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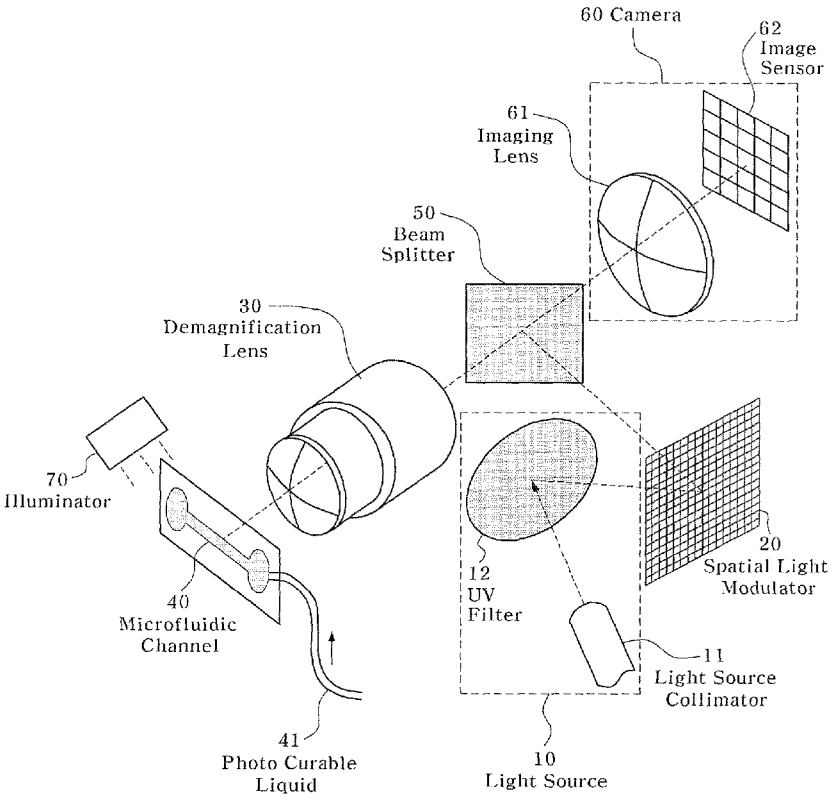
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(54) Title: OPTOFLUIDIC MASKLESS LITHOGRAPHY SYSTEM

(57) Abstract: An optofluidic maskless lithography system is provided. The optofluidic lithography system includes a light source; a spatial light modulator for modulating light provided by the light source; and a microfluidic channel including photocurable liquid flowing therein, wherein the microfluidic channel selectively cures the photocurable liquid according to the modulated light provided by the spatial light modulator.

FIG. 1



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【DESCRIPTION】

【Invention Title】

OPTOFLUIDIC MASKLESS LITHOGRAPHY SYSTEM

【Technical Field】

The present invention relates to an optofluidic lithography system, and more particularly, to an optofluidic maskless lithography system.

【Background Art】

Microparticles and microstructures have many applications, such as photonic materials, micro-electromechanical systems (MEMS), biomaterials, and self-assembly. In recent years, a continuous-flow lithography scheme has been proposed for creating such microparticles and microstructures (D. Dendukuri, D. Pregibon, J. Collins, T. Hatton, P. Doyle., "Continuous-Flow Lithography for High Throughput Microparticle Synthesis," Nature Materials, vol. 5, pp. 365-369, 2006). In the continuous-flow lithography scheme, photocurable liquid flows inside a microfluidic channel, is exposed to light having a predetermined shape and is selectively cured, thereby several types of free-floating microstructures are continuously created. Using the continuous-flow lithography scheme, microparticles and microstructures having various shapes, sizes and chemical compositions can be created more rapidly and easily.

However, the continuous-flow lithography scheme proposed in the above paper can create only microstructures having a certain shape because it uses a photomask. Accordingly, a photomask having a new shape must be manufactured and mounted to make microstructures having the new shape, which is costly and time-consuming. The continuous-flow lithography scheme proposed in the above paper employs a photomask that is not programmable in

real time and accordingly has limited temporal and spatial flexibility in creating the microstructures.

【Disclosure】

【Technical Problem】

Accordingly, an object of the present invention is to provide an optofluidic maskless lithography system.

Another object of the present invention is to provide an optofluidic lithography system that is capable of creating many types of microstructures through a single process.

Yet another object of the present invention is to provide an optofluidic lithography system that is capable of controlling creation of microstructures temporally and spatially. Here, controlling creation of microstructures temporally and spatially means that a microstructure having a different shape from a previous one can be created over time.

【Technical Solution】

The present invention provides an optofluidic lithography system including a light source; a spatial light modulator for modulating light provided by the light source; and a microfluidic channel including photocurable liquid flowing therein, wherein the microfluidic channel selectively cures the photocurable liquid according to the modulated light provided by the spatial light modulator.

【Advantageous Effects】

The optofluidic lithography system according to the present invention can eliminate a cost of manufacturing and replacing a mask, unlike a conventional optofluidic lithography system that requires mask replacement each time it creates a structure having a new shape.

Further, the optofluidic lithography system according to the present invention can create many types of microstructures through a single process.

Furthermore, the optofluidic lithography system according to the present invention can control creation of microstructures temporally and spatially.

The optofluidic lithography system according to the present invention can also create a structure having an arbitrary shape that is much larger than an exposure area.

