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Review paper

Zirconia based hydrophobic coatings exhibiting excellent durability for versatile use

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Abstract

Understanding how to manage the hydrophilicity and hydrophobicity of a surface has been the focus of a lot of research in recent years. The surface's energy often controls its hydrophobic state. There are numerous techniques to realize a change in the surface energy. Smart nano-based materials are being used to create super hydrophobic coatings that will serve as layers of defence against mechanical abrasion, corrosion, and fouling agents on the surface of metallic components. These coatings, which have recently gained popularity, have shown to be excellent choices for protecting steel pipelines. The recently created super hydrophobic coatings for glass surfaces, papers, cotton, steel pipes, etc., are examined in-depth and critically in this review study, emphasizing their use in different industries. It explains how to create super hydrophobic coatings on glass substrates using various techniques and the most recent research results on various coating production techniques. An in-depth discussion is also given to the recent applications of these created super hydrophobic coatings for treatments, including anti-bio fouling, dicing, and corrosion prevention over the past five years. According to the literature, spraying is the most adaptable and popular technique for creating super hydrophobic coatings for any substrate.

Keywords

Zirconium oxide; surface modification; coating methods; superhydrophobic coatings

Introduction

Superhydrophobic surfaces have progressively come to the public's attention. Superhydrophobic surfaces are super wetting surfaces with a sliding angle (SA) of less than 10° and a water contact angle (WCA) of more than 150°. Since that time, scientists have worked very hard to comprehend the physical makeup of living things and have developed a growing fascination with mimicking the characteristics of natural surfaces that are exceptionally hydrophobic [1]. In addition, more artificial materials are being produced that mimic natural structures. Nature's lead offers a desirable method for creating sophisticated materials. Using a binary structure, we discussed how super hydrophobic combines many features. For instance, a wear-resistant structure paired with a self-cleaning coating can result in valuable material used in various circumstances [2,3]. There are reasonable grounds to think that creating appropriate and flexible materials involves combining binary structures with multiple scales and features. The wettability condition on the surface is represented in Figure 1, and the wettability condition on the surface with angle is shown in Figure 2.

