Fabrication of Superhydrophobic Columnar Array Glass Surface by Glass Molding Process

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Abstract. Surface with mircostructure can realize superhydrophobic phenomenon and effectively reduce liquid-solid contact time, which has great significance in preventing material surface from atomization, icing and other adverse phenomena. However, superhydrophobic glass surface with columnar arrays is rarely reported, because it's difficult for hard and brittle glass material to be fabricated with this type structure by traditional manufacturing methods. This limits its wide application in practice. In order to realize high-efficiency fabrication, we took advantage of the viscoelastic properties of glass material to efficiently fabricate columnar arrays with diameter of 2 mm and height of 0.6 mm on the glass surface by glass molding process. Finally, the superhydrophobic was realized on the fabricated glass surface. The superhydrophobic glass surface with columnar array should have potential application in engineering and daily life.

Introduction

Dynamic state of the droplet is influenced by the contact surface when the droplet impacts different surfaces in the same state. In nature, many biological surfaces enable the droplet to create a special interfacial behavior between the liquid and solid surface [1]. The superhydrophobic surface has the most extensive research. Surface hydrophobicity is usually characterized by the contact angle between solid surface and water. The contact angle of the superhydrophobic surface is more than 150° [2]. Hydrophobicity is an important characteristic of solid surface, which is largely determined by the microstructure of the surface [3]. For polymer materials and low hardness metals such as aluminum and magnesium which are easy to be processed, 3D printing [4], chemical electrolysis [5], electrodeposition [6], and hydrothermal method [7] can be directly utilized to fabricate microstructural surfaces in order to realize superhydrophobic phenomena.

However, the above methods are limited to achieve superhydrophobic phenomena on the glass surface. In recent years, new methods have been applied to the manufacture of superhydrophobic glass surface with microstructures. Sutha et al. [8] fabricated superhydrophobic glass surfaces based on aluminium oxide coatings with amorphous interconnected porous network of nanoflakes. The contact angle of the prepared surface was 161° and exhibited superior self–cleaning behaviour at a tilting angle less than 10°. Zhang et al. [9] constructed a featured fibrosis network structure on the glass which was totally different from the reported porous structures. The contact angle of the superhydrophobic glass surface was as high as 166°. Yuan et al. [10] fabricate a nanostructured superhydrophobic film on glass by means of radio frequency magnetron sputtering. After annealing treatment and chemical modification, the as-prepared superhydrophobic glass surface exhibited a contact angle of 168.9°。

In this paper, we utilized a simple and easily-control method, glass molding process, to fabricate the superhydrophobic glass surface with columnar array. Glass molding process is widely regarded as one of the most efficient methods for glass forming which can efficiently and inexpensively fabricate glass surfaces with complex structures [11]. It is one-time forming of complex glass surfaces by applying a certain pressure to the glass at a certain temperature. As shown in Fig. 1, glass molding process is consisted of heating, pressing, annealing (gradual cooling) and cooling stages. This strategy is simple without excess material consumption.

