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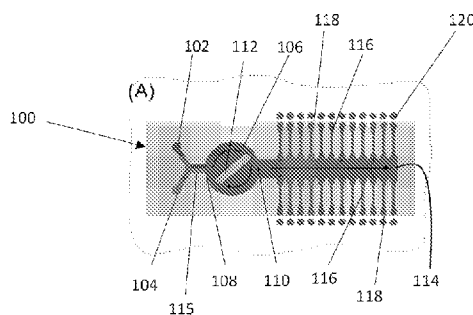


Figure 1

(57) Abstract: Disclosed is a droplet generation apparatus. The apparatus includes a plurality of fluid inlets for receiving respective fluids to be mixed, and a mixing chamber that has a mixing chamber inlet in communication with the plurality of fluid inlets, and a mixing chamber outlet. The mixing chamber includes, or is arranged to receive, a mixing element for stirring or agitating the fluids at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet. The mixing chamber outlet opens into an outlet channel that has at least one side channel extending generally transverse of the outlet channel, the at least one side channel being dimensioned to generate a droplet at an exit thereof when the homogeneous fluid mixture flows to the exit.

APPARATUS FOR GENERATING DROPLETS OF FLUID MIXTURES

TECHNICAL FIELD

5 The present disclosure relates to apparatus for fluidic mixing and the production of fluid droplets using such an apparatus. The present disclosure particularly relates to, but is not limited to, mixing polymer precursors to produce hydrogel particles.

10 BACKGROUND

It has become increasingly necessary to accurately mix viscous fluids to rapidly generate uniform droplets from the mixture. Droplets are important for many applications, including as templates for the production of micro-particles or capsules. For applications like these, it is often necessary to introduce or mix multiple reactants at a specific time to initiate a chemical reaction in the droplet. Microfluidic devices are advantageous for high degrees of control and uniformity in droplet generation, but mixing techniques are often slow or rely on non-standard equipment.

20 Traditionally, droplets have been produced in large stirred batches of immiscible fluids. Microfluidic techniques improve on these batch methods and offer precise control over droplet composition and size by mixing fluids during flow within devices with small physical dimensions. These droplets can function as "microreactors" for many different processes and applications including as templates for microparticles or capsules and it is often desirable to increase the throughput of produced droplets. For applications like these, it is often necessary to introduce or mix multiple reactants at a specific time to initiate a chemical reaction in the droplet.

30 Microfluidic mixers can be categorized as "passive" or "active" devices. Passive microfluidic devices operate using the diffusion of fluids inside channels for mixing. Active microfluidic mixing devices operate by stirring or agitating fluids using some externally supplied energy. There are numerous mechanisms for agitating fluids that have been explored including applying ultrasonic waves, embedded micro-

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pumps that alternate on-and-off, and inducing fluctuations of the electric field within a fluid.

It is desirable to provide an apparatus for both controlled mixing of fluids and
5 controlled generation of uniform droplets.

SUMMARY

Embodiments of the present disclosure provide a device that integrates the active
10 mixing of viscous fluids with rapid generation of uniform droplets of the resulting mixture.

Disclosed is a droplet generation apparatus comprising:

a plurality of fluid inlets for receiving respective fluids to be mixed;
15 a mixing chamber that has a mixing chamber inlet in communication with the plurality of fluid inlets, and a mixing chamber outlet;
wherein the mixing chamber comprises, or is arranged to receive, a mixing element for stirring or agitating the fluids at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet; and
20 wherein the mixing chamber outlet opens into an outlet channel that has at least one side channel extending generally transverse of the outlet channel, the at least one side channel being dimensioned to generate a droplet at an exit thereof when the homogeneous fluid mixture flows to the exit.

25 An upper surface of the mixing chamber may be coplanar with respective upper surfaces of the outlet channel and each side channel.

The outlet channel may have a depth greater than a depth of each side channel.
The outlet channel may have a depth at least 5 times that of each side channel.
30

The outlet channel may have a width greater than a width of each side channel.

The plurality of fluid inlets may be in communication with an inlet channel, the inlet channel being in communication with the mixing chamber inlet.
35

The, or each, side channel may taper outwardly adjacent the exit thereof. The, or each, side channel may have an inlet tapering inwardly from the outlet channel.

5 The droplet generation apparatus may comprise a plurality of side channels arranged in pairs, respective side channels of each pair extending from opposite sides of the outlet channel. The apparatus may comprise between 5 pairs and 50 pairs of side channels.

