SURFACE COATING BY PHYSICAL VAPOR DEPOSITION

Revision: 3/95
Product / Process: Physical vapor deposition coating
Process Code: N/A
Substitute for: Certain electroplating processes like cadmium plating
Waste Stream: N/A
Applicable EPA Hazardous Waste Codes: N/A
Applicable EPCRA Targeted Constituents: N/A

Introduction:
Physical Vapor Deposition (PVD) comprises a group of surface coating technologies used for decorative coating, tool coating, and other equipment coating applications, and also some self-supporting shapes. It is fundamentally an evaporative process in which the basic mechanism is an atom by atom transfer of material from the solid phase to the vapor phase and back to the solid phase, thus gradually building film thickness. Coatings produced by PVD processes have the advantages of high temperature strength, good impact strength, excellent abrasion resistance, and the capability to be deposited onto surfaces with complex shapes.

There are three basic processes considered PVD technology: ion plating, evaporation, and sputtering, all of which are normally carried out under vacuum. All three techniques must follow the same fundamental steps to develop a deposit, but they generate and deposit materials in somewhat differing manners, thus requiring equipment unique to each process.

PVD can be a desirable alternative to electroplating and possibly some painting applications, since PVD processes offer an ample selection of finishes that are not only less costly than electroplating, but they are also more durable and generally more environmentally "friendly" than traditional coating processes like electroplating and painting. PVD coatings are typically harder and more corrosion resistant than coatings applied by the electroplating process. In fact, some electroplated coatings are so soft they require a polymer topcoat to protect the surface finish. PVD coatings are usually so durable, protective topcoats are almost never necessary.

Description:
In addition to the three primary coating techniques comprising PVD processes (evaporation, ion plating, and sputtering), there are also many variations of these basic processes. Fundamentally, all three follow equivalent steps in order to form a film deposit, even though they employ somewhat different methods to achieve the same end.
PVD technology is extremely useful, allowing deposition of virtually any type of inorganic material and some organic materials: metals, alloys, and even mixtures of components. Deposit thickness can vary from several angstroms (1 angstrom equals $10^{-8}$ cm) to several millimeters, depending on the process and application. Film thickness in the 1 to 10 micron range (1 micron equals $10^{-4}$ cm) are the most common. Substrates or surfaces to be coated are an equally diverse group, and include some non-metals like plastics. Within the domain of the three processes exists a large variety of PVD coating selections; for example, some with finishes that resemble typical electroplated coatings, such as gold or brass.

Coatings are classified as either thick or thin films, and also diffusion coating or overlay. The thickness designation is based on application rather than a coating's actual thickness. A thick film is applied to take advantage of its bulk properties; for example, corrosion resistance. A thin film, in contrast, is selected for its surface properties such as a film that exhibits electron emission or catalytic activity. A diffusion coating results when the applied material actually diffuses on a molecular level between the molecules on the surface of the substrate, whereas an overlay coating is material deposited onto the surface of the substrate and bonded or attached there by adhesion.

All PVD processes must undergo three basic steps in order to form and deposit coatings:
1. Synthesis of the vapor species by -
   - Evaporation (i.e., vacuum vaporization of the coating's atoms),
   - Sputtering (vacuum ejection of particles from the film target due to the impingement of energetic projectile particles), and
   - Chemical vapors and gases (see Pollution Prevention Opportunity Data Sheet, "Surface Coating by Chemical Vapor Deposition").
1. The transfer of the vapor phase species from source to substrate by
   - Line-of-sight,
   - Molecular flow (without molecular collisions),
   - High partial pressure of coating material (high number of collisions during transport), and
   - Vapor species ionization by creating a plasma (also high number of collisions during transport).
1. Deposition and film growth on the substrate by nucleation and
other microstructure growth processes.

These steps can be independent or superimposed on each other depending on the desired characteristics. They can also impose some constraints; for example, line-of-sight transfer makes coating of annular spaces practically impossible. The final result of the coating/substrate composite is then a function not only of each material's individual properties, but also a function of the interaction of the materials as well as the process constraints.

