Advantages of Spin Coating Over Other Coating Techniques in the Formation of Superhydrophobic Surfaces

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Abstract: In this contemporary world, coating plays a vital role to improve the mechanical property of the material, complete chemistry and structure of the material need not be altered instead surface modification is more than enough to reduce the degradation of material through corrosion accumulation of the dust on the surface and the contact angle between the water and the surface is the major focus. the current article, current work gives the collective result of different types of coating like dip coating, sol-gel, spray coating, spin coating, plasma coating, chemical vapor deposition, and lithography in comparing all the methods of coating with spin coating it can convert the surface into a superhydrophobic surface with more contact angle of 165° with the coating microns of 10 to 30 micron, and dip-coating having a contact angle 160° with coating 3 microns, the sol-gel coating having contact angle 115°-165° with coating 20 microns, spray coating having contact angle 164° with coating 7 microns, plasma coating having contact angle 144° with coating 25 microns, chemical vapor deposition having contact angle 159.3°with 20 microns, lithography coating has a contact angle of 160° with coating 33 microns, whereas other coating techniques like dip, spray, plasma coating, chemical vapor deposition, and lithography have constraints with contact angle respectively.

Keywords: Coating, Glass, Solar panel, Superhydrophobic

I. INTRODUCTION

Superhydrophobic coatings have undergone various developments in recent years because of their excellent multipurpose qualities [1]. Natural superhydrophobic surfaces have gained a lot of attention because of the lotus leaf's inherent ability to self-clean. This effect is known as the "Lotus Effect" [2]. The micro- and nano-hierarchical surface structure of leaves and the material's low surface energy that deflects water droplets inspired the lotus effect [3]. It is generally known that various plant leaves display a range of characteristics, including the capacity to resist water, roll off the surface, and act as an antifouling [4], even when covered with polluted water or dust. An essay on the cleaning capabilities of a lotus leaf was published in 1997 [5].

After studying Super-Hydrophobicity after that [4], Dettre and Johnson conducted the first investigation on the phenomenon of Super-Hydrophobicity in 1964 [6]. Wilhelm Barthlott and Ehler investigated the self-cleaning capabilities of superhydrophobic micro-nanostructured surfaces in 1977, coining the name "lotus effect" to describe these properties [7]. Self-assembly technology is another name for the fundamental component of the self-cleaning (SC) approach, which can clean a surface without the help of an external device [8] and remove dust particles from the surface [7]. There has been a lot of interest in making artificial superhydrophobic surfaces during the last 25 years. Artificial superhydrophobic surfaces provide various benefits that can be measured and distinguished by their amazing capacity to ripple the water droplet. The sliding angle or contact angle of a liquid droplet on a perfectly flat surface, as well as the angle between the liquid-solid and liquid-vapor interfaces, are both components of the contact angle. The chemically homogeneous surface may be predicted [9] by Young's relation [10]. A surface is said to be superhydrophobic if the water contact angles (CA) are more than 150°, the sliding angles are lower than 5°, and the contact angle hysteresis (CAH) is lower than 10° [5] [11] [9].

$$\mathrm{Cos}\ \Theta = (\gamma AC - \gamma AR)/\ \gamma RC$$

Where the notation denotes C=gas, R=liquid, and A=solid, the c=contact angle (°) and γ=interfacial Surface tension measured in J/m2 are used. As seen in the equation above, Young's relation describes the equilibrium of the three interfacial tensions existing at the bubble point of a solid, liquid, and vaporous liquid droplet on a completely smooth hard surface [11].
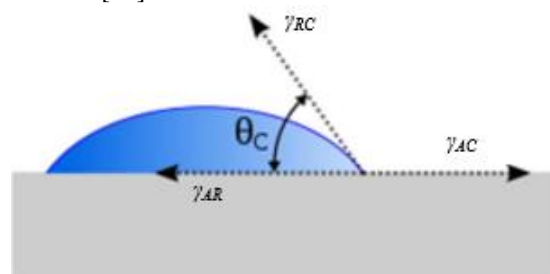

Fig. 1. Young's Model

In contrast, hydrophilic surfaces have a modest contact angle with a water droplet and a large surface free energy. Water droplets have a low surface free energy and a contact angle with hydrophobic surfaces that are more than 90°.

Surfaces that have a water slide angle hysteresis of lesser than 10° and a contact angle (WCA) of more than 150° are said to be superhydrophobic. A hydrophobic material is used to create a rough surface, or a rough surface may be chemically treated with a hydrophobic coating to create synthetic superhydrophobic surfaces [12]. Superhydrophobic surfaces offer a huge potential for "dust-phobicity" and little dust adhesion due to their capacity to clean themselves [13]. The contact angles of a water droplet with hydrophilic, hydrophobic, and superhydrophobic surfaces are shown in Fig. 2 [14].
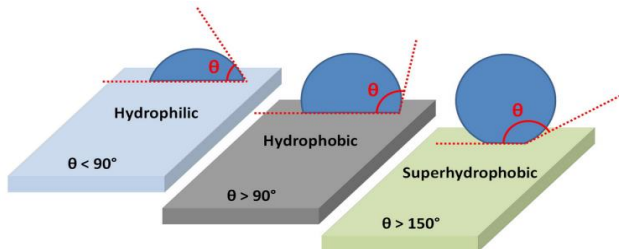

Fig. 2. Schematic diagram of a water droplet over surfaces that are hydrophilic, hydrophobic, and superhydrophobic.

