Investigating the Surface Superhydrophilic and Superhydrophobic Modification Using Nanoscale Bilayers Assembly on Stainless Steel Plate

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***Abstract*—This study investigated the use of nanoscale bilayers assembly for superhydrophilic and superhydrophobic surface modification on stainless steel plate. This study performed nanoscale bilayers assembly method ,as well as chemical vapor deposition (CVD) to perform fluorosilan treatment on the modification surface, to modify the surface structure and thereby the wettability of the surface at 16, 17, 18, and 19 bilayers. At 16 bilayers , the contact angle is 7°; at 17 bilayers , the contac t angle is 5°;at 18 bilayers , the contact angle is 4°, satisfying the requirement for superhydrophibicity; at 19 bilayers , the contact angle is 8°. According to experimental results, surface modification was able to reduce the contact angle of water on a stainless steel flat plate.The hydrophilic surface was further modified into a hydrophobic. Experimental results showed 18 bilayers to yield the largest contact angle of 153° (compared to 87° on the unmodified surface), corresponding to the highest surface superhydrophobicity.**

Keywords-superhydrophilic; superhydrophobic modification; nano-laminated assembly; contact angle

I. INTRODUCTION

Hydrophilicity of a surface is a main factor in the surface's evaporation heat transfer performance. Hydrophilicity can increase the ability of the droplet to spread across the surface and cover a larger surface area as well as decrease the fluid's contact angle and film thickness. This study used nanoscale bilayers assembly method to increase solid surface hydrophilicity. Wettability of a surface directly affects aspects of heat transfer performance. Either high hydrophobicity, or low wettability, corresponds to decreasing contact angle of a water droplet on a surface; superhydrophobic effect refers to the static contact angle of 150°or more that results in the rolling water droplet effect demonstrated by a lotus plant leaf, with its self-cleaning abilities. In 1932, Blodgett [1] first proposed and performed nanoscale bilayers assembly on glass for hydrophobic surface modification. In 1966, Iler et al. [2] also used the nanoscale bilayers assembly method to render the glass surface hydrophobic and unwettable. In 2006 Cebeci et al. [3] suggested values for several critical parameters during the assembly method that would yield good results. In 2001, Mitzi et al.[4] proposed the nanoscale bilayers assembly method, which employs the adhesion mechanism between anion and cation layers, for modifying surface properties such as roughness. In 2007, Bravo et al.[5] first utilized this method for hydrophobic surface modification by performing hydrophilic surface modification with the bilayers assembly method, then treated the coatings with fluorisilane on flat glass slides; they suggested a critical number of 15 bilayers such that a superhydrophobic surface can be achieved, with the static contact angle of about 155° for de-ionized water. This theoretical relationship between roughness and wettability of a surface was further investigated by Quéré[6] in 2008, showing that, for a surface coated with fluorosilane, roughness enhance the hydrophobicity of a surface. In 2010, Forrest et al.[7] showed, by performing boiling tests using water, that such surface modification on stainless steel plates can increase the boiling heat transfer coefficient by about 100%, with a static contact angle of 141° for 20 bilayers. From the above literature, it is clear that nano-laminated assembly technique has been used successfully for hydrophobic surface modifications. The objective of this paper is to find the optimal contact angle and the number of bilayers for surface hydrophobic modification using nanoscale bilayers assembly method. This method currently only achieved superhydrophilic angle on glass. Therefore, this study used nanoscale bilayers assembly for hydrophilic surface modification of stainless steel plates, then used the coated surfaces with fluorosilane using CVD, and then found superhydrophilic and the superhydrophobic optimal number of bilayers on stainless steel surfaces.

II. EXPERIMENTAL PROCEDURE

This work followed the full detailed procedure established by Wu et al.[8] in 2015 for hydrophilic surface modification bilayer coating and contact angle measurements, the CVD process established by Bravo et al.[5] for the fluorosilane deposition. Each stainless steel plate used for surface modification was 2 cm in length and 1 mm thick.

A. Hydrophlic Procedure

As Figure First, the adhesion layer(A) was applied, which can make the body layer more onto the substrate.Each for the adhesion layer contains immersing the substrate in cation solution for 10 minutes, de-ionized water for 2 minutes (to remove excess ions from the surface), (anion solution for 10 minutes, and de-ionized water for 2 minutes); with or the anion solution is PAH poly(allylamine) hydrochloride, and the cation solution is SPS sodium poly(styrene sulfonate), both titrated to pH4.0 with HCl. Five bilayers of pH4.0 PAH and SPS were applied to form the adhesion layer.

