Proceedings of CONF-MSS 2026 Symposium: Advanced Composite Materials and Polymer Chemistry
DOI: 10.54254/2755-2721/2026.AD33156

Surface Chemical Modification of Glass: Mechanisms and Application of Hydrophobic, Hydrophilic and Lipophobic Coating

Xingyan Guo

Xi'an Tieyi International Curriculum Center, Xi'an, China
guoxingyan2027@163.com

Abstract. Surface chemical modification of glass has emerged because traditional glass cannot meet the diverse requirements of modern industry. The crucial point of the modification is coating the bare glass with different outer layers. This paper systematically summarizes and illustrates the chemical mechanisms underlying the features of hydrophobic, hydrophilic, and lipophobic coatings on glass surfaces. For hydrophobic modification, mechanisms such as silanization, fluorine-containing grafting, and low-surface-energy layer deposition are analyzed, while hydrophilic coatings rely on hydroxyl group enrichment and sol-gel hydrolysis. Lipophobic coatings are achieved primarily through fluorochemical modification and hierarchical structure design to reduce oil adhesion and permeation. Furthermore, this work summarizes the cutting-edge applications of these modified glasses such as optoelectronics, automotive glass, biomedical devices, anti-fouling materials. In the following sections, the paper will highlight the relationship between modification mechanisms, surface properties, and functional performance. At the application part, the current challenges, including coating stability, biocompatibility, and large-scale preparation, are discussed, and future development directions for high-performance, environmentally friendly, and multi-functional glass surface chemical modification are prospected.

Keywords: Surface energy, contact angle, micro-structure, tension force

1. Introduction

As a widely used inorganic material, glass exhibits excellent optical transparency and chemical resistance, which makes it indispensable in optoelectronics, automotive and other industrial fields. However, bare glass can not meet such industrial needs. So the modified surface is necessary to apply it in different circumstance and some special environment such as fogging, oil contamination. In response to these requirements, surface chemical modification has become one of the most effective strategies to regulate the adhesion ability, antifouling and functional properties of the glass surface. In order to meet different requirements under different situations, this paper mainly classifies modified glass into hydrophilic, hydrophobic and lipophobic types based on surface energy differences. Hydrophilic coatings promote the formation of uniform water films to achieve

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.AD33156

anti-fog and easy-cleaning effects; hydrophobic coatings enable water droplets to roll off spontaneously; and lipophobic coatings further reduce surface energy to resist oil and organic pollutants. In the following, this paper will focus on the surface chemical modification of glass, systematically analyzing the formation mechanisms and influencing factors of hydrophilic, hydrophobic and lipophobic coatings and discussing their typical applications. Finally, the existing challenges and future development trends of functional modified glass are also prospected. It is expected that this paper will inspire subsequent research.

2. Hydrophilic glass

Hydrophilic glass is a type of modified glass with enhanced surface wettability. It's key feature is a water contact angle below 90°, and an ultra-hydrophilic state (below 10°) after specialized treatment. Such modification elevates surface energy and transforms the original hydrophobic surface into a highly hydrophilic one. The following two sections will fully explain the modification methods and core mechanisms (contact angle and surface energy) of hydrophilic glass.

2.1. Mechanism

As the introduction said, hydrophilic glass has enhanced surface wet-ability, typically exhibiting a water contact angle below 90°, but the question is -how to entrust the glass surface this feature? There are many approaches that have been applied. One of the common approaches to preparing hydrophilic glass is plasma treatment. Plasma treatment or laser coating is a physical modification method that enhances water spreading based on the Wenzel model [1] and capillary effects; the Wenzel model is described as follows: "Rough surfaces with different porous structures, including surface areas and PSDs, were fabricated by stacking different solid ratios of TiO_2 nanoparticles. These fluorinated surfaces exhibited an excellent hydrophobic performance." Professor Yamamoto has explained the principle of this approach. Plasma treatment imparts distinct hydrophilic properties, with the coating molecules exhibiting a contact angle of less than 4°. The less the contact angle is, the easier the liquid spread. Thus, liquids can adhere to it easily, and such glass exhibits hydrophilic properties [2].

