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A Sampling of PVD Tribological Coatings

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Preventing or lessening the wear of mechanical components continues to be a much sought-after goal of engineering and product development. Lessening wear that results from contact of two materials might be accomplished by changing one or both of the materials. However, in many instances this may not be not possible, because both materials must meet other requirements of strength, flexibility, or environmental resistance. In these cases, changing the <u>surface</u> properties of one or both materials may be the answer. This brief overview cannot attempt to present all the possible means of modifying a surface, such as annealing or ion implantation. One common and useful method of surface modification is deposition of a **tribological** coating. Again, this article will not attempt to cover all possible tribological coatings, but a few selected examples of coatings deposited by **physical vapor deposition (PVD)** techniques will illustrate the usefulness of this method for product development.

Titanium Nitride (TiN)

Perhaps the tribological coating that is most familiar to most people is titanium nitride (TiN), which is the gold-colored coating often found on better-quality drill bits. TiN is widely employed to extend the service life of expensive machining bits, molds, dies, cutting blades, and other tools that regularly see abrasive wear. Coating thicknesses range from a few tenths of a micron to a few microns (one micron = 0.00004”). TiN typically is deposited by physical vapor deposition, with common methods used being sputtering and ion plating. As an example, TiN may be applied to tool steel via reactive magnetron sputtering, with an applied substrate bias. This means that a titanium target rather than a TiN target is used, with a backfill gas mixture of argon (Ar) and nitrogen (N_2). Nitrogen reacts with the titanium surface during the deposition process to produce the ceramic coating. It is critically important to monitor the ratio of the two gases. Too much argon will produce a coating with a high metal content; the coating will be too soft for adequate wear resistance. Too much nitrogen will produce a coating that is brittle; the coating may crack off the surface after limited use. Applying a bias to the substrate during deposition will yield a coating with greater density and better wear resistance, but the deposition rate will be decreased, adding to the cost of coating.

TiN also is electrically conductive and somewhat lubricious. It is possible to obtain colors other than gold for the coating (shades toward the blue end of the spectrum) at the expense of losing some wear resistance.

Diamond-Like Carbon

Hard coatings of other nitrides, such as boron nitride (BN), may be produced by PVD. Many of these coatings have a crystallographic short-range order similar to that of diamond. Coatings of actual diamond may be produced by chemical vapor deposition (CVD) [1]. These coatings have desirable optical and biocompatibility properties. However, film stress may be a concern [2]. Another industrially important PVD hard coating is diamond-like carbon (DLC), which will be considered here for product development. DLC coatings display many of the desirable characteristics of true diamond coatings, e.g., hardness, abrasion resistance, low friction, and biocompatibility. They also have useful optical properties. But DLC coatings typically are lower in residual stress than are diamond coatings, and they may be less expensive to apply.

Earlier literature describes the use of chemical vapor deposition (CVD) for laying down a DLC coating [3]. CVD depositions use reactive gases to form a coating onto a substrate held at a relatively high temperature. Often there are other agents (e.g., a plasma) used to facilitate the CVD deposition. It is the requirement to use a substrate temperature much higher than that experienced during PVD processes that often makes PVD a more attractive option compared to CVD, possibly the only option. While CVD remains a useful approach for depositing DLC coatings [4], recent literature has begun to describe PVD methods for depositing these coatings [5-7]. Often these methods are somewhat novel arc discharge methods and not strictly one of the traditional PVD methods of sputtering, evaporation, or ion plating.

