Review

An Overview of Nano-structural Hard Coating Synthesis, Design, and Applications

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Abstract: Advanced nano structural hard coatings are thin materials films that range in thickness from a few nanometres to a few micrometres and are applied to different surfaces to increase their hardness and wear resistance. Physical vapour deposition (PVD) or chemical vapour deposition (CVD) methods are frequently used to deposit these coatings. These coating's distinctive characteristics result from their microstructure, which is made up of material columns or grains with a diameter of only a few nanometres. Increased hardness, higher wear resistance, and improved tribological properties result from these short dimensions. In applications with significant wear and/or high contact pressures, such as cutting tools, bearings, and engine parts, the usage of sophisticated nano structural hard coatings is crucial.

Advanced nano structural hard coatings include,

1. Amorphous carbon coatings with high hardness, low friction, and exceptional wear resistance are known as diamond-like carbon (DLC) coatings. DLC coatings are frequently used in a variety of industries, including the automotive, aerospace, and biomedical ones.
2. Coatings made of titanium nitride (TiN): These metallic coatings have high hardness and wear resistance. Cutting tool, machining, and aerospace industries frequently use TiN coatings.
3. Chromium nitride (CrN) coatings: These coatings have great corrosion resistance, good wear resistance, and high hardness. Cutting tools, gears, and bearings are just a few of the objects that use CrN coatings.
4. Tungsten carbide (WC) coatings: These coatings, which have a high degree of hardness and wear resistance, are frequently employed in cutting tools and other applications that require wear resistance.

Advanced nano structural hard coatings provide many advantages over conventional coatings, including better hardness, increased wear resistance, and improved tribological qualities. The automotive, aerospace, and biomedical industries are just a few that could use these coatings. In this paper the author will explain about the design synthesis and applications of advanced Nano structural hard coating in aerospace and automotive applications.

Keywords: Coating; Nano Structural; Tribological and Mechanical properties

1. Introduction

Thin films of substances are referred to be coatings when they are put to a surface to change certain characteristics. A coated surface's characteristics can be improved by changing its chemical, physical, or mechanical components, which can increase the surface's usefulness and tensile strength. Depending on their content and mode of application, coatings can be categorised into a variety of groups [1,2]. Here are a few typical coating types:

Coatings comprised of organic substances, such as polymers, resins, and paints, are referred to as organic coatings. Organic coatings are frequently applied to surfaces to prevent corrosion, add aesthetic value, and increase wear resistance. Coatings made of inorganic substances: These coatings

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are formed of inorganic substances like metals, ceramics, and glasses [3-6]. Inorganic coatings are frequently used to increase the surface hardness of materials, provide wear resistance, and provide thermal insulation [7–10]. Coatings with functional properties: These coatings are made to alter the surface characteristics of materials for certain uses. For instance, hydrophobic coatings are used to fend off water, whereas anti-reflective coatings are employed in optical applications to lessen reflection [11–15]. Coatings that provide protection: These coatings shield surfaces from harm brought on by environmental causes such corrosion, abrasion, and chemical attack. The automobile, aerospace, and marine sectors frequently use protective coatings. Thin coatings, ranging in thickness from a few nanometres to a few micrometres, are known as nanocoating's. In order to improve the surface characteristics of materials, such as their wear resistance, reduce friction, and improve their thermal properties, nanocoating's are frequently utilised. In many sectors, coatings are essential because they may dramatically improve the surface qualities of materials, increasing their utility, toughness, and performance [16,17]. As new materials and application techniques are created to enhance the characteristics of coated surfaces, coatings continue to be an important area of research and development. In applications with significant wear and/or high contact pressures, such as cutting tools, bearings, and engine parts, the usage of advanced nanostructure hard coatings is essential. By minimising wear and tear, these coatings can considerably increase the lifespan of these components [18–20]. Several industries, including automotive, aerospace, and biomedicine, where enhanced wear resistance, hardness, and durability are crucial, have been transformed by the development of superior nanostructure hard coatings. These coatings have made it possible to create engines that are more effective, cutting instruments that last longer, and biomedical implants that are resistant to wear. Advanced nanostructure hard coatings are an important field of research and development for many sectors because they provide many advantages over conventional coatings, such as better hardness, increased wear resistance, and improved tribological qualities. Advanced nano structural hard coatings are the subject of extensive study and research in several scientific fields, including materials science, surface engineering, and tribology [21–23]. Here are some opinions on this subject from various researchers:

According to a study in the Journal of Materials Science and Engineering, because of their nanoscale architecture, advanced nano structural hard coatings are harder and more resistant to wear than conventional coatings. The study also revealed that these coatings' qualities may be modified for particular purposes, giving them a great degree of adaptability [24].

Advanced nano structural hard coatings exhibit outstanding tribological features, such as low friction and wear rates, according to another study that was published in the journal Surface and Coatings Technology. The study also discovered that these coatings might be used on cutting equipment and biological devices [25].