Additionally, the use of certain metals or special high-surface-energy functional groups is also feasible. "Metals play a main role in the framework of biomaterials as most implants contain at least one metallic part. In particular, metallic biomaterials employed for orthopedic applications consist of titanium alloys, stainless steel, and Co-Cr–Mo alloys"stated Professor Sanguedolce [3]. As mentioned previously, certain alloys such as titanium oxide can also meet the requirements by isolating the bare glass from the external environment with a metal coating. Additionally, processing hydrophilic functional groups (such as hydroxyl and carboxyl groups), ion exchange, or chemical coating can form a stable hydrophilic adsorption layer. Essentially, these modifications reduce interfacial tension, enabling water to spread uniformly rather than form isolated droplets; they also introduce special components that can increase surface energy and transform the original hydrophobic surface into a highly hydrophilic one.

2.2. Application

Hydrophilic glass exhibits excellent performance in multiple fields. Firstly, in optical and display applications, it is used as camera lenses, display panels, and vehicle-mounted optical components, providing anti-fogging and anti-glare effects by preventing water condensation and maintaining high

DOI: 10.54254/2755-2721/2026.AD33156

light transmittance—this is because its low contact angle enables water to spread and be absorbed easily. In the medical field, hydrophilic glass is used as a substrate for biochips and cell culture dishes. Its high hydrophilicity promotes the uniform adsorption of proteins and nucleic acids, improves cell adhesion, and thus enhances detection accuracy and in vitro culture efficiency. It is also widely used in daily and industrial applications, such as architectural glass, automotive windows, and photovoltaic panels, achieving self-cleaning effects, reducing dust and moisture accumulation, and thereby improving the energy conversion efficiency of solar modules.

In conclusion, compared with unmodified glass, hydrophilic glass possesses stable long-term hydrophilicity, strong substrate compatibility, as well as favorable wear resistance and aging resistance. It has effectively solved the limitations caused by the hydrophobicity of natural glass and has broad application prospects in optics, biomedicine, and new energy industries.

3. Hydrophobic glass

Hydrophobic glass is designed to repel water; its core features are a water contact angle greater than 90°, with superhydrophobic surfaces exceeding 150° — "Non-wettable surfaces with high Water Contact Angles (WCAs) and facile sliding of drops, called superhydrophobic or ultrahydrophobic" [4]. This behavior stems from two key design principles: surface chemistry and surface topography.

3.1. Mechanism

To put it simply, hydrophobicity is achieved by coating glass with low-surface-energy materials such as fluorinated polymers, silanes, or Self-assembled Monolayers (SAMs). These components will be fully explained below. These materials reduce the surface free energy, minimizing the attractive forces between the glass and water molecules. For example, fluorosilane coatings create a non-polar surface that resists wetting; due to the repulsion between polar and non-polar components, water's polar nature makes it difficult to spread across such a substrate.

To facilitate understanding, nanoscale roughness is introduced to amplify the chemical hydrophobic effect, following the Cassie-Baxter model [5]: "Contact-angle adherence of a liquid suspended on surface microstructures, namely in a Cassie–Baxter state, is determined mainly by the receding contact line although not fully understood." This roughness traps air pockets between water droplets and the glass surface, reducing the actual liquid-solid contact area [5]. Techniques like plasma etching or sol-gel deposition are used to create hierarchical microstructures and so on. These structures, combined with low-energy coatings, enable water droplets to bead up and roll off the surface easily; this forms a phenomenon known as the "lotus effect" — a self-cleaning, superhydrophobic property traditionally observed on leaves [6]. To better illustrate this phenomenon, this paper uses the lotus effect to describe the behavior of water on hydrophobic glass.

3.2. Application

In the automotive industry, hydrophobic coatings on windshields and side mirrors ensure driving safety in wet conditions; they enable drivers to observe their surroundings even in severe fog or heavy rain. This is because water droplets roll off the surface without the need for wipers, maintaining clear visibility and reducing glare. Similarly, hydrophobic glass is used in skyscraper glass based on the same principle, which reduces the accumulation of rainwater, dirt, and grime. This self-cleaning effect minimizes maintenance costs and preserves the aesthetic appearance of buildings.

DOI: 10.54254/2755-2721/2026.AD33156

In the field of optoelectronics, hydrophobic glass is crucial for display screens used in daily electronic devices. It can repel water and dust, and these coatings maintain high light transmittance, ensuring the clarity of touchscreens and televisions.

4. Lipophobic glass

Lipophobic glass is a modified glass that repels oily substances. Such strong repulsion prevents most substances, such as dust and contaminants, from adhering to its surface.

