INTEGRATED VERTICAL SCREEN MICROFILTER SYSTEM USING INCLINED SU-8 STRUCTURES

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ABSTRACT

A multidimensional, vertical screen filter system is developed in which structures analogous to the mesh of a window screen are extended vertically through the cross-sectional area of a simultaneously-formed flow channel. Vertical screens with heights of up to 400 microns and aperture sizes of 10 microns have been achieved in a simple, multiexposure fabrication approach without the need for stacking or lamination. A triple filtering system with multiple inlet and outlet streams and three different mesh sizes of 57.3μm, 27.3μm, and 10.0μm in its horizontal diagonal has been simultaneously fabricated with flow channels and tested. Each mesh filters out microparticles larger than 35μm, 18μm, and 6μm, accordingly. In addition to microfiltering, the utility of the vertical screen filter structure as a passive micromixer has been demonstrated.

INTRODUCTION

Microfilters are essential parts of microanalysis systems, e.g., for micro particle sorting and sample injection filtering. Microfilters in combination with multiple analysis streams can also enhance mixing in low Reynolds number flow. A number of approaches to microfabricated filters have been presented, including ultrasonic [1], magnetic [2], and DEP (dielectrophoresis) methods [3] for active filtering or separation, and several micro sieve-type filters for passive filtering [4,5]. While micro active filters can be realized in a coplanar fashion with respect to the flow channels, they require additional processes for the fabrication or integration of active transducers. Micro passive filters utilize relatively simple fabrication processes and can supply a uniform mesh size for filtering. However, conventional passive microfilters typically utilize a configuration with a horizontal screen structure connected with a vertical channel, often requiring stacking or bonding between two pieces of channel or substrate, potentially leading to more interconnect and sealing issues. In order to address these issues, several in-plane and in-channel passive filters, such as multilevel planar microfilters [6] and *in situ* polymer porous filters [7], have been developed. In the multilevel planar microfilter [6], a shallow bypass channel branches from the main channel; the depth of the shallow channel sizes the filter and only vertical confinement is provided. In the porous filter [7], since it is fabricated by phase separation photo-polymerization, the porosity varies with the composition of the prepolymer mixture and the mesh uniformity is not guaranteed.

Passive filter techniques can also be utilized to enhance mixing, which in the micro scale is a critical issue in micro total analysis systems (μ-TAS). A number of passive mixing approaches have been developed to enhance microfluidic mixing, including the use of advection to create local turbulence such as in a case of three dimensional serpentine channel [8], and the use of fast diffusion in very low Reynolds number flow by means of injection through micronozzles [9] and geometrical lamination [10]. Therefore, a fabrication approach that could yield simple, in-plane microfilter structures may also be useful for micromixing.

Recently there has been much work in advanced lithographic techniques to create multidimensional SU-8 structures by unusual deposition and exposure techniques. Examples include microfluidic channels [11], epoxy-core conductors [12], inclined structures [13], and oblique structures [14]. In this work, a multi-dimensional, vertical screen micro filter system integrated with a simultaneously-formed flow system using inclined SU-8 fabrication techniques is presented. The vertical screen filter has a mesh analogous to that of a window screen, in which structures are extended vertically through the cross-sectional area of a flow channel. The vertical screen filter structure provides several specific benefits for μ-TAS or lab-on-chip systems. First, since the vertical filter is fabricated in the channel, no additional lamination or stacking for the connection with other fluidic components is necessary, thereby eliminating the need for interlayer sealing. Second, filter structures of controllable geometry (even including differing mesh-size) can be achieved using a single lithographic mask and simultaneously fabricated with the channel, which simplifies the fabrication process. Third, the process yields uniform diamond shape meshes throughout the entire filtering

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area, as opposed to the pillar approach, which gives only one-directional confinement.

