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Non-textured laser modification of silica glass surface: Wettability control and flow channel formation

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ABSTRACT

Local wettability of silica glass surface is modified by infrared laser irradiation. The silica glass surface exhibits hydrophobic property in the presence of $-CF_3$ or $-(CH_3)_2$ terminal functional groups, which are decomposed by thermal treatment, and degree of the decomposition depends on the applied heat. Laser irradiation can control the number of remaining functional groups according to the irradiation conditions; the contact angle of deionized water on the laser modified surfaces range from 100° to 40°. XPS analysis confirms that the variation in wettability corresponds to the number of remaining $-CF_3$ groups. The laser irradiation achieves surface modification without causing any cracks or damages to the surface, as observed by SEM and AFM; moreover, surface transparency to visible light and surface roughness remains unaffected. The proposed method is applied to plane flow channel systems. Dropped water spreads only on the hydrophilic and invisible line modified by the laser irradiation without formation of any grooves. This indicates that the modified line can act as a surface channel. Furthermore, self-transportation of liquid is also demonstrated on a channel with gradually-varied wettability along its length. A water droplet on a hydrophobic side is self-transported to a hydrophilic side due to contact-angle hysteresis force without any actuators or external forces.

1. Introduction

Surface wettability is one of the important properties for various surface applications, for example, fluid operation in lab on chips (LOC) or micro-total analysis systems (μTAS) [1–4]. Wettability is determined by surface energy, which depends on material composition, surface texture, and surface terminal groups. Wenzel [5,6] and Cassie [7] reported a relationship between surface texture and wettability, known as the Wenzel or Cassie equation. The Lotus effect, which is a well-known superhydrophobic phenomenon, is based on the effect of surface micro-texture on wettability. Industrially manufactured superhydrophobic surface was also realized by obtaining high-energy-density laser-induced micro- or nano-texture in one instance [8–10].

The effect of functional terminal group on wettability is also widely known and applied in various industries. For example, terminal trifluoromethyl group ($-CF_3$) leads to a high contact angle [11] and is used for mold release agents [12], water-repellent coatings [13] and anti-contamination coatings [14]. On the other hand, some terminal groups, such as hydroxyl group (—SiOH), result in a low contact angle or hydrophilicity [15].

Liquid spreads preferentially on a highly wettable surface; therefore, a locally modified surface with high-wettability can perform as a micro-channel. On the boundary of a high- and low-wettability surface, a liquid droplet is subject to contact angle hysteresis force and moves toward the high-wettability region; this phenomenon is applied to transport water droplets without involving any external forces. Conventionally, micro-channels consist of grooves formed by micro-milling [16,17], electrochemical discharge machining [18], short-pulse laser machining [19–22], and photo-lithography [23]. Although highly complex and precise micro-systems can be fabricated using these techniques, some of them require special and expensive equipment, cleaning process for removing debris or resist material, and multiple steps. Furthermore, conventional machining processes are often difficult to apply to materials with high corrosion resistance, electrical resistivity, and brittleness such as silica glass. Laser irradiation was previously proposed as a method for local modification of surface wettability of silicon and borosilicate glass and applied to designing novel surface channels based on the difference of wettability [24]. The mechanism of laser surface modification would relate to mainly two effects; one is increase of surface roughness by laser irradiation, which causes decrease of the contact angle. Another is decompo-

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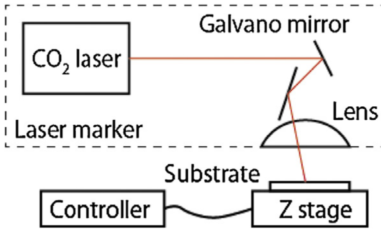

Fig. 1. Schematic of the laser equipment.

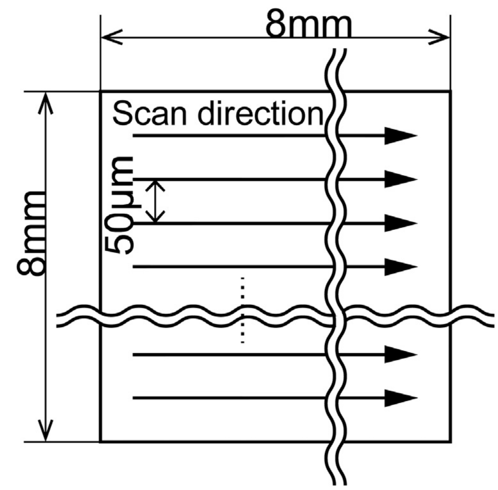

Fig. 2. Schematic of laser-induced surface modification.

sition of surface functional terminal groups because some of them are sensitive to heat. The second mechanism can be implemented using a conventional laser marker without engraving a groove on the surface.