4.1. Mechanism

Firstly, sufficient energy regulation is fundamental, following Young's equation: $\gamma S=\gamma SL+\gamma L$, in which "θ is the contact angle measured in the liquid, γL, γS and γSL the surface tensions of liquid, solid and solid-liquid surfaces, 'Young's equation'" [7]. It is known that conventional glass with high surface energy (300–400 mJ/m) is lipophobic. To achieve this, low-surface-energy substances such as fluorine-containing and silicone compounds are required to reduce oil adhesion.

Additionally, its microstructure is inspired by the "lotus effect", which has been fully explained in the hydrophilic section. This principle is also applicable to lipophobic glass. In fact, hydrophobic and lipophobic materials share the same core feature: repulsion to substances. However, lipophobic glass has stronger repulsion, enabling it to repel oily substances. From a microstructure perspective, the contact mode is altered to a "solid-liquid-gas" three-phase system, forming a "gas cushion" — an indispensable component (though not the most expensive) of underground natural gas storage [8].

4.2. Application

Based on these mechanisms, lipophobic glass has been widely used in various fields. Its application is most mature in electronic devices, where anti-fingerprint screens and optical components utilize this extreme repulsion.

In the automotive field, lipophobic glass ensures clear vision for windshields and keeps in-car displays clean. It is also used in the art field. In architecture, it enables self-cleaning walls for some skyscrapers that are difficult to clean manually.

5. Conclusion

Even though modified glass has been applied in many fields, it still has broad development prospects. One of the development directions is multi-functional and smart coatings. Admittedly, modified glass needs to be more intelligent. For example, when a disaster occurs, the glass used in skyscrapers is not intelligent enough to handle various situations, and broken glass can sometimes harm people. So Future development will focus on coatings that integrate multiple properties, such as superhydrophobic + self-healing, hydrophilicity or lipophobic + antibacterial functions. These smart surfaces can adapt to environmental changes (e.g., light, temperature, pH) and find wide applications in smart windows, self-cleaning medical devices, and anti-corrosion industrial components.

The next prospect is Sustainable & Eco-friendly Technologies. Environmental problems are a major issue that all countries invest considerable energy and resources in addressing. If eco-friendly glass can be applied, the substantial costs associated with recycling waste glass will be reduced. Components in the coating, such as fluorine-containing substances and other organic compounds, are toxic and will severely harm the environment. So there is a strong push to replace fluorinated

DOI: 10.54254/2755-2721/2026.AD33156

and toxic chemicals with bio-based modifiers (e.g., plant-derived silanes, biodegradable polymers) and water-based coating processes. This also aligns with global environmental regulations and the demand for green manufacturing.

References

[1] Yamamoto, T., Okubo, M., & Imai, N. (2004). Improvement on hydrophilic and hydrophobic properties of glass surface treated by nonthermal plasma induced by silent corona discharge. Plasma Chemistry and Plasma Processing, 24, 1-12.
[2] Sanguedolce, M., Rotella, G., Curcio, F., Pelaccia, R., Siciliani, V., Cassano, R., Orazi, L., & Filice, L. (2023). Effects of Ti6Al4V mechanical and thermal surface modification on the adhesion of a chitosan-bioactive glass coating. The International Journal of Advanced Manufacturing Technology, 125, 4621–4629.
[3] Han, T.-Y., Shr, J.-F., Wu, C.-F., & Hsieh, C.-T. (2007). A modified Wenzel model for hydrophobic behavior of nanostructured surfaces. Thin Solid Films, 515(11), 4666–4669.
[4] Ma, M., & Hill, R. M. (2006). Superhydrophobic surfaces. Current Opinion in Colloid & Interface Science, 11(4), 193–202.
[5] Liu, T. L., Chen, Z., & Kim, C.-J. (2015). A dynamic Cassie–Baxter model. Soft Matter, 11(8), 1589–1596. https://doi.org/10.1039/C4SM02691A
[6] Lee, H. J., & Michielsen, S. (2006). Lotus effect: superhydrophobicity. Journal of the Textile Institute, 97(5), 455–462.
[7] Adam, N. K. (1957). Use of the term 'Young's equation' for contact angles. Nature, 180, 809–810. https://doi.org/10.1038/180809a0
[8] Du, S., Bai, M., Shi, Y., Zha, Y., & Yan, D. (2024). A review of the utilization of CO_2 as a cushion gas in underground natural gas storage. Processes, 12(7), 1489.