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Sub-60 nm Nanofluidic Channels Fabricated by Glass-Glass Bonding

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Abstract- **A simple method is proposed to fabricate channels with a depth in the nanometer range on a borosilicate glass substrate without cost-expensive lithography. Nanochannels are constructed with bulk micromachining by BOE wet etching process. Sub-60 nm deep nanofluidic channels on chip are formed after glass-glass fusion bonding, which are confirmed by using various methods of nanometer scale measurement. The aspect ratio is down to 0.002 in our present experiments. The main advantage of the technique is the transparency of nanochannels, which allows optical fluorescence microscopy to be used for sensitive detection of nanofluidics and microfluidics.**

Keywords: **Nanochannels, Sub-60 nm deep nanofluidic channels, glass-glass fusion bonding**

I. INTRODUCTION

In the last decade, micromachining process has been employed to advance the development of microfluidic systems [1]. Recently, the scale down to nanometer dimensions of the fluidic channels opened a new world for fundamental and applied research of nanofluidics [2]. Nanochannels defined as channels with at least one cross section dimension on the nanometer scale are of great interest for one major reason. The nanometer scale of the channels allows the discovery of a new field, because the channel diameter is of the order of the size of the atoms or molecules comprising the fluid, and physical surface phenomena in nanochannels will dominate over bulk phenomena, more than in microchannels [3]. Therefore, fluid transport and molecular behavior at extremely small dimensions are desirable for investigation.

Nanofabrication of fluidic structures is a powerful tool for the product of nanochannels which are essential components in the nanofluidic system. However, previous fabrication techniques based on e-beam lithography, laser machining, fast atomic beam, focus ion beam, and nanoimprint lithography are all cost-expansive [4]. The key point is that earlier definition of nanochannels is on the cross-section, so the fabrication needs the above mentioned techniques. Now we present a simple fabrication method of 1-D nanochannels down to 60 nm scale by glass-glass bonding [5].

II. EXPERIMENTAL SECTION

A. pattern layout

A simple cross shape of microchannel was generated with the software AutoCAD 2004 and transferred onto a chrome mask as shown in Fig. 1. The channel was drawn with the length of 45 mm and with one of the three width: 10 μm, 30 μm, 50 μm. To achieve the depth depended on the control of the etching time in glass. Because the length of the channel was so long, and the aspect ratio between the depth and the width is so small, it would be a great challenge to avoid the collapse of 1-D nanochannels.

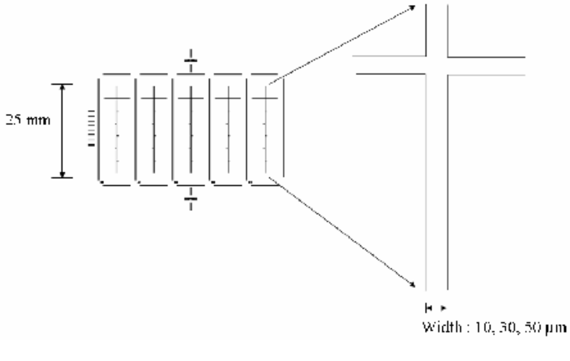


Fig.1. The schematic diagram of the nanofluidic chip.

B. Fabrication process of nanofluidic chips

The nanofluidic chip was fabricated on the substrate of borosilicate glass (Pyrex 7740) wafer. The diagram of the fabrication process is shown in Fig. 2. The glass chip was cleaned in a acetone solution, a piranha solution (H_2SO4: H_2O_2 = 3:1), and DI water in order. Then the dehydration was proceeded by blowing dry with nitrogen gas, and baking in a drying oven.

The fabrication of nanochannels was accomplished by standard photolithography. Because the depth of channels are on the nanometer range, it is not necessary to evaporate a metal film as an etch mask on the surface of glass. In our experiment, photoresist S1813 was coated to transfer patterns into the substrate, and soft baked at 95 ^{o}C for 5 min in a oven. After been exposed by a UV mask aligner, developed in a MF319 solution, the chip was hard baked for 20 min in a oven. Then, we got the thickness of the photoresist in 1.5 µm.

