

Progress in Replacing Decorative Electroplating Chrome Coatings on Plastics with Physical Vapor Deposition Coatings

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Decorative electroplated chrome coatings on plastics have been produced for decades. For environmental reasons, there has been a shift away from hexavalent chrome (Cr6) to trivalent chrome (Cr3) with increased investments towards elemental chrome PVD coatings to maintain the true chrome appearance. Stylists within industries such as automotive, still pine for the chrome look, but are looking for alternative solutions without the negative health impact of chrome electroplating and its processing effluents. For applications that must endure the sun, sand and highway, the acceptance criteria is increasing with exposures to a wider temperature range (from -70 to +150° C), higher levels of chemical attack from new highway deicing systems and from aggressive cleaning techniques. John A. Thornton [1] reported direct sputter deposition of chrome and other metals on ABS and base-coated ABS in 1975 and new developments continue to evolve to replace traditional decorative chrome plating.

Background

ABS (acrylonitrile-butadiene-styrene) has been widely used as substrates for vacuum deposition and electroplating since the 1960s. The material is relatively inexpensive and can be easily injection molded, but for most applications where the part is directly exposed, or viewed through a clear lens, a base coating (of paint) to smooth the surface of blush and flow lines prior to vacuum deposition has been required. A more expensive plating grade ABS is used for components to be electroplated. PVD processing has greatly opened up the materials that can be directly coated including: ABS with polycarbonate (PC) blends, polyamide (PA), polyetherimide (PEI), polybutylene terephthalate (PBT), polystyrene (PS) and others.

Launched in 1988, Truck-Lite Co. Inc., in Jamestown, NY, and Vergason Technology, Inc. (VTI®), in Van Etten, NY, directly applied PVD coatings to PC without using a paint base coating. By placing the metalizing equipment next to the injection molding press, the parts were coated immediately after molding, while they were warm, dry, and free of fingerprints and dust. Class A mold finishes, eliminating the application of excessive mold release and timely cleaning the gas

phase contamination from the mold surfaces were necessary to produce directly metalized mirror-like surfaces. After metalization, the substrates received the remaining processing steps in synchronous fashion until testing was completed and the parts were prepared for shipping. These techniques were the advent of LEAN manufacturing of PVD coatings which moved the metalization equipment upstream next to the injection molding operation. This is where the in-line process of Press Side® rapid cycle metalization was born and the scraps that fell off the large batch metalizing “King’s Table” became the food that launched a new genre of PVD processing for 3-D parts.

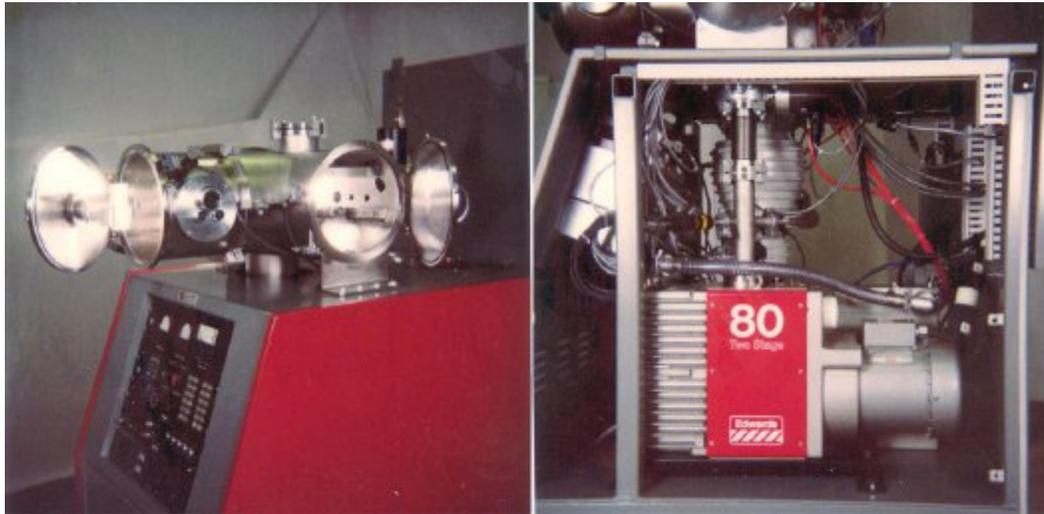


Fig. 1 - First known commercial rapid cycle metalizer capable of coating substrates directly after injection molding with VTI equipment. Door to door cycle time of 37 seconds. Photo: Vergason Technology used by permission of Truck-Lite Co. Inc.. www.truck-lite.com