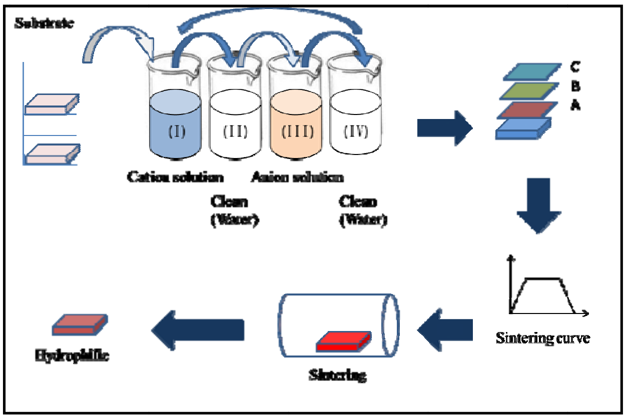

FIGURE I. NANO-LAMINATED ASSEMBLY PROCESS

As Figure I the body layer(B) can be applied after the application of adhesion layer. Each bilayer for the body layer consists of 10 minutes in pH7.5 PAH, 2 minutes in de-ionized water, 10 minutes in pH9.0 solution containing 0.03 wt.% of 7nm and 50nm SiO2 nanoparticles (titrated using a pH9.0 buffer). After the 5 adhesion bilayers, 16, 17, 18, and 19 body bilayers were applied to the plates.

The top layer(C) as Figure 1 is then applied after the body layer(s). One cycle for the top layer is similar to that for the body layer, except that the SiO2 colloidal solution only consists of 7nm particles. The plates keep to dry, and then they were placed in an oven and sintered at 500°C for 4 hours, with 1 additional hour for the temperature in the furnace to rise to the sintering temperature.

B. *Hydrophobic Procedure*

Hydrophobic surface modification can be performed after the nanoscale assembly hydrophilic modifications by CVD of fluorosilane to change the surface chemistry. Figure II shows the CVD device. The substrate was placed into a vacuum chamber, where the reduced pressure allows the fluorosilane compound to evaporate from another chamber and deposit onto the substrate. The reaction between the fluorosilane molecules and nanoscale film surface is allowed to go for about 1 hour.

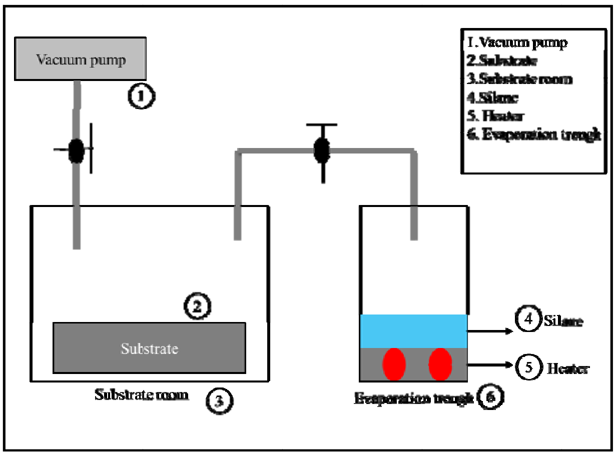

FIGURE II. SCHEMATIC OF CVD DEVICE

III. RESULTS AND DISCUSSIONS

A. *Hydrophilic*

This study successfully performed nanoscale bilayers assembly with SiO2 particles on stainless steel plates. Figure III shows a modification of surface structure by the wettability of the surface at 16, 17, 18, and 19 bilayers,respectively at 16 bilayers , the contact angle is 7°; at 17 bilayers , the contact angle is 5°;at 18 bilayers , the contact angle is 4°; at 19 bilayers , the contact angle is 8°. At 18 bilayers, the contact angle of 4° satisfies the requirement for superhydrophilicity.

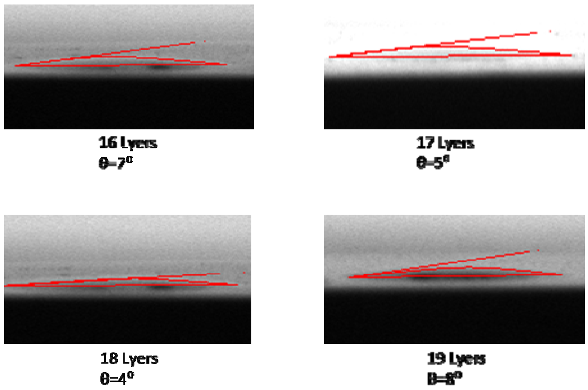

FIGURE III. CONTACT ANGLE (HYDROPHILIC)

This study successfully used nanoscale bilayers assembly technique to perform hydrophobic surface modifications on stainless steel plates. This study then used CVD of fluorosilane to make the surfaces hydrophobic..

