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Vacuum based coatings for engineering applications

V. VASUDEVA RAO[1] and V. RAVINDRA[2*]
[1] Cryogenic Engineering Centre, IIT Kharagpur
[2] School of Energy Science & Engineering Centre, IIT Kharagpur

Abstract: In the present modern age, vacuum based coatings are employed in every field of technology to reduce size and improve performance. The present paper briefly describes the physical concepts involved in vacuum coating for different applications along with technical details of necessary vacuum equipment.

Keywords: *Vacuum, PVD, CVD, Sputtering, Coating applications*

INTRODUCTION

Vacuum based coating is the deposition of a two-dimensional film on a surface in a vacuum (or low-pressure plasma) environment. These coatings are finding several engineering applications related to public life. These include laptops, mobile phones, LED-TVs, coated spectacles, solar-PV coatings, solar thermal coatings, diamond coated machine tools, decorative coatings and coatings on household items like utensils& packaging materials. Further, several industrial products and processes depend on metallic coatings for wear-resistance, corrosion resistance, thermal resistance, electrical transport, optical efficiency etc [1]. Vacuum environment gives advantages of reducing the boiling point of the material to be deposited (power saving) and increases the time to form the monolayer (less contamination like oxidation).

Vacuum coatings are broadly classified into two types: Physical vapour deposition (PVD) and Chemical vapour deposition (CVD). In Physical vapour deposition(PVD) material to be deposited as the coating is melted to create vapour for coating using resistively heated filament/ boat of refractive metal such as Mo, Ta, W, Nb under high vacuum. One can use several metallic vapour sources evaporating sequentially or simultaneously for controlling the thickness of individual layers by suitable shutters connected to process controllers for creating a composite film with required properties for an engineering application [2]. In CVD process, the material being deposited comes from a chemical vapour precursor that is decomposed by reduction or thermal decomposition—mostly on a hot surface. In contrast to PVD methods where the substance to be deposited is either solid or liquid, in CVD the substance is already in the vapour phase when admitted to the vacuum system. To deposit it, the substance must be thermally excited, i.e. by means of appropriate high temperatures or with a plasma.

Physical vapour deposition (PVD) coating techniques are mostly confined to making relatively thin films at a vacuum level of 10^{-4} to 10^{-9} mbar, whereas chemical vapour deposition (CVD) is used both for thin films as well as thick coatings up to 1 mm at relatively low vacuum levels. The present paper concentrates more on vacuum based PVD coatings and their engineering applications.

VACUUM BASED COATING UNITS FOR THIN FILM DEPOSITION

Vacuum coating units are specialized equipment consisting of modern vacuum pumps (Turbo, Cryo, Diffusion, Roots and Rotary), vacuum measuring gauges (Pirani, Penning, Bayord Alpert ionization gauge, RGA) and process controllers (mass flow controllers, temperature controllers, pressure controllers, HV/RF controllers). In addition, the manufacturers of specialized vacuum coating systems should be aware of vacuum chamber manufacturing (material selection, welding, brazing) and vacuum troubleshooting procedures (cleaning and leak detection) [3].

In most of the vacuum based PVD systems (Fig 1a), the distance between the vapour source and the substrate material (on which deposition takes place) is less than the mean free path at the operating vacuum so that there will be no scattering of the depositing vapor molecule, till they arrive at the substrate to form thin film coating.

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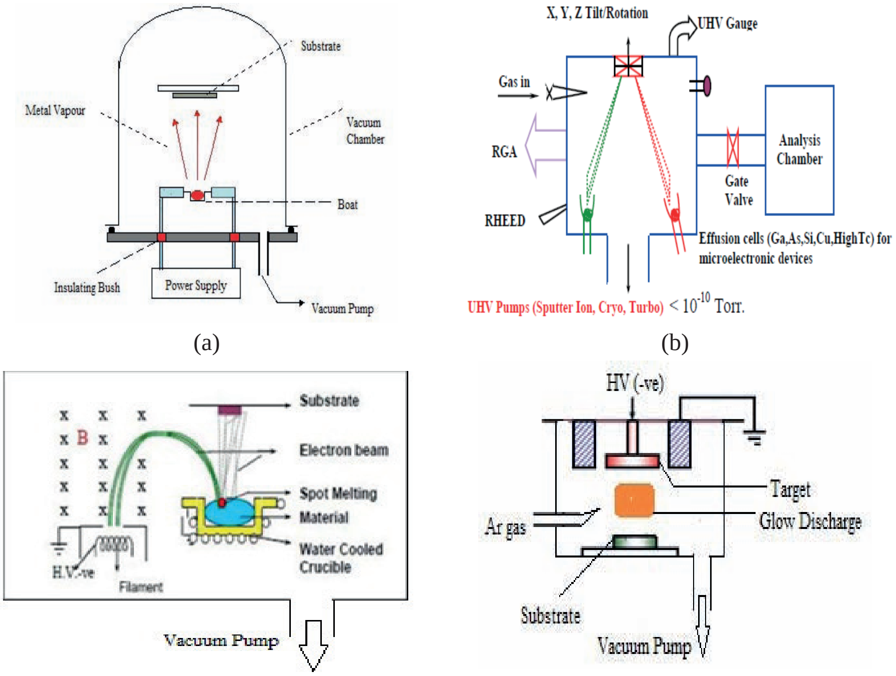
[*] Correspondence Authour E-mail - vvrao@cryo.iitkgp.ac.in

