FREE ACCESSIBLE MICROCHANNEL USING AIR-LIQUID INTERFACE WITH PATTERNED NANO-GEOMETRIC SURFACE BY HYBRID MASK LITHOGRAPHY

Masakuni Sugita[1], Shinya Sakuma[1], Fumihito Arai[1]
[1]*Nagoya University, Japan*

ABSTRACT

We succeeded in fabrication of a free accessible microchannel using an air-liquid interface. To pattern the air-liquid interface in the microfluidic chip, we utilized nano-geometric surface which encloses micropatterned massive nanopillars to enhance the wettability of the surface, which was fabricated by using the hybrid mask lithography technique. Novelties of this paper are shown as follows. (1) The contact angle of surface can be adjusted in wide range by fabricating the nano-geometric surface. (2) The free accessible microchannel was achieved by nano-geometric surface. (3) We succeeded in manipulation of a microparticle in the air-liquid interface microchannel by the magnetically driven microtool (MMT).

KEYWORDS

Air-liquid interface, Hybrid mask lithography, On-chip robotics, Nanopillar, Contact angle.

INTRODUCTION

In the bioengineering filed, cell manipulation is important to measure the specific parameters. Recently, the microfluidic chip which has been used for the miniaturization of chemical analysis is applied to manipulate or measure the cell [1]. In the microchannel of the microfluidic chip, the fluid flow is limited to single degree of freedom allows high-speed and continuous cell manipulation.

In previous work of our group, magnetically driven microtools (MMT) has been proposed for automation of cell manipulation [2]. The MMT made of magnetic material is placed in the microfluidic chip, and is actuated by external magnetic force. Because of high output force of mN order and high-speed drive of about 100 Hz [3], the MMT enables high- throughput cell manipulation by combination with microchannel.

However, the laminar flow in the microchannel was disturbed by flowing into the operation chamber of the MMT, as shown in Figure 1(a). The cell was also moved by the flow caused by the movement of MMT. These are one of serious problems to realize high-speed cell manipulation. To solve these problems, we proposed the free accessible microchannel formed by air-liquid interface, as shown in Figure 1(b).

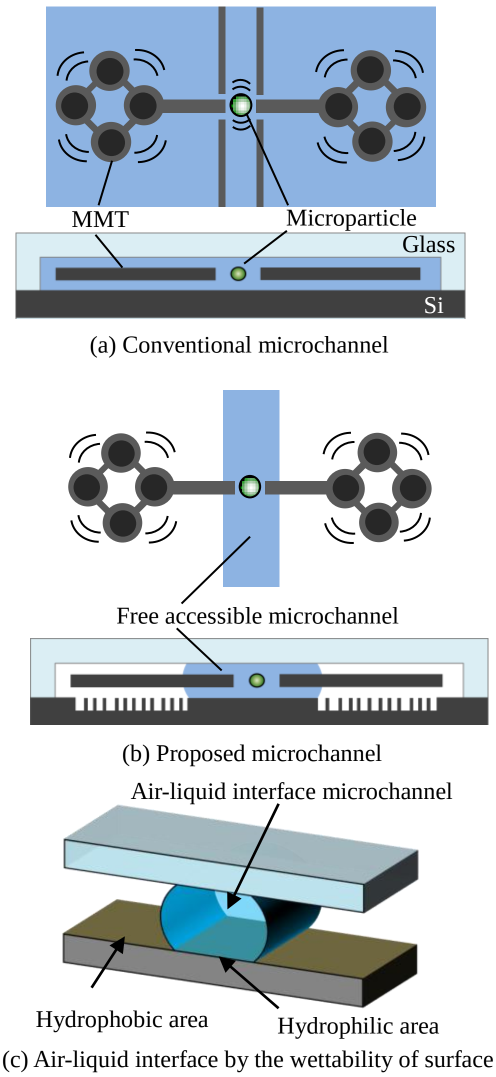


Figure 1: Concept of free accessible microchannel

THEORY

Air-liquid interface microchannel:

