SIZE-DEPENDENT PARTICLE FILTERATION USING MAGNETICALLY DRIVEN MICROTOOL AND CENTRIFUGAL FORCE IN MICROCHIP

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ABSTRACT

We succeeded in size-dependent filtration of microparticles by rotation of magnetically driven microtool (MMT) and centrifugal force in a microchip. Novelties of this paper are summarized as follows. (1) Filtering efficiency was improved than filtration by solely centrifugal force by MMT rotation. (2) Clogging of microparticles was avoided by swirling flow generated by rotation of 3D-MMT with fins. (3) This filtration is robust against pressure fluctuation in a microchip by mechanical particle separation using internal walls. Microparticles with different sizes flow in spiral microchannels and are separated according to their sizes by pass through under each sidewall of microchannels by centrifugal force. MMT is set inside the microchamber and rotated by external magnetic force. Rotation of MMT avoids the clogging of the microparticles and enhances the sorting efficiency. We demonstrated filtration of the microparticles in a microchip using 3D-MMT rotation and centrifugal force.

1. INTRODUCTION

Size-dependent filtration of microparticles such as copolymer beads and cells (from several μm to a hundred μm) is a very important microfluidic process for various research fields[1, 2]. In these days, many types of particle separation methods are developed for the separation of particles and cells, employing acoustic force, optical tweezers, electrostatic force and magnetic force [3-7]. These methods require external forces and modification of the particles prior to filtration, which may cause particle damage and complicate sample collection procedures. It is very important for biological and chemical analysis in a microchip to keep the target particles or cells intact during separation.

Recently, separation techniques based solely on the particle size and the hydrodynamic forces have been developed [8, 9]. Hydrodymanic particle separation does not cause damage to particles and can handle various particles with different properties such as electric permittivity and magnetism. Therefore, this approach eliminates the need for external fields or bead attachment. Research on size-based separation using hydrodymanic force has led to several techniques, including pinched flow fractionation (PFF) and deterministic lateral displacement. Both techniques allow for continuous particle separation, which is crucial to achieve large scale processing. Although these sorting techniques are capable of high efficiency separation, hydrodynamic force is not robust against pressure fluctuation inside microchannel.

In this paper, we proposed an on-chip particle filtration based on the centrifugal force and MMT rotation. We employed a microchip with three spiral microchannels. These microchannels are divided by internal walls with different clearances between the sidewalls and glass. Particles are separated according to their sizes by centrifugal force and internal walls. Our proposed method is robust against the pressure fluctuation inside microchannel because particles are separated mechanically by the sidewalls. 3D-MMT is employed for avoiding the clogging of particles and enhancing the particle separation. Size-dependent partilce filteration was performed successfully.

2. FILTERATION OF MICROPARTICLES USING MAGNETICALLY DRIVEN MICROTOOL AND CENTRIFUGAL FORCE

Principle of particle filtration

Figure 1 shows a schematic of a microchip. Figure 2 shows a principle of particle filtration. Microchip has one microchamber and three spiral microchannels. These microchannels function as particle filters. Each microchannel is connected to next microchnnel by the clearance between glass and bottom of sidewalls. Microparticles smaller than the clearance pass though the sidewall by centrifugal force, while particles bigger than it couldn't pass the sidewall. Particles with different sizes are separated according to their sizes. This filtration is robust against pressure fluctuation since particles are separated mechanically by sidewalls. When pressure is fluctuated, bigger particles do not move to the outside channel. Even if small particles move to the inner channel, these particles move to the outside channel again by centrifugal force.

Moreover, we employed 3D-MMT with fins to prevent microparticles from clogging and enhance the filtering. In microchamber, the rotation of the 3D-MMT generates swirling flow. These flow stirrer particles and avoid clogging of particles. Purity of the filtered particle can be improved by repetition of the filtration because the construction of circulating system is easy in the proposed method.