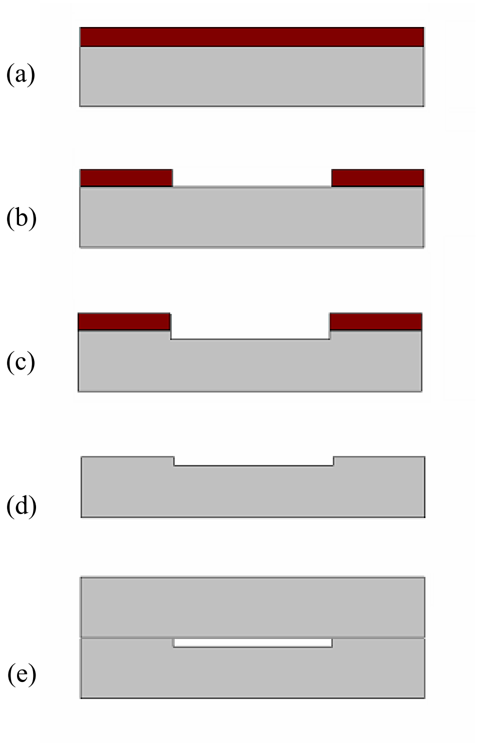


Fig.2. Fabrication process of the nanofluidic chip.
(a) PR coating (b) Photolithography (c) BOE wet etching
(d) PR lift-off (e) glass-glass fusion bonding.

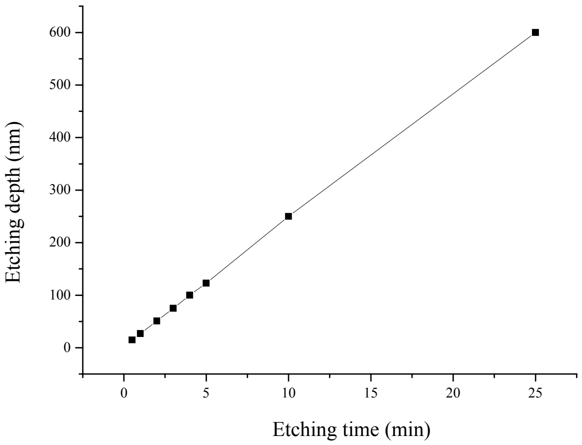


Fig.3. Diagram of the etching rate borosilicate of glass. The etching limitation of the resist for the depth of channels is about 600 nm.

