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Fabrication of superhydrophobic/superhydrophilic patterns on polyimide surface by ultraviolet laser direct texturing

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ABSTRACT

This paper presented a single-step processing method to fabricate either superhydrophobic or superhydrophilic patterns on different regions of polyimide surface by ultraviolet laser direct texturing. The effects of laser power intensity and pulse overlap on surface wettability were studied. When the laser power intensities applied were low ($< 5.5 \times 10^5$ W/cm^2), the wettability of polyimide surface would transform from pristine hydrophilicity to superhydrophobicity with an increase of the pulse overlap. However, when the laser power intensities applied were high ($> 5.5 \times 10^5$ W/cm^2), superhydrophilic surfaces could be obtained with increasing the pulse overlap. Thus, either superhydrophobic or superhydrophilic patterns would be fabricated by adjusting the laser power intensity and pulse overlap. Scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), Fourier transform infrared (FT-IR) spectroscopy, and water contact angle meter were employed to characterize the physical and chemical properties of the laser-textured surface, respectively. The results showed that surface roughness and chemical compositions were varied by changing these two laser parameters, and both the surface roughness and the surface chemistry contributed to the change of wetting behavior of polyimide patterns. The convenient and efficient method to create the patterns with superhydrophobicity and/or superhydrophilicity would have the potential applications in flexible electronics, microfluidics, bio-technical field, and so on.

1. Introduction

Over the past few decades, more and more attention has been given to fabricate superhydrophilic or superhydrophobic surface for the interest of both fundamental research and practical applications. For instance, superhydrophilic surfaces are good for the improvement of antifogging (Patel et al., 2010), self-cleaning (Son et al., 2012) and adhesive properties (Fateh et al., 2014). A superhydrophobic surface is suitable for self-cleaning of contaminations (Tang et al., 2017), reduction of fluid resistance (Zhou et al., 2011), and ease of cell adhesion (Zhu et al., 2014). Recently the patterns combining of these two extreme wetting properties have drawn more and more attention for their wide applications in microchannel (Hancock et al., 2011), cell screening (Ueda et al., 2012), microfluidics (Ueda and Levkin, 2013) and so on.

In general, the wettability of a material is governed by surface chemistry and roughness. It is possible to obtain the desired wettability by changing these two properties. Several methods have been proposed in the literature for the fabrication of superhydrophobic-superhydrophilic patterns such as ultraviolet (UV)-assisted chemical modification (Songok et al., 2014), plasma chemical treatment (Garrod et al., 2007), atom beam irradiation (Kinoshita et al., 2010) and printing techniques (Sun et al., 2016). For example, Songok et al. (2014) utilized a two-step fabrication process, i.e., high hydrophobic TiO_2 nanoparticle coating and ultraviolet irradiation through a photomask to generate said patterns. Garrod et al. (2007) reported a two-step plasma chemical methodology to fabricate superhydrophobic-superhydrophilic patterns. The method comprised the creation of superhydrophobic background followed by plasma deposition of a hydrophilic polymer.

Kinoshita et al. (2010) generated superhydrophobic-superhydrophilic micro-patterns on a carbon nanotube film using an atom beam facility. Superhydrophobic and superhydrophilic parts were caused by selective exposure to fluorine atom and oxygen atom beams, respectively. Sun et al. (2016) published a method for the fabrication of superhydrophilic-superhydrophobic surface by inkjet printing a sacrificial layer on a superhydrophilic surface. Then, the surface was modified by fluoroalkyl silanes and the printed water-soluble deposit was removed. Although these methods are widely implemented in research, they all have disadvantages for practical use. All of the above-

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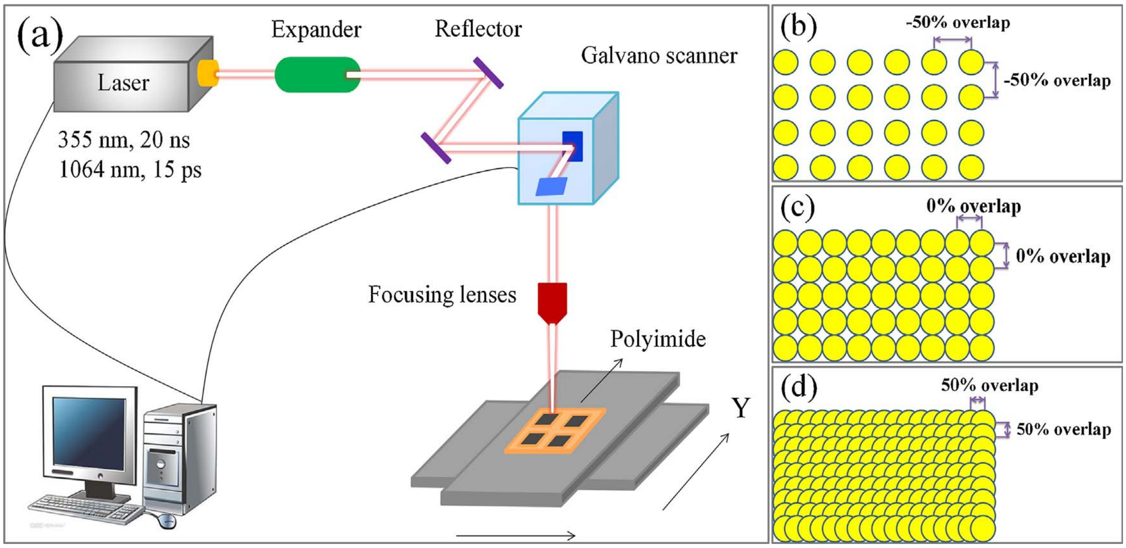

