FABRICATION OF VERTICAL AND HIGH-ASPECT-RATIO GLASS MICROFLUIDIC DEVICE BY BOROSILICATE GLASS MOLDING TO SILICON STRUCTURE

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ABSTRACT

We propose a fabrication method of vertical and high-aspect-ratio microfluidic device which is made of borosilicate glass. Glass microfluidic devices have high demand because of its chemical stability, good bio compatibility, and high optical transparency. We realized vertical glass microwells of 25 µm in diameter and 50 µm in depth(aspect ratio: 2), and micropillars of 3 µm in diameter and 25 µm in height (aspect ratio: ≈ 8). We also realized microfluidic device with pillars in the microchannel.

KEYWORDS: High-aspect ratio, Borosilicate glass, Thermal molding, Glass molding

INTRODUCTION

The glass equipments are the most widely used instrument in the field of biology and chemistry for its chemical stability and high optical transparency. Particularly, the borosilicate glass has the high resistance to thermal shock by its low-thermal expansion. However, because of the difficulty in micromachining of the glass, a lot of microfluidic device has been fabricated by combination of a molded-PDMS structure and a glass substrate.

Figure 1 shows the limitations in the four methods of the conventional glass micromachining: a wet etching, a dry etching, a laser processing, and a mechanical processing. The wet etching is limited to be isotropic and difficulty in the dimension reproducibility by undercutting as shown in Figure 1(a). The metal mask or Si mask is also required for the wet etching preventing from pinhole generation. Whereas the dry etching can realize precise micromachining, the low etching rate and the low etching selectivity between glass and photoresists are problems as shown in Figure 1(b) [1]. The laser processing and the mechanical processing lead to a rough surface and have difficulty in fabrication of the smooth surface [2] as shown in Figure 1(c). Especially, the minimum size of the mechanical workability is depend on the tool bit as shown in Figure 1(d). To solve these problems, we propose a fabrication method of the glass microfluidic device by molding the borosilicate glass to the high-aspect-ratio Si structure which can be easily achieved by DRIE (deep reactive ion etching).