Advanced nano structural hard coatings are crucial for enhancing the surface characteristics of materials, according to review research that was published in the journal Applied Surface Science. In addition to examining the impact of deposition parameters on the microstructure and characteristics of the coatings, the article covered the various deposition procedures utilised to produce these coatings [25].

The use of cutting-edge nano structural hard coatings on tools and machine components can greatly extend their lifetime and reduce wear, according to a study published in the Journal of Coatings Technology and Research. The investigation came to the conclusion that there is huge potential for these coatings to be used in numerous industrial applications [26,27].

Advanced nano structural hard coatings have exceptional corrosion resistance qualities, according to a study that was published in the journal Thin Solid Films, because of their dense, homogeneous microstructure. According to the study, these coatings can be utilised to safeguard materials that are vulnerable to corrosion [28].

Advanced nano structural hard coatings offer outstanding thermal stability, making them appropriate for use in high-temperature applications, according to a different study that was published in the journal Materials Letters. The study also discovered that these coatings might be used in the energy and aerospace sectors [29].

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The significance of cutting-edge nano structural hard coatings in enhancing the mechanical properties of materials was underlined in a review article published in the journal Advances in Materials Science. The implications of microstructure, content, and deposition parameters on these coatings' characteristics and prospective uses were covered in the paper [30].

Advanced nano structural hard coatings can greatly increase a material's wear resistance and reduce wear rates by up to 90%, according to a study that was published in the journal Journal of Materials Science and Technology. According to the study's findings, these coatings have a huge potential for usage in a variety of industrial applications, such as cutting tools, coatings that resist wear, and biomedical implants [31].

Advanced nano structural hard coatings have outstanding adhesion qualities, making them appropriate for use in coatings for medical implants and other applications where biocompatibility is crucial, according to a study published in the journal Journal of Alloys and Compounds [32].

Advanced nano structural hard coatings can dramatically reduce wear and friction in sliding contacts, making them appropriate for use in high-load applications like engine parts and gears, according to another study published in the journal Surface Science and Engineering [33].

The numerous deposition methods used to make cutting-edge nano structural hard coatings and their applications in diverse industries were covered in a review article that was published in the journal Advances in Surface Science. The article emphasised how crucial it is to manage these coatings' microstructure in order to maximise their qualities [34].

Advanced nano structural hard coatings can increase the wear resistance of materials by lowering the development of cracks and other wear-related damage, according to a study published in the journal Wear. The study also discovered that these coatings can lengthen a material's fatigue life, enabling it to be used in high-stress situations. The author will be explaining the design, synthesis and applications of Advanced Nano Structural Coating for aerospace and automotive sectors, as well as the recent developments [35].

2. . Design, synthesis and applications

The microstructure, chemistry, and deposition parameters of nanostructured hard coatings are customised to improve their qualities for particular applications. For instance, these coatings' microstructure can be altered to enhance their mechanical and tribological properties by altering the deposition temperature, deposition rate, and substrate bias voltage. To increase the hardness, wear resistance, and corrosion resistance of these coatings, the composition can be changed by adding substances like nitrogen, carbon, and boron [36].

Design: To best suit their qualities for particular applications, nanostructure hard coatings are designed by adjusting their microstructure, composition, and deposition conditions. To enhance the mechanical and tribological properties of the coatings, for instance, the deposition parameters, such as temperature and pressure, can be adjusted. To increase particular qualities, such as hardness or corrosion resistance, the composition of the coatings can be altered by adding alloying elements or altering the ratio of the components.

Synthesis: Several deposition processes, including PVD, CVD, and PECVD, are used to create nanostructure hard coatings. These methods entail the controlled deposition of thin films of various materials onto a substrate. The deposition method, content, and microstructure all affect the coatings' characteristics. For instance, although CVD may make coatings with great adherence and homogeneity, PVD can provide coatings with high hardness and wear resistance.

Applications: Nanostructure hard coatings have a wide range of uses, including the following:

a. Coatings that are resistant to wear: Nanostructure hard coatings can be employed as coatings that are resistant to wear in a variety of industrial applications, including cutting tools, bearings, and gears. These coatings lower maintenance expenses by enhancing the materials' wear resistance.

b. Biomedical implants: Protective coatings made of nanostructures can be applied to implants used in medicine, such as orthopaedic and dental implants. These coatings enhance biocompatibility and lower implant failure risk.

c. Applications in the aerospace and energy sectors: Nanostructure hard coatings can be employed as protective coatings for parts used in these sectors, including turbine blades, engine parts, and fuel cells. These coatings increase the components' heat stability and corrosion resistance.

d. Electronics: Hard coatings with nanostructures can serve as protective coatings for electronic components like solar cells and hard drives. The performance and durability of the devices are enhanced by these coatings.

Properties: Nanostructured hard coatings have exceptional tribological, mechanical, and corrosion resistant qualities. These coatings frequently feature strong wear resistance, low friction coefficients, and high hardness. These coatings' adhesion, toughness, and ductility can all be enhanced by engineering their microstructure.