Due to its capacity to self-clean, prevent sticking, and avoid contamination [15], superhydrophobic surfaces are occasionally referred to as self-cleaning surfaces. Solar PV panels and [86] [88] [90] aluminum alloys [80] [81] [87] have employed self-cleaning materials that are super-hydrophobic coatings on the above subtract because of their surface wettability and surface microstructure [16] [8]. Photovoltaic glass has tremendous potential for using water-repellent coating layers on glass substrates [17]. The effectiveness of solar energy systems, such as solar thermal collectors and photovoltaic modules, is compromised as a consequence of a decrease in the amount of sunlight transferred when dust, pollen, dirt, and other air pollutants and particles build up on their surfaces [11]. These efficiency losses in solar panels reduce the amount of electricity generated by PV modules by 35–40%. because the buildup of dust may dramatically lower the output efficiency of solar PV panels [18]. Water washing is a typical method for reducing dust accumulation [16]. By depositing a layer of low-surface energy nanomaterials on the glass surfaces after attaching low-surface energy materials to the surface in one of two ways—directly as a coating or by attaching low-surface energy materials to the surface of nanostructures—it is possible to reduce the surface energy of solid surfaces [13] [19]. Water droplets assume a spherical form and immediately flow off the surface when they come into contact with the tips of a rough structure. The rough structure's points also act as magnets for dust particles, which makes it easy for the spherical waterdrops to collect plenty of them and clean the surface. The water droplets' adhesion to the dust is greater than a solid, rough superhydrophobic surface. This article hypothesizes that the densely deposited dust particles with sizes ranging from submicron to millimeters on the surface that mimics a lotus leaf may ultimately self-clean by rolling water droplets. The self-cleaning capability of the superhydrophobic coatings was validated. Oil Red O powder was added to the coated surface as dust particles, as shown in Fig. 3a. As shown in the description of Fig. 3b below, the water droplets effectively caught the dust particles as they passed through the superhydrophobic surface. [20]
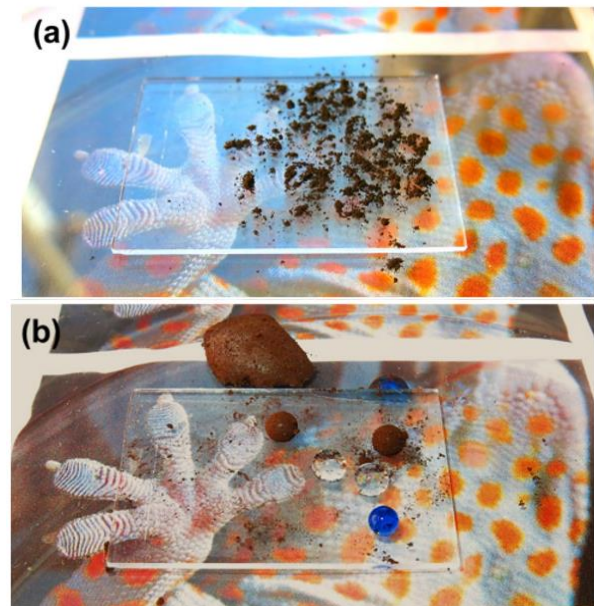

Fig. 3. (a) Spread dust particles (b) Self-cleaned superhydrophobic coating.

II. VARIOUS METHODS OF FABRICATION OF SUPERHYDROPHOBIC COATINGS

Micro- or nano-roughness and complex morphology are two features that are frequently used to identify surfaces that repel water. Another significant feature is repeating multi-scaled roughness, which is best defined as nano projections of micro-level morphology. Therefore, the abovementioned features on pseudo, surfaces may be created using the following manufacturing processes. In the subcategories that follow, some of the most popularly used techniques for creating superhydrophobic surfaces are described in Fig. 4. The techniques used to make the superhydrophobic coatings are covered in this work.
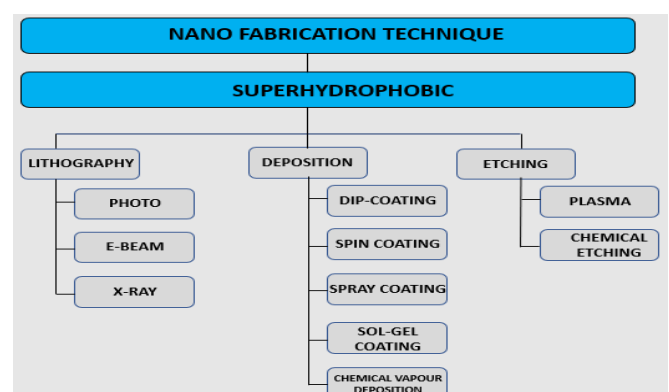

Fig. 4. Superhydrophobic surfaces are created using nanofabrication processes.

The characteristic high surface roughness of superhydrophobic coating processes, which results in substantial light dispersion, reduces the efficiency of solar panels [13].

Artificial superhydrophobic coatings have been produced using a variety of methods, such as sol-gel [21], lithography [22], the templating method, colloidal assembly and aggregation, layer-by-layer assembly, the plasma method, chemical vapor deposition [23], electrospinning, electro-spraying, and dip-coating [5].

A. Dip Coating

A quick and efficient method for creating coatings for superhydrophobic, self-cleaning silica is dip coating [24]. The dip coating technique is often used to create coatings with nanoparticles [22]. Colloidal self-assembly may be the most adaptable method for creating superhydrophobic surfaces since it has access to a wide array of cutting-edge self-cleaning methods and very homogenous colloidal particles in a range of sizes. The production of superhydrophobic surfaces by dip-coating is examined [25] using a nano-porous superhydrophobic coating. The dip-coating technique yields coatings with enormous, complicated shapes, a range of sizes, and a high level of quality. The solution is then applied to the surface using a dip-coating technique, and it is then dried [26]. Dip coating is used to prepare and apply the coating on glass plates. The dip coating method generates a water-contact angle (WCA) of about 170° and keeps it at about 550°C. The benefit of this method is that it works rapidly to provide a coating that can be used on any kind of coated substrate [27]. The goal of the current work is to create a silica-based hydrophobic surface with high adherence utilizing a single step of a conventional dip coating procedure without fluorination or any other kind of chemical treatment to lower the surface energy of the coating [22]. This strategy is highly useful for industrial applications since it allows you to reuse the solution up until the solute is consumed or evaporation occurs. The single- and dual-sized silica nanoparticles were dissolved in ethanol, silica sol, and acidic silica sol using the seed-growing method. Dual-sized particle coatings in ethanol with a 155° water contact angle demonstrated superhydrophobicity. A glass substrate was coated with silica-based superhydrophobic coatings using the dip-coating technique [28].

