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Applications Of Vacuum Coatings

Vacuum coatings are deposited in vacuum by physical vapor deposition (PVD) processes where material is vaporized by evaporation, physical sputtering, or arc vaporization, or by the decomposition of a chemical vapor precursor (chemical vapor deposition—CVD).

Electrically Conductive Films

Metal films are the most common electrical conductor films. The metal films may be used as blanket metallizations or can be formed into discrete conductor lines (stripes) by masking the substrate during deposition, or by subsequent photolythographic etching processes. Conductor lines are used in hybrid microcircuit technology and in the manufacture of semiconductor devices. Often, the electrical conductors are multilayer films (stacks) where each layer has a function. For example, the conductor film stack might have the composition: glass-Ti-Pd-Cu-Au. The Ti is the glue layer, the Pd provides corrosion resistance, the Cu is an electrical conductor, and the Au provides corrosion protection. Blanket metallization is used to provide electromagnetic interference (EMI) and radiofrequency interference (RFI) shielding on structures such as the plastic cases for cellular phones, electrodes for rigid and flexible capacitor electrodes, and surfaces for radar chaff.

Metal nitride, carbide, and silicide films are generally electrically conductive (Si_3N_4 and AlN are important exceptions). In some applications, films of these refractory materials are used to provide diffusion barriers between materials. For example, in semiconductor metallization, aluminum or gold electrode material will diffuse into the silicon during high-temperature processing. An electrically conductive titanium nitride film deposited on the silicon surface before the metal electrode is deposited will prevent the diffusion. Metal nitrides, such as tantalum nitride (TaN), are used as thin-film resistor materials. Non-transparent electrically conductive oxides, such as Cr_2O_3, PbO and RuO, are used as electrodes in high-temperature oxidizing atmospheres.

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Transparent Electrical Conductors

Transparent conductive oxide (TCO) films, such as In_2O_3, SnO_2, ZnO, and an alloy of indium oxide and tin oxide (ITO), have numerous applications, such as heaters on windows for defrosting, antistatic coatings on display screens, electrodes on flat-panel displays and electrochromic devices, and electrodes on both flexible (resistive) and rigid (capacitive) touch screens.

Electrical Insulators

Electrically insulating films are used to electrically isolate conducting components in semiconductor devices, and as a dielectric within capacitors. Common insulator film materials are SiO_2, Al_2O_3, Ta_2O_5, Si_3N_4, and AlN. Insulating layers of SiO_2, Si_2N_3, and glass are deposited by plasma-enhanced CVD (PECVD) for encapsulating conductor stripes in semiconductor processing.

Optical Films

Optical films, usually multilayer films, are films that affect the optical transmission or reflection of a surface. They are generally alternating layers of materials having high (Ge, Si, TiO_2, ZrO_2, SiO, CeO_2) and low (MgF_2, SiO_2) indices of refraction. A major application is the antireflection (AR) coatings on lenses. Optical film stacks can be used as optical filters. Neutral density or gray filters reduce the light intensity equally for all wavelengths. Broadband filters affect the transmission of radiation over a wide wavelength range, while narrow or monochromatic filters affect transmission over a very narrow wavelength region.

Some film stacks are a special type of optical film that have a color related to the angle of observation. They are used as security devices to prevent counterfeiting. These films are an outgrowth of the interference-colored films used for decorative films and, when pulverized, as pigments.

Thermal Control Coatings

The composition of the thermal control coatings on windows differs with the end result desired. If the object is to keep solar radiation from entering through the window, a multilayer film of glass-TiO_2-Cr-TiO_2 may be used (solar control coating). If the object is to keep heat in the room, a thin film of silver can be used to reflect 85–95 percent of the low-temperature infrared radiation back into the room (low-E coating). One such double-E coating is glass-ZnO-Ag-(Ti)-ZnO-Ag-(Ti)-ZnO-TiO_2. The ZnO provides an antireflective coating.

Other types of thermal-control coatings are use to absorb solar radiation (solar absorbers), selectively adsorb solar radiation and not emit infrared radiation (selective solar absorbers), or to have a high emissivity to enhance cooling by radiation.

Reflector Coatings

Metal films are widely used for reflector surfaces. Silver is often used when corrosion is not a problem, such as for back-surface mirrors. Aluminum can be used as a front-surface or back-surface reflector. Chromium is used on front-surface reflectors when corrosion is a problem, even though its reflectivity in the visible (60%) is less than that of aluminum (>90%). In some cases, multilayer films, similar to multilayer optical films, are used to selectively reflect certain wavelengths. Examples are cold mirrors that reflect the visible radiation but not the infrared wavelengths, and heat mirrors that reflect the infrared but not the visible. Heat mirrors are used to raise the internal temperature of halogen lamps. Cold mirrors are used to reduce the heat produced by stage lighting.

Packaging

Barrier coatings are used on flexible polymer films and paper for food packaging, to reduce the water vapor transmission rate (WVTR) and the oxygen transmission rate (OTR) through the packaging. The most common barrier coating material is aluminum, which is deposited on rolls of polymer film (web), then supplied to "convertors" that fabricate the packaging. In some cases, the metal coatings are deposited on a surface and then transferred to the packaging film. Layers of SiO_{2-x}, by reactive evaporation and PECVD, and composite coatings of [SiO_2:30% Al_2O_3] by e-beam co-evaporation, are used to form transparent barrier layers.