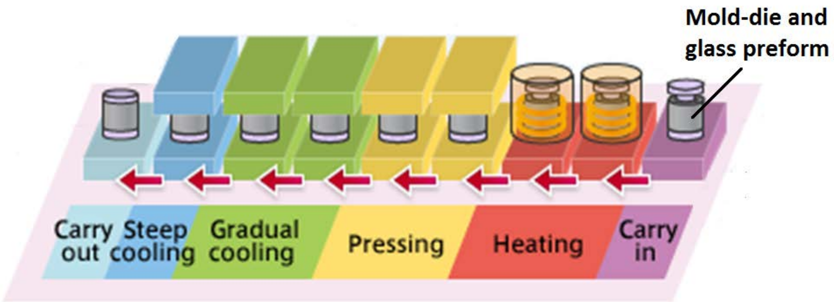


Fig. 1 Process of glass molding process

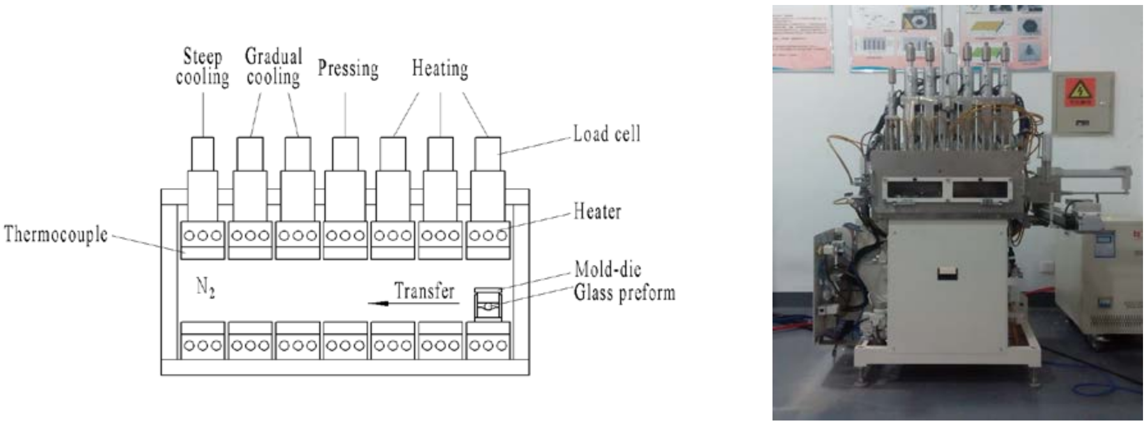
Here, we prepared a superhydrophobic columnar array glass surface with column diameter of 2.0 mm, column height of 0.6 mm, and column space of 0.2 mm. And the surface energy can be reduced by further chemical modification. The wettability of the glass surface was discussed in the present work.

Experimental

Materials. D-ZK3 low-melting glass preform with diameter of 9 mm and height of 2.5 mm was used as substrate from Chengdu Guangming Optical Elements Co., Ltd. 1H, 1H, 2H, 2H-perfluorodecyltriethoxysilane (FAS-17), acetone and ethanol were purchased from Jianyi Chemicals Co., Ltd., China. 1H, 1H, 2H, 2H-perfluorodecyltriethoxysilane was used as low surface energy material. Tungsten carbide and H13 mold steel were utilized to build the mold-die.

Preparation of superhydrophobic glass surface. The glass preform was placed on the mold-core. Then it was heated above the transition temperature T_g of glass. At this temperature, the glass substrate with columnar array structure was formed with increased pressure applied to the upper mold under the load control. Subsequently, the glass substrate was cooled slowly under constant holding pressure. Finally, the glass substrate and mold-die were rapidly cooled to the room temperature.

The molding process of glass substrate was conducted through PF-LF60A Glass Molding Equipment (SYS Co., Ltd., Japan). The photo and schematic of the equipment are shown in Fig. 2. During the whole molding process, the chamber was filled with nitrogen gas to form an anaerobic environment to prevent the mold-die from oxidation and adhesion with the glass substrate. The experimental conditions are shown in Table 1.



(a) (b)

Fig. 2 Glass molding equipment (PF-LF60A): (a) structure diagram; (b) schematic diagram.

After molding process, the glass substrate was cleaned with ethanol and deionized water respectively for 10 min in an ultrasonic cleaner in order to remove organics and dust. Then it was dried at 120℃ in an oven. Subsequently, 1H, 1H, 2H, 2H-perfluorodecyltriethoxysilane and ethanol with a mass ratio 1:100 were added in mixed solvent under stirring at ambient temperature for 10 min. The glass substrate were immersed into fluoroalkylsilane solution for 40 min, and heated at 120℃ for 10 min to achieve superhydrophboic performance.

