Trends in PVD Coating Technologies and Their Markets

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Abstract

The main reasons for using hard PVD coating technology is improvement of substrate materials, resulting in an improved tool life for instance or reduced wear and friction. In this article the trends in three main markets for PVD coating technology, the tool market, tribological coatings for automotive engines and the decorative coating market, are being explored. Apart from the market trends, the article will also highlight some trends in development of coating technology and the coatings themselves.

Trends in Tool Coating Technology

The first market to explore is the tool coating market (**Figure 1**). Tool life improvement is the result of several upgraded functionalities, depending on the use of the tool. Hardness, temperature resistance and the contact between the tool and the material that needs to be cut or formed can be positively influenced. In some cases coated tools can realize a tool life that is ten times longer than uncoated tools. One important trend that is influencing tool coatings is the cutting of lightweight materials. In the automotive industry, lightweight materials are being chosen because of less fuel consumption and less CO_2 emissions. As a result, materials such as aluminium, magnesium and carbon reinforced plastics are gaining importance. Apart from the reduced weight, these materials have one thing in common - they have the tendency to stick to the cutting tool resulting in shorter tool life. This trend has stimulated the development of tetrahydral amorphous carbon (ta-C) coating, which is a hydrogen-free diamond like carbon (DLC) coating with a low coefficient of friction.

Figure 1. *Tools during a production process in a vacuum chamber with plasma.*

Crossover Tribological Applications

It is a practical example of a crossover development originated from tribology and applied in the tool coating market. In tribological applications this hydrogen-free diamond like carbon (DLC) coating is used to reduce wear and friction. Applied to the tool industry, ta-C coatings have proven to be extremely suitable for cutting lightweight metals and fibre reinforced plastics that tend to stick to the tool. A ta-C coating for tools is much thinner with a typical layer thickness of 0.5 µm. With ta-C coating the tool life can be significantly increased. The coatings are deposited with arc deposition technology using circular shaped arc cathodes, guaranteeing a strong adhesion of the coating itself.

Cost Efficiency

In every industry cost efficiency is a driving factor that needs constant attention. The tool industry is no exception. The cost of the tool coatings is only a small part of the total cost of a tool, but because the coating process is positioned at the end of the production line, it is very important that the coating is of high quality. Therefore in tool coating, reliability is as important a factor as costs. Upon development of a new circular arc technology for depositing nitride coatings, companies will be focused on making many cost-of-ownership factors more efficient than ever before. Characteristics will be short batch times, high target efficiency and smooth coatings that need minimal post-treatment. A shift in benchmark coatings is happening now that proven technology has been expanded with a highly functional AlCrN coating for hobs used in gear cutting.

Sustainability

The awareness of sustainable production methods becomes more and more mainstream, also in the tool industry and related fields up and down the supply chain. Important factors here are the future scarcity of raw materials, energy consumption, renewable energy, toxicity of materials and recycling in biological or industrial circles. In the tool industry some answers to these challenges are found in higher tool speed and feed rates. Some coated tools can achieve not only longer cutting lengths, also a larger depth of cut per contact, saving time and energy along the way. The feed rate of meters per minute is deciding. Another trend that is driven by sustainability as well as cost efficiency is less use of cooling liquids. Dry cutting or minimum quantity lubrication (MQL) are trending, which leads to increased temperatures of the tool cutting edges and hence a need for improved oxidation resistance.

Temperature Resistance

The trends in the tool industry are all related. The trends for cost efficiency and environmental awareness lead to lower use of cooling fluids, which in turn leads to higher temperatures during cutting. The industry answers with a different choice of component materials and coatings that can withstand the high temperatures. Component materials such as titanium (Ti) and nickel (Ni) alloys are difficult to cut because of their sticking tendency and toughness, but ta-C coating will not bring any solutions here because of its operating temperature maximum of around 500 °C. Nitride coatings are therefore a better solution. They can function at operating temperature levels of up to 1100 °C or even 1500 °C (**Table 1**). Application directed development has been done to adapt the coatings made with circular arc technology to specific applications, such as high speed milling and roughing finishing. For cutting titanium the TiAlN coating produced with specific circular arc technology can give excellent results. Furthermore there are developments regarding silicon-containing nanocomposite coatings and fine-tuning AlTiN for specific applications.

