Feature

Exterior UV-Curable Topcoat For Physical Vapor Deposition Applications

By Kristy Wagner and Jennifer R. Smith

Because of the growing environmental concerns with chrome plating, finishers have been requesting a "greener" alternative. Coatings for multipurpose decorative and automotive lighting physical vapor deposition (PVD) applications have been used in the UV-curable coating industry for over 20 years. However, these coatings do not have the required durability to replace chrome plating. Red Spot has recently developed and launched a UV-curable topcoat for PVD that provides the performance characteristics needed to pass the original equipment manufacturers' (OEM) toughest requirements.

When decorative chrome plating is processed properly, it is a durable product. When short cuts are taken, the end product can fail in the field. Finishers have been asking for a safer, greener, quicker alternative without sacrificing appearance and performance.

This paper will address the current chrome plating process; challenges associated with developing durable coatings for PVD applications; an explanation of how the UV and PVD materials are applied; a list of advantages that the UV/PVD decorative process encompasses; and targeted end applications.

Chrome Plating

Chrome plating can be classified as either "hard chrome plating" or "decorative chrome plating." Hard chrome plating is typically used on steel and is very durable. It is applied as a thick layer (greater than a mil) on items such as hydraulic cylinder rods, piston rings, thread guides and gun bores. Decorative chrome plating is generally used on plastic materials and can vary in its durability, depending on the process. An electrodeless nickel layer must be applied first. The number of subsequent layers can vary, which can determine the finished quality. The fewer steps utilized, the lower the durability of the end product which can lead to quality defects of the chromed part in the field.

At the lowest end of the quality spectrum—one layer of nickel is followed by a layer of chrome. At the highest end—one or two layers of copper (for adhesion) and at least two layers of nickel (for smoothness, corrosion resistance and reflectivity), followed with the actual chrome layer(s). The actual layer of chrome is very thin, measuring 250 to 1,000 angstroms. The chrome gives the metal a bluish cast; protects the nickel from tarnishing; minimizes scratching; and also helps with corrosion resistance.

The process of chrome plating requires multiple steps. For optimum appearance, cleaning, polishing, buffing and rinsing should be done for each step in the process. In addition to the length of the process, chrome plating is not environmentally friendly. All of the waste products (including rinse water) are regulated and must be disposed of legally as hazardous waste. In addition, chrome plating is done with hexavalent chrome. This compound is an extreme health hazard. Without proper safeguards, very small amounts can leach into the ground water and contaminate large areas very quickly. Needless to say, this compound is closely regulated by the Environmental Protection Agency. It is becoming increasingly difficult to operate a chrome plating facility in the United States.

Despite all of the hazards of chrome plating, the end product is aesthetically pleasing. Consumers are drawn to bright finishes. When decorative chrome plating is processed properly, it is a durable product. When short cuts are taken, the end product can fail in the field. Finishers have been asking for a safer, greener, quicker alternative without sacrificing appearance and performance.

Chrome Alternatives Using UV/PVD Coatings

PVD on thermosets and thermoplastics has been around for many years. The automotive lighting market has been vacuum metallizing plastic reflectors and bezels for more than 20 years. PVD for non-automotive finishing has been in use even longer. Cosmetic packaging, interior decorative finishing, cell phones and lighting louvers are being finished with PVD. This technique provides a value-added aesthetic to the end-user by making plastic components appear to be metal. A variety of PVD metals can be applied. Aluminum is the most common metal used in automotive lighting. Tin is used for cell phones because it is non-conductive. Stainless steel, chrome, titanium, silver and nickel chrome are also used in the PVD industry.

PVD with a UV topcoat can also replace chrome plating for interior automotive applications. Since interior parts are not subjected to as severe exterior requirements, aluminum or other metals can be used instead of chrome or chrome alloy. However, the coating must pass a series of chemical resistance and abrasion resistance tests. Since UV topcoats can become tightly crosslinked when cured, they are a natural choice for interior automotive coatings. Resistance to sunscreen and insect repellent has been a challenge to many interior automotive thermal-cure coatings. However, UV-curable coatings have not shown to have problems with these chemicals.