To prevent the disturbance to the cell by the movement of MMT, the MMT is separated from the liquid of microchannel to the air area of the microfluidic chip. Only probe tip of the MMT penetrates into the microchannel through the air-liquid interface. Therefore, the turbulence of flow by the motion of MMT becomes minimized. In this paper, we patterned the two areas with different wettability to form air-liquid interface, as shown in Figure 1 (c). In consideration of biocompatibility, we controlled the wettability by the geometric surface without chemical treatment. The height of microchannel was 200 μm, and was designed to transfer a large cell such as an oocyte. We succeeded in forming the air-liquid interface microchannel in the microfluidic chip, and dispensing the microparticle with diameter of 100 μm from microchannel in the microfluidic chip.

Hybrid mask lithography:

It is a well-known phenomenon that nano-geometric structures on the surface contribute to enhance the wettability. Previously, several methods such as black silicon and electron-beam lithography are commonly used to fabricate the nanostructure. Black silicon which is needle like structure formed in mismatching condition of deep reactive ion etching (D-RIE) contributes to obtain the hydrophobic surface [4]. However, it is difficult to control of the height and the density of the nanostructure because this fabrication process depends on the condition of the etching gas and deposition gas. Electron-beam lithography is technique possible to fabricate the nanostructure with the order of under diffraction-limited of the photolithography [5]. In addition, this technique is able to control of the density, diameter, and shape of the nanostructure. However, this technique based on the scanning method, it takes long time to pattern large area.

By considering these problems, we have proposed the hybrid mask lithography technique to obtain the simple fabrication of the nanopillars with micro-pattern simultaneously. Briefly, the hybrid mask lithography was utilized the composite of positive photoresist and nanoparticle was exposed by using the two different masks of the photo mask and nanoparticle mask. Figure 2 shows the scanning electron microscope (SEM) images of the fabricated multi-scale structure. Coating hydrophilic or hydrophobic material on the fabricated nanopillars to enhance the wettability, we get the superhydrophilic or superhydrophobic surface to obtain the air-liquid interface microchannel.

The features of this process are summarized as follows. (1) We can get the multi-scale structures which are the microchannel pattern as well as nanopillars pattern simultaneously. Patterning area is as large as the size of wafer using only standard microfabrication processes. (2) We can control the density of nanopillars by changing the concentration of nanoparticle dispersed into photoresist. (3) We can control the height of the pillar as same as the micro-pattern which is the original surface of the substrate.

Fabrication:

The microfluidic chip is composed of several layers, as shown in Figure 3. The hydrophobic and hydrophilic areas are patterned on the Si substrate and the glass cover respectively to increase stability of air-liquid interface. Figure 4 shows the fabrication process of the microfluidic chip.

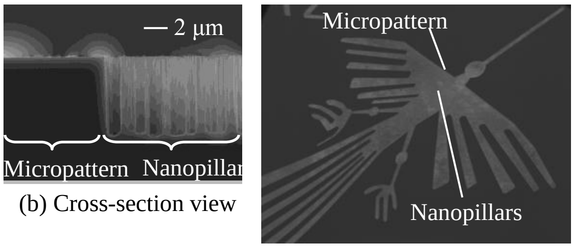
[Glass cover]
Fluorocarbon as hydrophobic material was patterned on the glass substrate by lift-off technique.

[PDMS spacer]
The PDMS sheet with the thickness of 200 μm was fabricated by molding of patterned substrate.

[Si substrate]
Microchannel pattern and nanopillars were fabricated simultaneously by hybrid mask lithography technique. To prevent interference between nanopillars and flowing microparticles in the microchannel, the bottom surface of the microchannel remained flat. Nanopillars were patterned around microchannel. The nanopillars coated with fluorocarbon hydrophilized the inside area of microchannel relatively.

[MMT]
The structure of MMT made by Si with the thickness of 200 μm was fabricated by D-RIE. The Ni part to obtain magnetic force is fabricated by electroplating to the hole of MMT. Ni parts are thicker than Si parts by etching the backside of MMT. As a result, the clearance between the probe of MMT and the nanopillars can be maintained to prevent contacts between them during the cell manipulation.

