coatings

Editorial

Coating Technology Makes Comprehensive Surface Protection Possible

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The tribology and wear protection of coatings has been an active and rapidly developing area for research and industries in recent years, with innovative coating materials, structures, and fabrication technologies. From the view of coating composition, one of the most widely studied organic coatings for wear protection is diamond-like carbon (DLC) due to its atomic high-strength bonding ability and, therefore, macroscopic wear resistance [1–3]. In a study by Stallard et al. [4], the authors investigated the tribological behavior of DLC coatings under various conditions, including dry sliding, water lubrication, and oil lubrication, and they found that DLC coatings had excellent wear resistance and low friction coefficients. Other studies have focused on optimizing the deposition parameters and properties of DLC coatings to further improve coating protection [5–7]. For example, McMaster et al. [8] developed a DLC coating with a multi-layered structure and found that the coating had superior wear resistance and fatigue resistance compared to a single-layer DLC coating. In addition, the other important coating category is the one compounded with metallic elements and has also been widely investigated for its wear protection performance [9,10]. For instance, TiAlN and TiSiN coatings have been studied for their high hardness and toughness, as well as their good adhesion to various substrates. In the study by Cai et al. [11], the authors developed a TiSiN coating with a gradient microstructure and found that the coating had excellent wear resistance and reduced friction under dry sliding conditions. Furthermore, in the study by Kavimani et al. [12], the authors developed a nanographene oxide/TiO_2 composite coating, which exhibits even better wear protection. Apparently, the tunability of coating compositions alone (e.g., metallic elements, silicon, fluorine, nitrogen, etc.) evokes tremendous interest with respect to research and application, not to mention the various coating techniques for fabricating innovative and high-performance coatings.

Different coating techniques were developed over decades. Plasma spraying, as a widely used technique, is a thermal spray process where a high-temperature plasma arc is used to melt and propel the coating material onto the substrate. Plasma-sprayed coatings are known for their excellent wear resistance, corrosion resistance, and thermal insulation properties. However, plasma spraying has limitations with respect to achieving coatings with high precision; thus, it is not suitable for coating complex shapes [13]. Ion implantation is another coating technique that is widely used for surface modification. Ion implantation is a process where ions are accelerated and implanted into the substrate material to modify its surface properties [14]. Obviously, ion implantation has the advantage of achieving coatings with high hardness and wear resistance, but it has limitations with respect to achieving high-thickness coatings. An efficient coating technology for corrosion protection is electrochemical deposition. Electrochemical deposition is a process where an electric current is used to deposit the coating material onto the substrate. Cheng and Jabbar [15] reviewed the electrodeposition of metal matrix composites. They reported that electrochemical deposition is widely used for coatings with good adhesion and corrosion resistance, whereas deposition on complex geometry remains a challenge for this coating technique because uniform solvent compositions and current density are critical parameters for coating process. Actually, based on different mechanisms, the above coating techniques

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can also be categorized by physical vapor deposition (PVD), e.g., ion implantation, and chemical vapor deposition (CVD), e.g., electrochemical deposition.

As the coating's thickness scales down to nanometers, more precision coating techniques, e.g., atomic layer deposition (ALD), emerge and fit within its scope. Atomic layer deposition (ALD) is a thin-film deposition technique that allows precise control over the thickness and composition of deposited films. ALD involves the alternating exposure of the substrate to two or more precursor gases, which react with the surface to deposit a thin film of material. In recent years, researchers have focused on developing new materials for ALD coatings, such as metal oxides, nitrides, and sulfides. These new materials offer unique properties, such as high electrical conductivity, optical transparency, and catalytic activity. Metal oxides are widely used as dielectric materials in microelectronic devices due to their high electrical insulation properties. ALD has been used to deposit high-quality metal oxide films onto substrates, such as silicon and metal foils. For example, Beladiya et al. [16] developed a method for depositing high-quality hafnium oxide (HfO_2) films onto flexible substrates using plasma-enhanced ALD. The HfO_2 films showed excellent electrical insulation properties, making them suitable for flexible electronic applications. Nitrides and sulfides are promising materials for various applications, such as energy storage and catalysis. ALD has been used to deposit high-quality nitride and sulfide films onto substrates, such as silicon and metal foils. For example, Mattinen et al. [17] developed a method for depositing high-quality molybdenum disulfide (MoS_2) films onto silicon substrates using thermal ALD. The MoS_2 films showed excellent catalytic activity, making them suitable for catalysis applications. In addition to new materials, researchers have also focused on developing new deposition methods for ALD coatings. Plasma-enhanced ALD (PEALD) is a method that involves using plasma to break down the precursor gas into reactive species that can react with the substrate's surface. PEALD can produce high-quality films with improved adhesion and uniformity. For example, Elers et al. [18] used PEALD to deposit a titanium nitride (TiN) film on a silicon substrate. The film showed excellent electrical conductivity properties, making it suitable for electronic device applications. Spatial ALD (SALD) is a method that involves using a mask to define the deposition area, resulting in patterned films with high resolution. SALD can produce films with precise thickness and composition control, making them suitable for various applications, such as microelectronics and sensors. For example, Kannan et al. [19] used SALD to deposit patterned zirconium oxide (ZrO_2) films on a silicon substrate. The patterned ZrO_2 films showed excellent electrical insulation properties, making them suitable for microelectronic applications.

While existing coating techniques alleviate damage and prevent failure by tailoring the coating's composition and microstructure, new technologies are continuously developed to improve coating performance. Laser cladding is a coating technique that is used for surface modification, repair, and restoration. Similarly to additive manufacturing, laser cladding is a process where a laser beam is used to melt and fuse the coating material onto the substrate. Zhu et al. [20] reviewed the principle, practice, and application of laser cladding. They reported that laser cladding is used in various applications such as aerospace, automotive, and biomedical coatings. Laser cladding has the advantage of achieving coatings with high precision and low heat input, but it has limitations in achieving coatings with high productivity. Another newly developed technique, surface severe plastic deformation (SSPD), was also used to process the substrate, and sequential coating layers were found to exhibit stronger adhesion [21]. SSPD was believed to induce activated sites with higher surface energy on substrates. During deposition processes, stronger atomic bonding eventually leads to good adhesion and high-quality coatings. From the above two examples, it can be observed that cross-discipline techniques can be applied in the coating field, and the techniques achieve unexpected high-quality coatings and efficient improvements. However, no matter what the coating compositions or mechanisms are, the fact is that more and more innovative technologies are incorporated to enrich the family of coating strategies, and such a topic is of significant interest.

In conclusion, coating technologies are a critical aspect of modern manufacturing and have many applications in various industries. It covers and involves multi-physics and many research fields. Advances in coating technology, including the development of new materials and deposition methods, will continue to drive innovation in industry and academia, leading to new products and applications. As such, further research and development in this field will be essential, and any breakthrough deserves significant attention from all research communities.

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