11. Kashani H, Amadeh A, Ghasemi H (2007) Room and high temperature wear behaviors of nickel and cobalt base weld overlay coatings on hot forging dies. Wear 262: 800–806.
12. Padaki M, Isloor AM, Nagaraja K, et al. (2011) Conversion of microfiltration membrane into nanofiltration membrane by vapour phase deposition of aluminium for desalination application. Desalination 274: 177–181.
13. Mattox DM (2010) Handbook of physical vapor deposition (PVD) processing, William Andrew.
14. Park S, Ikegami T, Ebihara K, et al. (2006) Structure and properties of transparent conductive doped ZnO films by pulsed laser deposition. Appl Surf Sci 253: 1522–1527.
15. Helmersson U, Lattemann M, Bohlmark J, et al. (2006) Review Ionized physical vapor deposition (IPVD): A review of technology and applications. Thin Solid Films 513: 1–24.
16. Somogyvári Z, Langer GA, Erdélyi G, et al. (2012) Sputtering yields for low-energy Ar+- and Ne+-ion bombardment. Vacuum 86: 1979–1982.
17. Roy D, Halder N, Chowdhury T, et al. (2015) Effects of Sputtering Process Parameters for PVD Based MEMS Design. IOSR J VLSI Signal Process 5: 69–77.
18. Carlsson J, Martin PM (2010) Chapter 7: Chemical Vapor Deposition, In: Martin PM, Handbook of Deposition Technologies for Films and Coatings: science, applications and technology, 3 Eds., Boston: William Andrew Publishing, 314–363.
19. Voevodin A, O'Neill J, Prasad S, et al. (1999) Nanocrystalline WC and WC/a-C composite coatings produced from intersected plasma fluxes at low deposition temperatures. J Vac Sci Technol A 17: 986–992.
20. Mattox DM (2010) Handbook of Physical Vapor Deposition (PVD) processing, William Andrew.
21. Trajkovska-Petkoska A, Nasov I (2014) Surface engineering of polymers: Case study: PVD coatings on polymers. Zaštita materijala 55: 3–10.
22. Pretorius R, Marais T, Theron C (1993) Thin film compound phase formation sequence: An effective heat of formation model. Mater Sci Rep 10: 1–83.
23. Alami J (2005) Plasma Characterization Thin Film Growth and Analysis in Highly Ionized Magnetron Sputtering [PhD thesis]. Linköping University.
24. Toku H, Pessoa RS, Maciel HS, et al. (2010) Influence of Process Parameters on the Growth of Pure-Phase Anatase and Rutile TiO2 Thin Films Deposited by Low Temperature Reactive Magnetron Sputtering. Braz J Phys 40: 340–343.
25. Seshan K (2012) Handbook of thin film deposition, William Andrew.
26. Bunshah RF (1982) Deposition technologies for films and coatings: developments and applications, Noyes Publications.
27. Mattox DM (1998) Atomistic Film Growth and Some Growth-Related Film Properties, Handbook of Physical Vapor Deposition (PVD) Processing.
28. Mahan JE (2000) Physical vapor deposition of thin films, Wiley-VCH.
29. Elshabini A, Elshabini-Riad AA, Barlow FD (1998) Thin film technology handbook, McGrawHill Professional.
30. Holmberg K, Mathews A (1994) Coatings tribology: a concept, critical aspects and future directions. Thin Solid Films 253: 173–178.
31. Kelly P, Arnell R (2000) Magnetron sputtering: a review of recent developments and applications. Vacuum 56: 159–172.
32. Kelly P, Arnell R, Ahmed W (1993) Some recent applications of materials deposited by unbalanced magnetron sputiering. Surf Eng 9: 287–292.
33. Ricciardi S (2012) Surface Chemical Functionalization based on Plasma Techniques, Lamberts Academics Publishing.
34. Cao G (2004) Nanostructures and nanomaterials: synthesis, properties and applications, 2 Eds., World Scientific.
35. Leydecker S (2008) Nano materials: in architecture, interior architecture and design, Walter de Gruyter.
36. Phillips RW, Raksha V (2003) Methods for producing enhanced interference pigments. U.S. Patent 6,52.
37. Herman MA, Sitter H (2012) Molecular beam epitaxy: fundamentals and current status, Springer Science & Business Media.
38. Chen Y, Bagnall D, Koh H, et al. (1998) Plasma assisted molecular beam epitaxy of ZnO on cplane sapphire: growth and characterization. J Appl Phys 84: 3912–3918.
39. Rinaldi F (2002) Basics of molecular beam epitaxy (MBE). Annual Report 2002, Optoelectronics Department, University of Ulm, 1–8.
40. Cho AY, Reinhart FK (1975) MBE technique for fabricating semiconductor devices having low series resistance. U.S. Patent 3,915,765.
41. Mergel D, Buschendorf D, Eggert S, et al. (2000) Density and refractive index of TiO2 films prepared by reactive evaporation. Thin Solid Films 371: 218–224
42. Pulker HK, Paesold G, Ritter E (1976) Refractive indices of TiO2 films produced by reactive evaporation of various titanium–oxygen phases. Appl Optics 15: 2986–2991.
43. Terashima T, Iijima K, Yamamoto K, et al. (1988) Single-crystal YBa2Cu3O7−x thin films by activated reactive evaporation. Jpn J Appl Phys 27: L91.
44. Bunshah R, Raghuram A (1972) Activated reactive evaporation process for high rate deposition of compounds. J Vac Sci Technol 9: 1385–1388.

