Surface & Coatings Technology 319 (2017) 213–218

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Wettability of microstructured Pyrex glass with hydrophobic and hydrophilic properties

Dong-Ki Lee [a], Young Hak Cho [b], Jong Whi Lee [b], Min Soo Park [b],*

[a] Graduate School of NID Fusion Technology, Seoul National University of Science and Technology, 232 Gongneung-ro, Nowon-gu, Seoul 01811, South Korea
[b] Department of Mechanical System and Design Engineering, Seoul National University of Science and Technology, 232 Gongneung-ro, Nowon-gu, Seoul 01811, South Korea

ARTICLE INFO

Article history:
Received 17 January 2017
Revised 3 April 2017
Accepted in revised form 10 April 2017
Available online 11 April 2017

Keywords:
Grooved hybrid surface
Hydrophobicity
Hydrophilicity
Laser-induced backside wet etching (LIBWE)
Wettability
Anisotropic wetting

ABSTRACT

A grooved hybrid surface that has silane-coated surface (hydrophobic surface) on ridges and uncoated surface (hydrophilic surface) inside groove was fabricated on a Pyrex glass substrate through the laser-induced backside wet etching (LIBWE) process. The wettability characteristics of the grooved hybrid surface were evaluated from static contact angles (CAs) measured in parallel and orthogonal directions. With an increase in the width of the hydrophobic ridge, the CAs increased from 24° to 104° in the parallel direction. Consequently, the anisotropic wetting property of the fabricated hybrid surface was confirmed. Results of moisture condensation experiments indicated that moisture condensed rapidly in the hydrophilic grooves. Furthermore, the diffuse reflection of light was prevented when the groove was completely filled with water.

1. Introduction

Superhydrophobic or superhydrophilic surfaces with distinct wettability characteristics have been studied for various anti-fogging [1–3] and self-cleaning [4,5] applications. The wettability of water on a solid surface is determined by the surface energy of a solid material and the surface roughness, which is defined as the ratio of the actual surface area to the projected surface area. Increasing the surface roughness of a solid material with low surface energy will usually increase the hydrophobicity of the material. In contrast, increasing the surface roughness of a solid material with high surface energy will usually increase the hydrophilicity of the material [6]. Fabrication of a suitable microstructured or nanostructured surface, which can control roughness, is generally necessary for achieving superhydrophobic or superhydrophilic surfaces since it is difficult to fabricate superhydrophobic or superhydrophilic surfaces directly on flat materials. Water droplets on these artificially fabricated superhydrophobic or superhydrophilic surfaces can exist in either the Cassie–Baxter state or the Wenzel state [7]. A water droplet in the Cassie–Baxter state is suspended on top of a textured surface with trapped air underneath. In contrast, a water droplet in the Wenzel state fills the space and has a low CA. A water droplet in this state is pinned to the surface.

Given the advantages of a hybrid surface originating from the extreme difference in wettability between its superhydrophilic and superhydrophobic regions, many studies have focused on various applications of hybrid surfaces, such as in chemical reactions [8], water harvesting [9–11], heat transfer [12,13], microfluidics systems [14], and cell biology [6,15]. Glass-based materials with excellent light transmittance, hardness, and chemical stability have been evaluated for changing the glass surface wettability [16,17]. Recently, Zahner [18] and Neto [19] fabricated hybrid surfaces with hydrophobic and hydrophilic properties on glass substrates by using photolithography processes, which are usually used for patterning a polymer material such as ultraviolet (UV) resin. However, these fabrication processes have several disadvantages, such as the following. A hybrid surface cannot be fabricated in a large area, and flexible manufacturing of the desired structure is difficult because of the requirement of a specific mask and a polymer material in photolithography processes. In other words, existing processes have low flexibility in shape change, so they cannot rapidly fabricate various design patterns on large-area substrate. Accordingly, Yu [20] reported a fabrication method for a nano-scale structured superhydrophobic or superhydrophilic surface on a glass substrate directly through the anisotropic wet etching process. However, such a structure is irregular and it can break easily under external stress. Moreover, the superhydrophobic and superhydrophilic surfaces are fabricated separately in this method, which makes fabrication of the desired hybrid surfaces difficult.

A previous study examined the wettability of hybrid surfaces with a geometrical structure constrained by the material (e.g., silicon [21])

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* Corresponding author.
E-mail addresses: dklee1124@seoultech.ac.kr (D.-K. Lee), yhcho@seoultech.ac.kr (Y.H. Cho), electric_ai@naver.com (J.W. Lee), pminsoo@seoultech.ac.kr (M.S. Park).

http://dx.doi.org/10.1016/j.surfcoat.2017.04.022
0257-8972/

because of the difficulty in direct machining of a brittle glass substrate. Direct machining of a glass substrate may cause damage to the substrate or to the machine tools during the machining process. Non-contact and unconventional machining methods (e.g., the electrochemical discharge [22], abrasive jet [23], and laser machining [24] methods) are generally used to machine a micro-structure on a glass substrate. Laser machining, which is a non-contact machining method, offers the advantages of a high machining speed and the non-requirement of tools. However, this method also has the disadvantages of high equipment cost because an ultra-short pulse laser is required to emit a large amount of energy in a short time for glass machining with high light permeability.