Decorative & Decorative/Wear Coatings

Metallization for strictly decorative purposes is a large market. Applications vary from coating polymer webs, which are then converted to decorative use, such as balloons and labels, to metallization of 3-D articles, such as sports trophies, zinc diecast or molded polymer decorative fixtures, and cosmetic containers. Often, these coatings consist of a reflective aluminum coating that is deposited on a smooth basecoat, then overcoated with a dyed lacquer to give the coating the desired color and texture.

In some applications, in addition to the decorative aspects of the coating, the coating is required to withstand wear. For example, titanium nitride (TiN) is gold colored, and titanium carbonitride (TiC_xN_y) can vary in color from gold to purple to black, depending on the composition. Zirconium nitride (ZrN) has the color of brass. Decorative/wear coatings are used on door hardware, plumbing fixtures, fashion items, marine hardware, and other such applications.

Hard Coatings

Hard coatings are often called metallurgical coatings and are a type of tribological coating. The hard coatings are used to increase the cutting efficiency and operational life of cutting tools, and to maintain the dimensional tolerances of components used in applications where wear can occur, such as injection molds. There are various classes of hard coating materials. They include: ionically bonded metal oxides (Al_2O_3, ZrO_2, and TiO_2), covalently bonded materials (SiC, B_4C, diamond, diamond-like-carbon [DLC], TiC, AlN, CrC, mixed carbide, nitride and carbonitride compound alloys, and cubic boron nitride), and some metal alloys (CoCrAlY, NiAl, NiCrBSi).

Hard coatings are also used to minimize fatigue-wear, such as is found in ball bearings. Coatings may be deposited on plastics to improve scratch resistance. In some cases, wear coatings (SiO_2 or Al_2O_3) may be applied to already hard surfaces, such as glass, to increase the scratch resistance.

Electrically Active Films

Doped silicon films are used in semiconductor devices, and these films are often deposited by a very sophisticated PVD evaporation technique called molecular beam epitaxy (MBE), or the low-pressure CVD technique of vapor phase epitaxy (VPE). Amorphous silicon for solar cells is deposited by PECVD on webs and rigid substrates. Electochromic films, which change optical transmission on the application of a voltage, depend on the diffusion of a mobile species in the film under an electrical field. Films of a material such as selenium can become electrically charged when exposed to light, and are used to hold the toner in photocopying machines.

Magnetic Storage Media

Magnetic materials are classified as hard or soft, depending on how hard it is to magnetize, demagnetize or switch the magnetic field. Soft magnetic materials, such as the Permalloys (Fe:40-80%Ni) and $Y_2Fe_5O_{12}$ (garnet) are used in memory storage devices where the data is changed often. Hard magnetic materials such as Fe_3O_4, Co:Ni:W, Co:Re, Gd:Co, and Gd:Tb:Fe are used in more permanent recording media, such as audiotapes.

Corrosion Protective Coatings

Protection from an aggressive chemical environment can be accomplished in several ways. The surface can be coated with an inert material, or with a material that forms a protective surface after reacting with the environment, or with a material that will be sacrificially removed to protect the underlying material. Tantalum, platinum, and carbon are inert in many chemical environments. For example, carbon coatings are used on metals that are implanted in the human body to provide biocompatibility.

Chromium, aluminum, silicon, and the MCrAlY (where M is Ni, Co, Fe) alloys will react with oxygen to form a coherent, protective oxide layer on the surface. The MCrAlY alloy coatings are used as protective coatings on aircraft engine turbine blades. Cadmium, aluminum, and Al:Zn alloys are used as galvanic sacrificial coatings on steel. Vacuum Cd-plating has the advantage over electroplated cadmium, in that there is no possibility of hydrogen embrittlement of high-strength steel.

Solid Film Lubricants

Thin-film solid lubricant films are of two types: the low-shear metal lubricants (*e.g.*, silver and lead), and the laminar-shearing compound materials (*e.g.*, MoS_2). The low-shear metal lubricants are used in high-torque applications, such as the rotating anodes in X-ray tubes. The low-shear compound materials are used in mechanical-bearing applications in vacuum, and where "lubricant creep" can be a problem.

Freestanding Structures

Freestanding structures are made by depositing a coating on a surface (mandrel), then separating the coating from the mandrel surface or dissolving the mandrel. The technique is useful for fabricating very thin structures, complex surfaces, or foils or sheets of materials that are hard to deform by rolling. Examples are beryllium windows used for X-ray transmission, boron thin-wall cones for high-frequency audio speakers, and Ti-V-Al metal alloy foils.

Basecoats for Electroplating

Materials that are difficult to electroplate because of rapid oxide formation can have an adherent basecoat applied by PVD processes, and then the coating built up by electrodeposition. Examples are plating on titanium, uranium, and zirconium, where a basecoat of a material such as nickel or copper is applied by a PVD process before the electroplated coating is built up.

Polymer Films

There is increasing interest in depositing polymer films in vacuum. These films can be formed by condensation of a monomer (followed by e-beam or UV curing to polymerize the monomer), or by plasma polymerization of the monomer. The monomer precursor can yield a carbon, silicon or boron-based polymer material that often contains hydrogen, chlorine, or fluorine. *P&SF*