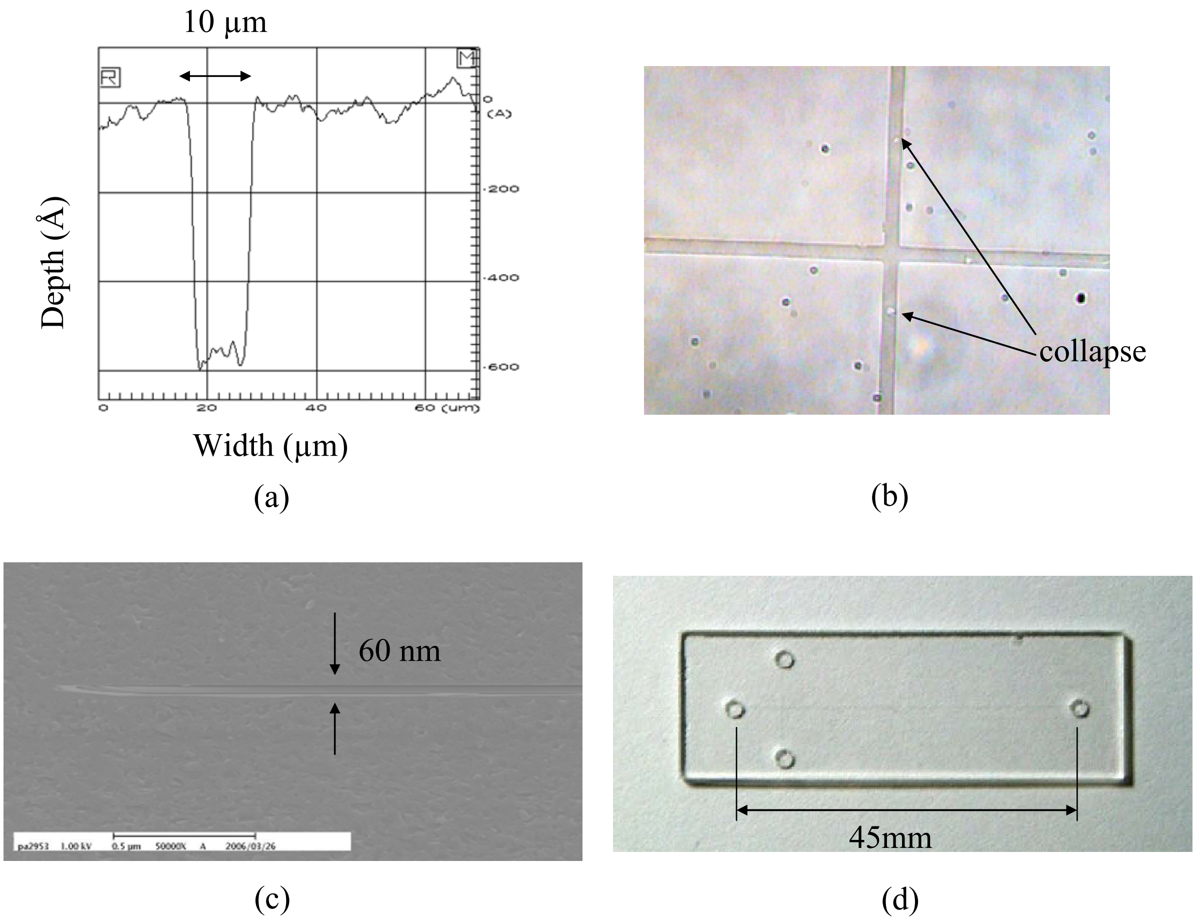
After this, the chip was immersed in a buffered oxide etchant (BOE 7:1) for wet etching at room temperature, directly followed by acetone dipping for 1 min to strip the resist. The depth of the nanochannels was controlled by the etching time, and measured by the surface profilometer. The statistics of the etching rate of borosilicate glass was calibrated in 25 nm/min, as shown in Fig. 3. It was shown that BOE etched borosilicate glass very slow comparing with soda-lime glass.

Before bonding, nanochannel glass and another cover glass with drilled via-holes were both cleaned in a piranha solution for 10 min and DI water for 5 min. Next, the two glass chips were aligned and contact with each other. Finally, thermal fusion bonding was performed in a programmable furnace at 630 ^{o}C in 6 hours with about 1.9~2.5 lb weights of Cu plate.

III. RESULTS AND DICUSSION

The experimental data of the fabrication process are shown in Fig. 4. The nano-dimension of nanochannels was substantiated by various methods of measurement.

Before fusion bonding, the surface profile was first measured by a surface profilometer in Fig.4 (a). It is shown that the depth with 60 nm by etching in 70 sec is



(a) (b)

(c) (d)

Fig.4. Measurements and observation of 10 µm wide and 60nm deep channels (a) roughness by profilometer (b) image by optical microscopy (c) cross section by SEM (d) a vertical view of the nanofluidic chip by digital camera.

the shallowest size in our experiments on account of the purpose of the further nano-effect study. Because the length and the width of nanochannels are long enough to see by optical microscopy, the image of the cross of channels after bonding is shown in Fig. 4 (b). The concave of the channels were obvious and the nanochannel is fabricated near perfectly with only a little collapse. Fig. 4 (c) shows a SEM cross section of a 60 nm height and 10 µm width channel. The internal space of nanochannels after bonding was completely maintained in a uniform trench configuration. Furthermore, there was no apparent interface between the top and bottom was observed.

Since we had confirmed that our fabricating and bonding method of channels was in nanometer scale, nanofluidic chips with various dimension were fabricated subsequently. This time, the depth of nanochannels was defined from 60 nm to 100 nm, width was defined from 10 µm to 50 µm. Fig. 5 shows all of the results of above chips. Accordingly, we found that the bonding temperature, aspect ratio (depth to width) and the applied pressure from gravity would be the critical factors of the successful fusion bonding.