Shortly after this, Vergason Technology expanded its in-house metalization and painting capabilities to process 4,500 Ford F150 truck center high mount stop lights per shift. These were injection molded by Truck-Lite and shipped to Vergason in specially designed containers, keeping the parts clean for processing within 24 hours of being molded (Fig. 2). Furthering this new processing technique, Vergason Technology presented its synchronous rapid cycle (<2 minute) PVD cell techniques in October 1995 to the Society of Automotive Engineers (SAE) Fall Lighting Committee Forum in Sarasota, Florida.



Fig. 2 – Ten parts per minute being cell processed in 1991. Steps included substrate pre-heating to 150°F (near to post molded temperatures), PVD coating of aluminum, paint top coating, and partial thermal cure of painted parts were then sealed in clean containers for full cure during shipment. Mask washer, positioned close the painting machine, could be used without any loss of production time. Photo: Vergason Technology

Method Comparisons

Electroplated Chrome: The process steps of applying chrome and other metal coatings to plastic are very different when comparing electroplating and PVD. In electroplating, numerous chemical baths and rinses are required to deposit 15 to 30 microns of metal for producing a durable chrome appearance. Electroplating processing steps are well known and can include: cleaning, conditioning, neutralizing, acid etching, catalyzing, accelerating, nickel flash, copper plating, nickel plating, chrome plating and effluent care and disposal.

PVD Chrome: For decades, paint base-coating (lacquering) has been widely used to provide a clean and smooth surface for PVD metal coatings. These paints were usually thermally cured, requiring 30 to 45 minutes at temperature in ovens. Many of today's paint base-coatings are ultraviolet (UV) cured in a matter of seconds, which increases quality yields by shortening the time the substrates are wet and prone to dust inclusion. Aluminum was the metal of choice due to its bright appearance and ability to expand and contract with the substrate without cracking. But, with as produced reflectivity between 85 and 90%, aluminum is highly specular, can take on an inexpensive look and does not have the depth of appearance produced with chrome or stainless steel.

PVD chrome can be applied with three primary methods: directly to a high quality substrate without a base-coating or clear coating (limited applications due to poor abrasion protection), over a base-coating (will require a thicker metal layer or be under a protective cover), or between a base-coating and clear coating. While newer environmentally safer low and non-VOC paints have been developed, PVD chrome that uses a base and/or clear coatings has paint waste stream effluent and disposal that must be managed.



Fig. 3 - Single Point Load VTI Press Side 4000 for high volume sputtered coatings. Photo: Vergason Technology

PVD Chrome Stress Management

Today's LEAN manufacturing processes that deploy PVD coatings and in-chamber top coatings are supplying batches of coated parts on the order of 45 seconds to a few minutes. While these fast cycles have reduced the production costs and increased the quality yields, attention must be paid to the material selection and process set up. If deposited at too high a rate, chrome, a very hard material, can exhibit cracking after thermal cycling, usually without a degradation of adhesion. Some techniques actually use controlled cracking to allow for substrate expansion and contraction without loss of the chrome coating. There are many processing tools available to control cracking of chrome coatings, including: pulsed power supplies, alloying of the target material, multilayered deposition and regular process controls. Figures 4 and 5 show some of these effects.



A B C
Fig. 4 – Base-coated ABS plaques with 300nm of chrome sputter deposited. Magnification 100X. Chamber pressure maintained at 2 milli-torr during deposition. A: deposition at 310

w/in²; B: deposition at 130 w/in²; C: deposition at 310 w/in² with alloy target. Cracking patterns from “mud flat” to “bamboo” (not shown) can be controlled through process parameters. Photos: Vergason Technology