Preparation of superhydrophobic silica coating:

Because of its exceptional inherent qualities, including non-toxicity, outstanding thermal, environmentally friendly coating [82] and mechanical stability, and simplicity of structural control, silica was chosen as one of the covering materials. As a result, it has generated a lot of attention and is often employed in the field of coating technology, particularly for the production of superhydrophobic silica coatings. A hydrophobic surface with a water contact angle of larger than 170° was created when a silicon wafer was submerged in a toluene solution of methyl trichlorosilane (MTCS). The technique described here is efficient and fairly priced for coating glass substrates with self-cleaning superhydrophobic surfaces. Methyl-trichlorosilane (MTCS) is phase separated on glass and silica surfaces to yield three-dimensional graphene in a variety of shapes, sizes, and forms. In this work, four methyl groups were quickly added to silica particles using methyl-trichlorosilane (MTCS), and these modified particles were subsequently coated onto a glass substrate material using only a conventional dip-coating procedure. At room temperature (about 27°C), the coatings were created using the standard dip-coating technique. Figure

5 shows a flowchart that illustrates the dip coating process. A spotless piece of glass received the solution, which was then applied, removed after five seconds, and allowed to air dry for five minutes. The identical specimen produced a uniform, rough-textured silica coating when the same coating method was applied twice more under predefined conditions. To improve the coating material's adherence to the substrate, all of the produced coatings were initially left at room temperature for an hour. The remaining solvent was subsequently removed from the materials by annealing them for five hours at 150°C with a ramping rate of 2°C/min in the air. The silica coatings made after one, two, and three dips were then thoroughly described using the right techniques [24].
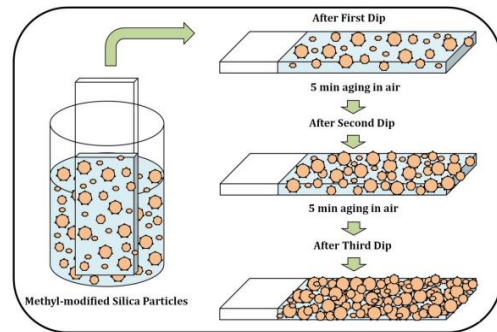

Fig. 5. Diagram demonstrating a simple dip-coating procedure for depositing silica particles with methyl modifications on a glass substrate.

Self-assembled superhydrophobic composite coatings are prepared using f-sio2.

Fluorinated nano-SiO2 (F-SiO2) nanoparticles are dissolved using the proper butyl acetate concentrations. After being exposed to the cell disruptor, the liquid was blended for two minutes with a polymer resin binder. Next, the first dip-coating solution is bought. The pertinent dip-lifting parameters, such as the drop speed, pulling speed, residence time in the air, and immersion duration, are determined when the dip-coating liquid and component are appropriately positioned on the soak-lifting machine. The samples are put in an oven set at 80°C for three hours after the soak-lifting procedure is complete in order to create self-assembling super-hydrophobic coatings. The drawing and dipping processes for the self-assembled superhydrophobic composite coating are shown schematically in Fig. 6 [25].
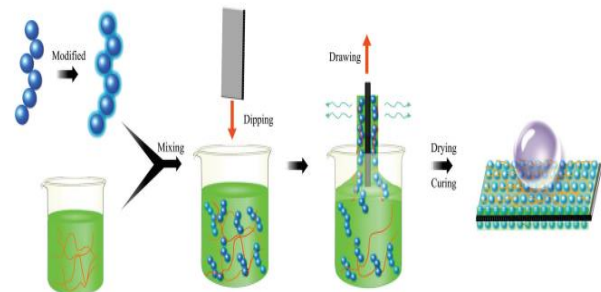

Fig. 6. The process of superhydrophobic composite coating's dipping is shown in the above diagram.