Aluminium Oxide Coatings

Another possibility to deal with temperature resistance is the use of aluminum oxide (Al_2O_3) coatings. The biggest challenge when depositing oxide coatings is in controlling the sputtering process. An Al_2O_3 coating is made by sputtering from an aluminum target in an argon (Ar) and oxygen (O_2) atmosphere. When using a single magnetron cathode during the deposition, the anode area surrounding the cathode will slowly become non-conductive resulting in unstable cathode behavior. Dual Magnetron Sputtering (DMS) technology can overcome this problem. Two magnetron sputtering cathodes on opposite sides of the PVD system are connected to one AC power supply. When one cathode is running on negative potential, the other cathode is positively charged, effectively acting as anode. In this way, a stable anode is established continuously during the complete deposition cycle. Proven T-mode (transition mode) technology deals with another challenge of Al_2O_3 coatings: balance in the oxygen flow. In order to deposit coatings with the right composition and with high deposition speed, it is crucial that the sputtering process takes place in the transition mode. T-mode technology introduces a loop on each of the two sputter cathodes to achieve this and prevent the target from being poisoned, which would cause a large decrease in deposition rate.

Tool Coatings	*Deposition Temperature Range °C*	*Maximum Operating Temperature °C*
TiN	<600	600
AlTiN	<600	900
AlTiN + W: C-H	150-450	450
AlTiN + Al_2O_3	450-600	1100
AlCrN	<600	1100
TiSiN	<600	1500
TiCN	<600	600
TiAlN	<600	800
TiN + TiAlN multilayer	<600	800
CrCN	450	600
ta-C	80-200	>500

Table 1. *An overview of tool coatings and their maximum temperatures.*

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Tribological coatings are all about reduction of wear and friction, sometimes in dry conditions, but mostly combined with lubrication within for example a car engine. The motivation behind a lot of the trends in tribology in the automotive industry is the need to reduce CO_2 emissions and fuel consumption on all continents. In different countries there are various regulations with corresponding goals and deadlines, but the bottom line is the same for everyone: CO_2 emissions should be significantly reduced by 2020-2025. Tribological coatings can contribute to this goal by reducing friction in the engine.

Coated Components

Originally plasma coating technology was developed to improve wear resistance of components. But since then friction reduction has become a hot issue. Many components, such as turbo diesel injection systems, piston rings, valve train components, piston pins, bearings and gears are being coated to reduce wear and friction and thus save fuel and reduce CO_2 emissions (**Table 2**). Layer thicknesses of Physical Vapor Deposition (PVD) and Plasma Assisted Chemical Vapor Deposition (PACVD) technologies vary between less than 1 micron up to more than 20 micrometer and hardness can vary between 1500 HV and more than 5000 HV. Process temperatures are ranging from 150 °C to more than 500 °C. Often these wear resistant coatings will be engineered with reduced friction properties, making them the dream of any engineer searching for solutions for highly loaded components inside engines.

Technology	***Arc Evaporation (PVD)***	***Sputtering (PVD)***	***High Voltage Discharge (PACVD)***
Typical Coatings	CrN, ta-C	CrN, metal DLC, ASIN	DLC, Silicon DLC
Surface	Rough (polish)	Smooth	Smooth
Typical Applications	Valve train components, diesel high pressure pump, diesel injector parts, piston rings	Valve train components, journal bearings	Piston parts, valve train components, diesel injector parts, diesel high pressure and oil pump parts, piston pins, gears

Table 2. *Technology, coatings and the engine components for which they are mainly used.*

Oil Viscosity

One of the trends that are really influencing tribological coating developments is the reduced viscosity of oils used in the engines. (**Figure 2**) Low viscosity oils are often chosen for their lower friction, but this will increase the risk of metal-to-metal contact, which will cause potentially more local wear. At those parts, tribological coatings can be applied to reduce wear and friction. Another factor influencing coating development is the fact that certain metals inside the coating have the availability to react with additives in the engine oils e.g. sulphides, thus creating beneficial highly lubricious metal-sulphide compounds. This is taken into account when developing optimum coatings for these applications. There are developments in doped carbon coatings to comply with these trends.

