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NOVEL MICROFLUIDIC PLATFORM WITH THROUGH-POLYDIMETHYLSILOXANE MICROTIP ELECTRODE ARRAY FOR ON-CHIP CELL ANALYSIS

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ABSTRACT

This paper proposes a novel concept of electrical feed-through interconnect of the microfluidic platform using conductive microtip electrode array which penetrates into a microfluidic channel through polydimethylsiloxane (PDMS) thin film. As the part of this concept, high aspect ratio microtip electrode with low apex radius and PDMS channel are fabricated and assembled. The proposed scheme has been successfully verified and characterized with the cyclic voltammetry measurement of photosynthetic reaction of a green algae cell in the microfluidic channel.

KEYWORDS

Microfluidic platform, Microtip electrode array, Through-PDMS interconnection.

INTRODUCTION

Conventionally, in-plane deposited metal has been used for the electrical interconnection of the PDMS-based microfluidic chip, through which the electrical signal is applied for particle sorting, electrochemical analysis and sensing with the principle of electrophoresis and dielectrophoresis [1-3].

However, in-plane electrode arrangement has disadvantages of geometric complexity and coupling problem with other electrodes, as the number of associated electrical parts increases. These problems can be a limitation factor when the microfluidic device is used at the applications that require high sensitive sensing of chemical or biological materials.

The aim of our work is the development of vertical feed-through in the microfluidic chip. The vertical feed-through interconnect methods are widely used in the semiconductor technology and MEMS packaging researches [4-6]. Compared to the in-plane designed electrode, the vertical electrical connection has advantages such as small footprint and simple arrangement of the device.

DESIGN

Fig. 1 shows the schematic view of the proposed feed-through interconnect. The microfluidic chip and the conductive microtip electrode array are vertically aligned and pressed for the insertion of the microtip end into the microfluidic chamber. A bottom layer of the fluidic chip is thin PDMS membrane with the thickness of 20 µm and the conductive microtip should have high aspect ratio and small apex radius to be inserted into the microfluidic channel through the thin PDMS membrane. The height of microtip electrode should be several tens of micrometer for penetrating thin PDMS film. In our group, such microtip electrode was researched with fabricating ultra-micro electrodes on the silicon mcirotip array [7].

Due to elasticity of the PDMS membrane and mechanical robustness of the silicon-based microtip, the tip end penetrates easily into the microfluidic channel through the thin PDMS membrane to form vertical feed-through interconnections for the microfluidic chip. If the PDMS film is excessively elastic, microtip electrode will push up the film to the chamber ceiling. In order to prevent this problem, round pillars are designed at appropriate location in the channel.

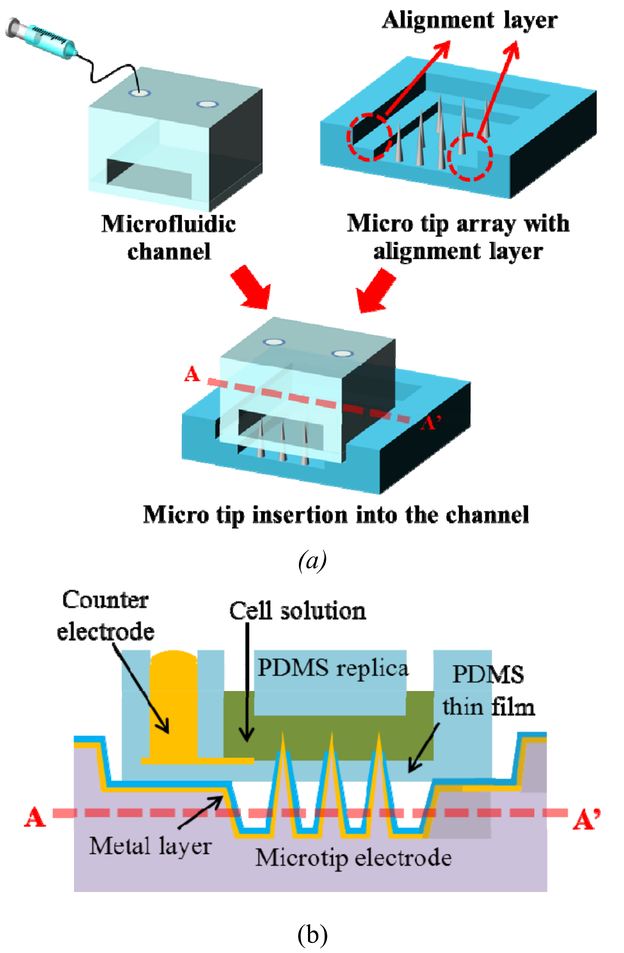


Figure 1: The schematic view of through-PDMS microtip electrode (a), and the cross-sectional view of the proposed concept.