[Microfluidic chip]
Each layer was assembled to the microfluidic chip, and the developed microfluidic chip is shown in Figure 5.



(b) Cross-section view

(a) Demonstration of hybrid mask lithography

Figure 2: SEM images of fabricated nanopillars enclosed micro-pattern with nanopillars [6]

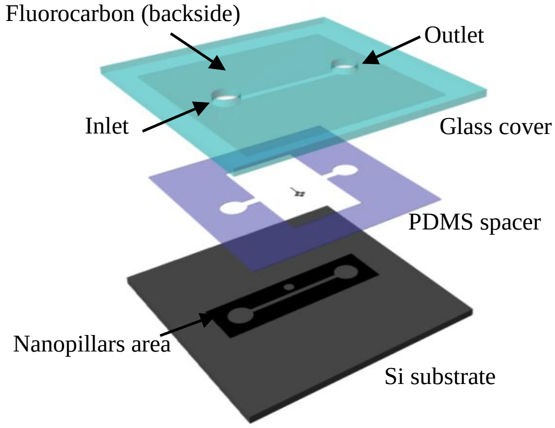


Figure 3: Layers of the microfluidic chip

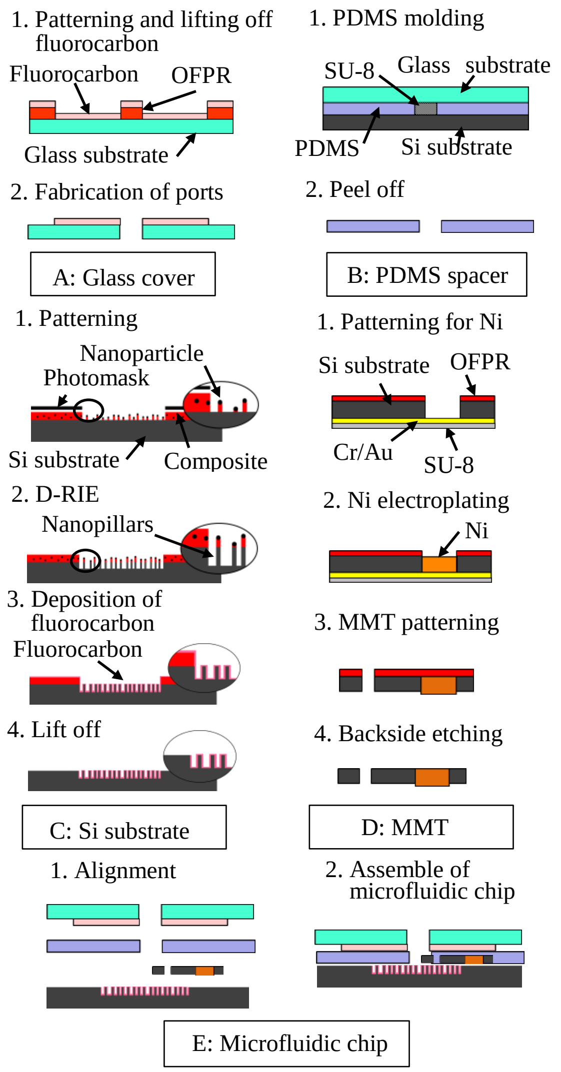


Figure 4: Fabrication process of microfluidic chip

EXPERIMENT

Figure 6 shows the contact angle of droplet as a function of density of the nanopillarss deposited with fluorocarbon or SiO_2. The blue dots represent the contact angle of nanopillars coated SiO_2, and the purple dots show the fluorocarbon-modified nanopillar. The SiO_2 nanopillar surface could change the contact angle from 0 degrees to 36 degrees. The contact angle of fluorocarbon nanopillar was changed from 113 degrees to 160 degrees. It was confirmed that the contact angle also can be controlled simply by changing of the concentration of the nanoparticle.