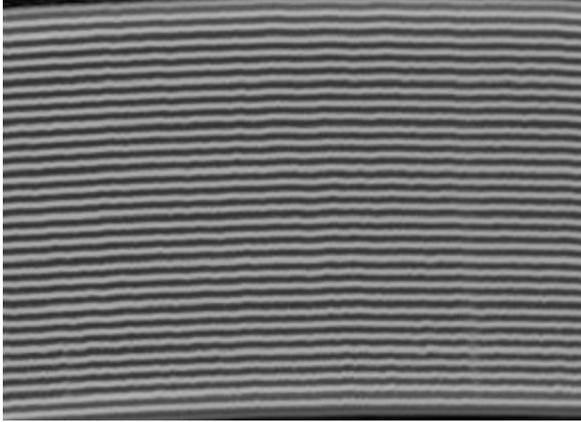


Fig. 5 – SEM micrograph of 10,000nm multilayer coating on acrylic substrate.
Photo: Vergason Technology

Color Matching PVD Chrome to Plated Chrome

Depositing PVD chrome utilizing commercially available equipment, such as the VTI PS4000SL sputtering system, will yield darker chrome than hexavalent plating baths. Reflectivity of 65% is typical for sputtered coatings, whereas 70-75% is common for plated chrome. Evaluating the source of the discrepancy indicates contamination of the film, most likely by hydrocarbon outgassing from the polymer substrate or the painted basecoat. This is easily confirmed by coating glass substrates, such as microscope slides, which matches the brightness of conventional plated chrome.

PVD chrome brightness is known to be affected by deposition pressure, substrate material, and basecoat paint chemistry. Lower pressure, both pre-sputter “base” pressure, and deposition pressure, improve brightness. Less, however, is understood about the base coat paint chemistry or substrate material, and their affect on film brightness. This research is ongoing. Also, as discussed later, chrome is often clear-coated with a UV or thermal cured paint for protection. These clear-coats have a tendency to darken the coating as well.

An alternative mindset is to not even try to match plated chrome brightness and color, but instead develop new standards for PVD chrome. Even though PVD chrome appears slightly darker than plated chrome, it is not displeasing to look at. In fact, to many, the color seems deeper and richer than conventional chrome. Unless samples of the two are placed side-by-side, only an expert would likely be able to notice the differences. If one were to insure all of the visual trim pieces on say a washing machine were produced via the same method, the aesthetics would be completely acceptable.

Another advantage of direct metalization is the ability to develop various gloss levels, and to create realistic durable appearances on the plastic parts. This is achieved by texturing the mold, to create a more custom look. Designers are looking for this flexibility, to supplement the traditional high gloss chrome for product differentiation and a premium look.

Durability Requirements

A key set of parameters which continue to dictate the development of PVD chrome are the environmental durability requirements. A general understanding of PVD chrome failure mechanisms would be helpful before launching into this section.

Chromium is a very hard metal. It has a very low coefficient of thermal expansion (CTE). It is self passivating, and will not oxidize beyond a few molecular thicknesses at the surface. This protects its metallic shine without the need for secondary passivation treatments. These are all excellent properties from a durability point of view. However, they can present significant challenges when trying to deposit chrome on plastic. As is often the case, very hard materials like chrome also exhibit brittleness (Fig. 4). Chrome is quite easily cracked if subjected to external stresses from thermal shock or impact. Intrinsic stresses can also be problematic, such as those created by CTE mismatch between the film and the substrate during deposition or in subsequent usage. The negative effects of these stresses can be minimized by keeping the chrome film as thin as possible, while still achieving the desired look. Films with thicknesses from 30 nm to 80 nm retain flexibility and will not fracture when subjected to moderate temperature excursions. However, these films are quite fragile relative to impact and abrasion and need secondary protection by a painted clear coat. Conversely, thicker chrome films of 200 nm to 600 nm exhibit excellent abrasion resistance, but often fail due to cracking, as discussed previously. Hence, the durability requirements often dictate which method, thick or thin, topcoat or no-topcoat, will be utilized. These requirements are unfortunately different for each general field of application, a few of which we touch on next.

Possibly the most difficult requirements belong to exterior automotive. Coatings must pass thermal shock, thermal cycling to extreme temperatures, gravelometer testing, UV testing, and Florida/Arizona sunshine testing. The impact and shock requirements dictate a thin film of chrome with a clear-coat. However, most clear-coats do not have sufficient hardness to provide long term abrasion resistance, and many cannot pass the UV exposure or sunshine tests. For this reason, PVD chrome has not been deployed in any significant volume in the exterior automotive market.