FABRICATION PROCESS

Microtip electrode

The fabrication step of the microtip is shown in Fig. 2. The substrate is p-type, 4-inch diameter, 525-µm thickness wafer. First, SiO_2 is deposited on a silicon wafer as a mask material. Through photolithography and etching step, SiO_2

is patterned as a round etching mask. A silicon substrate is etched vertically to form silicon pillar structures (figure 2(a)). Next, the silicon pillars are etched isotropically using SF_6 gas (figure 2(b)). At this step, silicon microtip structure is fabricated due to etch rate difference between top and bottom of silicon pillar. In our design, a surrounding area of the microtip array should be also etched because height of the microtip is lower than etching mask. For etching of the surrounding area without damaging silicon microtip, viscous photoresist is spin coated and patterned for protecting the end of microtip (figure 2(c)). The surrounding area of the microtip is vertically etched to form an alignment area (figure 2(d)). After removing step of photoresist in the plasma asher, the silicon microtips are coated with Cr/Au/ITO for the conductive layer and SiO_2 for the insulating layer (figure 2(e)). The metal thin films are deposited using sputtering system and SiO_2 is deposited using chemical vapor deposition (CVD). For electrical connection, insulation layer should be revealed only at the tip ends. On the deposited SiO_2 layer, viscous photoresist is spin coated and etched with SiO_2 layer until the metal thin film at the tip end is exposed (figure 2(f,g)). Finally, the remained photoresist at the surrounding area of microtip end is removed and the microtip electrode fabrication is completed (figure 2(h)).

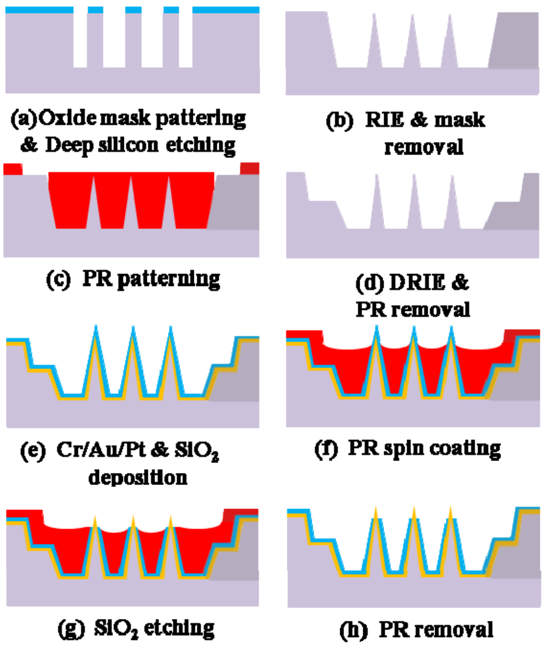


Figure 2: The fabrication process of microtip electrode array.

PDMS microfluidic chamber

First, p-type, 4-inch diameter, 525-µm thickness wafer was etched about 10 µm vertically using deep reactive ion etching (DRIE) process. On the etched silicon mold wafer, fluorocarbon solution was coated to increase surface hydrophobicity, which enables easy peeling of PDMS replica. A PDMS prepolymer (Sylgard 184, Dow Corning) is mixed with a curing agent of 10:1 (w/w) ratio and poured on the mold wafer (figure 3(a)). After curing the PDMS mixture at 70°C for 3 hours, the PDMS replica was detached from mold wafer. The cured PDMS replica was cut into appropriate size and inlet/outlet holes were formed by punching through the cut replica (figure 3(b)).

As shown in figure 3(c), the microfluidic chip is fabricated by bonding PDMS replica and thin film. On the cured PDMS film fabricated on a glass substrate, Ag and Cr/Au/Pt layers are patterned as the reference and counter electrode, respectively. The fabricated PDMS replica and thin film are treated with oxygen plasma and bonded together. After bonding, bonded PDMS molding and film is detached from glass substrate. Using silver epoxy, electrode in the chamber is electrically connected to outside (figure 3(d)). Next, the target cell solution is injected into the chamber for measurement. Finally, the microtip electrode array and the microfluidic chip are aligned (figure 3(e)) and assembled using an acryl jig, which can control vertical pressure in the assembly step with the compressed length of the elastic spring attached to a chip mounting plate (figure 3(f)).