45. Bunshah R (1981) The activated reactive evaporation process: Developments and applications. Thin Solid Films 80: 255–261.

46. Schultz PG, Xiang X, Goldwasser I, et al. (2006) Combinatorial synthesis and screening of nonbiological polymers. U.S. Patent 7,034,091.

47. Seyfert U, Heisig U, Teschner G, et al. (2015) 40 Years of Industrial Magnetron Sputtering in Europe. SVC Bulletin Fall 2015: 22–26.

48. Seshan K (2001) Handbook of thin-film deposition processes and Techniques, Principles, Methods, Equipment and Applications, Noyes Publications/William Andrew Publishing.

49. Teixeira V, Cui H, Meng L, et al. (2002) Amorphous ITO thin films prepared by DC sputtering for electrochromic applications. Thin Solid Films 420: 70–75.

50. Utsumi K, Iigusa H, Tokumaru R, et al. (2003) Study on In2O3–SnO2 transparent and conductive films prepared by d.c. sputtering using high density ceramic targets. Thin Solid Films 445: 229– 234.

51. Gómez A, Galeano A, Saldarriaga W, et al. (2015) Deposition of YBaCo4O7+δ thin films on (001)-SrTiO3 substrates by dc sputtering. Vacuum 119: 7–14.

52. Cash Jr JH, Cunningham JA (1972) Rf sputtering method. U.S. Patent 3,677,924.

53. You T, Niwa O, Tomita M, et al. (2002) Characterization and electrochemical properties of highly dispersed copper oxide/hydroxide nanoparticles in graphite-like carbon films prepared by RF sputtering method. Electrochem Commun 4: 468–471.

54. Torng C, Sivertsen JM, Judy JH, et al. (1990) Structure and bonding studies of the C: N thin films produced by rf sputtering method. J Mater Res 5: 2490–2496.

55. Kelly PJ, Arnell RD (2000) Magnetron sputtering: a review of recent developments and applications. Vacuum 56: 159–172.

56. Constantin DG, Apreutesei M, Arvinte R, et al. (2011) Magnetron sputtering technique used for coatings deposition; technologies and applications. 7th International Conference on Materials Science and Engineering.