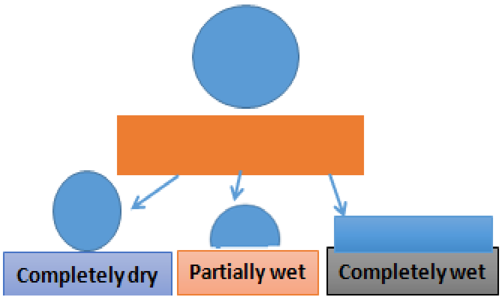

***Figure 1**. Wettability conditions on the surface*

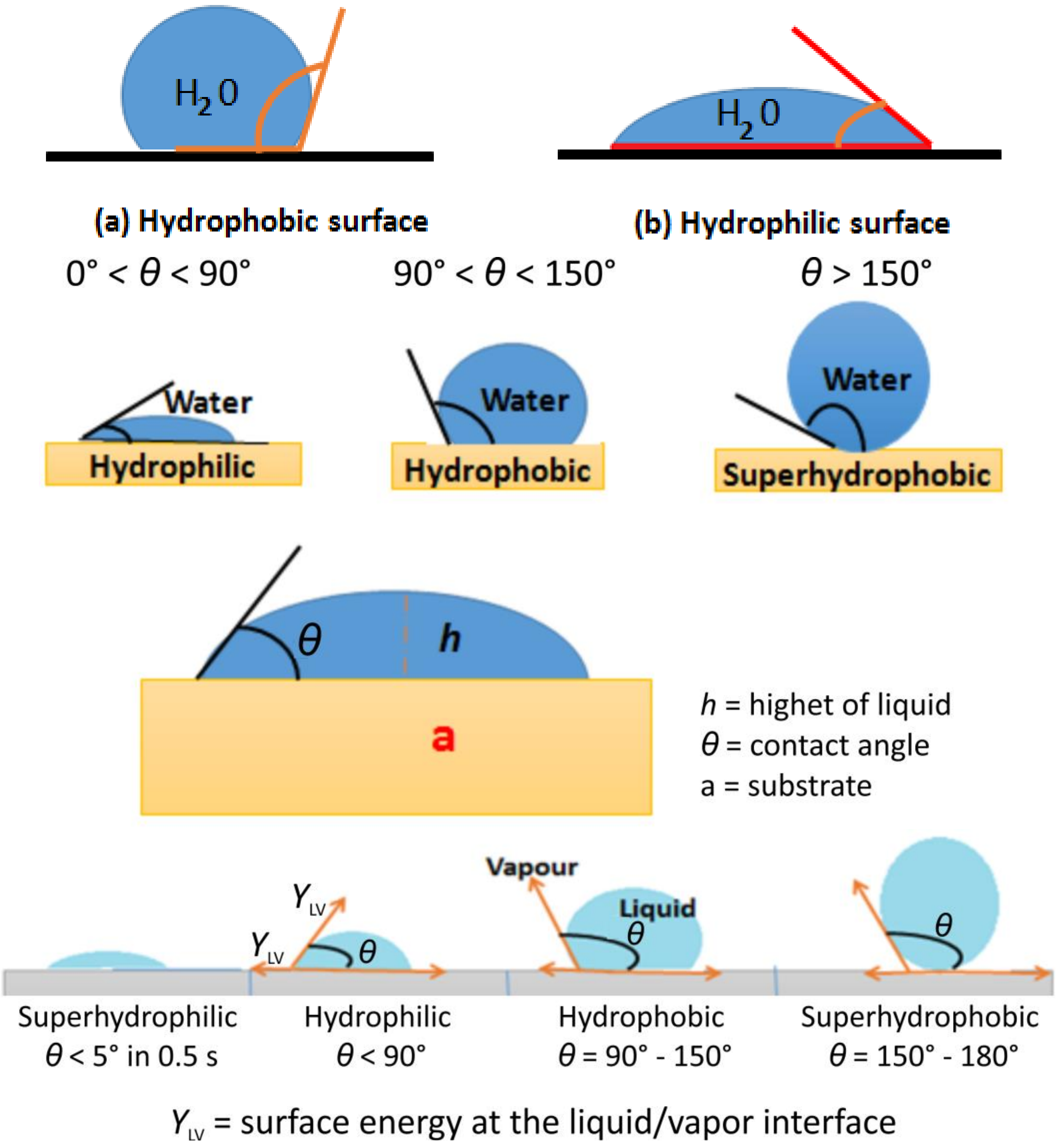

***Figure 2.** Wettability condition on a surface with an angle less than 90°*

The range of angles for the various wetting degrees in water and oil is represented in Table 1.

Table 1. *The range of angles for the various wetting degrees in water and oil.*

The contact angle	Wettability
$0° < \theta < 90°$	Hydrophilic
$90° < \theta < 180°$	Hydrophobic
θ is less 10°	Superhydrophilic
θ is greater than 150°	Superhydrophobic

A coating is a product used to alter the colour, gloss, damage resistance, or surface of other materials, such as antibiotics, or change permeability without altering the product's volume. For specific purposes, mechanical structures and parts are created. Several strict criteria for material selection must be satisfied before making these pieces. Physical qualities, mechanical properties (such as stress, compression, yield, torsion, fatigue, bending, and penetration), performance demands (such as wear resistance, hydrophobicity, and frictional strength), and thermal stability (such as thermal expansion) are all impacted by these restrictions. After the coating of ZrO_2, the various properties of substrates, such as electrical conductivity, corrosion resistance, dynamic stress (such as vibration and high-speed spinning), and conduction heat flow, are improved. Further consideration must be given to material availability, price, safety, and toxicity. For instance, it is well known that silver has excellent electrical conductivity values, but producing significant amounts of silver for such uses is prohibitively expensive [3]. Copper has high heat and electrical conductivities, making it a good material for brazing complex materials, but it also has low stiffness and wear resistance. NiTi alloys are recognized for their superelasticity (SE) and shape memory effect (SME), which can be utilized to develop innovative actuators.

In the case of rotating copper fins, the reliance on mechanical components is significantly decreased because of copper's resistance to wear mechanisms. Various methods have been used to solve these issues and enhance qualities, such as coating, alloying procedures, and heat treatment. In the literature, coating technology has the best percentage for this process since it can save costs and disregard flaws, rarely thicker than a micron. As a result, only a few materials must be created on various substrates. Several advantages may result from the method's ability to harden, change roughness, and enhance wettability and hydrophobicity [4]. There are numerous layers due to various uses and needs in multiple sectors. However, depending on the performance needed, coating technology is effective in several applications, notably corrosion prevention and wear protection [5]. Degradation of equipment material occurs when corrosion is developed in ways that make the environment more hostile to corrosion or negatively affect specific applications [6]. The benefits and drawbacks of the various deposition techniques for layered data will be demonstrated by examining these techniques. There are numerous techniques, but just a handful are significant and efficient. These techniques include micro-arc oxidation, chemical vapour deposition, PVD, thermal spray, sol-gel and the polymer layer.

Mechanical stability, corrosion resistance, and biocompatibility are crucial factors for specific coating types, biomedical applications, and careful trade-offs because of their variety of deposits, materials, densities and thicknesses [7]. The most crucial factor in developing a successful procedure is the choice of material, as it is with all forms of protection. Materials that can create a protective layer include metals, ceramics, and polymers. However, choosing the suitable composition for the deposited layer could be challenging because of the different coating techniques and fabric characteristics. BeO, Al, Ti, Hf, Zr, Ni, Co, Pt, MgO, ZrO_2, Al_2O_3, Y_2O_3, and N and PTFE are all used in the examples with attention paid to all the underutilized possibilities to consider the most popular solutions to prevent hydrophilic properties of the substrate [8]. Each feedstock material exhibits resistance to corrosion or wear, yet they all have unique melting points, mechanical characteristics, and chemical compositions. These models restrict the variety of materials that can be utilized in addition to the variety of powders, sticks, paper, and metal shapes they have in some projects. This evaluation does not cover all preservation techniques, including thermal treatment, mechanical treatment, and mechanical/chemical wrapping, and cleaning [9,10]. The review skims through the materials, their surface modification, and the coating method.

Techniques for dependable coating

In several industries, from the automotive and aviation sectors to microscopic biomedical devices embedded within the human body, the coating method protects specific levels or zones of structures subjected to dangerous circumstances [11,12]. Any process in which gaseous components solidify via condensation, reaction, or transformation is called vapour deposition. This technique can modify the substrate's mechanical, electrical, thermal, optical, corrosion, and wear properties. Techniques for vapour deposition can be separated into two categories: Physical vapour deposition passes a stream of impartial or ionized metal particles through the physical vapour deposition (PVD) setup, and the coating is held in place, as represented in Figure 3(a). It is possible to testify about the challenging coating using various PVD forms [13,14]. The most often used techniques are combined magnetron and bend forms, magnetron sputtering (or sputter particle plating), and cathodic bend vapour (plasma or circular segment particle plating).