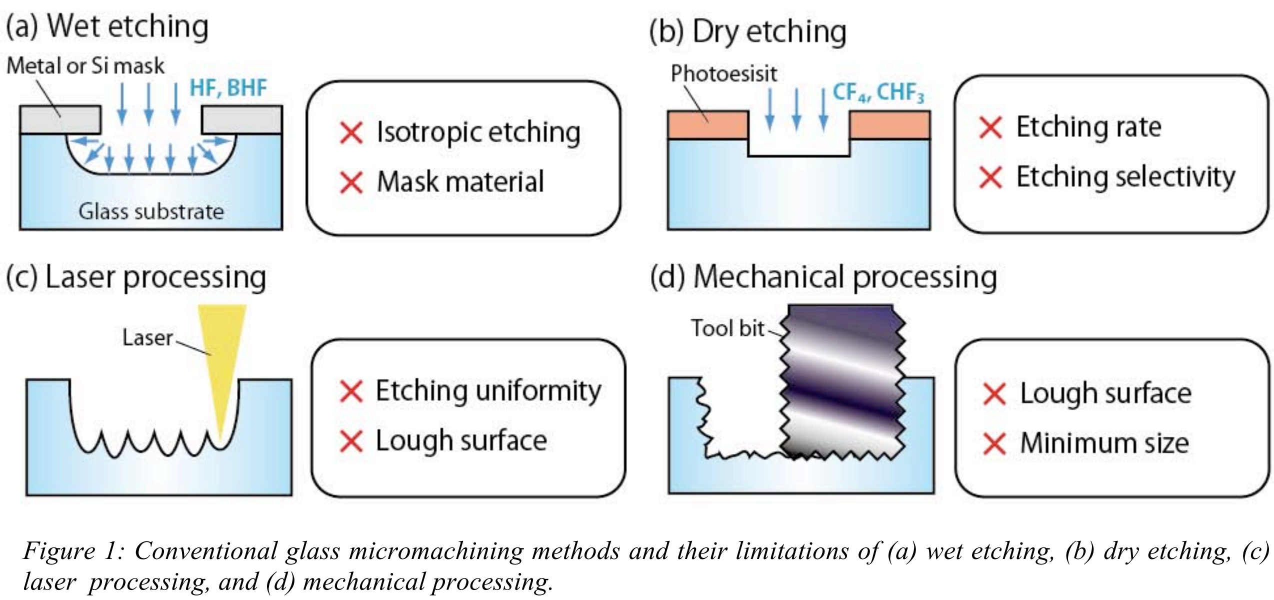

Figure 1: Conventional glass micromachining methods and their limitations of (a) wet etching, (b) dry etching, (c) laser processing, and (d) mechanical processing.

PRINCIPLE

Figures 2 shows the fabrication process of the high-aspect-ratio glass microfluidic device. First, the inverse pattern of the microfluidic device is patterned and etched to the Si substrate to form the mold as shown in Figure 2(a). Next, a bare substrate of the borosilicate glass is bonded to the Si mold under vacuum for eliminating the air from the channel structure of Si mold in Figure 2(b). Then, the bonded Si-glass substrate is heated at 1100˚C for 90 min in Figure 2(c). Because of the glass-transition temperature of the borosilicate glass is around 800˚C, the borosilicate glass is melted to the inverse channel structure of the Si mold. To make the glass surface flat, the glass side of the bonded substrate is polished by CMP (chemical mechanical polishing) as shown in Figure 2(d). Finally, the sacrifice layer etching is carried out to the Si mold by DRIE or wet etching as shown in Figure 2(e).

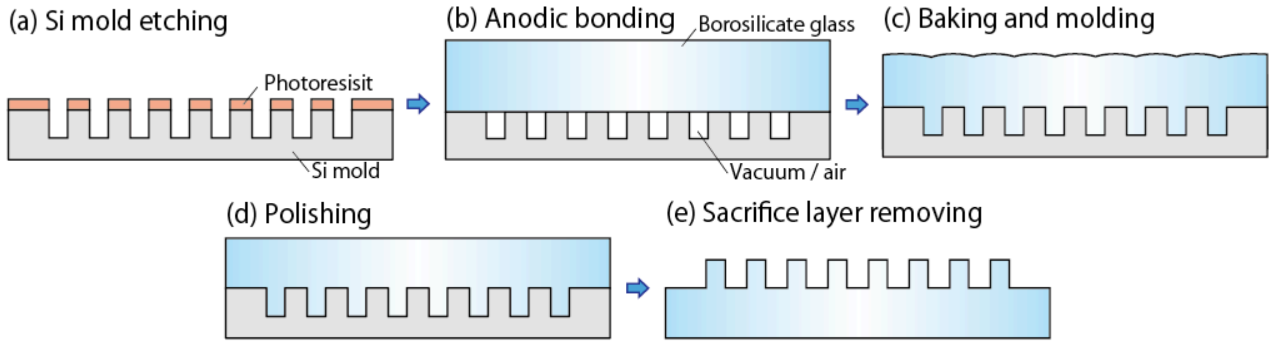

Figure 2: Fabrication process of the vertical and high-aspect-ratio microfluidic device. (a)Si mold is etched by DRIE. (b) Borosilicate glass bonded to Si mold in vacuum by anodic bonding. (c) Molding at 1100˚C. (d) Bottom side is polished. (e) Removing Si mold by Si etching.