57. Magnetron Sputtering Technology, 2019. Available from: http://www.directvacuum.com/pdf/ what_is_sputtering.pdf.

58. David JC (2014) Making Magnetron Sputtering Work: Modelling Reactive Sputtering Dynamics, Part 1. Available from: https://www.svc.org/DigitalLibrary/documents/2014_Fall_DC.pdf.

59.Arnell RD, Kelly PJ (1999) Recent advances in magnetron sputtering. Surf Coat Tech 112: 170– 176.

60. Musil J (1998) Recent advances in magnetron sputtering technology. Surf Coat Tech 100: 280– 286.

61. Suzuki Y, Teranishi K (2009) Reactive sputtering method. U.S. Patent 7,575,661.

62. Ishihara M, Li S, Yumoto H, et al. (1998) Control of preferential orientation of AlN films prepared by the reactive sputtering method. Thin Solid Films 316: 152–157.

63. Chistyakov R (2006) High-power pulsed magnetron sputtering. U.S. Patent 7,147,759.

64. Kouznetsov V, Macák K, Schneider JM, et al. (1999) A novel pulsed magnetron sputter technique utilizing very high target power densities. Surf Coat Tech 122: 290–293.

65. Sarakinos K, Alami J, Konstantinidis S (2010) High power pulsed magnetron sputtering: A review on scientific and engineering state of the art. Surf Coat Tech 204: 1661–1684.

66. Alami J, Bolz S, Sarakinos K (2009) High power pulsed magnetron sputtering: Fundamentals and applications. J Alloy Compd 483: 530–534.

67. Wasa K, Hayakawa S (1992) Handbook of sputter deposition technology, Noyes Publications.

68. Wasa K, Kitabatake M, Adachi H (2004) Thin film materials technology: sputtering of control compound materials, Springer Science & Business Media.

69. Wasa K, Kitabatake M, Adachi H (2004) Thin Film Processes, In: Wasa K, Kitabatake M, Adachi H, Thin Film Materials Technology, Norwich, NY: William Andrew Publishing, 17–69.

70. Liu X, Poon RWY, Kwok SCH, et al. (2004) Plasma surface modification of titanium for hard tissue replacements. Surf Coat Tech 186: 227–233.

71. Liu X, Chu PK, Ding C (2005) Surface modification of titanium, titanium alloys, and related materials for biomedical applications. Mat Sci Eng R 47: 49–121.

72. Albetran HMM (2016) Synthesis and characterisation of nanostructured TiO2 for photocatalytic applications [PhD thesis]. Curtin University.

73. Miller T (2010) An Investigation into the Growth and Characterisation of Thin Film Radioluminescent Phosphors for Neutron Diffraction Analysis [PhD thesis]. Nottingham Trent University.

74. Pessoa R, Fraga M, Santos L, et al. (2015) Nanostructured thin films based on TiO2 and/or SiC for use in photoelectrochemical cells: A review of the material characteristics, synthesis and recent applications. Mat Sci Semicon Proc 29: 56–68.

75. Kommu S, Wilson GM, Khomami B (2000) A Theoretical/Experimental Study of Silicon Epitaxy in Horizontal Single-Wafer Chemical Vapor Deposition Reactors. J Electrochem Soc 147: 1538–1550.

76. Pedersen H, Elliott SD (2014) Studying chemical vapor deposition processes with theoretical chemistry. Theor Chem Acc 133: 1476.

77. Fuller CB, Mahoney MW, Bingel WH (2006) Friction stir weld tool and method. U.S. Patent 6,994Z

78. Klamklang S (2007) Restaurant wastewater treatment by electrochemical oxidation in continuous process [PhD thesis].

79. Chemical Vapour Deposition, 2016. Available from: http://users.wfu.edu/ucerkb/Nan242/L09CVD_a.pdf.

80. Wang DN, White JM, Law KS, et al. (1991) Thermal CVD/PECVD reactor and use for thermal chemical vapor deposition of silicon dioxide and in-situ multi-step planarized process. U.S. Patent 5,000,113.