Vacuum compatible high current feed-throughs are connected to the base plate of the vacuum chamber for electric heating of boats and substrates. Substrate heating/cooling attachment in PVD units helps to grow crystalline / amorphous film. With the recent availability of large capacity Ultra-high Vacuum (UHV) Pumps, high quality thin films are being made by Molecular beams created through evaporation from hot solid sources without melting(effusion cells). Such coating units extending the PVD to UHV conditions are called molecular beam epitaxy units (Fig 1b).



(a) (b)

(c) (d)

Fig.1: Schematic diagrams of (a) thermal evaporation (PVD), (b)Molecular Beam Epitaxy (MBE) (c) e-beam deposition and (d) Sputtering deposition

Unlike electrical heating, electron beam heating (Fig 1c) and sputtering process (Fig 1d) can also be used for a deposition without melting the total source material. These methods also reduce contamination from support material and minimize the consumption of costly materials with high melting points. In electron beam deposition under vacuum, a concentrated e-beam is focused on a spot of the source material by suitable electric and magnetic fields for evaporation without any heating of bulk material.

In DC sputtering, a controlled discharge is created between the substrate (anode) and the source material (cathode) to be coated. The positive ions in discharge plasma are accelerated towards the cathode and act as machine tools to dislodge (sputtering) the material from the cathode through momentum transfer at the surface. These sputtered atoms from the cathodic target get deposited as a film/coating onto the substrate attached to the anode (usually grounded). We cannot use DC sputtering for non-conducting targets and hence, one uses RF sputtering for scratching the non-metallic target for film deposition. Both DC and RF sputterings can be extended to high vacuum conditions by adding magnetic confinement of plasma (magnetron sputtering).

ENGINEERING APPLICATIONS OF VACUUM COATINGS

Recently, the importance of relatively thick coatings using PVD is increasing for special engineering applications like thermal barrier coatings, corrosion protective coatings, wear resistant coatings & diamond like hard coatings under the broad discipline known as ‘Surface Engineering’[4]. Similarly, metallization coatings, optical layers and conducting films are finding applications in several modern technologies. These aspects are briefly explained in this section.

Wear/Corrosion resistance coatings

Gold coloured TiN coatings are used successfully on machine tools for improving their wear/ corrosion resistance properties. Coatings may be crystalline or amorphous depending on the processing conditions. These hard coatings increase the cutting efficiency and life of machine tools [5]. Hard coatings also are used to minimize fatigue-wear in ball bearings and to improve the scratch resistance of moulded plastic lenses and plastic aeroplane canopies. Vacuum coatings at surfaces are also effective in creating protection from an aggressive chemical environment. For example, carbon coatings are used on metals to be implanted in the human body. Similarly deposited coatings of cadmium, aluminium, and Al:Zn alloys are used for preventing galvanic corrosion of steels.

Vacuum coatings for metallization application

The aluminium metallization of polymer webs used in manufacturing power capacitors typically requires the system to be pumped out to 10^{-6} mbar range and when the deposition starts the pressure typically rises into the 10^{-4} mbar region. Roll-to-roll metallization, also known as web coating, is the process of creating patterned metal layers on a roll of flexible polymer film. Such flexible metallised polymer rolls are subsequently being slitted to the required dimensions on a slitting machine. Capacitor films for high power application are usually metal coated thin polymer films using thermal evaporation (PVD). These thin film materials are very sensitive to the alignment of the polymer rolls with respect to evaporating metal source in a high vacuum chamber ($\sim 10^{-4}$ torr) and control of proper speed & tension of web is very crucial. These thin metallised web coatings may tear under tension (required for moving the roll). This problem can be solved by running the tape on several support wheels to have multiple short free span lengths.

