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Arc Vaporization & Arc Vapor Deposition

Vacuum arcs used for PVD deposition of coatings are characterized by a high-current/low-voltage electric current flowing between electrodes in a good vacuum (vacuum arc) or low-pressure gas (gaseous arc). Generally, the arc is initiated by touching the electrode surfaces and then separating them, or by a high-voltage breakdown ("trigger arc") between the electrodes. The passage of the current causes vaporization of electrode material by the intense local heating of the "cathode spot" on a solid (consumable) cathode (cathodic arc), or by electron-heating, melting and vaporization of the anode (consumable) material (anodic arc). Some authors restrict the definition of an arc to a self-sustained process where the arc supplies all the electrons needed to sustain the arc, while others include separate electron-emitting processes that supply electrons to help sustain the arc (non-self-sustained arc).

Wright first reported the deposition and characterization of films deposited by arc vapor deposition in 1877. A "continuous" arc deposition process was patented in 1894 (applied for in 1884) by Edison, who described Wright's pulsed arc to the Patent Office as a "laboratory curiosity."

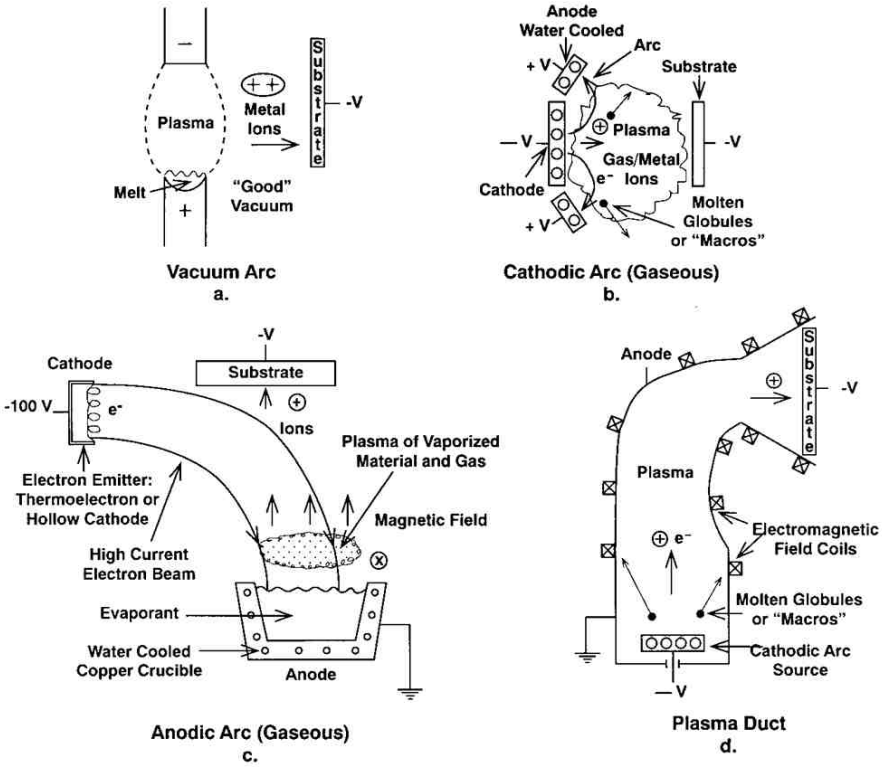

Fig. 1—Arc vaporization and arc vapor deposition configurations: 1a—Vacuum arc; 1b—Cathodic arc; 1c—Anodic arc; and 1d—Plasma duct (filtered arc).

Electric arcs have long been used in the metallurgy industry for "vacuum arc melting" (VAR) or "remelting," and have been a major concern in switching high-power electric circuits.

One advantage of the arc vapor source is that the high density of electrons between the electrodes causes very efficient ionization of the vaporized species. The ions thus formed may be multiply charged. Figure 1 shows some arc-vaporization and arc-vapor-deposition configurations. In a vacuum arc (Fig. 1a), the vapor necessary to sustain the arc is provided solely by the vaporizing electrode material, and the ionization provides a high flux of "film ions." In the gaseous arc (Fig. 1b & 1c), atoms of both the vaporized electrode material and the gas are ionized; the electrodes can be separated farther apart than in the vacuum arc. The gaseous arcs are the most often-used source for vacuum coating, although the vacuum arcs can also be used for ion sources in metal-ion beam-type sources.