B. SOL-GEL

The sol-gel technology combined with the dip-, spray-, or spin coating technique was one of the most widely used approaches for mixing micro/nano inorganic particles to generate surface roughness [29]. Over prior techniques, the sol-gel methodology offered a number of significant benefits. It is a low-cost method that is effective on substrates with broad surfaces and complex geometries [15]. However, very hydrophobic surfaces have been created using the sol-gel technique. Sol-gel synthesis methods have not created materials with a wide range of physicochemical characteristics for a very long period. Superhydrophobic silica sheets may be produced easily using the time-tested Sol-gel method [19]. We have shown the creation of transparent, superhydrophobic surface coatings on glass solar panel plates using a combination of chemical and microstructural approaches. The film's water contact angle was 165 degrees [30]. To make rough surfaces on different oxides, a better, more inexpensive, low-thermal-energy, and low-pressure sol-gel approach has been developed [3]. It is often essential to first generate surfaces with hierarchical roughness before afterward adding certain chemicals with low surface energy in order to produce superhydrophobic surfaces [31]. There are several ways in which the sol-gel-dip-coating (SGDC) Unique non-line-of-sight deposition technique capability can coat complex components and deposition is preferable to conventional deposition techniques [85]. Several attempts have led to the development of very hydrophobic glass. A high-transparency superhydrophobic glass coating was created by utilizing hexane solution modification with trimethylchlorosilane (TMCS) and SiO2 deposition [86] by SGDC. The very transparent superhydrophobic glass was created by mixing fluorinated tin oxide (FTO) with TMCS sheets. Tin oxide is dense and has a wide band gap. Fluorine, antimony, cadmium, and molybdenum were added to tin oxide to improve its electrical and optical characteristics. Solar cells often use a liner constructed of FTO film. Sol-gel technology was used to create FTO film, and its electrical and optical characteristics were assessed [8]. The resulting silica-based coatings have water contact angles of around 165° for both advancing and retreating, which prevents water droplets from rolling on them because of the significant CA hysteresis. Even though the achieved WCA was only approximately 123°, a modified sol-gel coating with silica filler produced uneven surfaces with a lotus-like structure. When the water droplets' Water Contact Angle (WCA) hit 150°, they began to roll away at a 3°–5° sliding angle [15]. Sol-gel synthesis has made it possible to cover glass surfaces with a strong, very hydrophobic, and transparent substance. Glass substrates were coated with a solid, very hydrophobic, transparent SiO2-based coating using the sol-gel technique at low temperatures. The ability of the superhydrophobic properties to endure impact damage was assessed both before and after an ultrasonication test and an impact from a water drop. Using the sol-gel technique, a silica-based coating with nanoscale roughness was applied to the glass substrate [32]. TiO2 sol was created using the conventional peroxo sol-gel procedure [31] [33]. As shown graphically in Fig. 7, a superhydrophobic coating might be produced on a glass substrate. In this case, sub-rough structures were created by piling hydrophilic TiO2 glass sheets on top of chemically modified octadecyl trichlorosilane (OTS). It has been shown that the hydroxyl groups on the Si-OH group of the produced glass slide and the Ti-OH coating on the TiO2 substrate combine to form the cross-linked chains of Ti-O-Si. As a consequence, on the glass surface, TiO2 coatings with excellent surface roughness were produced. To lower surface energy, the OTS monolayer was grafted onto the roughened surface of the TiO2-coated glass. The head of OTS (-SiCl3) must first be physisorption before it can interact with the layer of adsorbed water that covers the surface of the TiO2-coated glass and produce a silanol group (-Si (OH)3). OTS molecules are stably grafted onto the TiO2-coated glass surface via the "Si-O-Ti" strong chemical link, which is formed when the hydrolyzed head of OTS (-Si (OH)3) condenses with OH-groups on the surface of TiO2 films [34] [35].
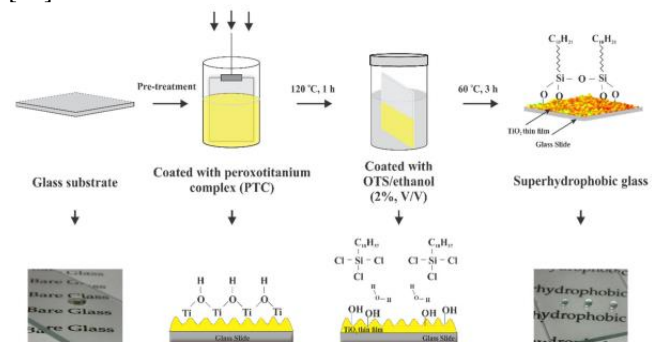

Fig. 7. The process of superhydrophobic surface creation.

When a condensation process takes place between nearby OTS molecules, the high alkyl chain groups (-C18H37) of the OTS tail are positioned. This process ultimately lowers the surface energy of the resultant coated glass [31], [36]. The coated glass created using this manufacturing process has superhydrophobic qualities as well as transparent and durable coatings. By first applying a thin coating of TiO2 to the glass substrate, followed by the surface modification of a fluorine-free compound of OTS, it has been successfully made to create superhydrophobic coatings that are transparent, mechanically stable, UV stable, chemically resistant, and chemically resistant. With a water contact angle of 160 degrees and an ultralow adhesion of 4 degrees, the coated glass displayed exceptional superhydrophobic qualities [29].

C. Spray Coating

We provide a rapid and affordable method for coating a variety of surfaces with a strong hydrophobic layer using a fluorine-free mixture of modified SiO2, epoxy resin, and polydimethylsiloxane (PDMS). With a contact angle of 159.5° and a rolling slope of 3.8°, this coating displays remarkable super-hydrophobicity [37]-[39]. To maintain the super-hydrophobicity on the different glass surfaces, [40] the functionalized SiO2 nanoparticles, polydimethylsiloxane (PDMS), and EP were all sprayed together in a fluorine-free solution [41].

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A variety of mechanical durability tests may be performed using the newly created super-hydrophobic coating [42] [84]. The super-hydrophobic coating may attain exceptional self-healing capabilities with a simple spraying approach [3].

The EP + PDMS@SiO2 super-hydrophobic coating was easily applied by spraying it on. 3.2 g of EP and 12 mL of ethyl acetate (EA) were well mixed before adding the OTS-modified n-SiO2. The mixture was then dispersed for 10 minutes using ultrasonic energy. Then, 1 g of dissolved PDMS and 4:1 and 10:1 of each curing agent for EP and PDMS were added to the combined EP@n-SiO2 solution. The mixed solution was then continuously magnetically stirred for 1.5 hours at 25°C. A series of samples were then sprayed with the uniform EP + PDMS@SiO2 solution using 0.6 MPa compressed air at a 20 cm distance between the sample and the spray cannon. After two hours of curing at 80 degrees Celsius, the coated samples all effectively produced a super-hydrophobic EP + PDMS@SiO2 coating. A crucial step in producing super-hydrophobic surfaces is the functionalization of SiO2 nanoparticles. The inclusion of modified SiO2 nanoparticles may further lower the coating's surface energy, which is the key argument in favor of preserving the coating's use as a superhydrophobic coating. Figure 8 depicts a production process using the spraying technique [42].
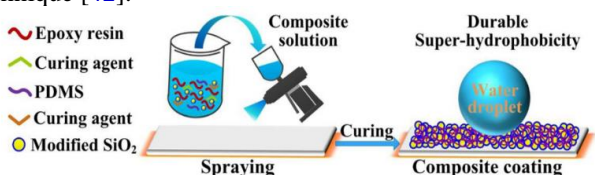

Fig. 8. Schematic illustration of the durable super-hydrophobic coating fabricated process.