Blanket metallization is used to shield mobile phones from electromagnetic interference (EMI). Similarly, in semiconductor based electronic devices, aluminium or gold films are used as electrodes on silicon. However, as these microelectronic circuits are processed at high-temperatures, an electrically conductive titanium nitride film is deposited on silicon surface before the metal electrode is deposited to prevent the metallic diffusion into silicon.

High Tc superconducting coatings

The recent development of high Tc superconducting tapes (2G-HTS) based on Yttrium Barium Copper Oxide (YBCO) coating are becoming technologically important. These 2G-HTS tapes in sufficient length are manufactured by depositing YBCO films on flexible metal substrates with different buffer and protection layers in high vacuum conditions. The deposition methods include pulsed laser deposition (PLD) and metal-organic chemical vapour deposition (MOCVD). These HTS tapes can carry very high currents without any electrical resistance. Intense efforts are going on around the world to use these coated superconducting tapes in electrical power, medical and nuclear applications [6]. Further, the HTS superconducting films by sputtering and MBE methods are going to play an important role in realising superconducting quantum computing.

Optical coatings

Vacuum based optical coatings are used in ophthalmic optics, lenses for cameras/optical instruments, optical filters, antireflection (AR) coatings and special mirrors. They are usually deposited in multiple layers to get desired transmission or reflection properties of glass or plastic substrates. The thickness and refractive index of individual coatings are controlled precisely and matched to each other. Quartz crystal thickness monitors are used to monitor the deposition rates and accumulated thicknesses of various layers. The vacuum system for these optical coaters consists of high vacuum pumps (Turbo molecular/Cryo/Diffusion) backed by a combination of a rotary vane pump and roots pump. Aluminium films are also widely used as front-surface reflectors for headlights along with an over-coat of the protective polymer film.

Packaging and Decorative Coatings

Recently, aluminium metal coatings on flexible polymer films and papers are being developed on a large scale for food packaging to reduce the water vapor transmission rate and oxygen transmission rate. Metallization for decorative purposes is also becoming a large market based on metallization of three- dimensional articles such as moulded polymer decorative fixtures and cosmetic containers. These coatings consist of a reflective aluminium coating deposited on a smooth base coat, followed by a dyed lacquer so that the coating gets the desired colour and texture along with corrosion/wear resistance. Similarly, gold coloured titanium nitride (TiN) and brass coloured zirconium nitride (ZrN) coatings with good scratch resistance are used on door hardware, plumbing fixtures and fashion items.

Coatings for solar thermal / PV applications

Both selective absorbing coatings and highly reflecting coatings are extensively used in harvesting solar energy in the form of heat. These coatings are useful for concentrating solar power (CSP) technologies which have a great promise in meeting the energy requirements of the world. The CSP technologies are classified into four types: Parabolic trough collector (PTC), Parabolic dish concentrator, linear Fresnel reflector and solar tower (ST). Among these, PTC and ST technologies are gaining more prominence. While the parabolic trough technology is a line focus technology, the solar tower is a point focus technology. In PTC we use highly reflective aluminium coatings on parabolic collector which focusses the solar energy on to an absorber tube located along the focal axis. The absorber tube is coated with multiple layers of different materials to effectively absorb the focussed solar radiation for conversion into useful heat [7].

Thin film based photovoltaic (PV) solar panels utilize one of the four technologies based on (i) Cadmium Telluride (CdTe), (ii) Amorphous silicon (A-Si), (iii) Copper Indium Gallium Selenide (CIGS) and (iv) Gallium Arsenide (GaAs) coatings. These panels are much smaller compared to conventional bulk silicon based panels. While GaAs and CIGS are yet to become cost effective, CdTe and A-Si have already penetrated the market with mass production strategies. The CdTe thin film solar cells are made on glass support consisting of several sub- layers. The deposition sequence of these sublayers is as follows:

A conductive tin oxide (ITO) is first deposited on glass support (substrate), followed by a transparent layer of Cadmium Sulphide (CdS) with high electrical resistivity.

A thin layer of CdTe is then applied, so that sunlight induced electrical carriers are generated at the interface between CdS and CdTe layers. A suitable thermal activation treatment is given at this stage to optimize the crystalline structure and electrical properties of solar cell.

Finally, a metallic compact layer is deposited for draining the carriers into the external circuit, followed by encapsulation and panelling.

The deposition methods adopted for CdS/CdTe solar panels include thermal evaporation, sputtering, close-spaced sublimation and vapour transport deposition[8].

CONCLUSIONS

It is very clear from the above studies, that public life in modern society involves several engineering applications of vacuum based coatings. This paper briefly presents the scientific principles of vacuum coating and their applications in various fields.

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