10 Each side channel may have a depth between about 1 micron and about 500 microns.

A depth of the mixing chamber may be between 1.5 times and 5 times the depth of the outlet channel.

15 The mixing chamber may have at least one side wall and a lower wall that transitions to said at least one side wall via a filleted region. The filleted region may have a radius of curvature between about $1/4$ and $1/3$ the depth of the mixing chamber.

20 The mixing chamber may transition to the outlet channel via a filleted portion. The filleted portion may have a radius of curvature between about $1/4$ and $1/3$ the depth of the mixing chamber.

25 The mixing element may be a magnetic stirrer that is driveable by a rotating magnetic field. The magnetic stirrer may have a length between about 0.5 times and about 0.9 times a diameter of the mixing chamber.

30 The, or each, side channel may be arranged such that a residence time of the homogeneous fluid mixture in the device is less than 5 seconds at flow rates of up to 15 mL/min.

The plurality of fluid inlets, the mixing chamber, the mixing chamber outlet channel, and the side channels may be formed as voids in a material selected from PDMS, plastic, and glass.

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Also disclosed herein is a system for droplet generation, comprising:

a droplet generation apparatus according to any one of claims 1 to 20;

a vessel for immersing the apparatus in a bath fluid that is immiscible with the homogeneous fluid mixture such that droplets remain suspended in the bath fluid after exiting the droplet generation apparatus.

An external surface of the apparatus may have an affinity for the bath fluid. The external surface of the apparatus may be coated or surface-treated to have an affinity for the bath fluid.

The bath fluid may be selected from fluorinated oil, mineral oil, silicone oil, and water.

Also disclosed herein is a method of generating droplets, comprising:

introducing a plurality of input fluids into respective fluid inlets that are in communication with a mixing chamber that has a mixing chamber inlet in communication with the plurality of fluid inlets, and a mixing chamber outlet that opens into an outlet channel that has at least one side channel extending generally transverse of the outlet channel, the at least one side channel being dimensioned to generate a droplet at an exit thereof when fluid flows to the exit; and

stirring or agitating the input fluids in the mixing chamber at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet; whereby the homogeneous fluid mixture flows to the outlet channel such that droplets of the homogeneous fluid mixture are generated at respective exits of respective side channels.

The method may further comprise controlling a flow rate of the input fluids such that the droplets exit the side channel or side channels prior to any chemical reaction occurring between reactants in the fluids.

The method may further comprise immersing at least the at least one side channel in a bath of a fluid that is immiscible with the input fluids.

The plurality of fluid inlets, the mixing chamber, the mixing chamber outlet channel, and the side channels may be formed as voids in a material selected from PDMS, plastic, and glass.

- 5 The material may have an affinity for the fluid of the bath.

The method may involve stirring or agitating using a magnetic stirring element driven by a rotating magnetic field.

10 **BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments of the present invention will now be described by way of non-limiting example only, with reference to the accompanying drawings in which:

- 15 Figure 1 shows (A) a top-down schematic of an example device, and (B) a apparatus in accordance with the present disclosure in operation for the production of spherical hydrogel particles.;

- Figure 2 shows side-view wireframe and shaded diagrams along with a top-down
20 wireframe of a device consistent with embodiments of the disclosure; and

Figure 3 illustrates a method of generating droplets.

DETAILED DESCRIPTION

25

- Droplet generation apparatuses described herein may interchangeably be referred to as devices. In any case, the apparatuses integrate active mixing of two or more fluid streams with at least one nozzle, and typically an array of nozzles, for generating uniform droplets. When an array of nozzles is used, the throughput
30 can be high.

- Figure 1(A) is a schematic of a droplet generation apparatus 100 for actively mixing two or more fluid streams and generating uniform droplets at high throughput. The apparatus 100 comprises a plurality, and presently two, fluid
35 inlets 102, 104. The apparatus 100 further comprises a mixing chamber 106 that

has a mixing chamber inlet 108 and a mixing chamber outlet 110. The mixing chamber 106 includes, or has within it, a mixing element 112. The mixing chamber outlet 110 opens into an outlet channel 114 that has at least one, and presently a plurality, of side channels 116.

5

Each of the fluid inlets 102, 104 receives a fluid to be mixed. The fluid may be drawn into the respective fluid inlets by capillary action, siphoning, under the action of a pump or via any other appropriate means. A pump is desirable since the flow rate through the apparatus 100 can be readily controlled and changed, if
10 desired.