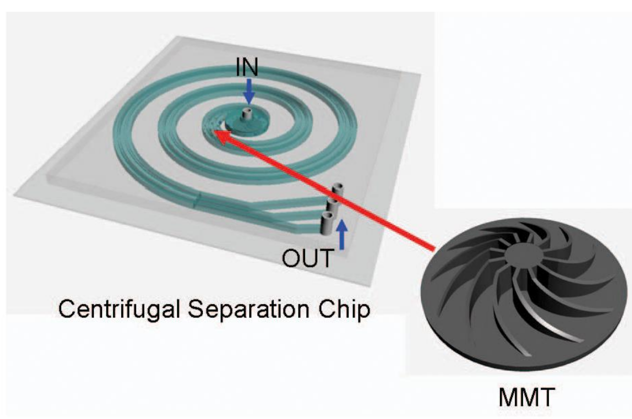

Figure 1: Schematic of size-dependent microparticle filtration using magnetically driven microtool and centrifugal force.

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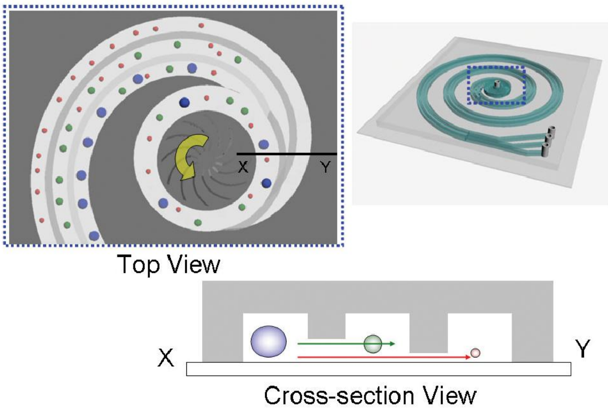


Figure 2: Principle of size-dependent particle sorting.

Fabrication of PDMS microchip

PDMS microchip with three spiral microchannels was fabricated using photolithography and replica molding techniques. The fabrication process of the PDMS microchip was shown in Figure 3. We employed SU-8 sheets and multi-exposure to make the microchip with the different height area. Each microchannel is 200 μm in wide and 128 mm in deep. The width of sidewall is 100 μm. The clearance of inner sidewall is 24 μm and that of outer sidewall is 58 μm.

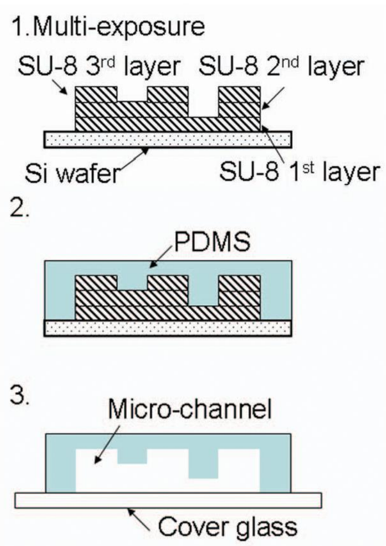


Figure 3: Fabrication process of PDMS microchip using multi-exposure.

Fabrication of 3D-MMT

Figure 4 shows the fabrication process of a 3D-MMT [10]. First, we spin coat KMPR (Kayaku MicroChem Co., Lt) resist on a glass substrate (thickness is about 120 μm), then use ultraviolet exposure to pattern the resist. We employed grayscale photolithography to make MMT three-dimensional structure [11]. In this process, backside exposure is required and a gray-scale mask is positioned at the opposite side of the glass substrate coated with KMPR. Exposure and development are the same processes as conventional photolithography.

Then, we coat a mixture of PDMS and magnetite (50 wt% of Fe_3O_4). After the bake (80 degrees of C), we use a striper liquid to remove the completed MMT with three-dimensional structure. Figure 5 shows the 3D-mold made of KMPR. By using replica molding method, the 3D-MMT made of PDMS mixed with magnetite is completed as shown in Figure 6. Moreover, we can produce a 3D-MMT having smooth curves within the only one exposure step.