In the process of chemical vapour deposition, a volatile precursor is introduced into a chamber and allowed to react (usually under vacuum). The precursor gas reacts or breaks down into the desired coating and bonds to the material surface when the chamber is heated to a reaction temperature.

The semiconductor industry extensively creates a robust, effective, high-performance layer on any substrate using high vacuum [15,16]. When mechanical components are placed close to one another, the CVD technique can be utilized to shield them from corrosion and wear, as shown in Figure 3 (b). In this procedure, a mixture of volatile material precursors is exposed to a wafer-shaped substrate, where the reaction results in the deposition of a material layer [17].

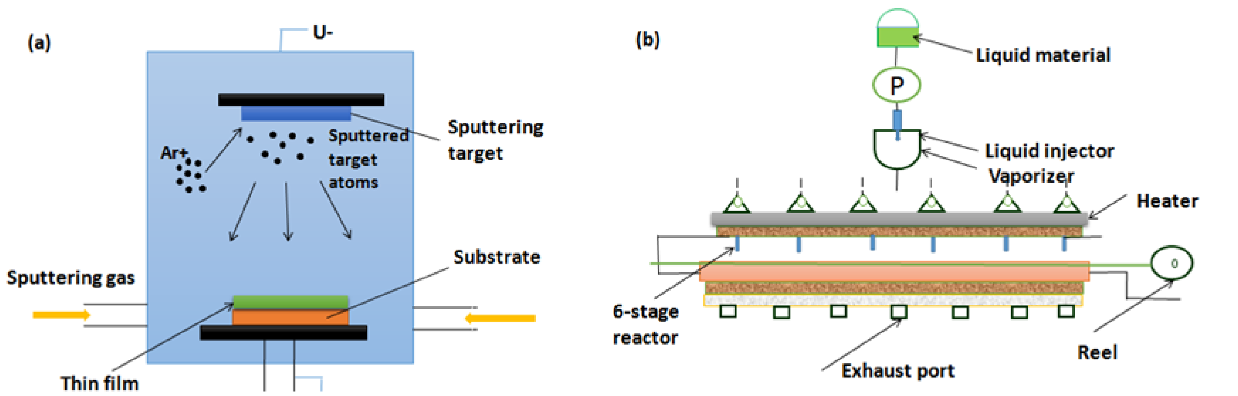

***Figure 3**. A schematic presentation of (a) physical vapour deposition (b) chemical vapour deposition CVD arrangement*

New materials are being developed for electronics, medicine, battery technology, and other vital fields. These materials should also be resistant to corrosion and wear [17,18]. Die-cast zinc and steel components are protected against cathodic corrosion by galvanic zinc coatings. The zinc coating shields the component from corrosive attacks, which degrades first. Targeted post-treatments can significantly slow down corrosive attacks on the zinc surface. Electroless coatings are represented in Figure 4(a). One of the methods for biomedical equipment is a sol-gel coating, shown in Figure 4(b). By conducting an in-depth study on its methods and uses, it is possible to facilitate the design and execution of experiments while maintaining confidence in the results [19-21]. Sol-gels, on the other hand, can enhance ion release and corrosion in current systems. Due to their liquid permeability, sol-gels can quickly and readily cover porous and damaged layers. Sol is made by dissolving a precursor to calcium phosphate (CaP) in distilled water or ethanol [22].

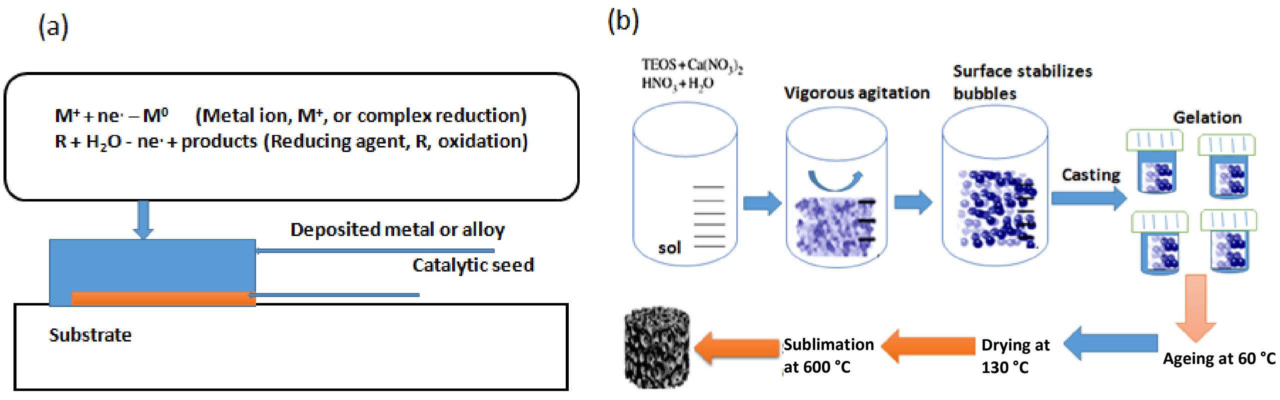

Figure 4. *(a) Electro-less coatings, (b) schematic diagram of sol-gel coating*

The term "warm sputtering" refers to processes that use heat to supply plasma, power, or chemicals to liquefy various electronic materials and spray the resulting liquid fabric over the edges of surfaces to provide a barrier covering [23]. These coatings offer reliable resistance to corrosion and wear. In this procedure, the materials are heated to a liquid or semi-finished condition by the warm medium; it is frequently produced by plasma release or chemical combustion and is subsequently sprayed with a tall, broad exposure on the substrate. The thicknesses obtained by heated sputtering preparation might vary from 20 µm to a few ml compared to galvanic coating, chemical vapour deposition (CVD), or PVD preparation. The most common varieties include plasma, blast, hot/cold, high-velocity air fuel (HVAF), high-velocity oxygen fuel (HVOF) and wire spraying [24,25]. The flow diagram of various thermal spraying processes is in Figure 5.