Benefits: Compared to conventional coatings, nanostructured hard coatings provide a number of advantages. Since they may be deposited at lower temperatures, there is less chance of substrate distortion or damage. Moreover, they adhere to the substrate with greater strength, enhancing the coating's longevity and resilience. In comparison to conventional coatings, nanostructured hard coatings are also less harmful to the environment because they may be applied with less harmful chemicals.

Properties that can be customised: Nanostructured hard coatings' characteristics can be modified to fit particular application needs. By adding nitrogen, carbon, or boron, for instance, the coatings' hardness and wear resistance can be improved. By adding a lubricant, such as molybdenum disulphide, the coatings' coefficient of friction can be reduced. The coatings' shape and thickness can also be modified to enhance certain attributes [37–40].

Durability: Nanostructured hard coatings are extremely robust and are resistant to extreme weather, including corrosive conditions and high temperatures. This qualifies them for usage in demanding applications including those in the aerospace and energy industries.

Cost-effective: Using nanostructured hard coatings can save money over time by lowering maintenance and replacement expenses. For instance, applying a nanostructured hard coating to a cutting tool can lengthen its usable life and lower the frequency of replacement.

Nitride coatings: As nanostructured hard coatings, nitride coatings including titanium nitride (TiN), aluminium nitride (AlN), and silicon nitride (SiN) are frequently utilised. These coatings have high wear resistance, corrosion resistance, and hardness qualities. They are frequently utilised in biomedical implants, moulds, and cutting instruments.

Coatings made of amorphous carbon and hydrogen are known as diamond-like carbon (DLC) coatings. They are a type of nanostructured hard coating. These coatings have strong wear resistance, low friction, and high hardness characteristics. They are frequently employed in products like biomedical implants, gears, and cutting instruments.

Oxide coatings: Another type of hard coating with a nanostructure is the oxide coating, which includes materials like zirconium oxide (ZrO2) and aluminium oxide (Al2O3). Cutting tools, medicinal implants, and aircraft components all frequently use these coatings because of their great hardness and wear resistance.

Coatings made of carbides: Nanostructured hard coatings made of carbides, such as tungsten carbide (WC) and titanium carbide (TiC), are also frequently utilised. These coatings have high wear resistance, corrosion resistance, and hardness qualities. They are frequently utilised in products including biomedical implants, wear-resistant coatings, and cutting instruments.

Coatings that are composed of a combination of several substances, such as nitrides, carbides, and oxides, are known as composite coatings. They are a type of nanostructured hard coating. These coatings have distinct mechanical and tribological characteristics that can be customised for certain uses [30–40].

3. Advantages:

Increased wear resistance: Compared to conventional coatings, nanostructured hard coatings offer dramatically enhanced wear resistance, resulting in longer lifetimes and lower maintenance costs.

Improved hardness: Compared to conventional coatings, nanostructured hard coatings often have hardness values that are higher, making them more durable and less prone to damage and deformation.

Improved corrosion resistance: Many nanostructured hard coatings have good corrosion resistance, which is crucial in challenging settings like those found in aerospace applications or biomedical implants.

Surface qualities can be improved by nanostructured hard coatings, including surface roughness, surface energy, and wettability. This can result in better adhesion and tribological properties.

Customizable qualities: Nanostructured hard coatings can be made to have certain properties depending on the application, such as biocompatibility, electrical conductivity, and temperature resistance.

3. Challenges:

Cost: Because they require more materials and production processes than conventional coatings, nanostructured hard coatings might be more expensive.

Challenges in deposition: The deposition of nanostructured hard coatings can be difficult, especially for substances with high melting points or that are difficult to evaporate.

Adhesion: It can be difficult to get excellent adhesion between the coating and the substrate, especially for complex geometries or uneven surfaces.

Scale-up: Producing nanostructured hard coatings on an industrial scale can be difficult, especially when using intricate deposition techniques like atomic layer deposition.

Health and safety: Using certain materials, such as metals and metal compounds, in nanostructured hard coatings can endanger employees' health and safety, especially during deposition and handling [1–25].

Conclusions

In conclusion, nanostructure hard coatings have become a promising class of materials with several uses in a variety of fields, including electronics, aerospace, automotive, biomedicine, and, etc. Many benefits are provided by these coatings, such as greater wear resistance, increased hardness, improved corrosion resistance, enhanced surface qualities, and customised features.

To obtain the desired qualities, the design and synthesis of these coatings entail careful selection and optimisation of the coating material, deposition method, and processing parameters. Nanostructure hard coatings are deposited using a variety of methods, such as PVD, CVD, thermal spray, electroplating, and laser-assisted deposition.

Although there are certain difficulties in producing and using nanostructure hard coatings, such as scale-up, adhesion, cost, and difficulties with deposition, these difficulties are being addressed through ongoing research and development.

In general, nanostructure hard coatings have considerable promise for enhancing the functionality and longevity of a variety of goods and applications, and they will continue to be a focus of active research and development in the years to ahead.

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