The fluid inlets 102, 104 are in communication with an inlet channel 115, the inlet channel 115 being in communication with the mixing chamber inlet 108. In the embodiment shown, the inlet solutions enter the device and combine into the inlet
15 channel 115 which leads to the mixing chamber. The fluids may remain separate in the inlet channel 115, or may start to mix and/or react in the inlet channel 115 prior to reaching the mixing chamber 106.

Although only two fluid inlets are shown, there may be three or more fluid inlets
20 as required. In the case of two fluid inlets, each of the fluid inlets will deliver a different fluid for mixing. In one example, the two inlet solutions are a monomer containing a catalyst and a monomer containing an initiator, the two monomers polymerizing shortly after mixing. In embodiments with three or more fluid inlets, each of the inlets may deliver a different fluid for mixing, or multiple fluid inlets
25 may deliver the same fluid provided that, overall, the three or more fluid inlets deliver at least two different fluids.

The mixing chamber inlet 108 is in communication with the fluid inlets 102, 104, such that the fluids are delivered from the fluid inlets 102, 104 through the mixing
30 chamber inlet 108 into the mixing chamber 106. The mixing element 112 is a physical body in the mixing chamber 106 that stirs or agitates the fluids at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet 110.

35

The mixing chamber 106 is generally circular. This reduces the amount of dead space in corners where fluids may reside unmixed, therefore reducing the uniformity of the reaction throughout the mixture. It will be appreciated that the mixing chamber 106 may be shaped depending on the shape of the mixing element 112 to ensure thorough mixing.

The mixing chamber 106 may also have a lower wall or base 212 as shown in Figure 2(A), that transitions into a side wall 214 via a filleted region 216. The filleted region may have any radius of curvature, such as between about one quarter and one third the depth of the mixing chamber 106. Similarly, the mixing chamber 106 transitions to the outlet channel 114 via a filleted portion 218. Again, the filleted portion may have a radius of curvature between about one quarter and about one third the depth of the mixing chamber 106.

15

The mixing element 112 is a magnetic bar. The magnetic bar or mixing element 112 can have any appropriate length such as between about 0.5 times and about 0.9 times a diameter of the mixing chamber.

The magnetic bar can be driven by a rotating magnetic field such as that produced by a standard benchtop stir-plate at a wide range of rotations per minute. The rapid stirring of the magnetic bar results in a homogeneous mixture of the inlet solutions even at total flowrates as high as 10 mL/min. The side channels 116 can be arranged such that a residence time of the homogeneous fluid mixture in the device is less than 5 seconds at flow rates of up to 15 mL/min. For example, where a lower residence time is desired, the flow rate may be increased by pumping, the mixing speed may be increased and the number of side channels 116 may be increased when compared with a device for handling lower flow rates.

Instead of a magnetic bar, the mixing element may be a rotor or other physical body for moving through the fluids to mix the fluids. The magnetic bar, rotor or other embodiments of the mixing element 112 may have a fixed mixing or rotational speed or may have a controllable mixing or rotational speed such that the speed can be selected depending on the fluids, the residence time of fluids in the mixing chamber 106 and other factors.

The mixing chamber outlet 110 opens into the outlet channel 114. The outlet channel 114 may have a single side channel 116 extending from it. However, in the present embodiment the channel 114 has a plurality of side channels 116 extending from it – i.e. there may be a single side channel, or a plurality of side channels 116, extending from the outlet channel 114. The plurality of side channels 116 are arranged in pairs, respective side channels 116 of each pair extending from opposite sides of the outlet channel 114. There may be any number of side channels or pairs of side channels. In some embodiments, there may be between 5 pairs and 50 pairs of side channels 116.

Each side channel is dimensioned to generate a droplet 120 at an exit 118 thereof when the homogeneous fluid mixture (i.e. mixture of fluids in chamber 106) flows to the exit. The side channels 116 extend generally transversely to the outlet channel 114 – i.e. across the outlet channel 114. This includes extending at roughly 90° to the outlet channel 114, and other angles relative to the outlet channel 114 that do not disrupt the rapid throughput and generation of uniform droplets using the apparatus 100.

In some embodiments, there may be multiple outlet channels 114 each of which may connect to a mixing chamber 106 at a separate mixing chamber outlet. Alternatively, or in addition, an outlet channel may branch into smaller channels before further branching into side channels at which droplets are generated. Other channel configurations will become apparent in view of the present disclosure.

The use of the apparatus 100 is reflected in Figure 1(B), showing solutions that undergo a polymerisation reaction on mixing. The resultant mixture produces droplets 122 that are stable in the continuous phase bath 124.