The optofluidic lithography system according to the present invention can also create structures having various composition ratios inside a single microfluidic channel.

【Description of Drawings】

The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 illustrates an optofluidic maskless lithography system according to an embodiment of the present invention;

FIG. 2 illustrates an example of the microfluidic channel 40 employed in the optofluidic lithography system of FIG. 1;

FIG. 3 illustrates microstructures created by the optofluidic lithography system according to an embodiment of the present invention;

FIG. 4 illustrates an example in which times and locations at which microstructures are created by the optofluidic lithography system are freely controlled in real time according to an embodiment of the present invention;

FIG. 5 illustrates an example in which a structure that is larger than an exposure area is created using the optofluidic lithography system according to an embodiment of the present invention;

FIG. 6 illustrates an example in which a microstructure having various compositions is created as several other photocurable liquids flow inside the microfluidic channel; and

FIG. 7 illustrates an example of a microstructure created using the optofluidic lithography system according to an embodiment of the present invention.

【Modes for Invention】

The invention is described more fully hereinafter with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure is thorough, and will fully convey the scope of the invention to those skilled in the art.

FIG. 1 illustrates an optofluidic maskless lithography system according to an embodiment of the present invention.

Referring to FIG. 1, an optofluidic lithography system includes a light source 10, a spatial light modulator 20, a demagnifying lens 30, and a microfluidic channel 40. The optofluidic lithography system may further include a beam splitter 50, a camera 60, and an illuminator 70, which are components required for monitoring the microfluidic channel 40.

The light source 10 provides light to the spatial light modulator 20 to cure a photocurable liquid 41 flowing inside the microfluidic channel 40. For example, the light source 10 may be an ultraviolet light source. The light source 10 may be a visible light source depending on a type of the photocurable liquid 41. The light source 10 may include an ultraviolet light source collimator 11 and an ultraviolet filter 12. The ultraviolet light source collimator 11 outputs collimated ultraviolet light. For example, the ultraviolet light source collimator 11 may include a 200W UV lamp (not shown)

and a fiber-based light guiding system (not shown). The ultraviolet filter 12 provides ultraviolet light in light provided by the ultraviolet light source collimator 11 to the spatial light modulator 20.

The spatial light modulator 20 modulates the light provided by the light source 10. In FIG. 1, the spatial light modulator 20 is shown as a two-dimensional, digital micromirror array. Alternatively, the spatial light modulator 20 may be a one-dimensional array, or may be made using another device such as a liquid crystal display (LCD). In the spatial light modulator 20, optical modulation is programmable. That is, the spatial light modulator 20 may selectively transfer the light via desired pixels included in the spatial light modulator 20 to the demagnifying lens 30 at a desired time. The optical modulation in the spatial light modulator 20 may be controlled, for example, by a computer (not shown). That is, images created by the computer are transferred to the programmable spatial light modulator 20, which controls a shape of light exposed to the microfluidic channel 40.

The demagnifying lens 30 demagnifies the modulated light provided by the spatial light modulator 20 and provides the resultant light to the microfluidic channel 40. For example, the demagnifying lens 30 may be a 10x microscope objective lens for projecting an image from the spatial light modulator 20 to a final object plane with a demagnification factor of about 5.

The photocurable liquid 41 flows inside the microfluidic channel 40 and is cured by the modulated light provided via the demagnifying lens 30. More specifically, microstructures or microparticles are created as the photocurable liquid 41 is cured inside the microfluidic channel 40, in which the photocurable liquid 41 continuously flows. The microstructures or microparticles have a shape that can be controlled by the programmable spatial light modulator 20.

The beam splitter 50 transfers the modulated light from the spatial light modulator 20 to the microfluidic channel 40 via the demagnifying lens

30. The beam splitter 50 also transfers an image input from the microfluidic channel 40 via the demagnifying lens 30, to the camera 60. For example, the beam splitter 50 may be a half mirror, as shown in FIG. 1.

The camera 60 outputs an electrical image signal corresponding to the image from the microfluidic channel 40. For example, the camera 60 may be a charge-coupled device (CCD) camera. The camera may include an imaging lens 61 and an image sensor 62. The imaging lens 61 receives the light from the beam splitter 50 and transfers it to the image sensor 62 so that an image is formed on the image sensor 62. The image sensor 62 provides an electrical image signal corresponding to the input light. That is, the image sensor 62 provides an electrical image signal corresponding to the image from the microfluidic channel 40.

The illuminator 70 provides illustration so that the camera 60 acquires the image from the microfluidic channel 40. Since there is only a small difference in refractive index between the cured microstructures and uncured photocurable liquid, it is desirable that offaxis illumination is used to show the cured microstructures.

The optofluidic lithography system shown in FIG. 1 employs the spatial light modulator, which eliminates the need for a mask, and can create microstructures at a desired time and place. While a conventional optofluidic lithography system using a mask can create only microstructures having a certain shape, the optofluidic lithography system shown in FIG. 1 can create microstructures having several shapes without requiring a mask. The optofluidic lithography system shown in FIG. 1 allows for real-time control of in-situ photopolymerization.