EXPERIMENTAL

Si substrate was patterned by photoresist (TSMR-V90, Tokyo Ohka Kogyo, Japan). The inverse channel structure is formed by ICP-RIE (MUC-21, STS, U.K.). Figures 3(a-g) shows the SEM images of Si molds. Figures 3(a-g) show the inverse structures of the Si molds. Figure 3(a) shows the pillars of 25 µm in diameter. The heights of the pillars were 50 µm. Figure 3(b) and Figure 3(c) show the holes of 5µm and 3µm in diameter, respectively. Figures 3(d-g) show the holes which shapes are heart, diamond, spade, clover, respectively. These Si molds were bonded with a bare Borosilicate glass (TEMPAX Float®, Schott, German) by thermal bonding machine (EVG 520, EV Group, Austria). The anodic bonding was carried out by 1000 V under 400 ˚C. The polishing process was carried out by CMP machine (MA-400D, Musashino Denshi, Japan) using the diamond slurry (9 µm) and CeO_2 slurry (0.5 µm). Si mold was etched by KOH and ICP-RIE.

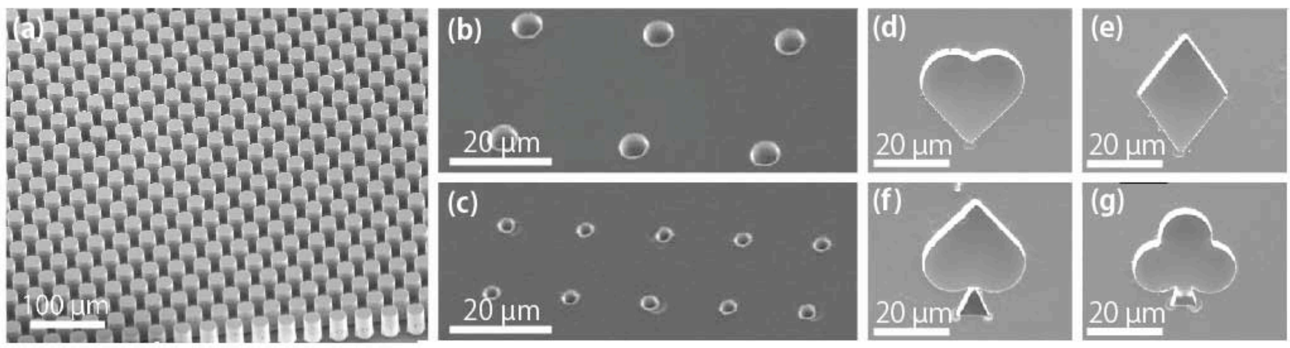

Figure 3: SEM images of the Si molds of the vertical and high-aspect-ratio microfluidic device. (a) pillars of 25 µm in diameter and 50 µm in height (b)(c) Holes of 5 µm and 3 µm in diameter, and about 25 µm in depth. (d (e)(f) 4 symbols of playing cards.

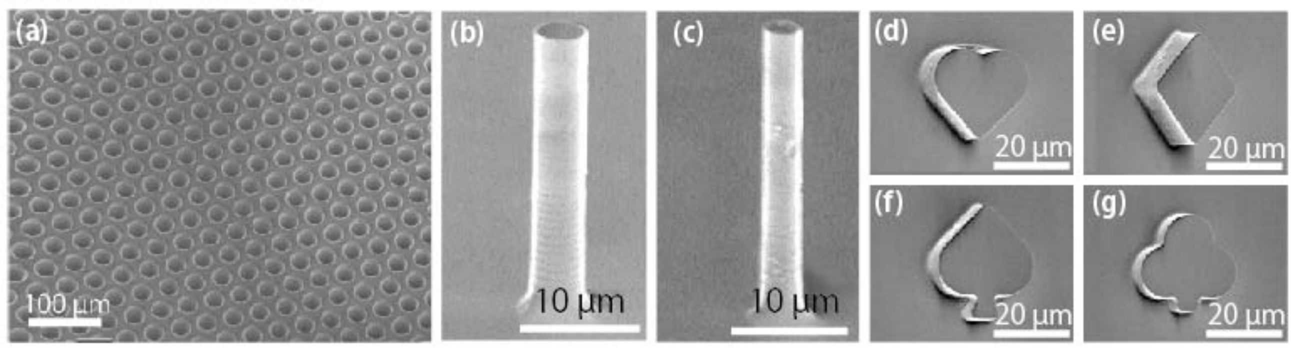

Figure 4: SEM images of molded glass structures. (a) Mold structure of microwells of 25 µm in diameter and 50 µm in depth. (b)(c) Molded micropillars of 5 µm and 3 µm in diameter and 25 µm in height. (d-g) Glass structures of 4 symbols of Playing cards.