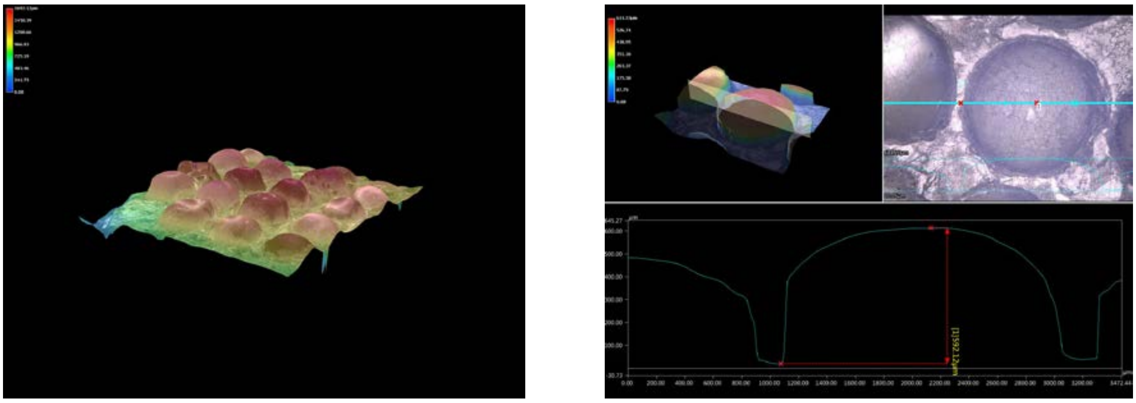
Table 1 Experimental Condition

Molding Parameters	Value
Pressing temperature (℃)	580
Pressing Pressure (MPa)	0.12
Cooling rate (℃/s)	1
Holding pressure (MPa)	0.1

Characterization. The morphology of the glass surface with columnar array after glass molding process was characterized by three dimensional laser scanning microscope (VHX-1000, Keyence, Japan). Deionized water droplets of about 15 μL were carefully dropped onto the glass surface through a syringe from the height of 5 mm above it. Contact angle were measured at ambient temperature. Five measurements were utilized at different positions to obtain the average value.

Results and discussion

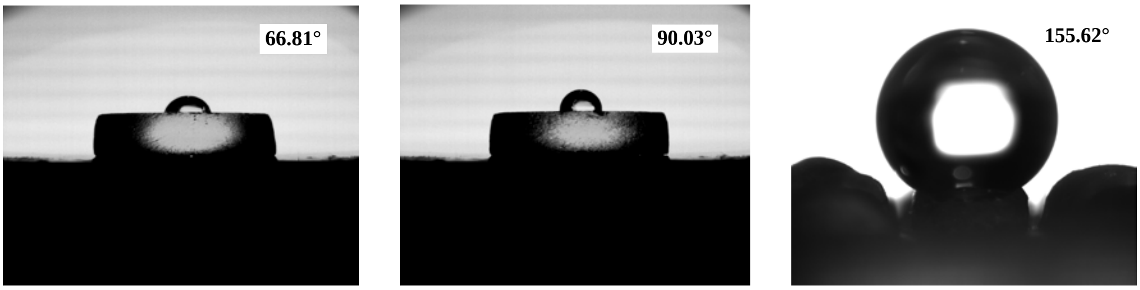
The 3D morphology and profile of the glass surface with columnar array are shown in Fig. 3. After glass molding process, the glass surface has multiple protruding micro column structure. The diameter of the micro column structure is about 2 mm and the height is about 600 μm. In addition, the space between two adjacent micro columnar structures is about 200 μm.



(a) (b)

Fig. 3 Morphology of glass surface with columnar array: (a) 3D morphology; (b) profile.