FIG. 2 illustrates an example of the microfluidic channel 40 employed in the optofluidic lithography system of FIG. 1. In FIG. 2, (a) is a longitudinal sectional view of the microfluidic channel 40, (b) is a lateral sectional view of the microfluidic channel 40, and (c) schematically

illustrates microstructures created by UV inside the microfluidic channel 40. The microfluidic channel 40 is made using a standard soft lithography scheme. Referring to FIG. 2, the microfluidic channel 40 is formed of a surrounding poly-dimethyl siloxane (PDMS). The microfluidic channel 40 has four surfaces, including one surface formed of a PDMS 43 coated on a glass substrate 42 and three surfaces formed of a PDMS mold 44. All the surfaces of the microfluidic channel 40 formed of the PDMS have oxygen inhibition layers (not shown) formed thereon. The oxygen inhibition layers allow the microstructures to be free-flowing. While, as the photocurable liquid 41, the polyethylene glycol (400) diacrylate (PEG-DA available from Polyscience) is used with a photoinitiator, other photoresists are available. Various particles, such as various semiconductor nanoparticles, e.g., quantum dots, normal nanoparticles, inorganic structures, micro semiconductor circuit chips, or heterogeneous polymer beads, may be included in the photocurable polymer. The photocurable liquid 41 is transferred to the microfluidic channel 40 via an inlet tube 45 and a first hole 46 formed in the PDMS mold 44, and the microstructures cured inside the microfluidic channel 40 are transferred to the exterior together with uncured photocurable liquid 41 via a second hole 47 formed in the PDMS mold 44 and an outlet tube 48. The tubes 45 and 48 and the holes 46 and 47 may be coupled by pipette tips 49 respectively.

FIG. 3 illustrates microstructures created by the optofluidic lithography system according to an embodiment of the present invention. In FIG. 3, creation of the microstructures is controlled temporally and spatially as a pattern of the optical modulation in the spatial light modulator is changed by a computer.

Referring to FIG. 3, first, five characters, "BINEL", are sequentially created by light curing ((a) to (f) in FIG. 3). In this way, microstructures having any shapes can be created with the optofluidic

lithography system. UV patterns formed by the spatial light modulator 20 are shown at the bottom left of (a) to (e) in FIG. 3.

(a) and (b) of FIG. 4 illustrate an example in which times and locations at which microstructures are created by the optofluidic lithography system are freely controlled in real time according to an embodiment of the present invention.

Referring to FIG. 4(a), microstructures having various shapes are sequentially created. UV patterns formed by the spatial light modulator 20 are shown at the bottom left of (i) to (iv) in FIG. 4(a).

Referring to FIG. 4(b), creation of the microstructures is controlled in real time. A PDMS microfluidic channel is prepared and a butterfly shape is exposed, resulting in a butterfly-shaped structure ((i) in FIG. 4(b)). When the butterfly-shaped structure is targeted and a circular ring shape around the butterfly-shaped structure is exposed while the butterfly-shaped structure flows down, a ring-shaped structure is formed ((ii) in FIG. 4(b)). The butterfly-shaped structure and the ring-shaped structure freely flow down ((iii) in FIG. 4(b)). With a conventional continuous-flow lithography scheme using a fixed mask, it is impossible to control the creation of the microstructures in real time. UV patterns formed by the spatial light modulator 20 are shown at the bottom left of (i) and (ii) in FIG. 4(b).

FIG. 5 illustrates an example in which a structure that is larger than an exposure area is created using the optofluidic lithography system according to an embodiment of the present invention. In FIG. 5, (a) illustrates a linear structure made by the optofluidic lithography system according to an embodiment of the present invention, (b) and (c) illustrate sinusoidal structures, (d) illustrates a chain-shaped structure, and (e) illustrates movement of a UV beam for creating a sinusoidal structure. In particular, in (a) of FIG. 5, the spatial light modulator holds the shape of the light to create a linear microstructure along the microfluidic channel.

In (b) to (d) of FIG. 5, the spatial light modulator continuously changes the shape of the modulated light to create an elongated microstructure (e.g., a sinusoidal or chain-shaped microstructure) along the microfluidic channel.

Referring to FIG. 5, continuous exposure of the microfluidic channel to a UV beam can result in the shapes shown in (a) to (d) of FIG. 5. In particular, when an exposure pattern represented by the spatial light modulator moves up or down to form the patterns shown in (b) to (d) of FIG. 5, as in moving-image reproduction, the structure created by continued flow of the photocurable liquid floats, resulting in an elongated sinusoidal or chain-shaped structure. In the example illustrated in FIG. 5, a microstructure having a length of a few mm or more is created with an exposed region having a radius of 100um or less. Since any exposure pattern, as well as a circular exposure pattern, can be reproduced in real time, a structure having any shape, as well as the structure shown in FIG. 5, can be created. With the conventional continuous-flow lithography scheme using a fixed mask, it is impossible to create the structure that is larger than an exposure area and has an arbitrary shape, as described above.

FIG. 6 illustrates an example in which a microstructure having various compositions is created as several other photocurable liquids flow inside the microfluidic channel. Referring to FIG. 6, when two different photocurable liquids flow inside a Y-branched microfluidic channel, they meet and flow without mixing with each other due to capillary action. With the optofluidic lithography system, a structure including two materials adhered to each other can be created by exposing an interface between the two materials. Microstructures having different compositions can also be simultaneously created.