Figures 4(a-g) show the molded structures to the borosilicate glass. Figure 4(a) shows the microwells of 25 µm in diameter and 50 µm in height (aspect ratio : 2). Figure 4(b) shows the micropillar of 5µm in diameter and 25 µm in height. Figure 4(c) shows the micropillar of 3 µm in diameter and 25 µm in height (aspect ratio : ≈ 8). Figure 4(d-g) show the glass bump structures of 4 symbols of the playing cards of heart, diamond, spade, and clover. These results confirm that the borosilicate glass was molded along the Si mold precisely. The vertical and high-aspect-ratio glass microfluidic device can be realized by the proposed precise glass molding method.

Figure 5 shows the microfluidic device with pillars in the channel. Figure 5(a) shows the Si mold of the inverse pattern of the microchannel with pillars. Figure 5(b) shows the molded glass microfluidic device of the microchannel with pillars. Figure 5(c) shows the magnified image of pillar structures of 30 μm in diameter.

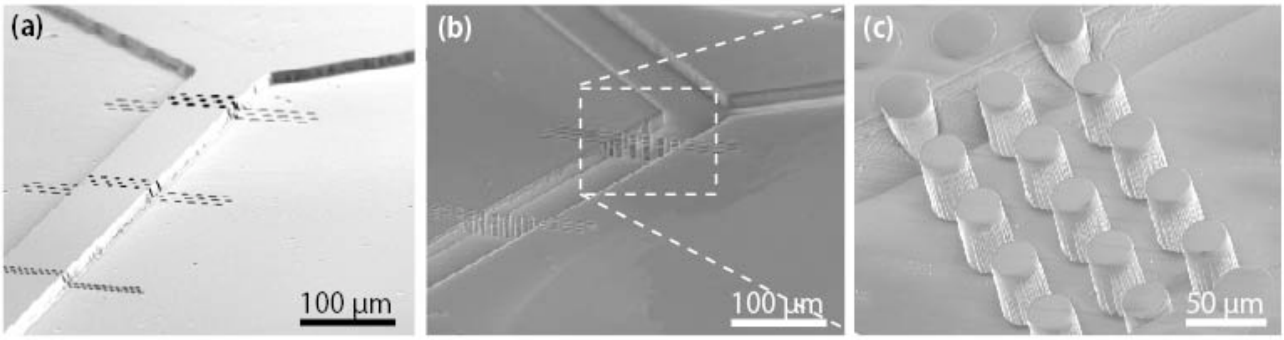

Figure 5: SEM images of fabricated glass microfluidic device. (a) Si mold of the microchannel with pillars. (b) molded glass microfluidic device of the microchannel with pillars. (c) Magnified image of pillar structures of 30 μm in diameter.

RESULTS AND DISCUSSION

We realized vertical, deep (~50 μm), and high-aspect-ratio (≈ 8) glass molding of the borosilicate glass. Additionally, the side scallops originated by the Bosch process of the Si mold are also observed on the sidewalls of the molded glass microwells and microchannels. This result indicates that very precise molding with sub-micron accuracy can be carried out.

CONCLUSION

To solve the difficulty in the glass micromachining, we propose a novel fabrication method of high-aspect-ratio glass molding for the fabrication of the microfluidic device. This process is carried out by conventional semiconductor facilities, so mass production is also possible. The accuracy of the workability is suitable for applications for embedded lens and waveguides in opto-microfluidic devices.

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