With reference to Figure 2, an upper surface 200 of the mixing chamber 106 is coplanar with respective upper surfaces 202, 204 of the outlet channel 114 and each side channel 116. By aligning upper surfaces 200, 202, 204 in the same horizontal plane, areas prevented from being trapped inside the apparatus 100.

In some embodiments, the mixing chamber 106 and the outlet channel 114 have the same depth. However, in the embodiment shown in Figure 2, the mixing chamber 106 is deeper than the outlet channel 114, and presently between 1.5 times and five times the depth of the outlet channel 114. Similarly, the outlet channel 114 is deeper than the side channels 116. By stepping the mixing chamber 106 to a shallower outlet channel 114, and then to even shallower side channels 116, a more uniform flow rate of fluid flow across the narrow side channels 116 is achieved. This generates droplets of a more consistent size.

10 In some embodiments, the outlet channel 114 has a depth at least five times that of each side channel 116. In this regard, each side channel 116 may have a depth between about 1 μm and about 500 μm . Moreover, as shown in Figure 2(C), the outlet channel 114 has a width greater than a width of each side channel 116.

15 The side channels 116 taper outwardly adjacent a respective exit 208. The shape of the exit 208 in each case may be selected based on the desired droplet size and characteristics of the apparatus 100. As such, the side channels 116 expand in width near the edge 210 of the apparatus 100 and terminate in a step-change in height at the edge 210. The step change may be the height X of the apparatus
20 100 or, if the polymerised mixture is buoyant in the continuous phase bath, the step change may be the depth of the bath to the exit of each side channel 116.

This side channels 116 similarly taper inwardly from the outlet channel 114. This ensures a smooth transition of mixture from the outlet channel 114 into the side
25 channels 116.

The apparatus 100 may be formed from a single, unitary piece of material. In some instances, the fluid inlets 102, 104, the mixing chamber 106, the mixing chamber outlet channel 110, and the side channels 116 are formed as voids in a
30 material selected from PDMS, plastic, and glass.

When used in a system for droplet generation, such as system 220, the apparatus 100 is immersed in a bath fluid 222 (in vessel 224) that is immiscible with the homogeneous fluid mixture such that droplets remain suspended in the bath fluid
35 after exiting the droplet generation apparatus. In some instances, the bath fluid

222 is immiscible with the inlet solutions, and is a fluid such as fluorinated oil for aqueous inlet fluid. The fluorinated oil may contain a surfactant. The bath may instead be mineral oil, silicon oil, water or another suitable fluid.

- 5 The materials that the apparatus 100 is made of or the surfaces (e.g. external surface and potentially also the internal surface) of the apparatus 100 may be modified to have an affinity for the immiscible bath fluid 222. For example, the apparatus 100 may be made of poly(dimethyl siloxane) or plastic that has been silanized to have an increased affinity for fluorinated oil.

10

Figure 3 shows a method 300 for generating droplets. The method 300 may be performed on an apparatus such as apparatus 100 or any other embodiment of the apparatus described herein. The method 300 involves:

- (302) introducing a plurality of input fluids into respective fluid inlets that
15 are in communication with a mixing chamber. Per apparatus 100, the mixing chamber has a mixing chamber inlet in communication with the plurality of fluid inlets, and a mixing chamber outlet that opens into an outlet channel. At least one side channel extends generally transverse of the outlet channel and each side channel is dimensioned to generate a droplet at an exit thereof when fluid flows
20 to the exit; and

(304) stirring or agitating the input fluids in the mixing chamber at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet.

The homogeneous fluid mixture flows to the outlet channel such that droplets of
25 the homogeneous fluid mixture are generated at respective exits of respective side channels.

The method 300 may also involve (306) controlling a flow rate of the input fluids such that the droplets exit the side channel or side channels prior to any chemical
30 reaction occurring between reactants in the fluids.

Embodiments of the present apparatus have been described that have two or more fluid inlets that lead to a mixing chamber containing an embedded magnetic stir bar that can be driven by a standard benchtop stir-plate. The mixing chamber
35 ensures a homogeneous fluid is delivered to each of the connected nozzles (outlets

or exits of side channels 116) that may be adapted from step-emulsification devices and designed to produce consistent droplet sizes over a wide range of flowrates. In the system embodiment, the nozzles exit into a large bath or other channel for droplets to complete any necessary reaction and be collected.