FIG. 7 illustrates an example of a microstructure created using the optofluidic lithography system according to an embodiment of the present invention. Micro semiconductor chips, structures or particles flow together

with the photocurable liquid and optofluidic lithography is performed to create a microstructure having the micro semiconductor chips, structures or particles embedded therein, as shown in FIG. 7. For example, the structures and the particles may be made of a polymer or an inorganic material.

It will be apparent to those skilled in the art that various modifications and variation can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

【Industrial Applicability】

The present invention can be efficiently applied to the field of an optofluidic lithography system and is capable of eliminating a cost of manufacturing and replacing a mask, unlike a conventional optofluidic lithography system that requires mask replacement each time it creates a structure having a new shape.

【CLAIMS】

【Claim 1】

An optofluidic lithography system comprising:

a light source;

a spatial light modulator for modulating light provided by the light source; and

a microfluidic channel including photocurable liquid flowing therein, wherein the microfluidic channel selectively cures the photocurable liquid according to the modulated light provided by the spatial light modulator.

【Claim 2】

The system of claim 1, further comprising a demagnifying lens for demagnifying the modulated light provided by the spatial light modulator and providing the resultant light to the microfluidic channel.

【Claim 3】

The system of claim 2, further comprising:

a camera for outputting an electrical image signal corresponding to an image from the microfluidic channel; and

a beam splitter for providing the modulated light from the spatial light modulator to the microfluidic channel via the demagnifying lens, and providing the image, which is provided from the microfluidic channel via the demagnifying lens, to the camera.

【Claim 4】

The system of claim 3, further comprising an illuminator for providing offaxis illumination to the microfluidic channel.

【Claim 5】

The system of any one of claims 1 to 4, wherein the spatial light modulator is a digital micromirror array.

【Claim 6】

The system of any one of claims 1 to 4, wherein an elongated microstructure is formed along the microfluidic channel as the spatial light modulator continuously changes a shape of the modulated light, the microstructure being created by curing photocurable liquid.

【Claim 7】

The system of any one of claims 1 to 4, wherein the spatial light modulator is a programmable spatial light modulator.

【Claim 8】

The system of any one of claims 1 to 4, wherein the microfluidic channel is formed of a surrounding PDMS.

【Claim 9】

The system of any one of claims 1 to 4, wherein the microfluidic channel includes oxygen inhibition layers formed on four faces thereof.

【Claim 10】

The system of any one of claims 1 to 4, wherein the photocurable liquid flows together with at least one of a micro semiconductor chip, structure and particle, and wherein the microstructure created by curing the photocurable liquid includes the at least one.