We applied the hybrid mask technique to fabricate the air-liquid interface microchannel. The superhydrophobic area on the Si substrate was fabricated using the composite of photoresist with nanoparticle of 0.40 %, and the height of nanopillars was 5 μm. These conditions stabilized the air-liquid interface. Circular hydrophilic area was patterned near the microchannel to dispense a microparticle there.

We confirmed that the air-liquid interface was formed by injection of DI water and polystyrene microbeads with diameter of 100 μm, as shown in Figure 7(a). Then, microbeads were transported at the max speed of 1.3 mm/s by fluidic control. Finally, we succeeded in dispensing the microbead from microchannel to the circular area by the probe of MMT through the air-liquid interface stably, as shown in Figure 7 (b) (c).

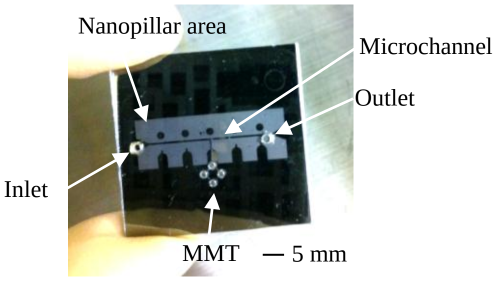


Figure 5: Fabricated microfluidic chip

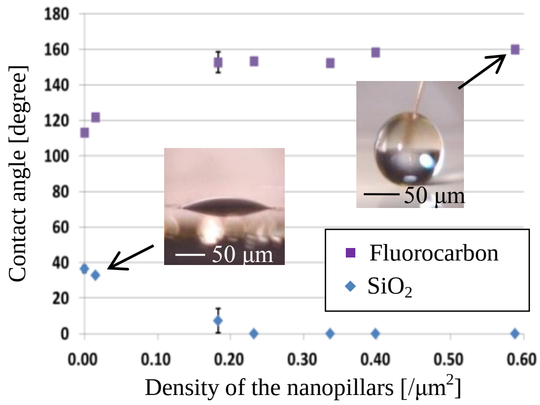
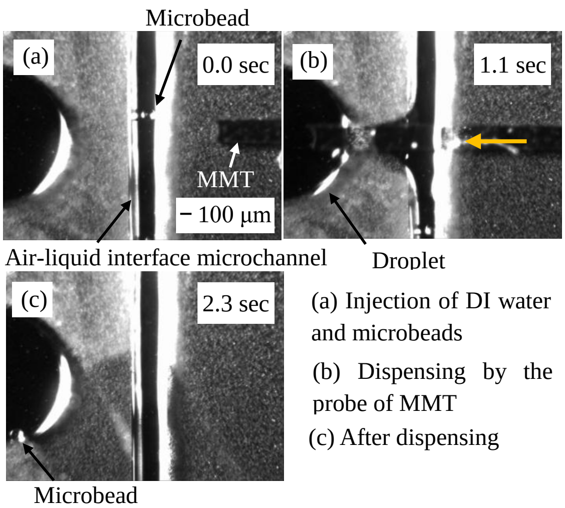


Figure 6: Contact angle of water droplet as a function of density of the nanopillars



(a) Injection of DI water and microbeads

(b) Dispensing by the probe of MMT

(c) After dispensing

Figure :7 Experiment of air-liquid interface microchannel

CONCLUSION

We proposed the free accessible microchannel wiyh air liquid interface for high-speed cell manipulation. Proposed air liquid interface microchannel was achieved by large area of nanopillars pattern fabricated with hybrid mask lithography technique. With this air liquid interface microchannel, we demonstrated dispensing of microparticle with MMT. On-chip robotics systems with this high speed manipulation by air liquid interface channel can extend many applications such as high speed cell manipulation or high throughput measurement of cellar characteristics.

ACKNOWLEDGEMENTS

This work is partially supported by Scientific Research from Ministry of Education, Culture, Sports, Science and Technology (23106002) and the JST-SENTAN.

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CONTACT

Masakuni Sugita +81-52-789-5220 or masakuni@biorobotics.mech.nagoya-u.ac.jp