This research offers a unique, practical method for creating super-hydrophobic coatings that perform superbly in all respects, and it should broaden the range of metal materials and super-hydrophobic surfaces that may be used in challenging wetting situations [42]. The layer-by-layer (L-b-L) spraying assembly method is an additional spraying technique. This technique has the required replacement for the dipping LbL [43] assembly because it alternately sprays aqueous solutions of polyelectrolytes with opposing charges onto substrate surfaces [51]. Assemblies produced by spraying LbL are far superior to those produced by dip coating for changing structures and compositions in films. They could be put together rapidly. It is more practical to spray LbL assemblies than to dip them since this method also makes it straightforward to deposit films on surfaces across broad regions [38].
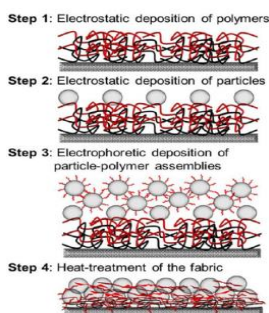

Fig. 9. Diagrams showing the recommended manufacturing method for anti-wetting fabric coating [44].

Fig 9 shows that layer-by-layer(L-b-L) fabrication steps
Step 1: Electrostatically deposit multilayered polymers on the cloth.
Step 2 involves electrostatically depositing nanoparticles on the fabric's polymer layers.
Step 3: Electrophoretic deposition is used to deposit the polymer and nanoparticle assemblies (EPD).
Step 4: The cloth is heated to improve mechanical durability and achieve a water contact angle greater than 150°.

D. Spin Coating

The spin coating's only function is to uniformly apply light coatings to flat surfaces. A simple process is used to apply a little amount of liquid glue in the center of a substrate, and the substrate is swiftly rotated (often at a speed of around 3000 rpm). This adhesive would finally hit the substrate's edge and eventually peel off due to centrifugal force, leaving a thin resin covering on the exterior. The spin process's parameters and other components may depend on the kind of resin utilized (viscosity, drying rate, percentage of particles, surface tension, etc.). The characteristics of coated films are described in terms of exhaust vapor, acceleration, and maximum rotating speed. Coats are spun with a device called a spinner, sometimes referred to as a coated [45]. Nanomaterials were spin-coated onto a plain (standard colonnaded) surface to improve their surface quality [46]. The capacity of the spin-coating nanoparticles to convert a hydrophobic barrier into a sticky one when touched is noteworthy. A sliding superhydrophobic coating may then be produced after another spin-coating step utilizing silica nanoparticles to provide an inter-roughness pattern. This is possible to produce superhydrophobic surfaces with a hydrophilic surface larger than 150° and low contact angle hysteresis (10°) by simply spin-coating the silica particles onto a silicon wafer [47]. Dopamine hydrochloride was acquired from The Endura Chemicals Company, Ltd. and utilized in accordance with instructions. Using the Stuber method, 430 nm silica particles were produced. 27 Usually, 20 millilitres of ethanol and 5 mL of a weak acid are stirred for 30 minutes. 20 minutes were spent stirring the 100 mL container containing 10 mL of water, 20 milliliters of ethanol, and 5 mL of ammonia water. Dropwise added the (tetraethoxysilane)TEOS solution, which had spent five hours at room temperature being stirred continuously. The stirring process can occur by adopting gears in the spinning machine [83] [89] The silica spheres were eventually recovered after many centrifugation cycles and ethanol washings. The structure of silica particles was investigated using a Sony S-4700 transmission electron working at 15 kV. Azolo biphenyl polymers and derivatives were created and described in the electronic supplementary information (ESI) [47]. Using the spin coating method, a superhydrophobic coating was applied to the glass surface using SiO2 nanoparticles that had been changed by hexadecyltrimethoxysilane (HDTMS) and polymethyl methacrylate (PMMA).

The major goal of this research is to create chemically, thermally, and mechanically stable superhydrophobic coatings on glass surfaces. 0.4 g of PMMA was dissolved in 20 ml of toluene by stirring the mixture for 15 minutes. After that, 0.8 g of SiO_2 nanoparticles and 0.4 ml of HDTMS were combined, stirred for 15 minutes, and then ultrasonically sounded for 20 minutes. After 15 minutes of stirring and 20 minutes of ethanol addition, the mixture underwent a 20-minute ultrasonic treatment. Using a spin coater and the aforementioned solution, the coating on the glass substrate was completed in three phases, as shown in Fig. 10. The procedure was broken down into three steps: the first was performed for 30 seconds at 1000 revolutions per minute (rpm), the second for 30 seconds at 1500 rpm, and the third for 60 seconds at 2000 rpm. The coated glass was spin-coated before being dried in a hot air oven for an hour at 100°C. The spin coating method was used to create a superhydrophobic PMMA-based coating on a glass surface utilizing silica nanoparticle and HDTMS. Superhydrophobicity is possible with a water contact angle of 165° and a sliding angle of 7° [46].
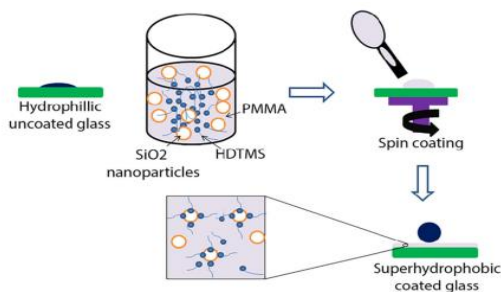

Fig. 10. Schematic diagram showing the preparation of superhydrophobic coating on glass substrate using a spin coating technique.