FABRICATION

There are two approaches for the inclined exposure scheme. One is a conventional front-side inclined exposure, in which an SU-8 coated substrate in contact with an optical mask is tilted at a certain angle and is exposed. The other is to use back-side exposure through a UV-transparent substrate, in which the substrate has a pre-patterned opaque metal layer. SU-8 is coated on the substrate, and the substrate is turned over and exposed at the desired angle. Figure 1 details the fabrication process with back-side exposure. A chromium-coated glass plate is used as a substrate. After patterning of the chromium for channel and filter definition, SU-8 is coated on the plate to a thickness that will ultimately define the channel height (1a). After the SU-8 is baked, the substrate is turned over and multiply exposed at different angles of inclination from multiple directions in order to form latent images of the vertical meshes as well as the flow channel walls. This exposure is followed by a post-exposure bake to cross-link the SU-8 (1b). Before developing, a low energy dose exposure through a second mask to link the ends of the filter screen is optionally utilized (1c). A single develop step forms the filters as well as the channels simultaneously (1d). Polydimethylsiloxane (PDMS) coated glass is used as a secure top cover and the channel is completed by clamping or gluing the top and the bottom glass plates (1e).

Figure 2a shows a 600μm thick SU-8 pattern exposed through a 15μm diameter window with different

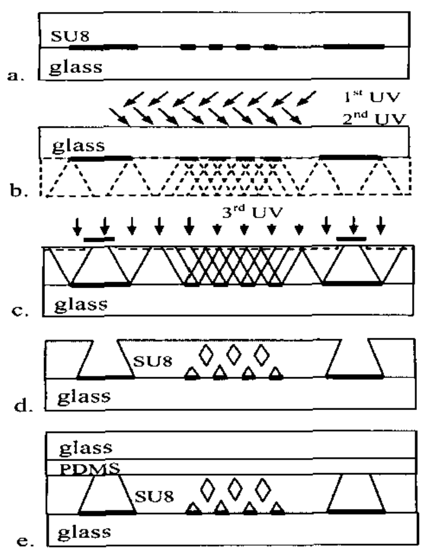

Figure 1. Fabrication process.

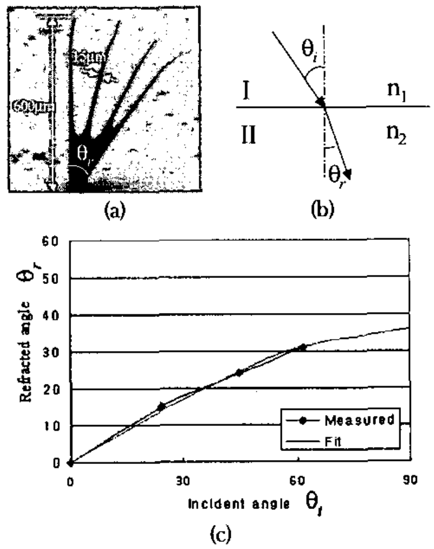

Figure 2. Angular dependence of exposure

angles of UV incidence using the backside exposure technique. The measured refracted angles are 0°, 15°, 24°, and 31° for incident angles of 0°, 24°, 45°, and 62°, respectively, in Figure 2c. Curve fitting using Snell's law ($n_1\sin\theta_i = n_2\sin\theta_r$) gives a refractive index of about 1.7 for SU-8, which agrees with literature values [15].

MICROFILTER SYSTEM

A single stage of an integrated microfilter is shown in Figure 3. A mask layout with 50μm space and 50μm width of transparent square array is depicted in Figure 3a, in which each array row is separated by 150μm.

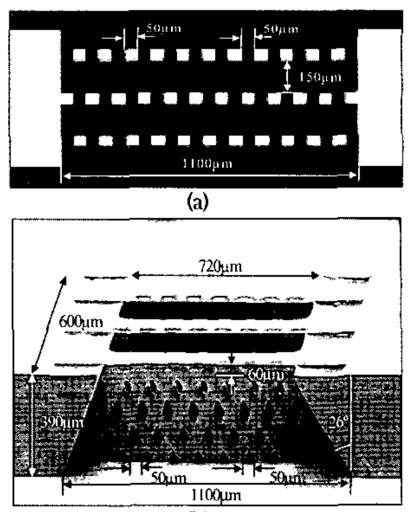

Figure 3. Single stage of vertical screen filter;(a) mask layout, (b) resultant vertical screen filter

An incident angle of 48° results in a refracted angle of approximately 26°, and the resultant diamond shape opening has a 50μm horizontal diagonal and a 100μm vertical diagonal. While the bottom channel width is 1100μm, the upper channel width becomes narrower (720μm) resulting from back-side exposure, with a channel height of 390μm in Figure 3b.