FIG. 1

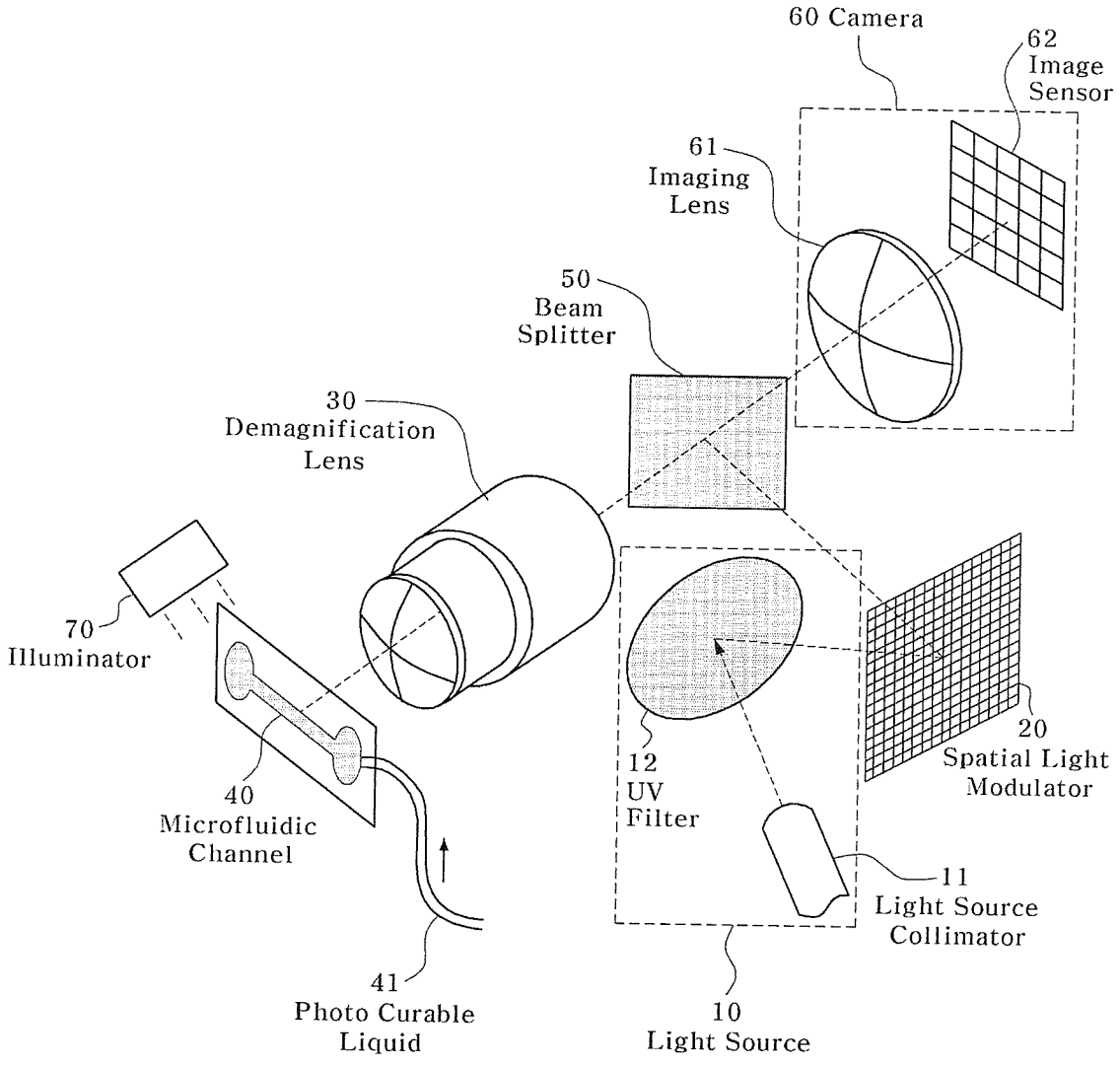

60 Camera
62
Image
Sensor
61
Imaging
Lens
50
Beam
Splitter
30
Demagnification
Lens
70
Illuminator
40
Microfluidic
Channel
41
Photo Curable
Liquid
12
UV
Filter
20
Spatial Light
Modulator
11
Light Source
Collimator
10
Light Source

FIG. 2

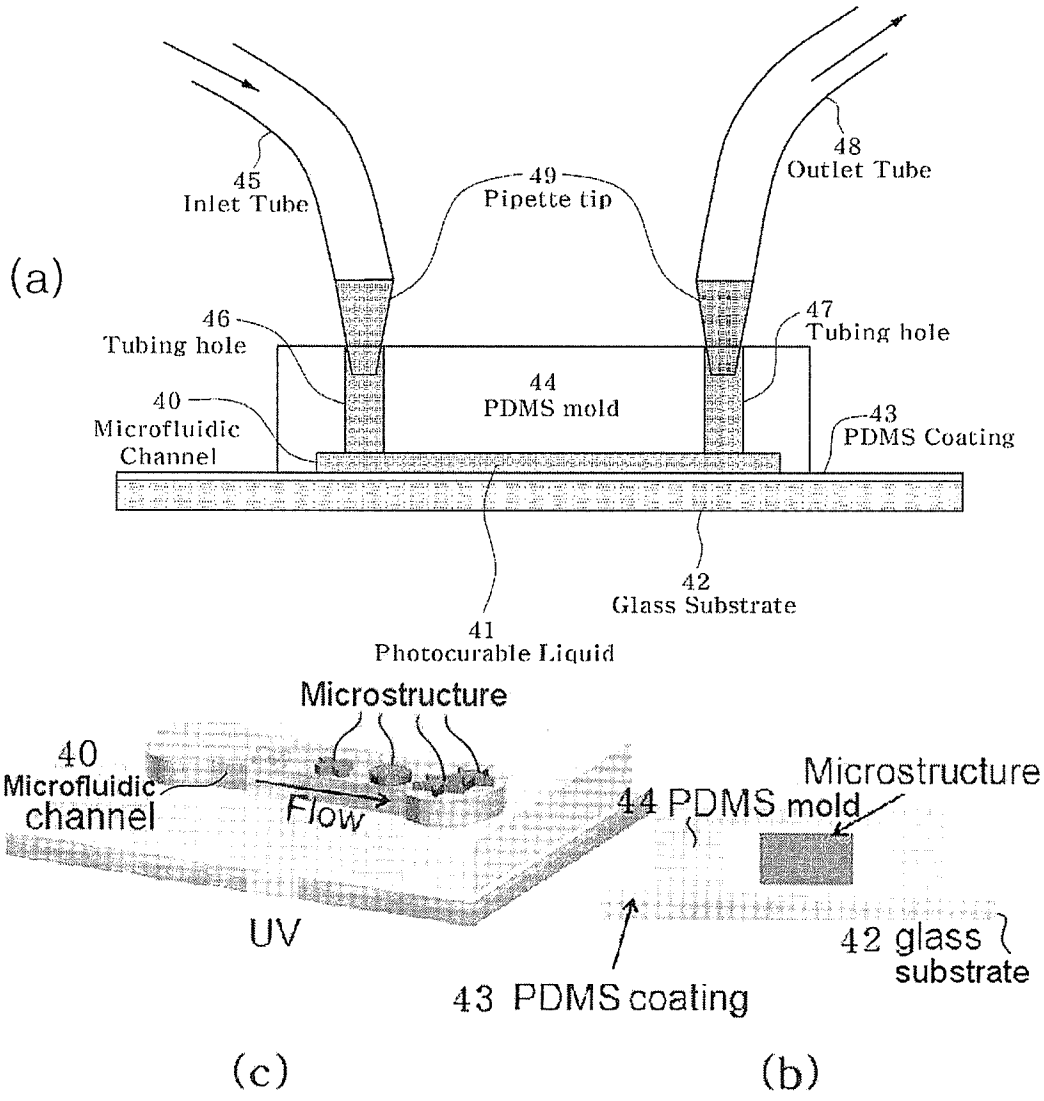

(a)
45
Inlet Tube
49
Pipette tip
48
Outlet Tube
46
Tubing hole
47
Tubing hole
44
PDMS mold
40
Microfluidic
Channel
43
PDMS Coating
42
Glass Substrate
41
Photocurable Liquid
Microstructure
40
Microfluidic
channel
Flow
UV
Microstructure
44 PDMS mold
42 glass
substrate
43 PDMS coating
(c)
(b)