81. Hirose Y, Terasawa Y (1986) Synthesis of diamond thin films by thermal CVD using organic compounds. Jpn J Appl Phys 25: L519.

82. Petzoldt F, Piglmayer K, Kräuter W, et al. (1984) Lateral growth rates in laser CVD of microstructures. Appl Phys A-Mater 35: 155–159.

83. Sousa P, Silvestre A, Popovici N, et al. (2005) Morphological and structural characterization of CrO2/Cr2O3 films grown by Laser-CVD. Appl Surf Sci 247: 423–428.

84. Matsui S, Kaito T, Fujita J, et al. (2000) Three-dimensional nanostructure fabrication by focused-ion-beam chemical vapor deposition. J Vac Sci Technol B 18: 3181–3184.

85. Inoue K, Michimori M, Okuyama M, et al. (1987) Low temperature growth of SiO2 thin film by double-excitation photo-CVD. Jpn J Appl Phys 26: 805

86. Tanimoto S, Matsui M, Kamisako K, et al. (1992) Investigation on leakage current reduction of photo-CVD tantalum oxide films accomplished by active oxygen annealing. J Electrochem Soc 139: 320–328.

87. Price J, Wu S (1987) Plasma enhanced CVD. U.S. Patent 4,692,343.

88. Li Y, Mann D, Rolandi M, et al. (2004) Preferential growth of semiconducting single-walled carbon nanotubes by a plasma enhanced CVD method. Nano Lett 4: 317–321.

89. Hozumi A, Takai O (1997) Preparation of ultra water-repellent films by microwave plasmaenhanced CVD. Thin Solid Films 303: 222–225.

90. Hitchman ML, Jensen KF (1993) Chemical vapor deposition: principles and applications, Elsevier.

91. Graniel O, Weber M, Balme S, et al. (2018) Atomic layer deposition for biosensing applications. Biosens Bioelectron 122: 147–159.

92. Suntola T, Antson J (1977) Method for producing compound thin films. U.S. Patent 4,058,430.

93. Guo HC, Ye E, Li Z, et al. (2017) Recent progress of atomic layer deposition on polymeric materials. Mat Sci Eng C-Mater 70: 1182–1191.

94. George SM (2009) Atomic layer deposition: an overview. Chem Rev 110: 111–131.

95. Miikkulainen V, Leskelä M, Ritala M, et al. (2013) Crystallinity of inorganic films grown by atomic layer deposition: Overview and general trends. J Appl Phys 113: 2.

96. Bohr MT, Chau RS, Ghani T, et al. (2007) The high-k solution. IEEE Spectrum 44: 29–35.

97. Yan B, Li X, Bai Z, et al. (2017) A review of atomic layer deposition providing high performance lithium sulfur batteries. J Power Sources 338: 34–48.

98.Ozer N, Lampert CM (1998) Electrochromic characterization of sol–gel deposited coatings. Sol Energ Mat Sol C 54: 147–156.

99.Ghoranneviss ZG (2016) Effects of various deposition times and RF powers on CdTe thin film grow using magnetron sputtering. J Theor Appl Phys 10: 225–231.

100. Alfonso E, Cubillos G, Olaya J (2012) Thin film growth through sputtering technique and its applications, INTECH Open Access Publisher.

101. Lewis B, Anderson JC (1978) Nucleation and growth of thin films, New York: Academic Press.

102. Venables JA, Spiller GDT (1983) Nucleation and growth of thin films, In: Surface Mobilities on Solid Materials, Springer, 341–404.

103. Lewis B, Campbell D (1967) Nucleation and initial-growth behavior of thin-film deposits. J Vac Sci Technol 4: 209–218.

104. Lane G, Anderson J (1975) The nucleation and initial growth of gold films deposited onto sodium chloride by ion-beam sputtering. Thin Solid Films 26: 5–23.