Table 2 shows various coating methods and their advantages and disadvantages, and Table 3 shows certain uses for nanoparticles in coatings and their purposes.

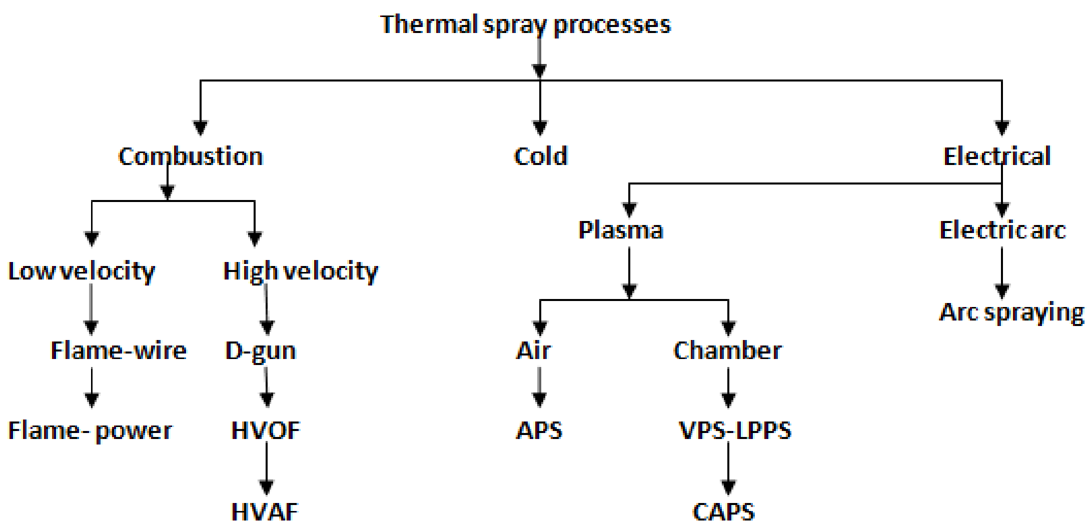

Figure 5. *Flow diagram of thermal spraying process*

***Table 2**. Various coating methods and their advantages and disadvantages with references.*

Deposition process	Advantages	Disadvantages	Ref.
PVD	Mechanical, erosion and tastefully satisfying highlights are possible/ /adjustable lean film testimony, erosion resistance	High speed is necessary for polymer deposition, wear impacts corrosion protection, and control deterioration is challenging	[26-29]
MAO	Improved High hardness, resistance to corrosion, biological applications-friendly porous structure, and a variety of porosity scales across the thickness	Mostly applicable to valve metals	[30-32]
Cold spray	This method is less complicated and more reasonably priced when considering alternative thermal spray techniques	Limited operating temperature range; mainly used for soft and hard metal surfaces; ineffective in extremely cold temperatures; low efficiency and durability due to low temperatures demanding situations	[33-36]
Warm spray	Suitable for heat-sensitive materials or materials that are susceptible to oxidation at high temperatures	Settings that are severe and have impurity issues	[37-39]
ELD	Less wear, low-corrosion, use in high-temperature and decorative applications	It is applicable to conductive substrates	[40-43]
Sol-gel	Thick and multilayered coatings, strong adhesion in biomedical applications for corrosion and ion release avoidance	Coating thickness control, a slow cycle time, and the potential for coating failure on multilayered coating systems during heat treatment	[44,45]
Arc wire spray	Coatings provide resistance to wear and corrosion on the internal engine surface	Only conductive materials and wires can be used as the coating layer	[46]
CVD	Operation at low and ambient pressure, deposition of multiple materials with varied microstates, and protection against corrosion and wear	There should be a lot of electricity, heat-resistant equipment and minimal waste of coating	[47]
HVOC	Compatibility with non-conductive surfaces, excellent substrate adhesion, high coating layer density, as well as resistance to wear and corrosion	Needs a heat source, a wide range of powder sizes (5 to 60 μm), numerous process variables, and a restricted size distribution	[48]

***Table 3.** Certain uses for nanoparticles in coatings and their purposes*

Illustrations of nanomaterials	Merits/effect	Application in industry	Function	Ref.
Zinc or aluminium can be coated using nano-TiO_2 and nano-clay(Hydrotalcite $Mg_4Al_2(OH)12CO_3{\times}H_2O$).	Wood fading (caused by the bleeding of complex compounds like tannins) is slowed down by nanoclay coatings.	Construction wood fire protection, glass, plastic	Wood preservation and corrosion prevention	[49]
Zinc oxide polystyrene (ZnO/PS)	Wood fadingis slowed down by nanoclay coatings.	Automobile, preser-vation of wood, and construction	Wood presser-vation and cor-rosion prevention	[50]
Oxides on mica flakes or SiO_2 spheres, carbon black, with metal pigments (TiO_2, Fe_2O_3, Fe_3O_4, SiO_2, and Cr_2O_3) ZnO.	The effects of metal pigments will be enhanced, the pigments and fillers will be stabilized, and dispersion paints will perform better. Phyllosilicates and sheet silicates prevent crack formation and improve fade resistance	Construction, consumer products (furniture), and the automotive industry	Repeatable paints, easily dispersible paints, colour effects (flip-flop effect), and colour brilliance and shade	[51]
SiO_2	A layer of heat-insulating carbon foam and then a coating of flame-resistant ceramic is produced on the surface of the wood when a specific temperature is reached.	Construction protection wood against fire	Fire retardant	[52]