Although automotive lighting is an exterior market, the reflectors are protected by a polycarbonate lens that has a weatherable and scratch-resistant coating. The base coat/PVD /topcoat need only withstand the rigors of a high-heat environment. For a true exterior durable product, the requirements are more stringent. In order to match the appearance of chrome plating, PVD chrome is naturally the first choice. PVD aluminum could be used to match the appearance of chrome plating, but its lack of exterior durability can be a potential problem. Although the metal will be protected by a clear coat, if the topcoat becomes chipped, the chance of moisture reaching the metal layer increases. When PVD aluminum is exposed to water, it can start to oxidize at best, and lose adhesion to the base coat at worst. PVD chrome does not have this tendency; therefore, chrome or a chrome alloy is both the aesthetic and durable choice to replace chrome plating for exterior applications.

With the right formulations, PVD chrome on plastic can be a replacement for decorative chrome plating. UV-curable coatings are an environmental and processing improvement with added design flexibility.

The main target of the UV-curable topcoat development for PVD was to replace traditional inorganic chrome with a layer system of organic and inorganic materials. As illustrated in Figure 1, this involves applying a UV base coat on the substrate followed by a PVD metal layer, and lastly the UV protective topcoat. Challenges associated with the development of each of these layers and the processing of each are explained in the following paragraphs.

Substrate

A wide variety of thermoset and thermoplastic substrates can be coated with the UV base coat. PC, ABS, PC/ABS, PA/PPE and PC/PBT are commonly used plastics for exterior rigid and semi-rigid automotive parts.

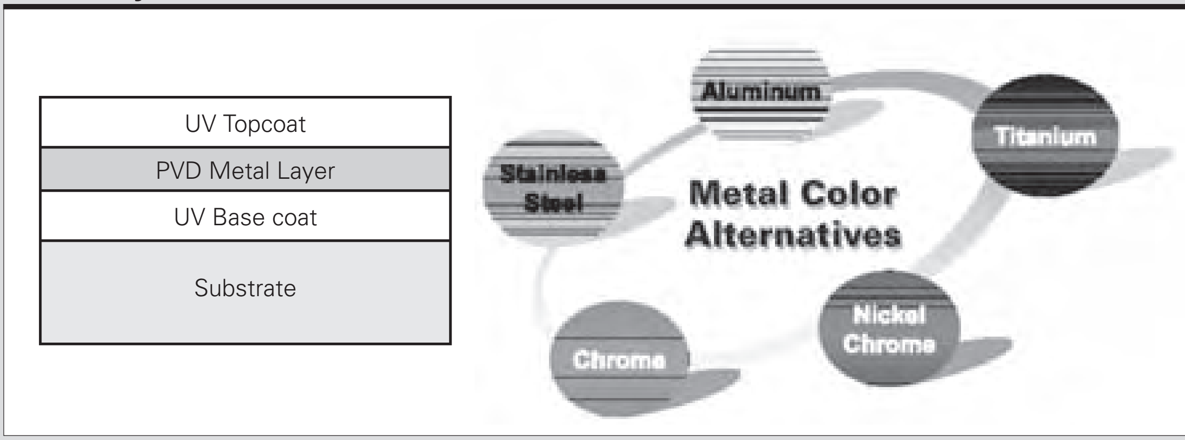
UV Base coat

The surface that the metal is deposited on must be smooth and continuous. If it is not, the metal will not be reflective and can lead to a dull appearance. Some parts are direct metalized. However, this requires a higher grade of thermoplastic. It also demands that molds must be kept in optimum condition and polished regularly to ensure the surface of the parts are free from defects. To compensate for less-than-stellar conditions, a base coat is applied to ensure optimum smoothness.