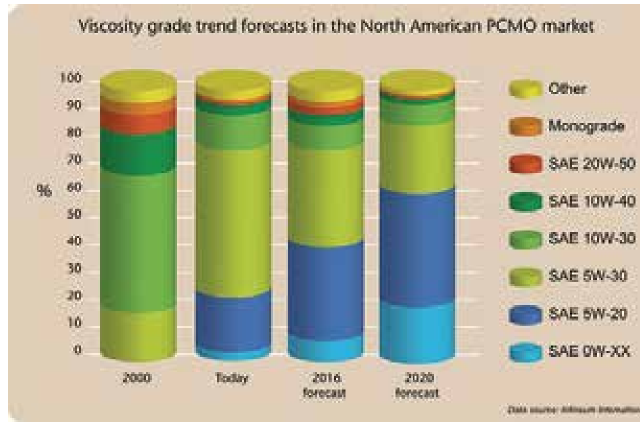

Figure 2. *Oil viscosity trends in the North American market (Source: Insight, Infineum International Limited, September 2012)*

Productivity and Automation

Forced by economic factors, productivity is always an issue in the automotive industry; both among OEMs and their tier-1 suppliers. For manufacturers this means that they are always working hard to supply the best possible machine cost of ownership for certain applications. Increased productivity can be achieved by optimizing batch loads and reducing cycle times. Further reduction of cost of ownership can be achieved by optimizing machine features, such as highly efficient target utilization or introducing new inline production concepts. Additionally efficiency can be achieved on auxiliary equipment, such as automation of handling, inspection, etc. Looking at the possibilities for coating production, inline production can be an efficient solution for applying wear resistant coatings on three-dimensional components.

Temperature Resistance

Traditionally a plasma bombardment process is used for etching, in which the bombarding argon ions are driven by an electrical field. However, for more complex geometries and inside sharp corners this etching technology is less effective. For these complex geometries enhanced plasma source etching has been developed which can reach all difficult corners and edges. Just like the trend in tool coating technology, also in the automotive industry there is a need for high temperature resistance. Materials have to resist higher loads and temperatures as a result of developments in turbo changing and downsizing of engines as well as the lower viscosity of oil. An answer to this trend can be doped a-C:H coatings and doped ta-C. A lot of development has been done where these diamond like carbon (DLC) coatings are doped with tungsten, silicon and also chromium. Characterizations have been done after heating at 450 °C- 500 °C as well as high temperature tribological tests at test temperatures of up to 500 °C. Already industry is using this technology in real life applications.

Microwave Technology

In line with the trend for increased productivity, microwave technology has been researched. In the traditional process (PACVD) of producing DLC coatings, hydrocarbon gas (C_2H_2) enters the vacuum chamber. Due to a high potential difference across the chamber, the gas will be cracked and plasma will be created, using a negative bias voltage. In the PACVD microwave process, the start is the same, but the addition of microwave energy increases the ionization density and consequently the deposition rate, density and structure of the coating. This creates possibilities to further reduce cost of ownership, as the improved deposition rate does not increase the process temperature, which is often limited by the maximum temperature the coated parts can resist. More development needs to be done before microwave technology becomes available for mass production.

Across Markets

Crossing borders gives a lot of advantages for all industries. They can use the knowledge and the mistakes made in other markets to optimize technology for their own production processes. The developments on the hydrogen-free DLC coating ta-C for example has first been optimized for tribological coatings, then the tool coating market became interested in ta-C for cutting of lightweight materials and fibre reinforced plastics. With the development of CrN coatings produced by an improved circular arc technology for the tribological market, it was a reversed process. The technology was initially developed for tool coatings, but its increased smoothness and highly efficient target utilization makes it interesting for tribological applications as well.

Trends in Decorative Coating Technology

Decorative coatings are influenced by many trends, some regarding fashion, others regarding functionality and production methods. Conventionally, the decorative coating markets such as sanitary equipment, door hardware, automotive decoration and consumer products are looking for an improvement of lifespan, scratch resistance and brilliant colors. Times are changing and although these factors are still of importance, other elements are often taken into account as well.

