

Understanding Physical Vapor Deposition Coatings

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Physical vapor deposition describes a specific category of thin-film vacuum coating processes. The definition of PVD coating can be broken down as follows:

- **Physical**—Individual atoms and molecules are physically liberated from the source of the pure “donor” material, known as the source or target.
- **Vapor**—The physical atoms and molecules are vaporized in a vacuum vessel.
- **Deposition**—The vapor is deposited in a microscopically thin layer onto substrates that share the space in the vacuum vessel. The presence of reactive gases such as nitrogen, oxygen, or hydrocarbons result in nitrides, oxides, or carbides of the target material being formed by chemical reactions between the vaporized metal atoms and the reactive gas species.

The most common of these thin-film vacuum coating processes include evaporation (e.g., using a cathodic arc or thermal technique), ion beam deposition, and sputtering (e.g., using plasmas). All PVD coating processes must occur inside a vacuum chamber so that the vaporized materials do not react with any atmospheric contaminants that could interfere with the

microscopic layer of coating, or with the adhesion of the growing thin film to the substrate. In the specific case of cathodic arc, the vaporization occurs as a direct result of the application of an electrical arc to the surface of the target.

Functional vs. Decorative

The two main subcategories of this type of coating are functional and decorative hardcoatings. While they are often made of the same materials, both types may be applied using different thickness specifications to optimize them for a specific application. Functional hardcoatings are used to impart properties such as scratch resistance, toughness, thermal protection, environmental stability/corrosion resistance, friction reduction, and wear reduction.

Decorative hardcoatings are used to impart color to substrates. One example of this is in the use of different colored coatings on metallic shims of different thicknesses, which allow quick and reliable visual recognition in a busy assembly area. Likewise, some surgical scalpels are decoratively hardcoated for ease of blade size identification in surgical units.

Some hardcoatings serve the dual purpose of both decorative and functional coatings. Architectural window glass is a good example of this combination of benefits that results from PVD coating.

Applications and Benefits

Few manufactured goods in the world today have not taken advantage of the performance benefits of PVD coatings, either in their construction or final form. PVD coatings benefit manufacturers and machinists that want to decrease machining time by taking advantage of increased speeds and feeds, reduce downtime by extending tool change-out intervals, decrease maintenance costs by extending the life of components, and expand product capability with performance-enhancing features. Another key benefit of these vacuum-deposited thin film hardcoatings is that they usually present a substantially reduced environmental impact when compared to plating and other wet chemistry-based coatings.



In the tool coating arena, the main purpose of the coating is to control the friction and wear of a specific surface on a cutting or forming tool.

The kitchen and bath fixture industry has made extensive use of PVD hardcoatings to produce shiny, durable finishes on a variety of fixtures. The automotive industry has utilized PVD coatings on engine components, windshields and rearview/sideview mirrors, decorative emblems, engine sensors, and other components. In addition, the automotive mag wheel market is making extensive use of hardcoatings as replacements for the hard chrome coating on rims of years past. In the medical industry, PVD coatings offer benefits such as reduced material adherence, color coding, enhanced scalpel edge lifetime, and reduced corrosion, as well as the ability to provide radiopaque layers and produce hydrophobic or hydrophilic surfaces.

In the tool coating arena, the main purpose of the coating is to control the friction and wear of a specific surface on a cutting or forming tool. In many instances, this simply translates to keeping the cutting edge sharp and preventing material buildup on the rest of the tool.

The typical PVD vacuum chamber is able to produce a variety of nitride, oxide, and carbide thin films by evaporating or sputtering pure metals in a



AlTiN coatings are superior in many machining applications due to their increased hardness and increased oxidation resistance, as well as an age-hardening effect.

vessel containing nitrogen, oxygen, and carbon-based gases. For instance, in the optical coating market, depositions of Ti, Zr, Ta, and Si in the presence of an oxygen partial pressure can form clear optical films of oxides such as TiO₂, ZrO₂,

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In the medical industry, PVD coatings can provide radiopaque layers, as with this woven polyetheretherketone (PEEK) after tantalum coating.

Ta₂O₅, and SiO₂. These films are all electrically insulating in their stoichiometric oxide form. In the hardcoating market, depositions of Ti, Zr, Al, Cr, and Si in the

presence of nitrogen and acetylene can form alloys and intermetallic compounds such as TiN, TiCN, ZrN, TiAlCN, AlTiN, CrN, TiAlSiN, AlCrN, TiSiN,

and other combinations. These thin films are usually classified as ceramics, though the majority of them are actually electrically conductive.

Since various thin-film coatings respond differently to particular tool substrates and the various materials being machined, specific coatings are generally recommended for specific applications. For example, TiAlN can be grown as either a monolayer or gradient film structure for stable cut machining operations, or as a multilayer structure for interrupted cutting; each of the three structures can be grown with a variety of Ti-to-Al ratios as well.

Some “universal” coatings offer a measurable performance boost for a variety of machining operations, and they serve a fair volume of the market. This is the role that TiN has served since the early 1980s, when PVD tool coatings hit the market in mass. Newly engineered coatings are also constantly being developed to meet specific needs in the industry. These coatings will slowly become more widely accepted and used as more data is released on their improved performance characteristics.