Illustrations of nanomaterials	Merits/effect	Application in industry	Function	Ref.
Specifically, polymer gel and organic-inorganic hybrid polymers	Self-healing materials	Automotive	Switchable (electrochromic, photochromic, thermochromic)	[53]
Organically modified ceramics (organic-inorganic hybrid polymers) are created when nanosilica or colloidal silica is encased in resin particles and polymerizes.	Protection from algae and fungi, resistance to water and dirt, and anti-graffiti protection.	Automobiles, facade construction, and glass	Self-cleaning or readily cleaned	[54,55]
Transparent iron oxide, needle-shaped particles with a length of 50-100 nm and a width of 2 nm; TiO_2, ZnO, CeO_2, iron oxide pigments	Enhanced UV protection, IR and visible light blocking, and climate control inside	Building (facades), preservation of wood, glass and plastics	UV defence, IR reflection, or IR absorption	[56]
Synthetic amorphous silica Oxide	Create fresh rheological qualities, such as elasticity and thixotropy.	Various	Optimized flow characteristics	[57]
Transparent iron oxide, needle-shaped particles with a length of 50-100 nm and a width of 2 nm; TiO_2, ZnO, CeO_2, iron oxide pigments	Enhanced UV protection, IR and visible light blocking, and climate control inside	Building (facades), preservation of wood, glass and plastics	UV defence, IR reflection, or IR absorption	[58]
Fullerenes, carbon nanotubes (CNT), etc.	Improved spraying techniques	Automotive	Conductive paint coats for electrostatic spray painting	[58]
ZnO_6, TiO_2, and Ag	Grease, filth, bacteria, fungi, algae, odours, and other pollutants are eliminated, and NOx and ozone are converted into harmless chemicals in the atmosphere.	Road surface, vehicles, wood privation glass	Photocatalytic effect, antimicrobial effect	[59]

Deposition of zirconium oxide films

Thin film deposition processes fall into two categories: chemical and physical. Atoms from chemical precursors are deposited on the substrate through the liquid and gaseous phases in the chemical deposition process. Still, the physical deposition process transfers atoms directly onto the substrate using a solid source and a gaseous phase.

High-tech tools and equipment are needed for physical approaches. Chemical approaches provide ease of functioning and excellent product quality. The ZrO_2 layers have become very popular due to the films made using diverse methodologies that demonstrate varied physical and chemical features related to electricity [60]. The sol-gel method has long been the most widely used traditional method for synthesising zirconium oxide. Hydrated zirconium oxide's macro dispersed powder product is not preferred for large-scale industrial sorptive and catalytic operations. A translucent solid gel of zirconium oxide material offers several practical applications if created using sol-gel synthesis. Only a few studies have been published on the electrolysis of zirconium chloride salts, the preparation of zirconium oxide gels using zirconium alkoxides, hazardous ammonium-generating reagents [60], and mineral zirconium salts. Sol-gel formation is seen schematically in Figure 6.

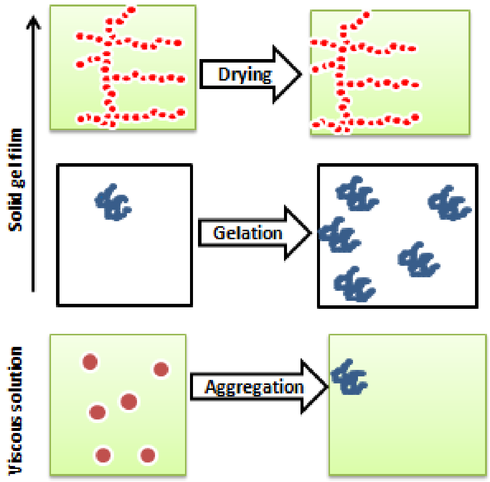

***Figure 6**. Sol-gel formations*

The electrochemical process used to grow ZrO_2 films produced during the anodization of zirconium was examined. Zirconium anodic oxidation was reported. For the oxidation process, a KOH and K_2SiO_3 solution were employed. Three different voltages were used for the anodization process: 100, 200, and 400 V. The investigation demonstrated that between 100 and 200 V, the surface shape of zirconium did not change during oxidation. Significant surface morphological alteration and silicon incorporation into the generated oxide layer were reported at 400 V. In the presence of Ringer's physiological solution, anodic oxidation of zirconium resulted in a notable improvement in corrosion resistance [61].

Sputtering is the method most frequently employed for ZrO_2 thin film deposition. Sputtering can be done in two ways: directly utilizing ZrO_2 as a source material or directly using the Zr target (see Fig. 7(a)). Zr thin films were created on silicon nitride substrates using an ultrahigh vacuum and a Zr metal target [62]. Moreover, ZrO_2 films were produced at ambient temperature using plasma oxidation. ZrO_2 thin films with a thickness range of 2.5 to 8 nm were formed on Si (001) substrate through reactive sputtering. M-ZrO_2 thin films were created using reactive DC magnetron sputtering from a Zr metal target at an ambient temperature of 400 °C with 100 to 400 W power. ZrO_2 as a target and reactive radiofrequency (RF) magnetron sputtering to build ZrO_2 films at 200 to 300 °C.