The present study overcomes the above mentioned drawbacks by fabricating a grooved hybrid surface with ridges of various widths on a Pyrex glass substrate through the laser-induced backside wet etching (LIBWE) process using a relatively inexpensive near-IR laser. Previous studies presented that a nanosecond laser with a short wavelength should be used in the LIBWE process because reducing their beam size is easy, and they have a low reflectivity [25,26]. In a recent study, a near-infrared laser with a relatively low cost and a high power irradiation was used for the LIBWE process [27]. Also, a grooved hydrophobic surfaces with a high CA (i.e., greater than 150°), a grooved hydrophilic surfaces with a low CA (i.e., under 30°) were prepared. Static CAs were evaluated and analyzed according to various geometric parameters on different surfaces. We also confirmed that water filled the groove with a hydrophilic surface after dipping the grooved hybrid surface in water. Then, the effects of the water occupying the grooves on the light permeability after immersion are evaluated from microscope images.

2. Experimental setup

2.1. Fabrication of grooved hybrid surface

Fig. 1(a) shows a schematic view of fabrication processes for the grooved hybrid surface. A pulsed fiber laser (SPI Lasers, Nd:YAG) was used for the LIBWE process in the study. The laser had a wavelength of 1064 nm, maximum pulse repetition of 500 kHz, maximum power of 20 W, and pulse duration of 200 ns. An F-theta lens with a focal length of 163 mm was used to concentrate the laser beam in the microstructure fabrication by using a galvanometer. The laser had a spot size of 55 μm on the glass surface. The substrate was Pyrex glass with a size of 25 × 25 mm and a thickness of 0.7 mm. The glass substrates used for the fabrication of grooved hybrid surface were first cleaned in acetone and isopropyl alcohol (IPA) solutions. The substrates were then rinsed in deionized water by using an ultrasonic bath. A silane coating was performed in order to convert the hydrophilic property of the glass to hydrophobic property. Generally, the degree of hydrophobization varies depending on the silane coating method [28]. Vapor deposition was used in this study, which was a coating method to obtain a hydrophobic surface easily [29,30]. The substrate along with 2–3 drops (use pipet) of tridecafluoro-1,1,2,2-tetrahydrooctyltrichlorosilane in petri dish was placed in vacuum desiccator for 30 min at 20 °C, $\sim 10^{-2}$ atm. The grooved hybrid surfaces with height of 10 μm, groove width of 200 μm, and ridge of various widths were fabricated on silane-coated glass substrates through the LIBWE process by using a 50 kHz and 0.4 mJ laser. The scan speed of the laser beam was set to 300 mm/s to prevent damage to the glass substrates. The laser irradiation was repeated 550 times up to the height of 10 μm. Ridges of various widths (i.e., 25, 50, 100, 200, 300, and 400 μm) were fabricated by controlling the laser beam path with the EzCAD software. Finally, the topographies of the grooved hybrid surfaces were investigated using a surface-scanning confocal laser profiler (LT-9010 M, Keyence). The measurement spot was 2 μm in diameter, and the measurement resolution was 10 nm. Additionally, the grooved hydrophilic surfaces were fabricated by the LIBWE process without chemical treatment. The grooved hydrophobic surfaces were fabricated through chemical treatment after the LIBWE process. Fig. 1(b) shows schematic view of the fabricated specimens.

2.2. CA measurement

A CA goniometer (KSV CAM-200) was used to measure the static CAs of water droplets on the grooved surfaces. First, 0.5 μL of water droplets was dropped on the grooved surfaces by using automated dispenser. Then, the CAs were measured from the images captured by the computer software. In this study, all the CAs measurements were conducted five times on each specimen under the condition such as 1 atm, 20 °C and a relative humidity level of 65%, and their average values were used. Also, all the CAs were measured in direction parallel and orthogonal to the grooved lines (Fig. 2), because the grooved surfaces exhibited an anisotropic wetting property in certain structural direction. Further, measurements of the water droplets on the grooved hybrid surfaces were performed from the top by using a microscope. Accordingly, the effects of the grooved hybrid surfaces on the wetting property were determined through a comparative analysis of the resulting water droplet shape.

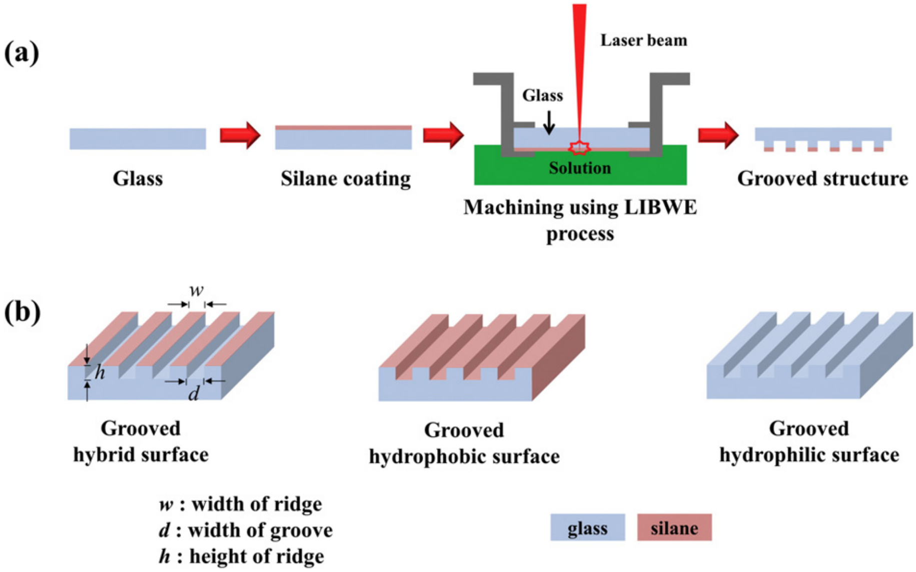

Fig. 1. (a) Schematic view of the fabrication processes for the grooved hybrid surface. (b) three types of specimens.