B. *Hydrophobic*

Figure IV shows the contact angle measurements of deionized water on unmodified and modified stainless steel surfaces. At 16 bilayers, the contact angle is 135°, at 17 bilayers , the contact angle is 147°; at 18 bilayers, the contact angle is 153°, satisfying the requirement for superhydrophobicity; at 19 bilayers, the contact angle is 122°. Therefore, the results show 18 bilayers as the optimal number of bilayers for superhydrophobicity.

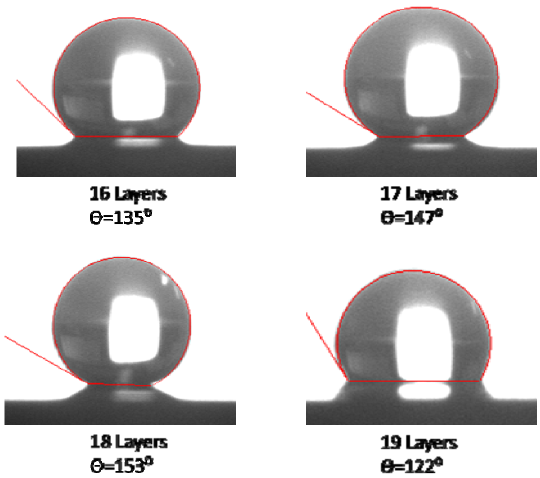

FIGURE IV. CONTACT ANGLE (HYDROPHOBIC)

C. Layers and Contact Angle Relationship

According to experimental results, as shown in figure V, for hydrophobic contact angles, at 16 bilayers, the contact angle is 135°; at 17 bilayers , the contact angle is 147°; at 18 bilayers, the contact angle is 153°, at 19 bilayers , the contact angle is 122°.For hydrophilic contact angles, at 16 bilayers , the contact angle is 7°; at 17 bilayers, the contact angle is 5°; at 18 bilayers, the contact angle is 4°, at 19 bilayers, the contact angle is 8°. The optimal results with the best contact angles(153° and 4°)occurred at 18 bilayers. Thus, 18 bilayers were used as a dividing point. Figure 5 shows in hydrophobic performance the contact angle increases before 18 bilayers, and the contact angle decreases after 19 bilayers. In hydrophilic performance the contact angle is decreased before 18 bilayers, and the contact angle increases after 19 bilayers.

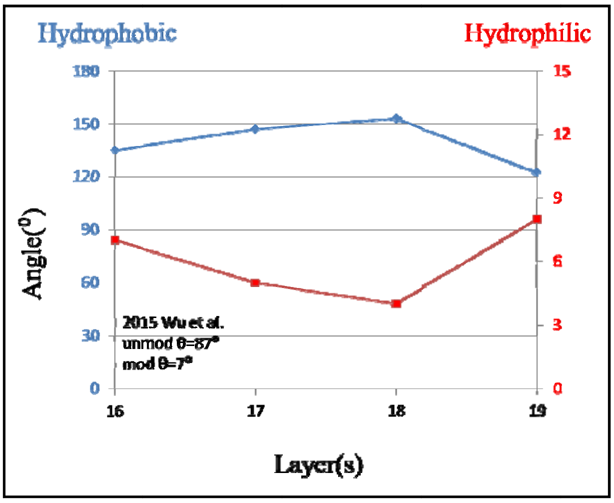

FIGURE V. LAYERS AND CONTACT ANGLE RELATIONSHIP

IV. CONCLUSION

This study successfully utilized nanoscale bilayers assembly film technique by fluorosilane chemical vapor deposition for surface hydrophobic modification on stainless steel plates.

1. According to experimental results for hydrophilic surface modification, at 18 bilayers, the contact angle is 4° achieving superhydrophilic.

2. According to experimental results for hydrophobic surface modification, 18 bilayers is the optimal number of coatings, with the maximum contact angle of 153° achieving superhydrophobic.

3. The relationship between layers and contact angle was successfully estabilshed.

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