There are normally two methods for creating the superhydrophobic surface using this procedure. One method is to aggregate or assemble the silica particles using spin coating or dip coating to produce a rough surface. The alternative method comprises spin coating and the addition of alkyl silane or fluoroalkyl silane chemicals to produce hydrophobic silica or silica composite nanoparticles during the costa del process
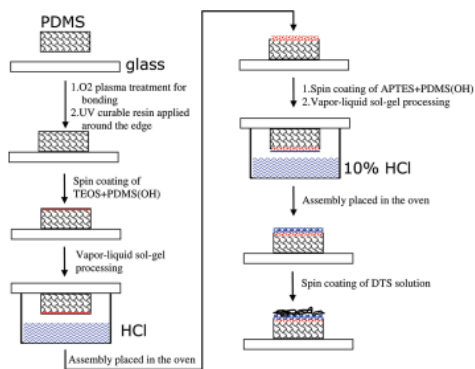

Fig. 11. Schematic of vapor-liquid sol-gel processing in conjunction with the spin coating process.

That is seen in Figure 11 above. By producing two layers of SiO_2 nanoparticles and spin-coating the polydimethylsiloxane (PDMS) substrate with dodecyl trichlorosilane (DTS) solution, the superhydrophobic surface

is produced. The substrate is allowed to cool to ambient temperature after removal [48]. A droplet of either TEOS (tetraethoxysilane) and PDMS(OH) or 3-aminopropyltriethoxysilane (APTES and PDMS(OH)) with a volume ratio of 5:1 was used to cover the first coating of SiO_2 particles. The following stage included spinning the coat at 1000 rpm for 10 seconds. The assemblage was left at room temperature for 5 minutes before being exposed to a 10% HCl vapor for a further 5 minutes of reaction time. The assembly was then subjected to the same heating and cooling processes as previously after that. The last step, which entailed applying surface modification or laying hydrophobic material, was examined using three different approaches [49]. We are producing a superhydrophobic surface on a PDMS substrate [50]. Two layers of SiO_2 particles created using a vapor-liquid sol-gel technique in a mixture of spin-coating of at least 50% DTS solution entirely cover the same fault structure on the PDMS exterior. As a consequence, the surface becomes extremely hydrophilic and has a static contact angle of 162, a sliding angle of 2, and a CAH under 5. Two layers of SiO_2 particles are required for the hydrophobic oligomeric siloxane to spin coat the DTS solution at a concentration of more than 30% weight percent and produce the wrinkle-like shape. Many of the substrates affixed to the modified PDMS might become very hydrophobic using this technique. A novel method for creating a superhydrophobic surface was created on a PDMS substrate. The wrinkled structure on the PDMS layer is completely covered by two layers of SiO_2 particles created by the vapor-liquid sol-gel method in combination with spin-coating of at least 50% DTS solution. This results in a very hydrophobic surface, with a surface contact angle of 162 static, a CAH of less than 5°, and a slide slope of 2° [49].

E. Plasma Coating

Plasma spraying has become a standard in the field of mechanical engineering due to the ability to produce superhydrophobic surfaces on glass substrates utilizing materials with extremely high potential [51], [52]. As a result, thermal spray coatings have substantially more potential. Some surfaces have a propensity for water droplets to collect and roll off quickly, creating a trail of dirt and debris in their wake [53]. Superhydrophobic coatings were made possible by the brilliant atmosphere that the plasma polymerization process produced. Under ambient circumstances, a tetramethyl silane precursor may be used to produce such coatings on a variety of substrates in a single process. Glass surfaces may be exposed to the plasma's emitted dust without any pre- or post-treatment required [54]. When hydrogen was removed from the mixture of the input gases, a coating was created that lacked the superhydrophobic feature [55], [56]. The ideas behind these methods would be the easiest to put into practice and the most flexible for a variety of substrates. Plasma polymerization and deposition techniques may be used in a single phase to achieve this.

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To create superhydrophobic coatings, a number of plasma-based approaches have been employed. The ease of usage of single-step plasma polymerization and deposition techniques is increasing their appeal [57]. Superhydrophobic coatings must be installed on flat silicon substrates using a single plasma method to create hydrophobic nanoscale topographic features. To accomplish these properties, it is feasible to produce hydrophobic particles with a strong surface attachment. Glow-discharge plasma polymerization techniques have the potential to convert reactive gases into solid particles. Because high-energy plasma polymerization techniques include a number of atomic reactions, they are much more intricate and imprecise than traditional chemical polymerization procedures [51]. The ability to swiftly and cheaply produce hydrophobic coating layers on glass substrates using non-thermal plasma polymerization technologies is very promising [58].