Figure 4 shows three different mesh-sized filters integrated with flow channels, which are simultaneously fabricated. Each filter has a differing mesh size so as to be able to sort a different size distribution of particles. The resultant horizontal diagonal extent of the threads of each filter mesh is 57.3μm, 27.3μm, and 10.0μm, respectively in Figure 5. Also, uniform opening distribution is observed.

To determine the utility of the filter, poly-(L-lactic glycolic) acid copolymer microparticles multimodally

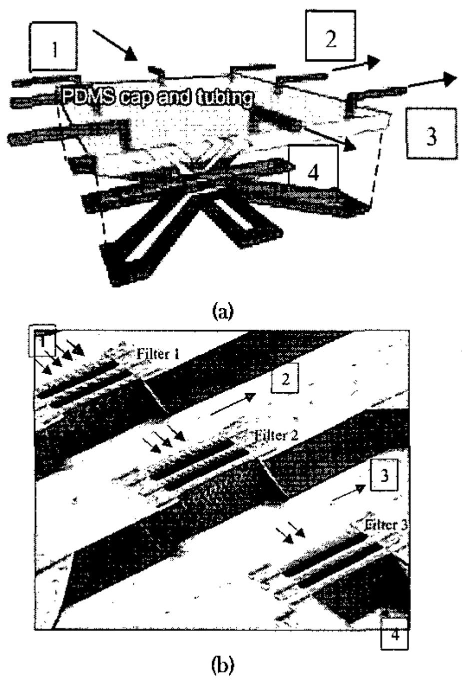

Figure 4. *Three integrated filter and channels for multiple diameter particle separation; (a) overall schematic, (b) SEM picture in filtering area*

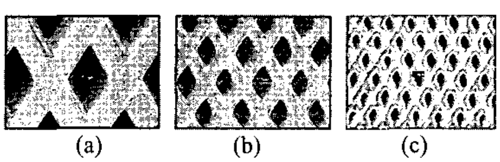

Figure 5. *Different mesh sizes; (a) filter 1, (b) filter 2 (c) filter. Horizontal diagonal has been measured to be 57.3μm, 27.3μm, and 10.0μm, respectively.*

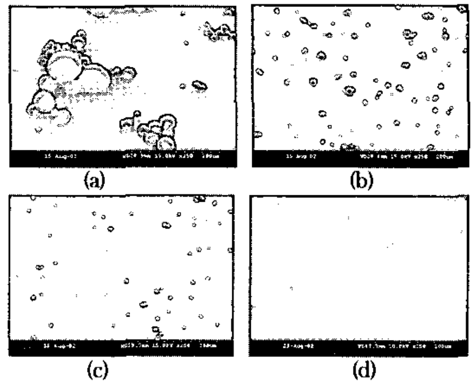

Figure 6. *Micro particles after filtering; (a) original micro particle mixture (1~100μm), (b) after filter 1 (1~35μm), (c) after filter 2(1~18μm), (d) after filter 3 (1~6μm). All images in Figure 6 are shown at the same magnification.*

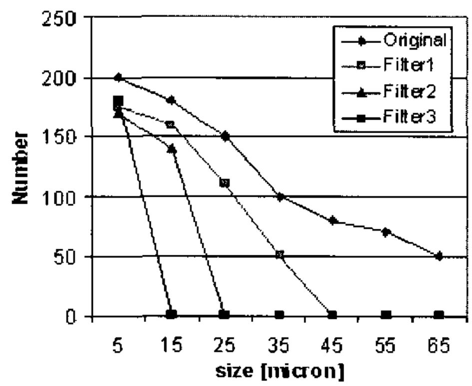

Figure 7. *Number of micro particles in 1mm by 1mm area after each filtering, as determined by SEM investigation of dried aliquots of fluid removed from each separation channel.*