For the most robust system and for adequate performance of an exterior durable coating UV/PVD system, a UV-curable base coat is necessary. A successful coating must have excellent adhesion to a variety of substrates as well as be able to accept PVD metals. Chrome is more durable than aluminum, so the base coat was

Figure 1

UV/PVD system



formulated to target the PVD chrome metal. Because chrome is a very rigid metal, many commercial base coats that work well with aluminum may not work with chrome. Stress cracking is a very common failure mode if it is not formulated specifically for PVD chrome. Many thermal cure coatings lack the proper cross-link density to be used with the more rigid metals.

The UV base coat serves as a leveling coat to provide a smooth surface, which helps contribute to the brightness of the metal. Typical DFT is 10-25µm. The UV material can be applied to the substrate by several different application methods, the most common methods are spray and flowcoat. After applying the base coat, solvents are evacuated from the liquid coating prior to curing the film. The typical recommendation for solvent flash-off is 1-3 minutes of infrared (IR) radiation or 5-7 minutes convection at 150°-175°F. The final step in the process is a UV cure using standard mercury bulbs with 2,000 mJ/cm^2 minimum.

Physical Vapor Deposition

PVD is the deposition of a metal onto a substrate through changes in the physical state of the metal (solid to gas to solid). A very thin layer of metal (approximately 600-1,000 angstroms) is deposited onto the base coat layer. A wide variety of metals can be deposited, including aluminum, chrome, titanium, stainless steel, nickel chrome, tin, etc. The PVD layer can be deposited by a variety of methods—the two most common are thermal evaporation and sputtering. Both are done in a vacuum, but the metals are deposited differently.

Thermal Evaporation is the deposition of a metal via thermal vaporization in a vacuum environment. The metal is in the form of a cane. It is placed inside a tungsten coil (the number of coils can vary depending on size of the chamber). Once the chamber is pumped down to a vacuum, the tungsten filaments are heated to 1,200°F (for aluminum), enough to melt the metal. The power to the filaments is then increased to roughly double the temperature and the metal is evaporated. The metal then re-condenses on the parts in the chamber.

Sputtering is the deposition process in which atoms on a solid metal target are ejected into the gas phase due to bombardment of the material by high-energy ions. The bombardment releases atoms from the metal target, which are deposited directly onto the part within the vacuum chamber. Metal thickness will vary depending on the cycle time and power applied to the target.

Alloys can be used with either method, but they will be deposited differently. With thermal evaporation, the metal with the lowest melt temperature will evaporate first and deposit onto the part. Rather than having a deposition of an alloy, there will be two distinct metal layers. For example, nickel melts around 2,500°F and chrome has a melting point around 3,400°F. When thermally evaporated, the nickel will melt, evaporate and condense on the parts followed by the melting, evaporation and deposition of the chromium—two distinct layers of metal. With sputtering, the metals will deposit at the same time to have a true nickel chrome alloy.

UV Topcoat

To protect the metal, a topcoat needs to be applied. This can vary from a thin layer of in-chamber siloxane or to a thicker thermal or UV-curable topcoat. The choice will vary depending on the application and needed performance requirements. For exterior purposes, there are currently OEM-approved thermal, two-component coatings and thermal-powder coatings on the market. However, these coatings are not a panacea. The 2K coatings lack both environmental and processing friendliness. Powder coatings are more environmentally friendly. However, not only do the long bake times hinder productivity, the high temperatures required to cure the powder will not work with most thermoplastic substrates. A UV-cured coating would meet both the environmental and process requests.

Until recently, there have not been acceptable UV topcoats to protect the PVD chrome. PVD aluminum, which is less rigid than chrome, is much easier to adhere to. Although initial adhesion to chrome is relatively easy to achieve, maintaining that adhesion after humidity, water immersion and weathering can be a bigger challenge. In order to obtain proper adhesion to chrome, the coating needs to have low shrinkage and lower crosslink density. However, these characteristics can lead to a soft, easily marred coating that cannot withstand the testing rigors of an OEM specification. It is imperative to find the balance between too rigid to get adhesion and too soft to pass resistance testing.