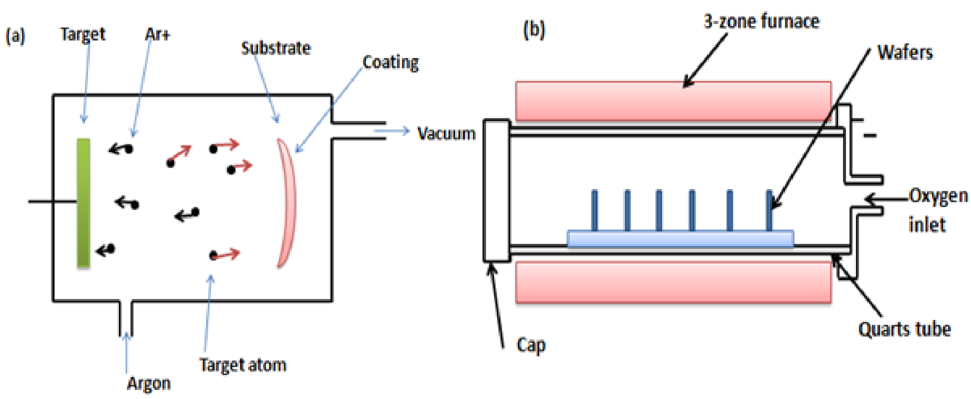

***Figure 7**. Schematic diagram of (a) sputtering method and (b) thermal oxidation method*

Synchrotron X-ray diffraction is used to study the amorphous-to-cubic (a-c) crystallization of nano ZrO_2. The alterations in lattice parameters and crystallite size as the cubic phase was detected were examined using Rietveld analysis. Utilizing a reverse Monte Carlo (RMC) simulation, the specifics of the local structure during the crystallization process and the partial pair distribution functions (PDFs) of Zr-Zr and Zr-O during the crystallization were computed. The investigation demonstrated that the amorphous phase crystallizes into tetragonal and monoclinic ZrO_2 during oxidation. Figure 7(b) displays the thermal oxidation schematic diagram [62].

One of the more advanced deposition methods is atom layer deposition (ALD). ALD provides high thickness uniformity over a wide substrate area and accurate thickness control. In ALD, surface saturation reactions govern film growth, while the quantity of deposition cycles governs film thickness. Figure 8 shows the schematic of the ALD technique. A partial monolayer of the material is deposited on the substrate with each surface reaction cycle. Synthesized crystallinity-controlled zirconium oxide coatings on nitrogen-doped carbon nanotubes by ALD using tetrakis(dimethyl-amido) zirconium(IV) and water as a precursor. Scanning and transmission electron microscopy (TEM) revealed that the 100-cycle ZrO_2 tubular films were uniformly produced on NCNTs. The TEM, Raman spectroscopy, and X-ray diffraction showed that the crystallinity of the formed ZrO_2 films could be regulated by adjusting the deposition temperatures within the range of 100 to 250 °C [63].

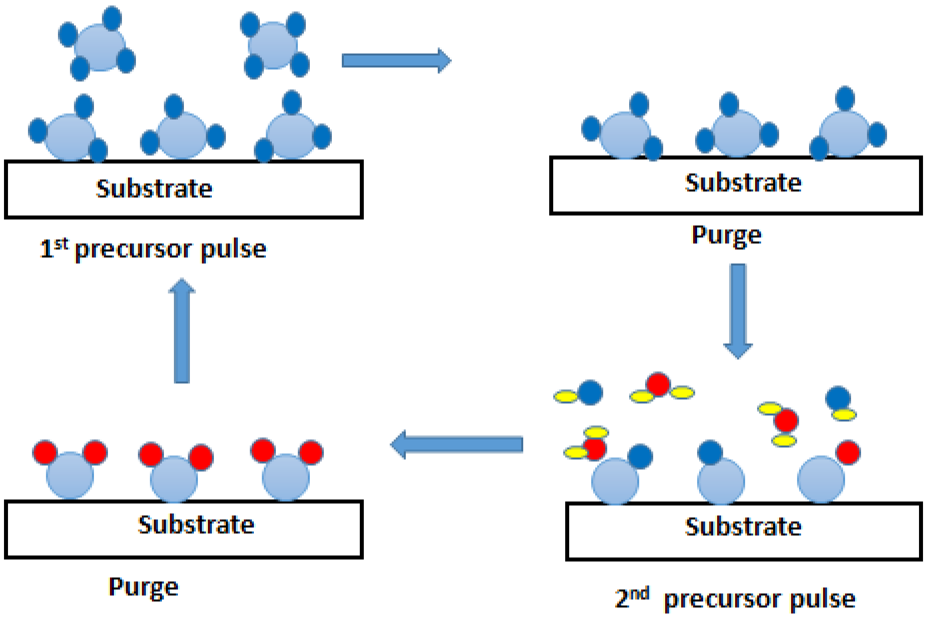

***Figure 8**. Atomic layer depositions*

In the microwave combustion method**,** ZrO_2 nanocrystals were synthesized by several researchers utilising the microwave combustion technique (MCM) using urea as fuel in the absence of surfactant, catalyst, or template. Figure 9 provides a diagrammatic illustration of MCW. ZrO_2 nanocrystals produced by microwave combustion have been used to study the photocatalytic degradation (PCD) of vital endocrine and 4-chlorophenol (4-CP) disrupting chemicals in aqueous medium [63]. The investigation proved that ZrO_2 exhibited photocatalytic activity, and ZrO_2-TiO_2 mixed oxide catalysts were tested for 4-CP PCD. To create zirconium oxide, the anticipated combustion reaction is shown in Equation (1).