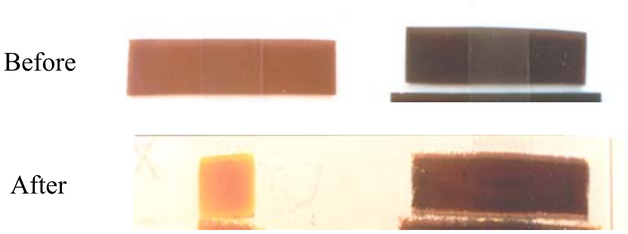
Multi-Layer Coatings

Multi-layer coatings can be highly desirable because of the breadth of design possibilities. Different material layers and layer thicknesses may be used, the order of the layers may be varied, and even the gradation from one layer to the next may be varied to advantage. However, there are at least two important constraints that need to be considered. One is the potential for separation of layers (delamination) which might occur for a variety of reasons, such as unacceptable mismatch in coefficient of thermal expansion between two adjacent layers. This particular problem often can be overcome using a graded interface. Another problem may be interdiffusion of materials. One or both materials of adjacent layers may be able to freely mix with the other layer, altering or destroying the very purpose of the multilayer structure. Used in a controlled manner, however, this may desirably lead to a coating of mixed composition (see the next section).

A couple of examples will be used to illustrate the usefulness of PVD multi-layer coatings to product development. The use of sputtered coatings of TiB_2/TiC or of TiN/SiN_x has been proposed for working edges of cutting tools [4]. The layers of the coatings reportedly do not intermix at temperatures up to 1000 °C. In the case of the TiN/SiN_x coatings, the amorphous SiN_x layer is believed to limit columnar structure of the coating by periodically interrupting the growth of the TiN layer by design. These coatings are said to exhibit superior wear properties compared to traditional TiN coatings. In another example, a patent [5] describes the use of sputtered coatings of alternating layers of metal and ceramic, such as Ti/TiN, for wear resistance. Such a coating would, for example, provide protection against solid particle erosion on the leading edge of airfoils. Finally, PVD multilayer coatings are commonly found in optical applications. While many of these coatings are considered to be “hard” insofar as providing some resistance to scratching, they would not be considered appropriate for the tooling applications described here.

Mixed Composition Coatings

Not all PVD coatings are homogeneous and of a single material, or a heterogeneous multi-layer of different pure materials. Some coatings are relatively homogeneous, but the coating material is not “pure.” It may be a superlattice such as the solid ionic conductor β”-alumina, or it may have a poorly defined stoichiometry resulting from a “mixed” chemistry.



An example of this is shown at left. Kapton® HN [10] is a polymer material with excellent properties including resistance to many chemicals. However, it does not stand up well against monatomic oxygen (O) and ultraviolet radiation (UV), e.g. as found in the environment of low Earth orbit (LEO), where it has been used in foldable panels for solar arrays.

The left-hand sample shown above is a 5-mil thick foil of virgin Kapton® HN, exposed for 158 hr in a plasma chamber (air backfill) at 100 W power. Such a plasma contains both O and UV, and so provides some simulation of the LEO environment. The sample is seen to have been completely eroded away, except for a small patch that was somewhat protected by clear tape used to mount the sample. The right-hand sample was exposed at the same time as the left-hand sample. But this second sample had a sputtered coating to provide protection. One such coating is aluminum oxyfluoride. Such a coating provides benefits from each of its “parent” materials. In this case, the aluminum oxide provides resistance to atomic oxygen and UV. However, by itself it is not an especially flexible coating, such as would be needed when deploying a folded substrate. The PTFE provides such flexibility to this mixed coating. The resulting coating is not quite as flexible as a coating of pure PTFE or as chemically resistant as a coating of pure aluminum oxide, but it provides a very good compromise between the two. The entire ensemble of properties of a mixed coating, however, cannot always be accurately predicted from the properties of its parents. There remains a certain amount of trial and error with such coatings.

Summary

Chemistry and materials science can be used to help improve products during the product development cycle. Modifying surface chemistry is one method to improve wear resistance. Other improvements can be tailored to meet your needs. For more information about enhancing your product performance, contact Bjorksten | bit 7.

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10) Kapton® is a registered trademark of E.I. DuPont de Nemours and Co. Corp., Wilmington, DE.

Key Words

Product Development
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