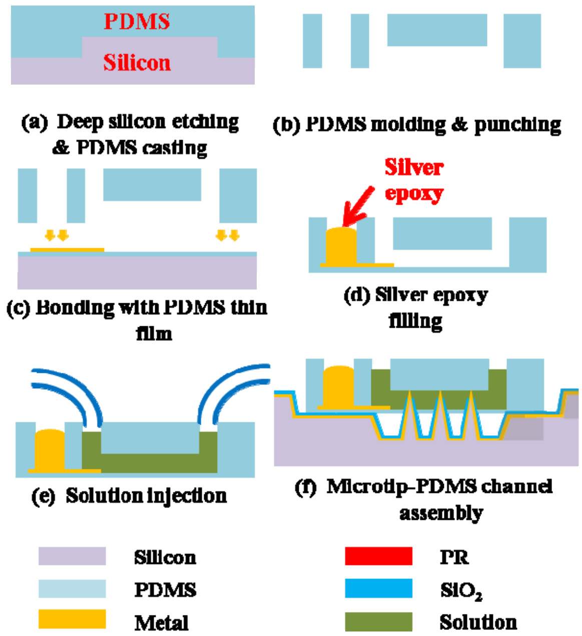
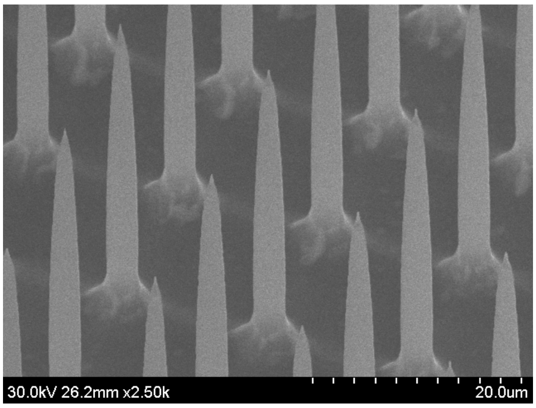


Figure 3: The fabrication process of PDMS microfluidic channel.

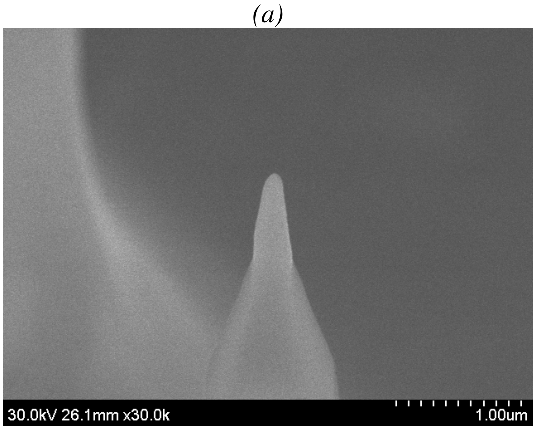
FABRICATION RESULTS

Fabrication results of the microtip are depicted in figure 4. The conductive microtip structure with high aspect ratio, small apex radius and the height of tens of micron scale was fabricated and the conductive layer is insulated except the tip ends. The height of the fabricated PDMS chamber is 10 µm and the thickness of the PDMS film is 23.1 µm (figure 5(a)). Target cell is injected into the channel for measurement, and stacked in the chamber (figure 5(b)).

As shown in figure 6, the microtip end is successfully inserted inside the chamber through the PDMS membrane and well aligned in the fluidic channel. The pillar structure which prevents collapse of the chamber ceiling is fabricated in the channel. After assembly process, some microtip electrodes are embedded in the pillar structure, and others are inserted in the channel inside.

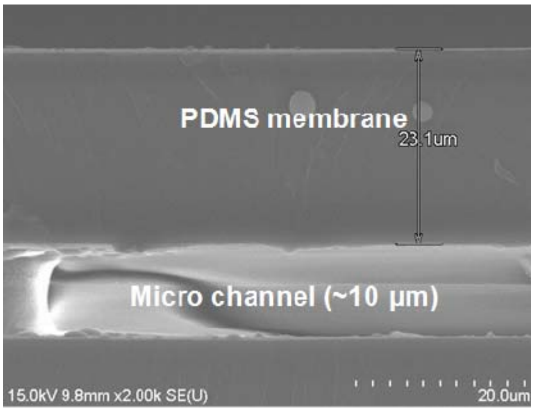


(a)