Interior automotive trim is a much easier application. The abrasion specifications and UV exposure limits are more relaxed. In this application a thin chrome film with clear-coat can be a winner. Surfaces which are exposed are typically subject to only mild abrasion with a soft cloth and certain chemicals for cleaning. Testing protocol varies widely per application and can include interesting tests for specific chemical resistance, such as sunscreen, mustard, cleaning chemicals, hand cream, etc. Additionally, if the trim piece will be permanently mounted behind a protective cover, such as inside an instrument panel, the thin chrome film does not need the clear-coat.

The appliance market offers great opportunities for PVD chrome (as well as other metallic finishes, such as stainless steel). Abrasion, chemical, and thermal requirements are all moderate. Most of the chrome on laundry appliances today is hexavalent chrome plating produced in China. Many American-based manufacturers have expressed interest in "on-shoring" these parts. In this market, a key challenge is color-matching. As the industry migrates toward PVD chrome, there will likely be an extended period of time where plated and PVD chrome are both utilized.



Fig. 6 - Modern kitchens using range handles, knobs and panels of the THERMITAL™ process. Photo: Mar-Bal. www.mar-bal.com

Mar-Bal, in Chagrin Falls, Ohio, has developed a new process for the demanding appliance industry called THERMITAL™. This process produces components that are superior to thermoplastics with higher mechanical strength, better acoustical performances and higher temperature tolerances and has the Haptics (feel) and look of solid stainless steel at a fraction of the cost. By specifying THERMITAL™, there has been recent acceptance and excitement in the appliance marketplace by OEM designers and engineers delivering high aesthetics while maintaining tough mechanical strength requirements.

In each of these applications, a finish free of clear-coat would represent the closest aesthetic match to conventional plated chrome. Thornton produced such surfaces in 1975 and companies are having moderate success in this respect with their proprietary processes, some through controlled cracking of the chrome layer.

Winona PVD Coatings, LLC has introduced a proprietary PVD chrome coating for OEM automotive wheels utilizing powder paint base and clear coatings. While these finishes are not on plastic substrates, this similar appearance can be achieved on plastic-clad wheels, wheel covers and center caps.



Fig. 7 - Before and after pictures of PVD Chrome on automotive wheels. Photo: Winona PVD Coatings www.g-chrome.com

Conclusion

PVD coatings and methods are rapidly advancing as a replacement for decorative electroplated chrome in the automotive, appliance, consumer products and other markets. The ability to fully process the components in a synchronous fashion from molding to shipping is saving much time and cost, and is helping American manufacturers compete with off-shore processing still using Cr6 materials. It is not surprising that companies active in this arena wish to keep their processes secret. The PVD chrome market is substantial, and while new technologies and know-how are being developed the “holy grail” will be to provide a cost-effective direct metalized PVD chrome appearance with no base-coat or clear-coat, exhibiting the same color, brightness, and environmental durability as plated chrome.

References:

[1] John A. Thornton, Telic Corporation, Sputter Deposition onto Plastics, 18th Annual SVC Technical Conference, Santa Monica, California, May 1975

About the authors:

Gary Vergason: founded Vergason Technology, Inc. (VTI) in 1986 and serves as its President & CEO. Working in the vacuum coating industry since 1980, Gary has authored a number of U.S. patents in the field of vacuum coatings. In 1996, he was named New York State Small Businessman of the Year by NY Gov. Pataki. Gary belongs to numerous engineering societies and has been an invited speaker at international and national technical conferences. Before founding VTI, Gary held technical, operational, and management positions at Borg-Warner (Journeyman Maintenance Electrician), 3M Company (Field Service Technician), Multi-Arc Vacuum Systems, Inc. (Engineering Manager) and Perkin-Elmer Corporation (Operations Manager). He has served on several Boards of Directors including currently serving at the Advanced Materials Manufacturing Center at Rhodes State College in Lima, Ohio.

Mark Fitch: joined Vergason Technology, Inc. 2005. As Executive Vice President he is responsible for the corporate business development and growth strategy. He also participates in the general management of the company. Prior to joining VTI, he held various technical, operational, marketing, and senior management positions with Corning, Inc. (Sr. Development Scientist), Geltech, Inc. (Vice President of Operations), and LightPath Technologies, Inc. (Sr. Vice President, Business Development). He has been granted six U.S. patents in the area of optical

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