5

This apparatus has many advantages over existing devices, including precise control over droplet size and uniformity, and a high frequency of automated generation. Existing active microfluidic mixing devices often either are complicated to fabricate, rely on non-standard equipment, or require particular properties of the fluids being mixed (e.g. can tolerate high heat, differing electrical conductivity, etc.). The present apparatus is simple to fabricate, does not have particular restrictions on the fluids, and operates using standard laboratory equipment. The speed of mixing can be easily tuned to accommodate different flowrates or fluid viscosities.

15

For existing passive microfluidic devices to mitigate the slow rate of mixing via diffusion, the cross-sectional dimensions of channels may be reduced. However, at high flowrates (such as for high throughputs) this necessitates a much longer channel length overall and increases the footprint of the device which is undesirable. Passive devices often split a channel into multiple small channels that recombine to increase the surface area of mixing, however these can become complicated to fabricate. Furthermore, if mixing occurs too slowly, this will result in an inhomogeneous mixture flowing through the device and portions of the fluid potentially reacting too early. For example, a fluid mixture that produces a polymerization reaction might solidify within a device, clogging it. In the present apparatus, the rapidity of mixing and the close proximity of the mixing chamber to the droplet generation nozzles reduces the risk of a chemical reaction occurring inside the device if that is undesirable.

30 The apparatus described herein can be used for the generation of uniform hydrogel template particles for the crystallization of pharmaceutical drugs, for example.

Many modifications will be apparent to those skilled in the art without departing from the scope of the present invention.

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Throughout this specification, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

CLAIMS

1. A droplet generation apparatus comprising:
 - a plurality of fluid inlets for receiving respective fluids to be mixed;
 - 5 a mixing chamber that has a mixing chamber inlet in communication with the plurality of fluid inlets, and a mixing chamber outlet;
 - wherein the mixing chamber comprises, or is arranged to receive, a mixing element for stirring or agitating the fluids at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet; and
 - 10 wherein the mixing chamber outlet opens into an outlet channel that has at least one side channel extending generally transverse of the outlet channel, the at least one side channel being dimensioned to generate a droplet at an exit thereof when the homogeneous fluid mixture flows to the exit.
- 15 2. A droplet generation apparatus according to claim 1, wherein an upper surface of the mixing chamber is coplanar with respective upper surfaces of the outlet channel and each side channel.
3. A droplet generation apparatus according to claim 1 or claim 2, wherein the
20 outlet channel has a depth greater than a depth of each side channel.
4. A droplet generation apparatus according to claim 3, wherein the outlet channel has a depth at least 5 times that of each side channel.
- 25 5. A droplet generation apparatus according to any one of the preceding claims, wherein the outlet channel has a width greater than a width of each side channel.
6. A droplet generation apparatus according to any one of the preceding claims,
30 wherein the plurality of fluid inlets are in communication with an inlet channel, the inlet channel being in communication with the mixing chamber inlet.
7. A droplet generation apparatus according to any one of the preceding claims, wherein the, or each, side channel tapers outwardly adjacent the exit thereof.

8. A droplet generation apparatus according to claim 7, wherein the, or each, side channel has an inlet tapering inwardly from the outlet channel.
9. A droplet generation apparatus according to any one of the preceding claims,
5 comprising a plurality of side channels arranged in pairs, respective side channels of each pair extending from opposite sides of the outlet channel.
10. A droplet generation apparatus according to claim 9, comprising between 5 pairs and 50 pairs of side channels.
- 10 11. A droplet generation apparatus according to any one of the preceding claims, wherein each side channel has a depth between about 1 micron and about 500 microns.
- 15 12. A droplet generation apparatus according to any one of the preceding claims, wherein a depth of the mixing chamber is between 1.5 times and 5 times the depth of the outlet channel.
- 20 13. A droplet generation apparatus according to any one of the preceding claims, wherein the mixing chamber has at least one side wall and a lower wall that transitions to said at least one side wall via a filleted region.
- 25 14. A droplet generation apparatus according to claim 13, wherein the filleted region has a radius of curvature between about $1/4$ and $1/3$ the depth of the mixing chamber.
- 30 15. A droplet generation apparatus according to any one of the preceding claims, wherein the mixing chamber transitions to the outlet channel via a filleted portion.
16. A droplet generation apparatus according to claim 15, wherein the filleted portion has a radius of curvature between about $1/4$ and $1/3$ the depth of the mixing chamber.