Fig. 1. (a) Schematic diagrams of laser processing system, (b) −50% pulse overlap, (c) 0% pulse overlap, and (d) 50% pulse overlap.

mentioned techniques are multi-step and complex. Furthermore, most approaches require the use of masks, which limit the flexibility in changing the type of patterns. These shortcomings restrict the practical applications of producing superhydrophobic-superhydrophilic patterns. Developing a facile and green method that overcomes these limitations for the fabrication of superhydrophilic-superhydrophobic surface remained a big challenge.

Laser direct texturing is a competitive method for inducing significant changes in surface chemistry and roughness, and then affecting the wetting property. It is a simple, non-contact and selective fabrication technology, which can be applied to various types of materials, including metals, ceramics and polymers. There are mainly two aspects of studies on the use of laser for controlling wettability of materials. The first one is the fabrication of one type of extreme wettability (i.e., superhydrophobicity or superhydrophilicity) by laser texturing. Liang et al. (2014) employed femtosecond laser ablation to prepare superhydrophobic polytetrafluoroethylene (PTFE) surfaces. Tseng et al. (2010) fabricated superhydrophilic patterns on a silicon surface using a pulsed Nd:YAG laser. The other one is the fabrication of superhydrophobic-superhydrophilic patterned surfaces by laser irradiation with the assist of chemical treatment. Lee et al. (2014) fabricated superhydrophobic-superhydrophilic patterns on aluminum specimen. First, the whole superhydrophobic surface was obtained by chemical modification, and then, the surface was patterned by laser irradiation to achieve selective superhydrophilicity.

Polyimide (PI) has been widely used in different fields, like microtechnology and aerospace industry due to its high performance, such as good mechanical property, good dielectric property and high thermal stability (Zheng et al., 2012). However, because of the mediocre wetting property, it has limited practical applications in microelectronics (Meddeb et al., 2016) and microfluidic device (Scheen et al., 2011). Some researchers have studied the modification of polyimide wetting properties by laser ablation. Least and Willis (2013) realized hydrophobic polyimide surface by low fluence ablation using a pulsed, frequency tripled Nd:YLF laser. Oliveira et al. (2010) created superhydrophobic polyimide surfaces using KrF laser ablation at fluence above the ablation threshold. However, to the best of our knowledge, none of the previous works have reported on the one-step fabrication of either superhydrophobic or superhydrophilic patterns on different regions of polyimide surface. Hence, an attempt has been made to fabricate the said patterns and this is of great interest to the present work.

In this paper, we demonstrated a facile technique for the fabrication of either superhydrophobic or superhydrophilic patterns on different regions of polyimide surface just by ultraviolet laser direct texturing. Different wetting behaviors were realized by controlling the laser power intensity and pulse overlap. The textured surface could exhibit extreme wetting properties of superhydrophobicity or superhydrophilicity. Combining these two extreme wetting properties in two-dimensional patterns on polyimide surface would have considerable potential in microelectronics and microfluidic devices.

2. Experiment section

2.1. Material

PMDA-ODA polyimide films with a thickness of 50 μm from Shenzhen Nuoyishun electronics Co. Ltd (Guangdong, China) were used in the experiment. Before UV laser texturing, polyimide films were cut into small samples, and then ultrasonically cleaned in acetone and deionized water for 10 min, respectively.

2.2. Experimental methods

A nanosecond pulsed UV laser (355 nm wavelength, third harmonic of a Nd:YAG laser) with maximum output power of 9.5 W and maximum repetition rate of 100 kHz was used for this experiment. The laser beam had a Gaussian energy density profile and the focused diameter at $1/e^2$ of its maximum intensity was approximately 10 μm. An F-Theta objective lens ($f = 103$ mm) and a two mirror galvo-scanning system were used to focus and scan the beam in the x-y direction. The laser beam was scanning line by line in the horizontal direction with single pass. Two main processing parameters with respect to the wetting properties were selected by experimenting with laser power intensity and pulse overlap. The overlap corresponding to horizontal direction was the same as vertical direction. The power intensity was adjusted in the range of 2.6×10^4 W/cm^2 to 2.0×10^6 W/cm^2. The pulse overlap varied from 10% to 90% at low power intensity and from −40% to 40% at high power intensity. A simple schematic diagram of the laser processing system was shown in Fig. 1a. Fig. 1b–d showed the pulse overlap was −50%, 0% and 50% respectively. To remove the debris after laser texturing, polyimide samples were blown with high-pressure argon (Ar) gas, which could avoid the effect of water ultrasonic cleaning on surface chemistry.