Cutting and forming tools receive a tremendous amount of heat and abrasive wear, which leads to tool failure, decreased productivity, and machine downtime. To alleviate this problem, PVD coatings can be used that feature a nano-hardness of 20-40 GPa. (As a reference point, common steels are in the 2 GPa range, and bulk cubic boron nitride is around 50 GPa.) The strong hardness of the thin coatings provides tools with greater protection against abrasive wear while only marginally increasing the dimensions of the tool. However, hardcoatings that are applied to softer, malleable substrates may fail under use because of the hardness or flexibility mismatch between coating and substrate. Extreme thermal expansion mismatches between a coating and substrate can also cause adhesion failure during use if the localized temperature at the tool-to-workpiece increases too much.

In addition, PVD coatings can provide parts with significantly lower friction than uncoated substrates. Lower friction reduces resistance between the tools and the materials being worked, which means tools can work with less force required to drive the tool and less heat buildup at the working edge of the tool. (The temperature at the tool-to-workpiece interface during machining can exceed 700°C.) Machinists often rely on the heat transfer to the formed cutting chips during the machining operation to remove much of the heat from the cutting zone. Lubricious coatings aid in rapid chip movement by preventing material sticking to the tool because of the reduced friction and inertness of the coatings.

Because of these characteristics, PVD coating successfully extends the lifespan of tools. This allows machines to run longer between tool changeouts and prolongs the life of finished components such as wear plates and guides.

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PVD Case Study

The application of ceramic PVD coatings has achieved an important place in industrial manufacturing over the past several decades. While these high-performance ceramic coatings could be considered a mature industry with a broad list of current applications, the continual growth of R&D in the materials science field is providing a continual increase in the number of material and chemical compositions.

The introduction of TiAlN in a 50/50 ratio in the late 1980s was followed by other research efforts that evolved into Al-rich coatings, commonly called AlTiN. These new coatings, developed and refined by a variety of worldwide technical groups, were superior in many machining applications because the new thin films had increased hardness, increased oxidation resistance, and an age-hardening effect that occurred during the machining operations.

Further research and development by various technology centers resulted in the introduction of titanium aluminum silicon nitride (TiAlSi₃N₄).* This nanocomposite coating exhibits extremely high nanohardness and heat resistance. The addition of the Si to the composition allows for the formation of Si₃N₄ as the amorphous matrix, with nanocrystalline TiAlN grains embedded within the matrix, thus forming a nanocomposite final structure. This new structure further increases the performance of the new coating over the previously available TiAlN and AlTiN structures.

Identifying a Problem

MacLean-Curtis, LLC is a division of MacLean-Fogg Component Solutions (MFCS), a leading supplier of innovative fasteners, forgings, machined components, and engineered plastics serving diverse industries. The MacLean-Curtis division is a leading supplier of precision CNC and screw-machined components, including gear blanks, parking system components, engine timing, and power steering connectors, for OEMs and tier-ones in automotive and other markets. The company maintains a commitment to modern manufacturing

technology and demonstrates a collective talent for creative problem solving in engineering.

A MacLean-Curtis Lean Basic PDCA team wanted to address one of the common “pains” for machinists in the Buffalo plant—clearing chips. One associate at Curtis proposed to his teammates a way to address the 2-min micro-breaks he needed to take every 10 min to

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remove chips while running a multi-spindle machine. The associate had to stop the machine to clear chips from the tooling area a minimum of 50 times per shift. The team listened to his account of chip buildup and the importance of avoiding excess chips that would cause tool damage or even tool holder blowout.

Redesigning the Tool

The team consulted an engineering supervisor to discuss the previous engineering success he had had converting tooling to “chip breaker” designs. They discussed the formation of the chip at the tool edge due to the red-hot steel being removed in fine ribbons and what could be done to reduce it.

The engineer redesigned the forming tool to add a chip-breaker feature and then contacted ACS for suggestions on more recent hard coatings that might offer superior performance for this specific application. ACS suggested the newer TiAlSi₃N₄ nanocomposite coating because of its low friction feature, coupled with its durability in high-heat and high-friction cutting applications.

During machining, the chip breaker works by creating a ramped feature on the top edge of the tool. The chip forms at the cutting edge, travels a short distance, and then breaks off when it changes direction up the ramp. This allows the chip to fall away from the tool and avoids the steel buildup that could cause a blowout. If chips are not cleared, a tool blowout will occur, resulting in additional downtime and expensive tool holder damage. The nanocomposite coating reduces friction at the cutting edge and along the chip formation path, thus assisting in rapid chip removal with reduced chance of chip buildup.

Enjoying the Benefits

The new tool has a 47% increase in tool life, going from 1,700 to 2,500 cycles per tool change. This also results in reduced tool change frequency. Curtis will realize a \$7,800 annual tool cost reduction and has already achieved a 200-piece increase in production per shift.

With these encouraging results, a second tool has been redesigned and is in testing. Once both tools are in place, the expected savings in micro-break downtime is expected to exceed 30 min per shift, with additional associated tool life savings and tool changeover reduction.

Continual Innovation

While everyone’s daily activities may not deal directly with hardcoatings, we all touch multiple items each day that rely on PVD coatings. Whether it’s our eyeglasses, the barrier coating on the inside of a potato chip bag, computer hard drives and flash drives, electronic devices, mag wheels, or cutting tools, PVD coatings surround us and extend the lifespan and functionality of many items in our everyday lives. The opportunities for increased productivity are limited only by the end user’s willingness to test various coatings in various applications. ☐

For more information, visit www.acscoating.com. MacLean-Curtis can be found online at www.macleanfoggcs.com.

*Marketed by Platit under the trade name nACO®.