The properly formulated UV-curable topcoat can meet these demands. It can pass up to five pints of gravel chip resistance at room temperature and -30°C; resistance to various solvents and cleaners (such as Armor All Protectant, Windex, Fantastik, Chrome Cleaner, Car Wash Chemicals); 49°C humidity for 240 hours; 80°C water soak for three hours; 3,000 kJs Xenon accelerated weathering; and two years natural weathering.

The topcoat serving as a protective layer is necessary due to the metal being deposited so thinly. The exterior UV topcoat can be applied by several different methods, the most common methods are spray and flowcoat. After applying the topcoat, solvents are evacuated from the liquid coating, prior to curing the film. The typical recommendation for solvent flash-off is 1-3 minutes of IR or 5-7 minutes convection at 150°F-175°F. The final step in the process is the UV cure, 6,000-9,000 mJ/cm^2 with a standard mercury bulb. Recommended film builds are 10-25µm.

Advantages Using UV/PVD Coatings

In a direct comparison, PVD chrome samples with a UV-curable topcoat have shown to have the same performance as decorative chrome plating and be superior in hydroflouric acid tests. Chrome plating has shown to have superior scratch resistance. However, if the UV topcoat is compared to approved systems in the market today—2K clear coat for automotive bumpers and fascias; thermal cure powder for automotive clear coats—there is no difference in scratch resistance. Additionally, there are alternative processing methods for the topcoat that increase the surface hardness to be comparable to that of chrome plating.

Environmentally Friendly

PVD chrome with the right topcoat offers many advantages over decorative chrome plating. Environmentally, there is no question that PVD/UV coatings are the better choice. With no hexavalent chrome exposure or disposal and no hazardous waste to report, UV-curable coatings make for a much safer work environment.

Increased Throughput

From applying the base coat until packaging of the finished part, the work-in-process can be as short as 15 minutes. Depending on the desired thickness of the chrome plating, the process can take several hours.

Wide Range of Plastic Substrates

Certain thermoplastics, like PA/PPE, cannot be chrome plated. Others cannot take the heat involved. This is not the case with UV coatings and PVD processing.

Wide Range of Appearances

PVD equipment supplier experts are able to achieve numerous metal colors by using a mixture of various metals and gases within the vacuum chamber.

In addition, the topcoat can be modified to provide a satin finish or low-gloss finish, which has become popular for interior automotive applications. Although this same color effect can be achieved by using a chrome-plated process, the part must first go through a lengthy preparation process.

Design Flexibility

Another option available with the PVD process is backlighting. By adjusting the deposition process, parts can be produced that look opaque—but when a light is shone through the metal, a pre-applied cutout image can be illuminated.

Applications that require some flexibility have not been chrome plated successfully. The UV/PVD option opens up this area. To obtain the highest level of flexibility, coating and metal choices are critical.

Lower Capital Investment

Compared to a chrome-plating line, the capital investment for a PVD line is much more cost effective. The fact that a UV/PVD line has a smaller footprint is a huge advantage for potential end-finishers who are considering bringing the finishing in-house, which allows for better quality control of the end product.

Targeted Applications

Testing has been completed for several automotive and heavy truck

OEM specifications. Targeted parts are components that are currently classified as decorative chrome plating on plastic substrates. This includes interior, exterior and under-the-hood components such as badges, various trim pieces, door handles, console parts, mirrors housings, wheel hubs, grilles, air filter housings, etc.

The PVD/UV-cured technology has been approved for some vehicle applications such as the new Ford Taurus's taillight surrounds and the interior door parts for the Jeep Compass and Patriot. Several end-component applications at various OEMs are in the process of obtaining part approvals.

Conclusion

The automotive market continues to value bright finishes for exterior and interior components. Decorative chrome plating can provide this look aesthetically. However, the issues associated environmentally and with the work-in-process have created a need for a new technology alternative. With the proper formulation, UV coatings in combination with the PVD process can offer an environmental, economic and performance alternative.

Acknowledgements

Special thanks to Chris Mack, UV chemist, and Dave Ingle, UV applications engineer, from Red Spot Paint & Varnish. ◗

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