$$ZrO(NO_3)_2{\times}2H_2O + CO(NH_2)_2(s) + O_2(g) \rightarrow ZrO_2(g)+4\ H_2O(g) + CO_2(g) + O_2(g) + 2\ NH_2(g) \qquad (1)$$

Chemical techniques such as meniscus, spray, spin, dip, pulsed laser, and electrochemical deposition are employed to create mesoporous metal oxides. Mesoporous films with pore sizes ranging from 2 to 50 nm are helpful for catalysis and sorption. Promising uses for mesoporous thin films include photonic materials, selective permeation, sensors, sorption membranes, and photonic materials. Numerous studies have been published on developing novel synthesis techniques and characterizing mesoporous thin films with different pore sizes and chemical compositions.

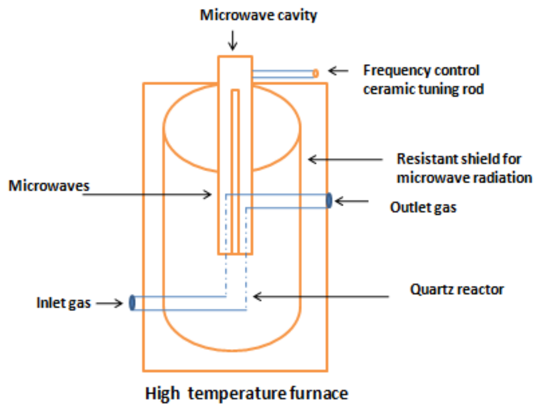

***Figure 9**. Setup of microwave combustion method*

Compared to SiO_2-derived films, zirconia is an exceptional material as determined by its physical and chemical characteristics. Because zirconia can tolerate extreme oxidising and alkaline conditions, it can be utilised to alter the surface characteristics of materials. Its refractive index, thermal resistance, and thermal expansion coefficient are all relatively high. These properties make it suitable for metal coating [63].

Required properties of ZrO_2 and their effect on different substrates

Properties of ZrO_2

With its high melting point (2680 °C), broad oxidation resistance, high refractive index, and wide region of low absorption from the near-UV (above 240 nm) to the mid-IR (below 8 mm) range, zirconium oxide (ZrO_2) is a significant material for innovation [64]. Numerous applications, including laser mirrors, broadband interference filters, and ionic conductors, find this combination of features attractive. For usage in optical and microelectronic devices, an amorphous ZrO_2 film is always favoured over a polycrystalline one, even though ZrO_2 thin films frequently condense in a partly crystalline condition. Scattering from these crystallites and grain boundaries in ZrO_2 films can lead to the degradation of optical components when subjected to high temperatures or laser intensities. Moreover, non-uniformities in the film's *k* values and film thickness will arise from distinct anisotropic crystalline phases, and grain boundaries may negatively impact the leakage current properties of crystalline ZrO_2 thin films. Table 4 discusses the different materials and their contact angle below.

***Table 4.** The angle of contact of different surfaces*

Materials name	Contact angle, °	Materials name	Contact angle, °
Hepta decafluorode cyltrim ethoxy silane	115	Diamond	87
(Heptafluoroisopropoxy) propyltrichlorosilane	109-111	Graphite	86
Poly(tetrafluoroethylene)	108-111	Talc	50-55
Poly(propylene)	108	Steel	70-75
Octadecyldimethylchlorosilane	110	Gold, typical (see gold, clean)	66
Poly(ethylene)	88-103	Kaolin	42-46
Poly(styrene)	94	Platinum	40
Poly(chlorotrifluoroethylene)	90	Silicon nitride	28-30
Human skin	75-90	Gold, clean	<10

Different properties and contents of the test materials of ZrO_2

This work assesses the water sorption/solubility, hardness, elastic modulus, and transverse strength of zirconium oxide nanoparticles (nano-ZrO_2) added to heat-cured poly methyl meth-acrylate (PMMA). Based on the amount of nano Added to heat-cured PMMA, the specimens were split into four groups: group 1 received 5% nano-ZrO_2, group 2 received 10 % nano-ZrO_2, group 3 received 20 % nano-ZrO_2, and Group 4 received controls [64]. Table 5 shows the results of the specimens with different quantities of ZrO_2 added in PMMC.

Table 5. *Results of the tested specimens*

Sample	Transverse strength, MPa	Modulus of elasticity	Microhardness values, g
ZrO_2(5 %) + PMMC	0.739	0.481	0.529
ZrO_2(10 %) + PMMC	0.579	0.684	0.029
ZrO_2(20 %) + PMMC	0.853	0.353	0.009
ZrO_2(RC) + PMMC	0.579	0.529	0.353

The magnetron sputtering method will be used in this work to deposit zirconium oxide films at argon partial pressures of 45, 55, 62 and 67 %. This work explores the impact of argon partial pressure on the optical, wettability, and structural characteristics of zirconium oxide coatings [65,66]. Table 6 shows the variation of pressure with different film parameters.