In the deposition of vacuum coatings, the most commonly encountered arc vaporization source is the DC "cathodic-arc source," as shown in Fig. 1b. Electrons for sustaining the arc are formed by electron emission from a "cathode spot" that moves about on the cathode. The cathodic arc may be random, constrained by a weak magnetic field or surrounding insulator, or "steered" by a stronger, shaped magnetic field. The magnetic field can be either stationary or moving and is used make the arc move over the solid cathode surface, which prevents the arc from "attaching" to a specific area of the target and giving non-uniform erosion of the arcing target. The anode of the arc discharge can be either the chamber walls or an electrically isolated, cooled electrode. In many applications, multiple arc sources are used to achieve uniform deposition over large areas. In one design, pairs of electrically isolated electrodes act alternately as the cathode and the anode of the arcing circuit. This, along with pulsed-power substrate biasing, has provided better arcing conditions for deposition of electrically insulating coatings. Many of the patents on cathodic arc sources were developed in the early 1970s and the patent rights have expired.

The solid cathode arc source has an advantage that alloys can be easily vaporized and the coating retains the source composition. In reactive deposition, a reactive gas is used in the plasma arc, and "poisoning" of the vaporizing surface by compound formation is not a great concern since thin electrically insulating films are easily disrupted by the arc. The arc sources are often used in an ion plating configuration where there is a negative bias (applied or "self-bias") on the substrate that accelerates film ions and gas ions to the substrate surface. Bombardment by the energetic ions enhances the chemical reactions to form compounds and densifies the film by "atomic peening." In some cases, microarcing on the substrate can be a problem. This

can be minimized by using pulsed-power biasing.

A major disadvantage of the cathodic arc source are the molten globules or "macros" that are ejected from the cathode surface by the arcing process. These globules deposit on the substrate, producing bumps on the coating surface that may be undesirable. The size and number of macros is generally inversely proportional to the melting point of the source material. There has been a great deal of effort in trying to eliminate these globules. One technique, shown in Fig. 1d, is to use a curved "plasma duct" ("filtered arc") design, where the electrons in the plasma are magnetically deflected and the charged ions follow the electrons out of line-of-sight of the arc source. The globules and uncharged condensable atoms deposit on the walls of the duct. This results in a greatly decreased deposition rate compared to when the substrates are placed close to the arc source.

The cathodic-arc-vapor-deposition technique was introduced as an industrial coating process in the U.S. in the early 1980s. It is used to deposit coatings of metals and various forms of carbon, and to reactively deposit oxide, nitride, carbide, and carbonitride coatings for decorative/wear and hard-coating applications.

In the non-self-sustaining "anodic-arc" source shown in Fig. 1c, the electrons are produced by either a thermoelectron-emitting filament or a hot-hollow-cathode (hollow cathode discharge—HCD) electron emitter. The electrons are accelerated away from the cathode and may be magnetically deflected to melt and evaporate material in an anodic (or grounded) crucible, which may be water-cooled. The high density of low-energy electrons above the evaporating surface produces high ionization of the evaporating material. The anodic arc has the advantage over the cathodic arc in that no molten particles are ejected. Anodic arc vaporization has the disadvantage of thermal evaporation from a liquid surface; it is difficult to vaporize alloys and retain the composition of the source material.

Anodic-arc-reactive-vapor deposition has been used commercially to deposit oxide, nitride, and oxynitride coatings for optical and wear applications since about 1977.

An advantage of the high ionization of the vaporized material in arc vaporization is that the positive "film ions" along with gaseous ions can sputter a surface that is biased negatively. The high "self-sputtering" rate that can be attained with high-bias voltages can be used to sputter-clean a surface without depositing a film. The high bombardment energy can promote diffusion and reaction, thus modifying the surface and making it more amenable to good adhesion between the coating and the surface. A coating can then be deposited by reducing the substrate bias.

One deposition system design provides for the planar arc cathode to become a planar-magnetron sputtering cathode by rearranging the magnetic fields in the cathode. This system allows the use of a steered cathodic arc source configuration to provide film ions for sputter-cleaning and interface formation, then converting to planar-magnetron sputtering for building up the coating thickness. This procedure minimizes the number of globules that are deposited during the deposition process. The process is called the "arc-bonded-sputtering (ABS™)" process by its developers.

Arc vapor deposition has played an increasingly important role as an industrial coating process since its introduction in about 1980. It has an important segment of the market for decorative/wear coatings, hard coatings, and optical coatings. P&SF

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