Firstly, if the bonding temperature is lower than 630 ^{o}C, it will take longer to make two glass being fused. Oppositely, if the temperature is surpass 630 ^{o}C, it will

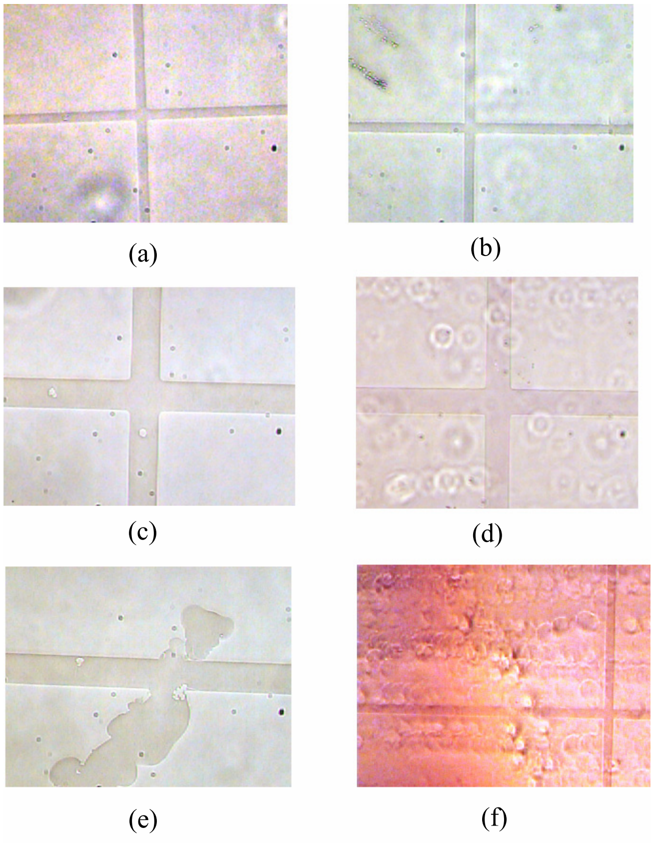


Fig.5. Optical micrograph of other successful (a)(b)(c)(d), damaged (e) or collapsed (f) nanochannels. (a) 10 µm wide and 80 nm deep channels (b) 10 µm wide and 100 nm deep channels (c) 30 µm wide and 80 nm deep channels (d) 50 µm wide and 100 nm deep channels (e) 30 µm wide and 60 nm deep damaged channels (f) 50 µm wide and 80 nm deep collapsed channels

make the channel deformed very easily. So, the optimal bonding temperature is 630 ^{o}C based on our results. On the other hand, there is a cross correlation between the aspect ratio and applied pressure affecting the fusion bonding. Fig.4(b), fig.5(a), fig.5(b) were bonded with 1.98 lb, 2.2 lb, 2.5 lb. respectively. Their aspect ratio were 0.006, 0.008, 0.01. The above results imply that with the smaller the aspect ratio, reducing the applied pressure will be necessary for the fusion bonding of nanochannels. For one step further, under a certain applied pressure due to the minimum weight needed for fusion bonding, to get a larger width must be accompanied with a larger depth at the same time. It was confirmed by the results in fig. 5 (c) and (d). Based on our current technique, the smallest aspect ratio we can get is about 0.002 as fig. 5 (d). The nanochannels would be damaged or collapse if the aspect ratio was lower than 0.002 as Fig. 5 (e) and (f).

IV. CONCLUSIONS

We have demonstrated a simple process to fabricate 60 nm deep nanofluidic channels on a glass chip. We found that to achieve a successful nanochannel, the bonding process seems more critical than etching. Therefore, three parameters of temperature, aspect ratio and applied pressure for the glass fusion bonding were further discussed. We believe that our technology is a valuable tool for making nanochannels. It is the core competence used for nano-fabrication and ultra sensitive detection system in the future, like the nanoelectro- mechanical systems and Micro/Nano Total Analysis Systems.

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