The problems associated with the above-mentioned local laser modification are unstable wettability of the as-received surface and small variation of contact angle before and after laser irradiation. The as-received silicon surface, which is covered with a natural oxide layer, had a contact angle of around 40°. The decrement was around 10° after modification without surface morphology change and it was only around 20° even with morphology change [24]. The small decrement in contact angle causes difficulty in precise control of the contact angle and enhancement of contact angle hysteresis.

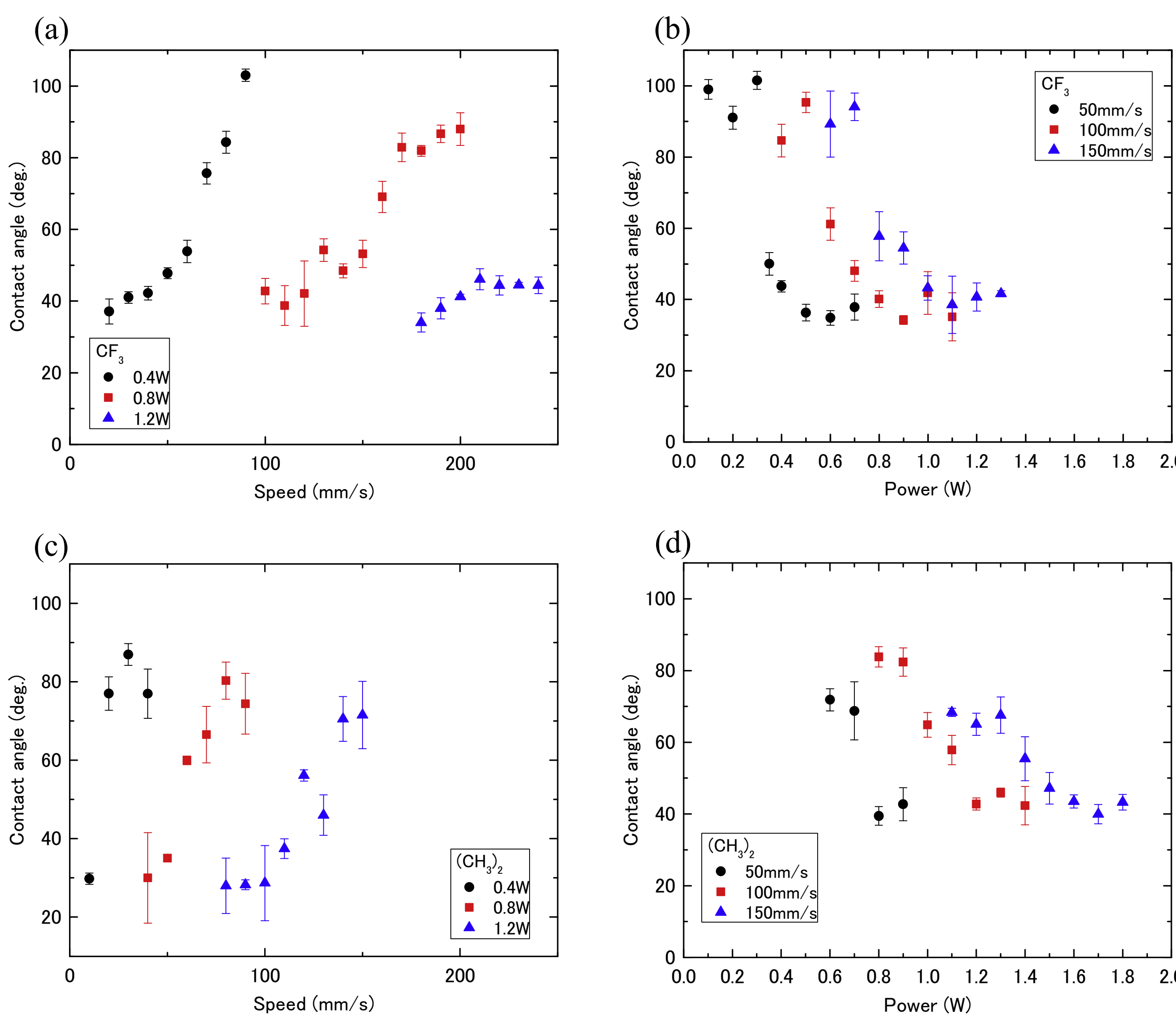

Fig. 3. Contact angles after laser modification for (a), (b) CF_3 treatment, and (c), (d) $(CH_3)_2$ treatment. Modification were carried out under different (a), (c) scanning speed and (b), (d) laser power.