Replacement Electroplating

An important trend in the coating industry in general is the need to avoid the use of Cr^{+6} in production processes, because it is carcinogenic and will be banned by more and more governments in the near future. Regulations such as REACH (Registration, Evaluation and Authorization of Chemical Substances, 2007), directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (2011) and directive 2012/19/EU on waste electrical and electronic equipment (2012) have a great impact on new investments in coating equipment. Electroplating, the conventional way of hardening substrates, will have to change into environmentally friendlier and healthier alternatives. PVD coating is one of those alternatives. Because the coatings are deposited in a vacuum chamber, the technology is clean and without risks. More and more original equipment manufacturers (OEMs) in sanitary and door hardware initiate the search for alternative technologies that

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will safeguard their markets. In plating on plastics the same thing is happening. The tier-1 suppliers of the automotive industry that are profiting from the trend to reduce the weight of cars, are often large plastic molding companies that do not want to invest in old technologies, but are looking for state-of-the-art technologies.

Dark colors

Consumers love dark, shiny colors, such as piano black, dark chrome, anthracite black, or oil rubbed bronze. All of these colors can be made with PVD coatings. Diamond like carbon (DLC) coatings, deposited by either magnetron sputtering or PACVD are solutions to produce anthracite black and black-like colors. Sputtered TiCN is also a possibility. Most colors will be made by metal carbon nitride coatings, in which the metal can be Cr, Zr, Ti, Al or some kinds of alloys. Of course reproducibility of these colors is a must.

Hydrophobic Layers

Scratch resistance has always been an important reason for coating with decorative PVD layers, but there is also something like perception of scratches. When a PVD coating is complemented with a HMDSO layer on top of the PVD coating that gives the product its color, this layer ensures that the scratches will be less visible and the surface will be easier to clean. The topcoat is deposited by PACVD using an HMDSO precursor. The silicon oxide (SiO_x) coating has a low surface energy leading to strong hydrophobic properties and its contact angles exceed 90 degrees.

Translucent Parts

Cars and fashion, two words that belong together. The automotive industry is a very fashionable industry; car models are replacing each other faster and faster, which means that colors, geometries and styles will last only so long before the next trend becomes visible. At this moment translucent parts are becoming more and more popular in the automotive industry. With a very thin Cr layer it is possible to change the atmosphere in the car from daylight (chrome color) to night time (red or blue shine). The part made of transparent plastic, such as PPMA or PC, needs to be well activated by argon ions out of a plasma source. When this process step is ready the part will be coated with a Cr layer before it is backlit to create this stunning effect. The logos of the automotive brands will sometimes be engraved by laser into the parts, so the symbol becomes clearly lit (**Figure 3**). It is also possible to apply an HMDSO top layer on such parts.

Productivity

Forced by economic factors and globalization, there is a need to increase the product life cycle of many products. In practice this means that products will become more and more standardized, volumes increase and products will be reused. PVD coatings can add functionalities to the products, but these coatings need to be mass-produced to remain economical. Inline production can be an answer to this trend. With a few chambers an inline production platform will increase productivity substantially compared to batch production and it gives the possibility to integrate the machine into a fully automated production plant.

Figure 3. *Example of translucent plate with thin Cr coating held above a lamp.*

Conclusion

The trends in tool, tribological, and decorative markets provide many opportunities for PVD and PACVD coating technology. A great deal of research and development is done by teams consisting of coating equipment manufacturers, universities and the industry to improve and optimize coatings. Extra attention should be given to the crossovers between different markets. Experiences from one application can give a lot of input for further development of technologies and coating solutions for another application, sometimes in a completely different market. Crossovers can speed up developments significantly.

About the Author *Michiel Eerden*

Michiel Eerden graduated in Applied Physics from the Eindhoven University of Technology in The Netherlands in 1995. He has worked for IHI Hauzer Techno Coating for over 18 years, initially as process engineer involved in development of PVD coatings in the tribological, decorative and tool coating field. His first SVC paper was in 2002. He has acted in several positions in engineering and sales before taking over his current position as Product Manager Tool Coating.
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