FIG. 3

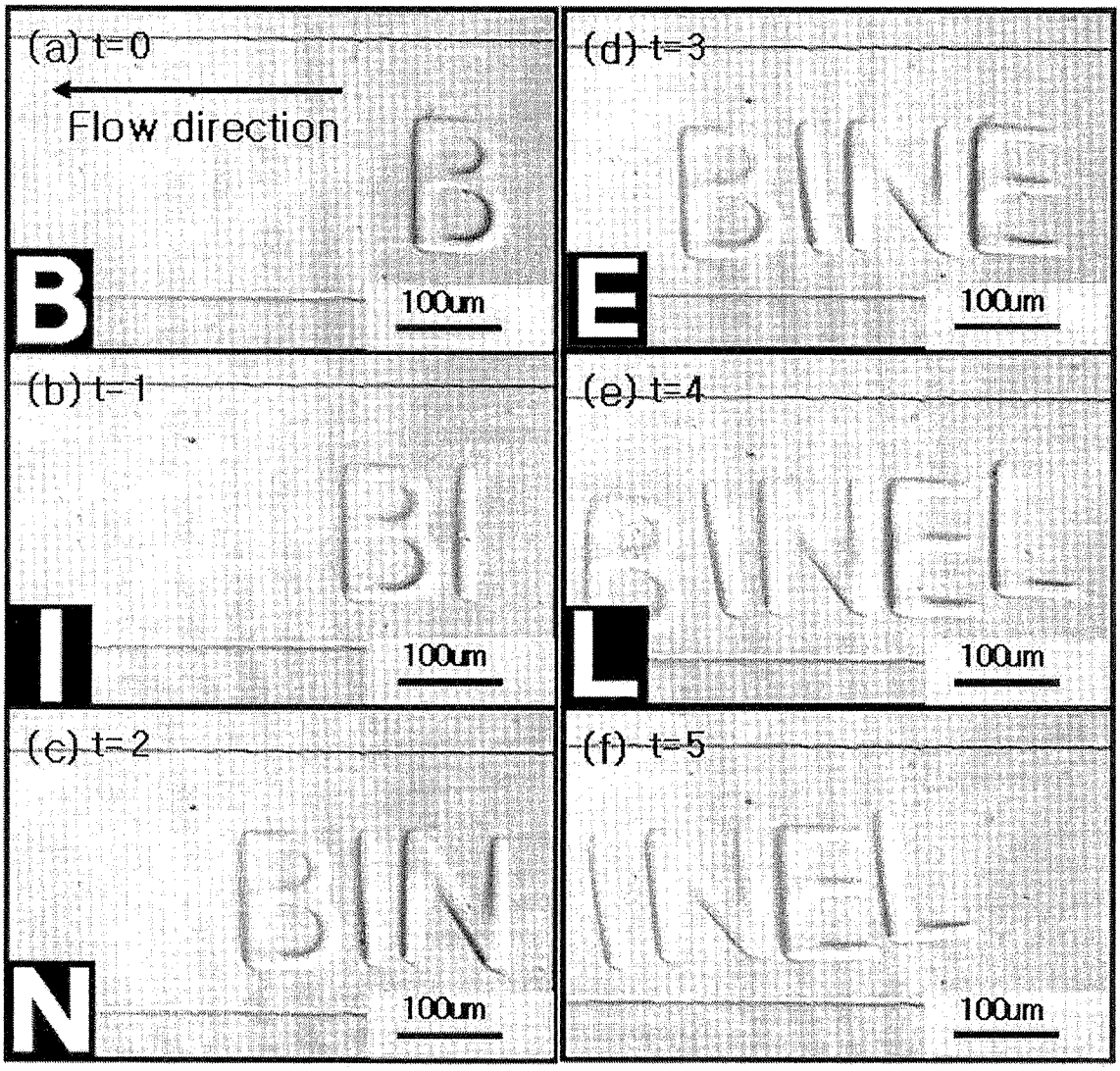

(a) t=0
Flow direction
B
100um
(d) t=3
BINE
100um
(b) t=1
BI
100um
(e) t=4
BINEL
100um
(c) t=2
BIN
100um
(f) t=5
INEL
100um