NiTi Plasma Coating Surface Morphology Analysis:

Microcavities may be observed on the coating's outer surface. Thus, it is necessary to describe the irregularities in terms of the average surface roughness. This might be due to ineffective heat transmission from plasma to particles or from particles to nanoparticles. Additionally, it is thought that the surface imperfections make surface roughness, this shows the result of the defrosted particle's deposition [53]. The accumulation of numerous splat layers in the present study results in an increase in surface roughness as a result of layer-by-layer splat generation during the plasma deposition cycle. The surface morphology of the NiTi plasma sprayed coating was examined. In addition to the considerations already discussed, organic material deposition caused by air adsorption on coating surfaces also contributes to the development of superhydrophobic characteristics.
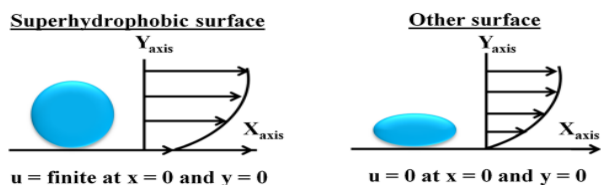

Fig.12.Superhydrophobicity and slip condition for superhydrophobic surface and general case

Due to the existence of microroughness in the form of micro-cavities on the surface in the case of plasma coating, the slip condition offers increasing force in the opposite direction as the impingement after droplet impingement Fig. 12. As a consequence, the affected droplets acquire a repellent property. By encouraging the recoiling feature, this phenomenon increases the contact angle. In order to go further into the subject, droplet behavior during impingement is examined using energy balance and the fluid dynamics theory. Fluid dynamics is first used to explain the behavior before the concept of energy balance is introduced [53].

F. Chemical Vapor Deposition

Chemical vapor deposition (CVD) is now being used to produce hydrophobic films, which is of great interest [59]. The CVD technique deposits a solid material, such as silica, onto a substrate by a gas phase or surface reaction [60]. In this study, it is shown that the silicon oxide materials mentioned in the previous section on silicon oxides may be coated using effective CVD techniques. Naturally, only a few of these reactions are often used in the production of industrial glass coatings. In the parts that follow, I go through some of the most well-liked and possibly profitable replies [61] This study describes the use of chemical vapor deposition (CVD) technology for covering glass. The limited definition of glass forces us to exclusively deal with oxidic substrates. range of temperatures for coatings. The pyrolytic spray coating zone may be excluded from CVD using a more precise description. Due of this, the focus of the text will mostly be on the qualities of regular glasses. Maintain the coating temperature below 500 °C, depending on the kind of glass. The coating target's targeted surface finish and form [62].

Silicon oxides:

The applied deposition system's experimental arrangement is shown schematically in Fig. 13. Despite using a plasma source that is a commercially available plasma BLASTER MEF system, the plasma jet nozzle has been modified to spray liquids or liquid-dispersed particle materials into the active plasma volume. The compact assembly that forms the system's foundation is made up of two parts an electrical supply unit and a supply of process gas. The real plasma nozzle serves as the inner stick metallic electrode while the DC pulsed plasma ignites between the two cylindrical electrodes. Using water-free compressed air as the process gas and driving the plasma through the nozzle at pressures of 4-6 bar. Maximum electron energies in the cold plasma produced by the plasma BLASTER MEF vary from 12 to 16 eV [63].

Fig.13. Layout of the APCVD plasma jet coating plant system

The plasma by varying the burst time and frequency, BLASTER's electrical output may be altered concurrently from 60 to 500W. For the film-forming procedure to produce the silicon oxide matrix, hexamethyldisiloxane was employed as an organosilicone precursor material. In an STS 03 CH evaporation device, the HMDSO was evaporated before being combined with the process gas and delivered into the plasma. The gas silane is a typical precursor for silicon dioxide. The breakdown of the precursor molecules in the plasma was probably mostly caused by collisions with excited oxygen and nitrogen states, and the deposition at the substrate was likely caused by interactions between the oxygen from the original precursor and the exciting air [64].

Even when the temperature is as low as room temperature, it interacts spontaneously with oxygen (called pyrophoric behavior). The amount of silane must be maintained low (1%), which will halt this reaction and allow for the formation of a film rather than a powder. Around 400°C, the rate of film deposition accelerates. The oxidation of silane is thought to involve free radical intermediates [65]. Free radicals must be removed from the process and slowed down by radical traps like ethylene in order to employ substrate temperatures over 600°C [61]. When oxygen is available in significant amounts, this method produces completely oxidized Si02 films with a low refractive index of 1.45. Silane reacts with less oxidizing oxygen sources such as carbon dioxide [59] or nitrous oxide [66] [67] to produce silicon suboxides with higher refractive indices, up to around 2. Dichlorosilane and oxygen may also be used to produce silicon dioxide films. On salt-containing substrates like soda-lime glass, rapid deposition rates have been observed [68]. The ability to cover lengthy sections of flat glass with uniformly thick, high-quality coatings using chemical vapor deposition has been shown. It has been found that a number of oxides, nitrides, silicides, silicon, and metals have chemical predecessors. Large-scale machinery has been created to apply CVD coatings on cut glass or for creating float glass. When compared to alternative processes, such as sputtering, vacuum evaporation, glow discharge, sol-gel dipping, and electroless deposition, atmospheric pressure CVD is a less costly way to deposit thin films [61]. Using the m   d shown in Fig. 14, SiO2-coated ZnO nanoparticle arrays with great transparency and resistance to UV light were produced. The superhydrophobicity strongly depends on the length of the ZnO nanorods and the SiO2 layer. The coating may be applied to flexible thin PET sheets and glass with contact angles of 157° and 160°, respectively. Extremely durable and unchangeable, it maintains its shape even after repeated bending (coating on PET). Additionally, the film is exceptionally transmissive (93–95%) and UV-resistant. When applied to a solar cell panel, the superhydrophobic SiO2/ZnO nanocomposite coating had no impact on how the sun cell devices functioned [69]

Fig. 14. Perfluorodecyltriethoxysilane (PTES) superhydrophobic SiO2-coated ZnO nanorod arrays on glass are prepared as shown in the above figure.