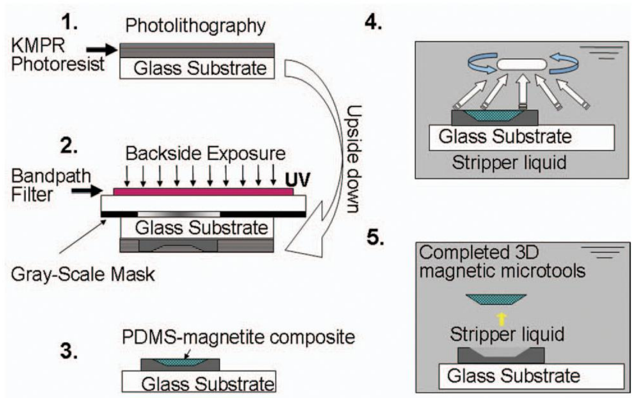


Figure 4: Fabrication process of 3D-MMT using gray scale lithography.

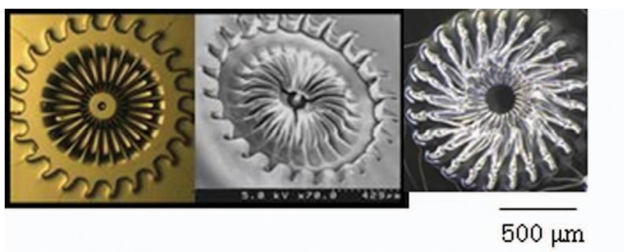


Figure 5: Photographs of 3D-molds made of KMPR.

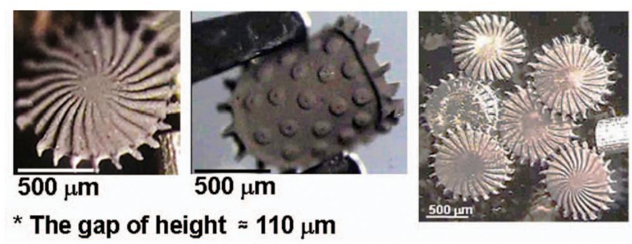


Figure 6: Photographs of 3D-MMTs.

Analysis of swirling flow generated by rotation of 3D-MMT

The rotation of the 3D-MMT with fins generates the swirling flow in the microchamber. This swirling flow is useful not only to avoid clogging of the particles in a microchamber but also to enhance the centrifugal separation of particles. Figure 7 shows the FEM analysis result of distribution of velocity around the rotating 2D (Flat)-MMT and 3D (Tapered)-MMT. Particles move obliquely downward on the 3D-MMT. On the other hand, particles on the 2D-MMT receive lateral force only. We confirmed that 3D-MMT can avoid deposition of the particles on the MMT and pump the particles to the spiral microchannels continuously.

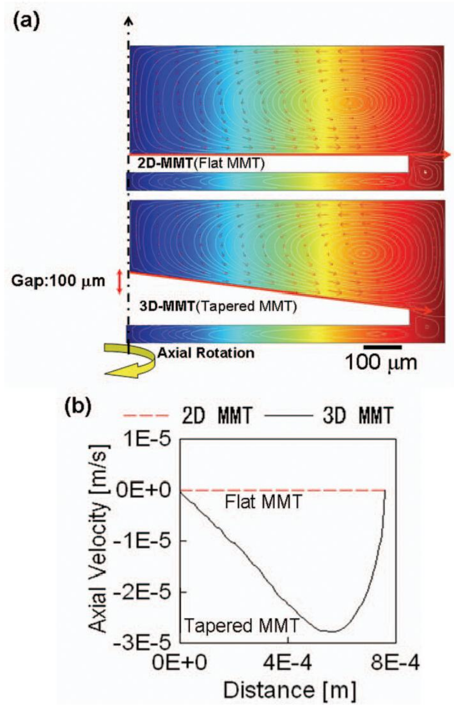
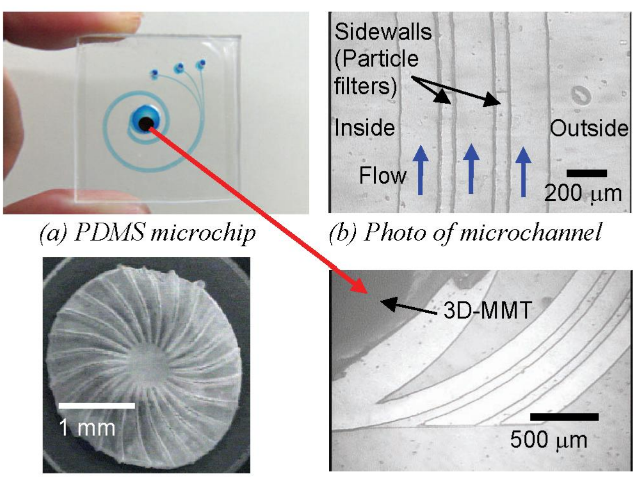