FIG. 4

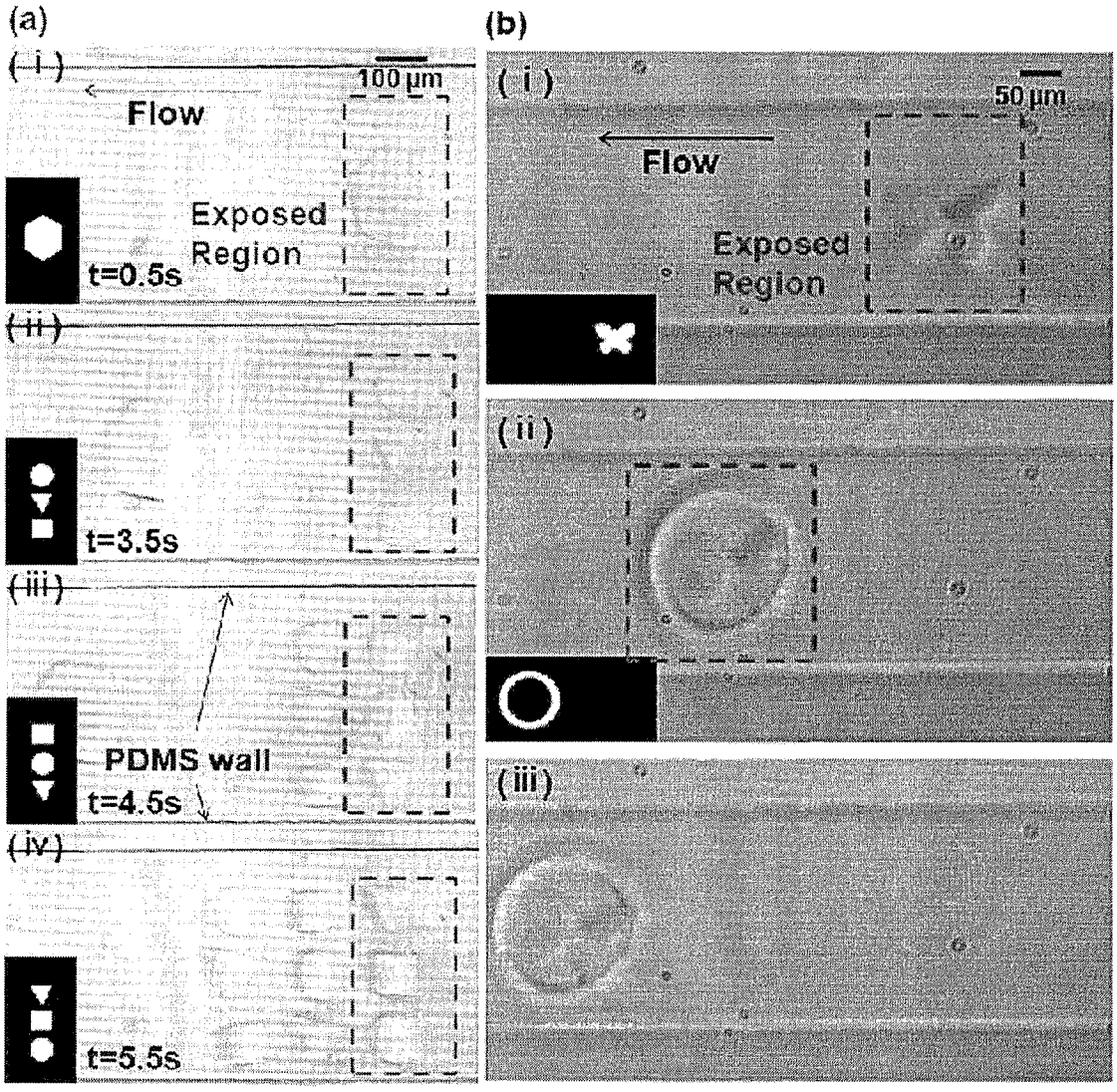

(a)
(i)
100 μm
Flow
Exposed
Region
t=0.5s
(ii)
t=3.5s
(iii)
PDMS wall
t=4.5s
(iv)
t=5.5s
(b)
(i)
50 μm
Flow
Exposed
Region
(ii)
(iii)