The contact angle of the original glass surface and the columnar array glass surface were measured as shown in Fig. 4, respectively. Fig. 4(a) shows that the original glass surface has hydrophilicity and its contact angle is 66.81°. After modification of fluoroalkylsilane solution, its contact angle rises to 90.03°, as shown in Fig. 4(b). In order to realize superhydrophobic glass surface with high-efficiency fabrication, the columnar array structure was fabricated subsequently on the original glass surface by glass molding process. And the glass surface exhibits superhydrophobic property after chemical modification. This transition of the glass surface wettability mainly due to the influence of the molded micro columnar array structure. And the contact angle of the glass surface with columnar array becomes 155.62°, as shown in Fig. 4(c).



(a) (b) (c)

Fig. 4 Contact angles of the glass surface: (a) original glass surface; (b) modified glass surface; (c) glass surface with columnar array after chemical modification.

Summary

In the present study, we fabricated superhydrophobic glass surface with columnar array by utilizing glass molding process and coating the surface with a layer of fluoroalkylsilane solution. Superhydrophobic phenomenon was present on the prepared glass surface whose columnar diameter = 2 mm, columnar height = 0.6 mm, and the space = 0.2 mm. Moreover, this glass surface exhibited good superhydrophobic property with contact angle = 155.62°. Meanwhile, its fabrication was efficiency and low-cost. This work resolved the problem that the superhydrophobic is difficult to achieve on the hard and brittle material surface over large-area fabrication. This will promote the practical applications of the superhydrophobic glass surface.

References

[1] Q. David, Wetting and Roughness, Annual Review of Materials Research. 38 (2008) 71-99.

[2] L. P. Wen, T. Ye and J. Lei, Bioinspired Super-Wettability from Fundamental Research to Practical Applications, Angewandte Chemie International Edition. 54 (2015) 3387-3399.

[3] N. Akira, A. Kouki, H. Kazuhito and W. Toshiya, Preparation of hard super-hydrophobic films with visible light transmission, Thin Solid Films. 376 (2000) 140-143.

[4] Y. Yang, X. J. Li, X. Zheng, Z. Y. Chen, Q. F. Zhou and Y. Chen, 3D-Printed Biomimetic Super-Hydrophobic Structure for Microdroplet Manipulation and Oil/Water Separation, Advanced Materials. 30 (2018) 1704912.

[5] J. S. Liang, K. Y. Liu, D. Z. Wang, H. Li, P. F. Li, S. Z. Li, S. J. Su, S. C. Xu and Y. Luo, Facile fabrication of superhydrophilic/superhydrophobic surface on titaniumsubstrate by single-step anodization and fluorination, Appl. Surface Science. 338 (2015) 126-136.

[6] Y. Liu, X. M. Yin, J. J. Zhang, S. R. Yu, Z. W. Han and L. Q. Ren, A electro-deposition process for fabrication of biomimetic super-hydrophobic surface and its corrosion resistance on magnesium alloy, Electrochimica Acta., 125 (2014) 395-403.

[7] H. Y. Ji, G. Chen, J. Yang, J. Hu, H. J. Song and Y. T. Tao, A simple approach to fabricatestable superhydrophobic glass surfaces, Applied Surface Science. 266 (2013) 105–109.

[8] S. Sutha, S. Sisira, R. Baldev and K. R. Ravi, Transparent alumina based superhydrophobic self-cleaning coatings for solar cell cover glass applications, Solar Energy Materials and Solar Cells. 165 (2017) 128-137.

[9] F. Zhang, Z. W. Shi, Y. J. Jiang, C. Y. Xu, Z. H. Wu, Y. Y. Wang and C. S. Peng, Fabrication of transparent superhydrophobic glass with fibered-silica network, Applied Surface Science. 407 (2017) 526-531.

[10] Y. Yuan, Y. Z. Duan, Z. P. Zuo, L. J. Yang and R. J. Liao, Novel, stable and durable superhydrophobic film on glass prepared by RF magnetron sputtering, Materials Letters. 199 (2017) 97-100.

[11] S. H. Yin, H. P. Jia, G. H. Zhang, F. J. Chen and K. J. Zhu, Review of small aspheric glass lens molding technologies, Frontiers of Mechanical Engineering. 12 (2017) 66-76.