Figure 7: Distribution of velocity around the rotating 2D (Flat) and 3D (Tapered)-MMT. (a) Velocity distribution, (b) Profiles of axial velocity along the lateral component.

EXPERIMENTATAL

Experimental setup

Figures 8 and 9 show the experimental setup. The PDMS microchip was fabricated by photolithography and replica molding techniques. Small particles move to the outside microchannel through the sidewalls as shown in Fig. 8 (b). 3D-MMT with fins was made by grayscale photolithography as shown in Figure 8 (c) and positioned in the microchamber. MMT is 3 mm in diameter and 80 μm in thickness. MMT is rotated by the external rotational magnetic field as shown in Figure 9.



(a) PDMS microchip *(b) Photo of microchannel*

(c) SEM image of 3D-MMT *(d) MMT in microchip*

Figure 8: Experimental setup.

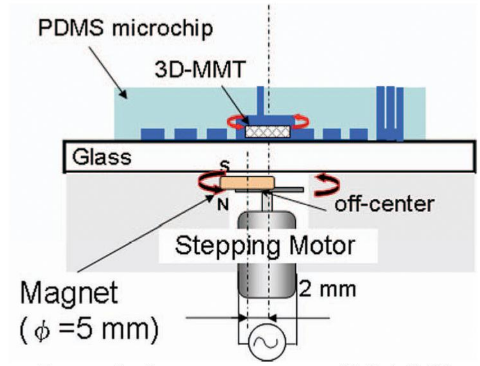
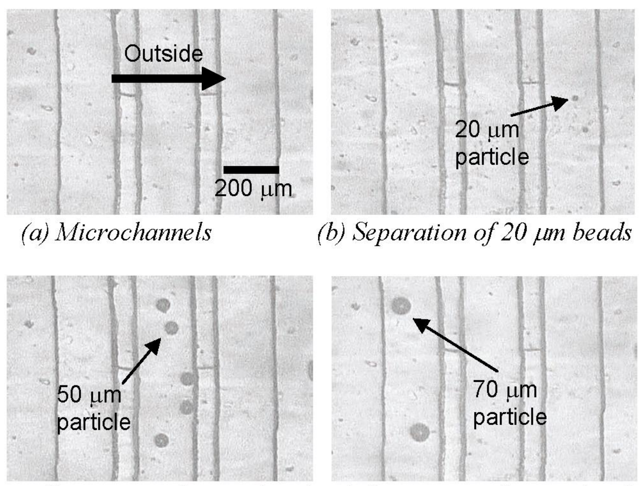


Figure 9: Actuation system of 3D-MMT.

Particle filtering using single-size particle

We used polystyrene particles for experiments. The sizes of microparticles are 20 μm, 50 μm, and 70 μm. Each particle is expected to be separated to the outer, middle, and inner microchannel. Particles were introduced from microchamber by using a syringe pump.