FIG. 5

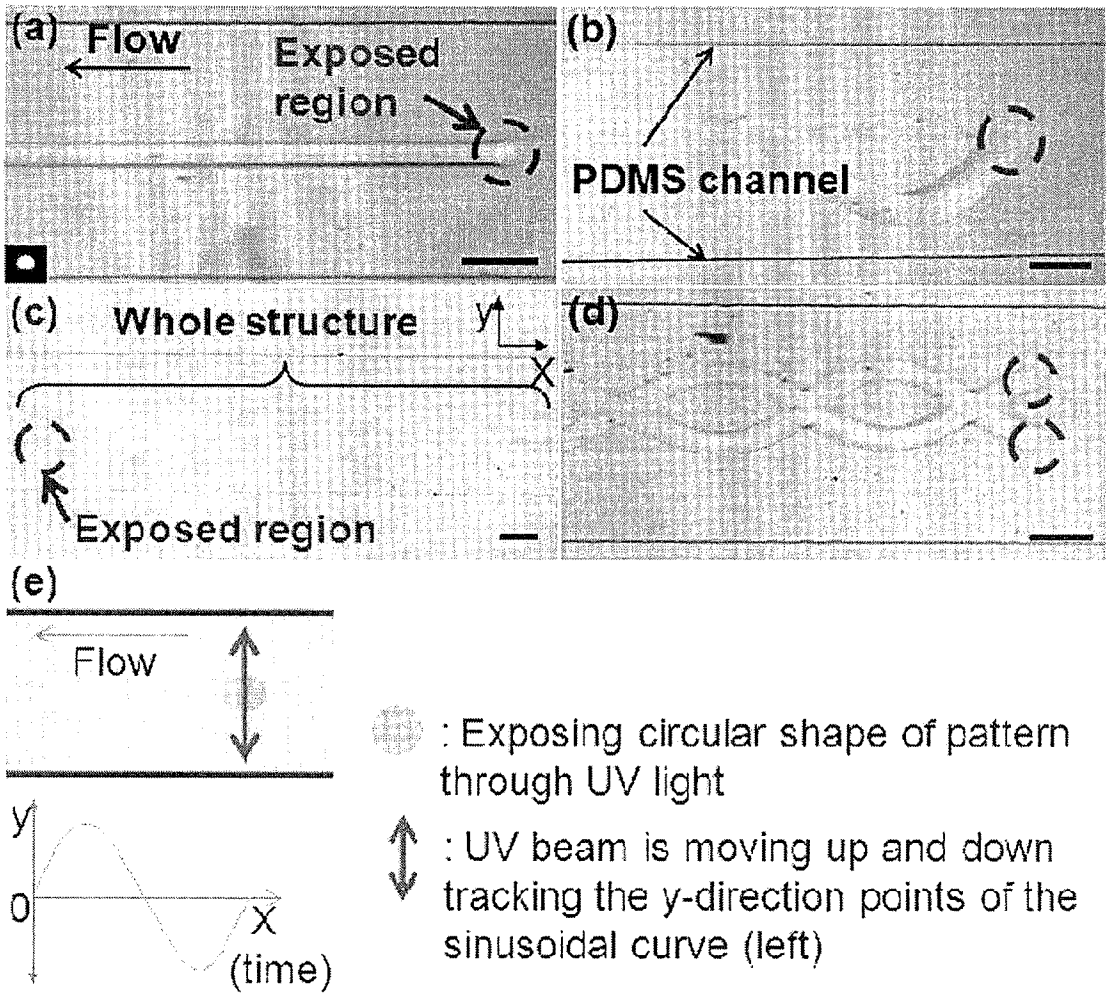

(a)
Flow
Exposed region
(b)
PDMS channel
(c)
Whole structure
y
x
Exposed region
(d)
(e)
Flow
y
0
x
(time)
: Exposing circular shape of pattern through UV light
: UV beam is moving up and down tracking the y-direction points of the sinusoidal curve (left)

FIG. 6

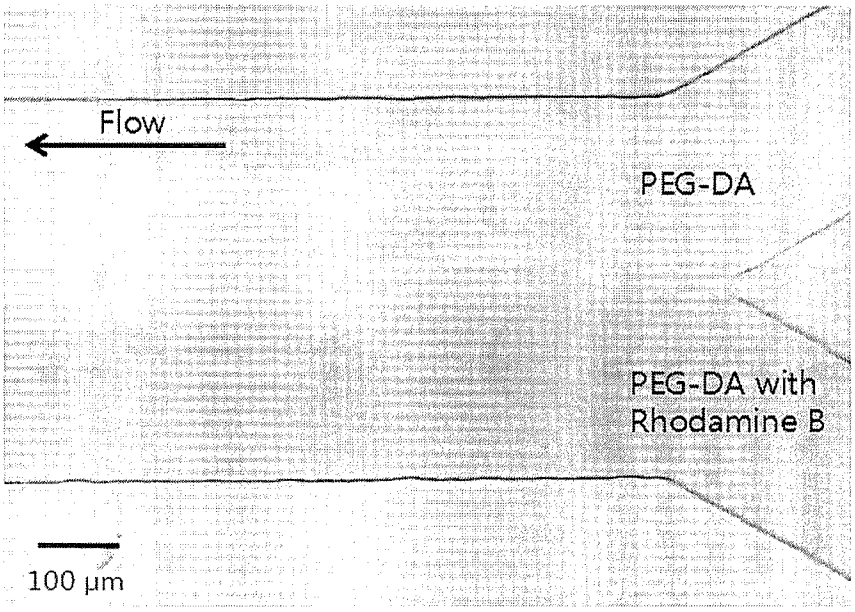
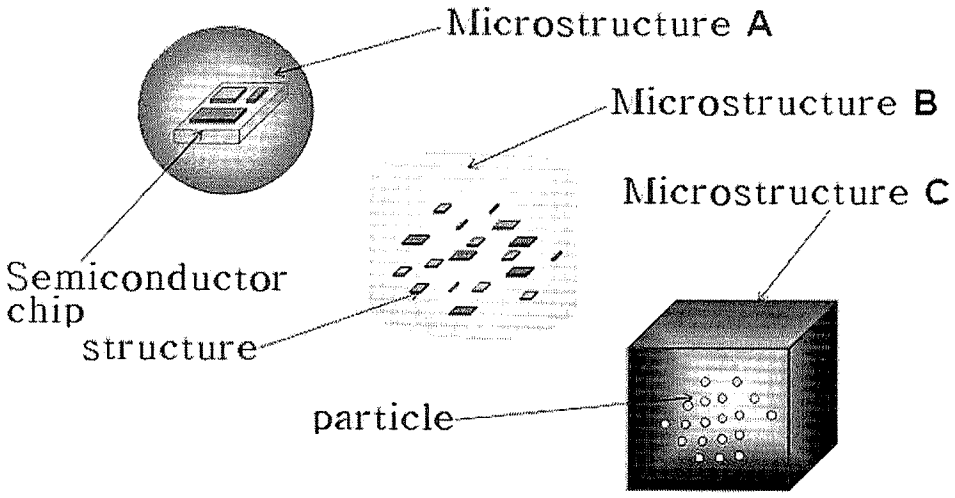


FIG. 7


Microstructure A
Microstructure B
Microstructure C
Semiconductor chip structure
particle