The selection criteria for determining the best method of PVD are dependent on several factors; they include:

1. Material to be deposited
2. Rate of deposition
3. Limitations imposed by the substrate, e.g., the maximum deposition temperature
4. Adhesion of the deposit to the substrate
5. Throwing power (rate and thickness distribution of the deposition process, i.e., the higher the throwing power, the better the process' ability to coat irregularly-shaped objects with uniform thickness)
6. Purity of target materials
7. Apparatus required and the availability of the apparatus
8. Cost
9. Ecological considerations
10. Abundance of deposition material

More than one technique can be used to deposit a given film; however, the selection of the best technique may require some experience and/or experimentation.

**Materials Compatibility:** PVD coating processes are compatible with most metals and some plastics either as coatings or as substrates. However, temperature constraints may limit the degree to which dense coatings can be deposited on some plastics. Finally, PVD processes do not normally produce the kind of coatings that work well where lubricity is required. Thus, PVD coatings are not usually good choices for parts such as fasteners.

**Safety and Health:** The safety and health issues must be evaluated on a case-by-case basis.

Consult your local Industrial Health specialist, your local health and safety personnel, and the appropriate MSDS prior to implementing any
Benefits: Composite materials, such as PVD-coated products, are inherently more economical than pure materials, as well as being environmentally preferred because they tend to provide a combination product with more desirable characteristics overall.

PVD coating processes can be used to control surface properties by application of a film. The desired performance improvement is thus often complemented by the conservation of precious natural resources. This is the case because surface coatings can be engineered to achieve a desired special characteristic often superior in functionality to any other single material, and thereby also allowing the substrate or bulk material to be made of common, less costly materials. For example, some components require high strength for which a metal substrate such as steel is preferred while at the same time corrosion resistance is also required, so an alloy or non-ferrous metal like chromium might be selected for the coating. The resulting composite product is superior to a pure product of either metal. In this way, conservation of scarce alloys and precious metals should be enhanced by more widespread use and further improvement in the application of surface coatings.

PVD coatings are typically harder and more corrosion resistant than either the bulk material or electroplated coatings, prolonging equipment lifetimes, and thereby also reducing costs.

Application of surface coating using one of the PVD processes should result in a reduction in the amount of hazardous wastes produced compared to electroplating and other metal finishing processes that use large quantities of toxic and hazardous chemicals. For example, the cadmium plating process is extremely messy, whereas, in comparison, physical vapor deposition is a relatively clean process with only a small amount of excess or waste metal generated.

Economic Analysis: Economic considerations are probably the primary hindrance to conversion of more plating operations to any of the vapor deposition processes. Several hundred thousand dollars is the order of magnitude capital cost for a new vapor deposition installation. Operating costs are, however, roughly equal to electroplating, although plating can be slightly less labor intensive.

Major Assumptions: Physical vapor deposition techniques operate at very high temperatures and very high vacuums; thus, they require some special care and also generate a lot of heat. Cooling water availability is
required to dissipate the large heat loads. An Ion Vapor Deposition system operating at Hill AFB requires a cooling water heat sink to dissipate on the order of 260,000 BTU/hr during normal operation.

A PVD process is not likely to be a good pollution prevention alternative for small scale, low cost operations given its high capital requirement and special maintenance needs. Nevertheless, PVD should not be immediately assumed as a nonviable process. It is a viable pollution prevention alternative to plating, and thus merits consideration especially by large scale, high volume users like major maintenance facilities.

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For ion plating expertise

Mr. Brad Christensen  
Environmental Engineer  
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Hill AFB, Utah  
(801) 777-2341, DSN 777-2341
Has experience with a couple of aluminum ion vapor deposition systems that were installed to replace a cadmium plating operation. Large and small steel components are plated at this location.

Mr. Mark Childs, 2558

Vendors:  McDonnell Douglas  
Pure Tech Inc., Carmel, NY

Approving Authority:  Approving authority is controlled locally and is not required by the major claimant.

Note:  This recommendation should be implemented only after engineering approval has been granted by cognizant authority.