First, we introduced single-size particles to confirm the function of our proposed particle filter. We succeeded in filtration of the particles according to their sizes by centrifugal force and MMT rotation as shown in Figure 10. Particles which are bigger than the clearance between the sidewall and glass did not pass through the sidewall even if pressure was distributed. This system could separate more than 360 particles per second. From these results, we confirmed that the proposed method can be employed as continuous particle filter.



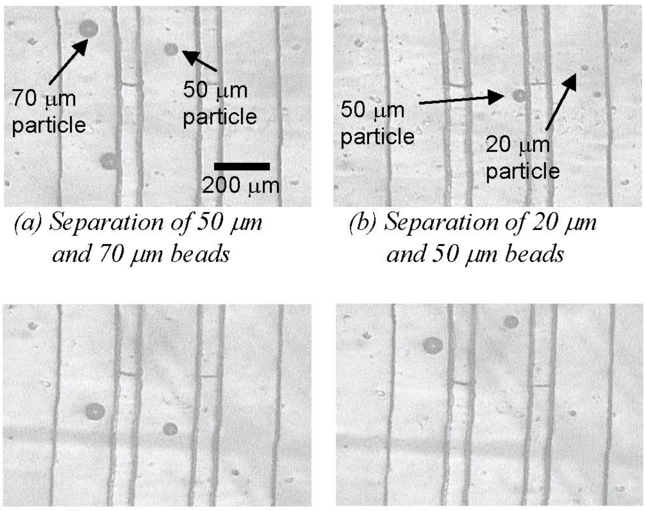
(a) Microchannels *(b) Separation of 20 μm beads*

(c) Separation of 50 μm beads *(d) Separation of 70 μm beads*

Figure 10: Experimental result of particle filtering.

Particle filtering using multi-size particles

Then, we performed the particle filtration using a solution including particles of different size. We used polystyrene particles for this experiment. The sizes are 20 μm, 50 μm, and 70 μm. Experimental results are shown in Figure 11. We succeeded in the filtration of the particles of two sizes by centrifugal force and MMT rotation as shown in Figures 11 (a), 11(b). We also succeeded in the filtration of the particles of three sizes as shown in Figures 11 (c), 11(d). From Table 1, MMT rotation improves sorting efficiency. Microchip and MMT are low cost and disposal. Therefore, proposed system is economical and suited for biomedical applications.



(a) Separation of 50 μm and 70 μm beads *(b) Separation of 20 μm and 50 μm beads*

(c) Separation of 20 μm, 50 μm and 70 μm beads *(d) After separation*

Figure 10: Experimental result of particle filtering.

Table 1: Comparison of filtering efficiency between with MMT rotation and without MMT rotation.

Particle size	20 μm		50 μm		70 μm	
MMT rotation	With out	With	With out	With	With out	With
Outer channel	24%	38%	0%	0	0%	0%
Middle channel	43%	32%	64%	81%	0%	0%
Inner channel	33%	30%	36%	19%	100%	100%

CONCLUSIONS

Size-dependent filtration of microparticles by rotation of magnetically driven microtool and centrifugal force in a microchip was developed. We succeeded in size-dependent filtration of particles of multi sizes. Rotation of 3D-MMT avoided the clogging of the particles in the microchamber and enhanced the efficiency of filtration. 3D-MMT is fabricated by grayscale lithography. Rotation of 3D-MMT with fin generates the swirling flow. Microparticles in the microchamber move to the microchannel without clogging by this flow. This flow also enhances the centrifugal separation of microparticles. PDMS microchip with three spiral microchannels and one microchamber was fabricated by using multi-exposure method. Each sidewall between each microchannel has different clearance to glass surface. Particles are separated to each microchannel by passing through the clearance. Our method is robust against pressure disturbance because particles are separated mechanically by sidewalls. We can increase the number of the flittering size by increasing the number of the spiral microchannel and adjusting the clearance between sidewall and glass surface.

Microchip and MMT are low cost and disposal. Proposed system is economical and suited for biomedical applications. This technique for continuous particle filtration will make great contributions for cell biology and chemistry.

ACKNOWLEDGEMENT

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