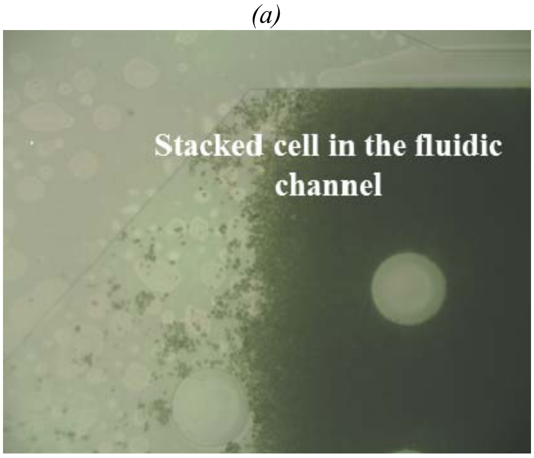


(b)

Figure 4: The fabricated microtip electrode array (a), and the enlarged figure of the microtip end.



(a)



(b)

Figure 5: The fabricated PDMS microfluidic chamber(a) and the injected cells in the chamber(b).

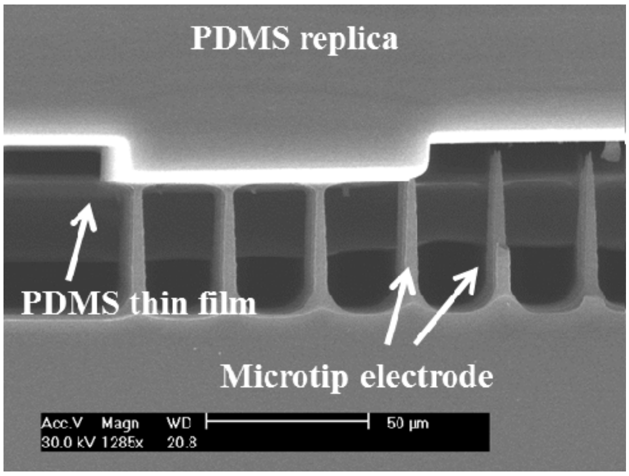


Figure 6: Assembled microtip electrode into PDMS fluidic chip.

MEASUREMENTS

Insertion of the microtip electrode into the fluidic channel after assembly process was characterized by cyclic voltammetry (CV) measurements. Before measurement, chlorella cells which are green algae are injected densely with buffer solution in the fluidic channel. Figure 7 shows the CV measurement results by assembly step. Controlling pressure in the assembly step with the elastic spring compression over 7 mm, current started to be measured and this is the evidence for the insertion of microtip inside the channel. These results show the successful insertion of the microtip electrode into the fluidic channel and possibility of on-chip cell analysis with the proposed feed-through interconnect.

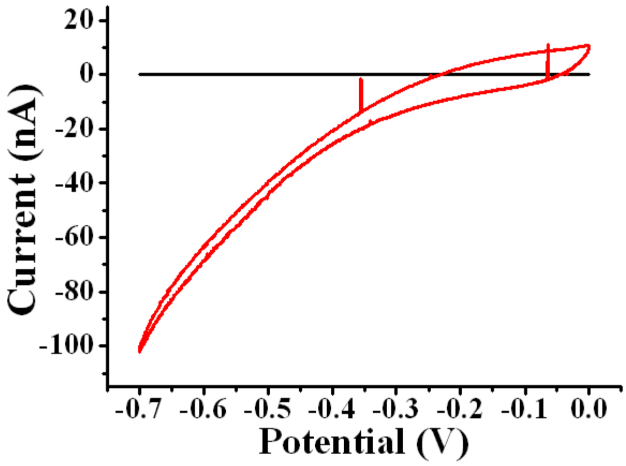


Figure 7: CV measurement results without pressing on the assembly step (black line) and with pressing on the assembly step (red line).

CONCLUSION

We have designed and fabricated the noble concept of applying electrical connection vertically in the PDMS microfluidic channel using insertion of microtip electrode and thin PDMS film. Microtip electrode is fabricated with high aspect ratio and low apex radius. The alignment layer which enables connecting both devices is formed with additional deep etching of surrounding area of microtip. Assembly process is done by inserting microtip electrode into PDMS thin film with pressure. The assembly data was verified using CV measurement data of on/off pressure.

We find the possibility of vertical electric connection in the microfluidic chip using microtip electrode insertion. And it can be used at various applications of sensing or sorting biological material.

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