distributed in the range of 1μm to 100μm diameter were manufactured using an emulsion technique. The particles were suspended in water, and the mixture was injected into the channel inlet 1 in Figure 4. The filtered particles were collected through bypass and filtering outlet 2, 3, and 4 as shown in Figure 4. An aliquot of sample was taken from each outlet, transferred to slide glass, dried, and examined using SEM (Figure 6). The first screen filtered particles of larger than 35μm, while the second and third screens filtered particles of 18μm and 6μm, respectively. The statistical distribution of the filtered particles in 10μm divisions is shown in Figure 7, and demonstrates that this simple fabrication technique can easily produce flow channels integrated with vertically-extended, functional filter screens across their cross-section.

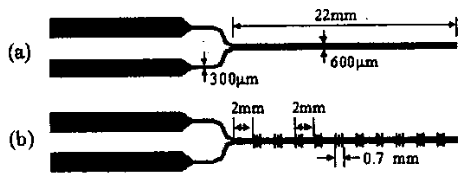

Figure 8. Two micro channels for mixing assay; (a) reference channel, (b) channel with screens

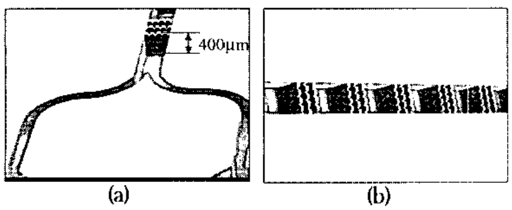

Figure 9. SEM pictures of channel with screens; (a) connection of two fluidic channel, (b) five screens

MICROMIXER APPLICATION

For micromixers, forming the vertical screen filters inside the channel provokes disturbance in the flow and leads to faster mixing. Figure 8 shows the mixing test structures, one without any screen, with mixing region (i.e., after the channels merge) 22mm long and 600µm wide; and one with similar dimensions and 10 stages of screen disturbance placed inside the channel with 2mm pitch, where each disturbance stage consists of three screens being 200µm apart from each other (the screen structure is basically the same as that of the filter except for a screen wall thickness of 100µm instead of 50µm in Figure 3). The channel has been fabricated to have a vertical profile in Figure 9 instead of an inclined side wall as Figure 3 for better mixing observation from the top.

Mixing performance has been evaluated by observing the color variation of diluted Safranine O red dye relative to water. Figure 10 shows photographs for mixing progress taken from the windows between stages. The leftmost image for both 10a and 10b is taken 1mm downstream from the channel merging point and is called the image of the 0^{th} stage. The next is taken 3mm downstream from the merging point and called the image of the 1^{st} stage, and so on. While two separate flows are shown in the reference channel until the seventh stage, complete mixing is observed in the screen channel after the sixth stage, which is about 3.5 seconds after two flows meet. The flow rate is 30µl/min and the Reynolds number is 2.

CONCLUSION

A multidimensional, vertical screen fabrication technique using inclined SU-8 patterning has been

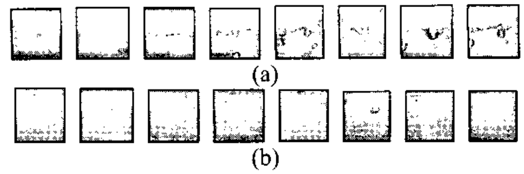

Figure 10. Photographs of mixing progress with the number of stage (after the 0th stage to the 7th stage in sequence from the left); (a) reference channel, (b) channel with the screens

proposed and its utility for micro fluidic systems has been demonstrated. A filter with 10µm uniform mesh size and 400µm in height has been achieved. Three different mesh-sized integrated filters have been fabricated with other fluidic channels simultaneously. The system carried out its filtering performance successfully according to its mesh size. The application of the vertical screen has been extended to a micro fluidic mixer. Fluidic mixing has been enhanced with the screen structure and takes approximately 3.5 seconds while the reference channel with no screen shows that two separate streams remain in the same time frame.

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