Table 6. ZrO_2 thin film parameters (properties) calculated on the basis of variation in pressure

Change in pressure, %	Band gap, eV	Index of refraction	Thickness, nm	Surface roughness, nm
45	4.28	1.53	433	1.75
55	4.34	1.53	408	1.42
62	4.44	1.52	391	1.24
67	4.46	1.52	385	1.07

Properties of ZrO_2 using the low-temperature atomic layer deposition

This study characterized ZrO_2 films made using the atomic layer deposition technique as the encapsulating layer for organic electronics devices. The impacts of oxidants such as water (H_2O) and ozone (O_3), as well as tetrakis(dimethylamido) zirconium(IV) growth temperature, were investigated. The X-ray diffraction study shows that the 80 nm-thick films formed at 80 °C had a significantly lower amorphous nature than those grown at 140 and 200 °C. SEM analysis showed that the films' crystallinity significantly impacts the surface morphology [67]. The water vapour transmission rate of the 80 nm thick ZrO_2 films may be reduced from 3.74103 to 6.09104 g m^{-2} day^{-1} (using 80° H_2O as the oxidant) in a controlled environment with 20 °C and 60 % relative humidity. Moreover, the brightness decay time of the organic light-emitting diodes combined with ZrO_2 films produced from O_3 at 80 °C was dramatically changed without causing harm. This was ascribed to the enhanced barrier property of the lower-temperature ZrO_2 layer to the almost homogeneous microscopic surface and amorphous microscopic bulk. The average height of crystallites in H_2O and O_3-based ZrO_2 films deposited at various temperatures is shown in Table 7 [68].

Table 7. Low-temperature ZrO_2 film deposition range

Temperature of deposition, °C	Height of H_2O based ZrO_2 film, nm	Height of O_3-based ZrO_2 film based on O_3, nm
80	8.4±0.13	3.8±0.1
140	14.7±0.2	10.7±0.1
200	21.2±0.2	15.2±0.2

Conclusion and future scope

First of all, numerous methodological angles are presented in this review. This article aims to promote an understanding of the usage of several types of coatings techniques of zirconium oxide, wear-reduction procedures, advantages, disadvantages, and properties of zirconium oxide used for different substrates and quantities. If the coatings process and techniques are increased, the membrane's sealing will also be improved, and it will have less porosity and better corrosion resistance. Aerospace, ground turbines, car production, ceramics and glass, printing, pulp and paper, metallurgy, medical, nuclear power, cement plant spray, and waste treatment are just a few industries that frequently use anti-corrosion coatings. Chemical/physical vapour deposition (CVD/PVD), micro-arc oxidation (MAO), electrode position (for example, galvanic coating), electrophoretic deposition (EPD), sol-gel, and various thermal sputtering procedures (for example, HVOF, plasma, cold, thermal, and arc sputtering) are the most effective thermal sputtering techniques. Since the teaching process employs various strategies to position certain items on the website, selecting the appropriate materials is crucial to achieving a good process. Heat can be used in some procedures to transform food into liquids and semi-solids as clumps, droplets, and particles.

In conclusion, thermal operations such as various types of thermal spraying are made more efficient by using high-temperature and high-speed plasma jets. This method enables the processing of the raw material at low temperatures and fast speeds while removing the detrimental impacts of the high melting points of ceramics and superalloys. In these situations, layers that might be hundreds of microns thick are created. Depending on the process, the layered microstructure may contain oxide and carbide inclusions and porosity. The only applications for deposition coatings based on evaporation technology are the coating of equipment and the protection of sliding mechanical parts. These thin films have good corrosion/wear resistance. Biomaterials for use in bone implants and medical equipment usually use micro-arc oxidation, a high conversion of randomization. The metals Al, Ti, Zr, Hf, V, and Nb are frequently used as substrates for valves. Strong substrate/layer adhesion and porosity are provided by the coating created by MAO during bone development, which is crucial for biomaterial coatings. According to the pace or duration of plant degradation, The porous microstructure also improves corrosion resistance and makes it easier to estimate plant longevity using engineering models. Another tested substance, sol-gel, has numerous nutritional advantages, and since an aqueous solution serves as the process' carrier, the process' quality is unaffected by the geometry's intricacy. Sol-gel deposits are utilized as a sealant to strengthen the corrosion resistance of porous substrates and coatings. Despite the versatility and layering capabilities of the sol-gel technique, the fabrication could be faster and more efficient. Another type of water purification technology uses electrochemical processes that rely on the charge difference between the chemical cell's anode and cathode.

Superhydrophobic coatings offer much potential for industrial applications; therefore, they're getting much attention. Because of its special characteristics, which include self-cleaning, antifogging, drag reduction, corrosion resistance, anti-icing, and ice-phobic capabilities, it is anticipated that their fields of application will grow in the future. This study thoroughly examines super hydrophobic coatings in the application domains of vehicles, marine, aircraft, solar energy, and architecture buildings based on the requirement for significant functionalities and performance conformities. The thickness of zirconium oxide sheets reduces from 433 to 385 nm with increasing argon partial pressure. The band gap rises from 4.28 to 4.46 eV as the thickness of the zirconium oxide sheet decreases, yet the gearbox increases. The coats of zirconium oxide dissipate water with a 45% partial argon pressure and a maximum contact angle of 101°. The maximum aniline contact angle for zirconium oxide sheets is 52° at a partial pressure of 67 % argon. The paper overviews the various operating materials and the importance of zirconium oxide in hydrophobic coating for ultra hydrophobic applications.

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