They produced indium oxide microparticles with random distribution and vertical alignment using the deposition of chemical vapors approach. The static water contact angle was shown to be significantly influenced by the nanorods' alignment. According to Fig. 14. The haphazardly aligned nanorods display a value of 133.7°slide angle of 6.8°. In comparison, the contact angle and sliding angle of indium oxide nanorods that are vertically aligned are 159.3° and 4.8°, respectively [69].

G. Lithography

Lithography is a well-known technique that is regularly used to create surfaces that are very superhydrophobic with precise control over the surface structure. Lithography is a method that may be used to design surfaces with micro- or nanostructures of different sizes, spacings, and forms, such as square or circular pillars. To cover a substrate in lithography, a thick master mask layer is usually used. After that, the whole substrate is exposed to a procedure that removes some of the exposed substrate material, allowing for the creation of a structured surface that is in opposition to the pattern of the mask layer. To control the reaction, a variety of methods may be utilized, including a photoactive polymer and UV light (photolithography), X-rays, electron beams, or lasers [13]. In a silicon wafer, arrays of nanopits or nanopillars were created using electron beam lithography to create superhydrophobic surfaces. Advantages and drawbacks to each lithography technique exist [70]. The patterned surfaces were chemically altered using octadecyl trichlorosilane (OTS) to produce superhydrophobicity [9].
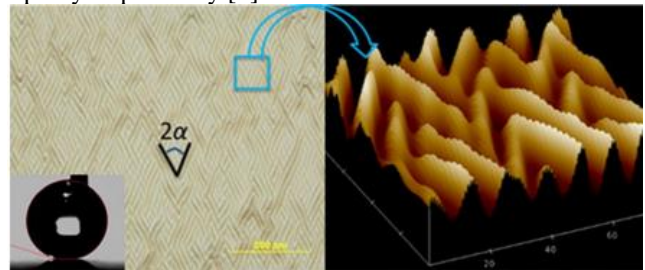

Fig. 15. Optical microscope and AFM images of the hierarchical wrinkles with Prepatterned grooved nanostructures [81].

Microfabrication lithography, which combines UV photolithography with nano processing, was used to create superhydrophobic surfaces [71], [72]. This strategy can result in precise designs at the nanoscale. Then, to establish the multilayer surface structure, researchers took advantage of a spontaneous wrinkle process to create minute wrinkles, as seen in Fig. 15. Additionally, they demonstrated that the wettability could be adjusted between hydrophobicity and superhydrophobicity by varying the thickness of the first layer [73]. SEM micrographs are captured by scanning electron microscope [78] [79]. Using the lithography method, superhydrophobic surfaces were also created (repellent to oils with low surface tension). On polydimethylsiloxane (PDMS) substrates, inverse-trapezoidal microstructures were produced via lithography [9]. The "bond-detach lithography" method presented is based on bonding and detaching PDMS, and it could be a quick and affordable alternative to current lithographic techniques. The reported "bond-detach lithography" method, which is based on bonding and nonbonding PDMS, may be used to quickly and affordably create features at both the micro- and nanoscales [9]. A few minutes are all that each patterning cycle lasts. Each patterning cycle just takes a few minutes, and the stamp may be used again. There are no concerns with "ink" smearing as there are with many other non-traditional lithography methods when using the bond-detach lithography (BDL) method since it does not use external factors like electrostatic force, heat, load/pressure, or advanced surface preparation. For BDL, a parallel process technique, to effectively transfer patterns at the water level, the surface must have a water contact angle of 160° and a sliding angle of 5° [74].

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Table- I: Different materials coatings with various types of surface modification to achieve super hydrophobicity.

Sl. No	TYPES OF COATING	MATERIALS	CONTACT ANGLE	THICKNESS
1	SPIN	polymethylmethacrylate	165° [46]	10-30μm[76]
2	SPRAY	polydimethylsiloxane	164° [77]	7μm [77]
3	PLASMA	silica polymers	144° [54]	25 μm[54]
4	SOL-GEL	trimethylchlorosilane	115° -165°[30]	15-20μm[30]
5	DIP-COATING	methyltrichlorosilane	170°[75]	3μm[26]
6	CHEMICAL VAPOR DEPOSITION	SiO2-coated ZnO perfluorodecyltriethoxysilane	159.3°[59]	10μm-20μm[59]
7	LITHOGRAPHY	octadecyl- trichlorosilane (OTS)	160°	33μm

III. CONCLUSION

In this review express the fundamental methodology to create super hydrophobicity was described in detail. The rough surfaces that chemically changed on the glass surface to generate an artificial superhydrophobic surface with a contact angle higher than 150° are key parameters in creating the super hydrophobicity surface. This paper provides an overview of various methods of coating glass that create a superhydrophobic surface. The dip-coating method is a fast-coating method to create a superhydrophobic surface that will be used on all types of the glass substrate and achieve 170° the cost of the material used in dip coating is less than the plasma coating and more than other coatings. The sol-gel process took a long time to develop the superhydrophobic coating with a water contact angle of 165°. Spin coating's key benefit is that the coating surface is extremely thin, reaching a water contact angle of more than 165°. Spray coating is a quick and inexpensive method of producing a strong superhydrophobic coating and obtaining a water contact angle of 159°. Although the material used in plasma coating is costlier, it is a one of the types of coating that is more effective at producing superhydrophobic coatings. The most economical method for producing a superhydrophobic surface with a 160° water contact angle is chemical vapor deposition. One technique for producing a superhydrophobic surface at a 160° water contact angle is photolithography. The spin coating has been recognized as the most efficient, affordable, and economically feasible processing technique for the creation of superhydrophobic coatings.

The control parameters of these processes must thus be optimized in order to create sophisticated superhydrophobic coatings for a variety of applications.

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