- 17.A droplet generation apparatus according to any one of the preceding claims,
wherein the mixing element is a magnetic stirrer that is driveable by a rotating
magnetic field.
- 5 18.A droplet generation apparatus according to claim 17, wherein the magnetic
stirrer has a length between about 0.5 times and about 0.9 times a diameter
of the mixing chamber.
- 10 19.A droplet generation apparatus according to any one of the preceding claims,
wherein the, or each, side channel is arranged such that a residence time of
the homogeneous fluid mixture in the device is less than 5 seconds at flow
rates of up to 15 mL/min.
- 15 20.A droplet generation apparatus according to any one of the preceding claims,
wherein the plurality of fluid inlets, the mixing chamber, the mixing chamber
outlet channel, and the side channels are formed as voids in a material selected
from PDMS, plastic, and glass.
- 20 21.A system for droplet generation, comprising:
a droplet generation apparatus according to any one of claims 1 to 20;
a vessel for immersing the apparatus in a bath fluid that is immiscible with
the homogeneous fluid mixture such that droplets remain suspended in the bath
fluid after exiting the droplet generation apparatus.
- 25 22.A system according to claim 21, wherein an external surface of the apparatus
has an affinity for the bath fluid.
- 23.A system according to claim 22, wherein the external surface of the apparatus
is coated or surface-treated to have an affinity for the bath fluid.
- 30 24.A system according to any one of claims 21 to 23, wherein the bath fluid is
selected from fluorinated oil, mineral oil, silicone oil, and water.
25. A method of generating droplets, comprising:

introducing a plurality of input fluids into respective fluid inlets that are in communication with a mixing chamber that has a mixing chamber inlet in communication with the plurality of fluid inlets, and a mixing chamber outlet that opens into an outlet channel that has at least one side channel extending generally transverse of the outlet channel, the at least one side channel being dimensioned to generate a droplet at an exit thereof when fluid flows to the exit; and

stirring or agitating the input fluids in the mixing chamber at a speed sufficient to produce a homogeneous fluid mixture at the mixing chamber outlet;

whereby the homogeneous fluid mixture flows to the outlet channel such that droplets of the homogeneous fluid mixture are generated at respective exits of respective side channels.

26.A method according to claim 25, comprising controlling a flow rate of the input fluids such that the droplets exit the side channel or side channels prior to any chemical reaction occurring between reactants in the fluids.

27.A method according to claim 25 or claim 26, comprising immersing at least the at least one side channel in a bath of a fluid that is immiscible with the input fluids.

28.A method according to any one of claims 25 to 27, wherein the plurality of fluid inlets, the mixing chamber, the mixing chamber outlet channel, and the side channels are formed as voids in a material selected from PDMS, plastic, and glass.

29.A method according to claim 28 when appended to claim 27, wherein the material has an affinity for the fluid of the bath.

30.A method according to any one of claims 25 to 29, wherein said stirring or agitating is effected by a magnetic stirring element driven by a rotating magnetic field.

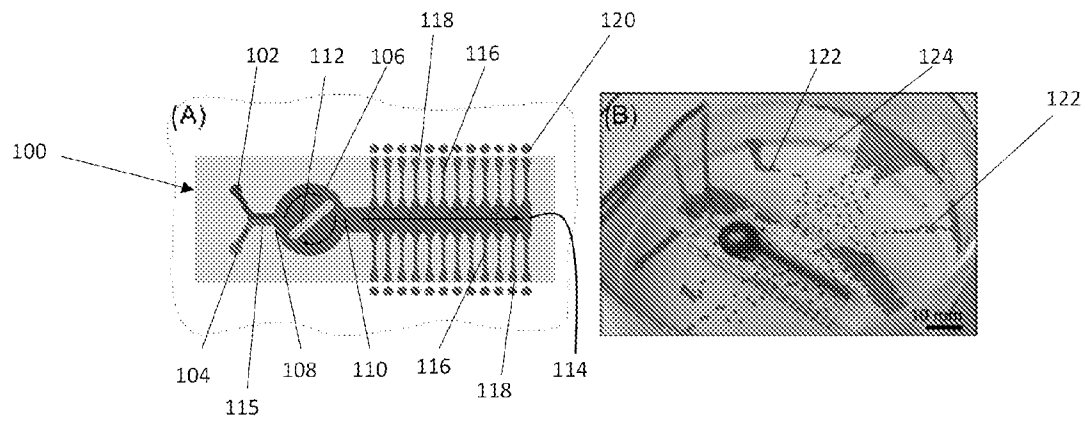


Figure 1

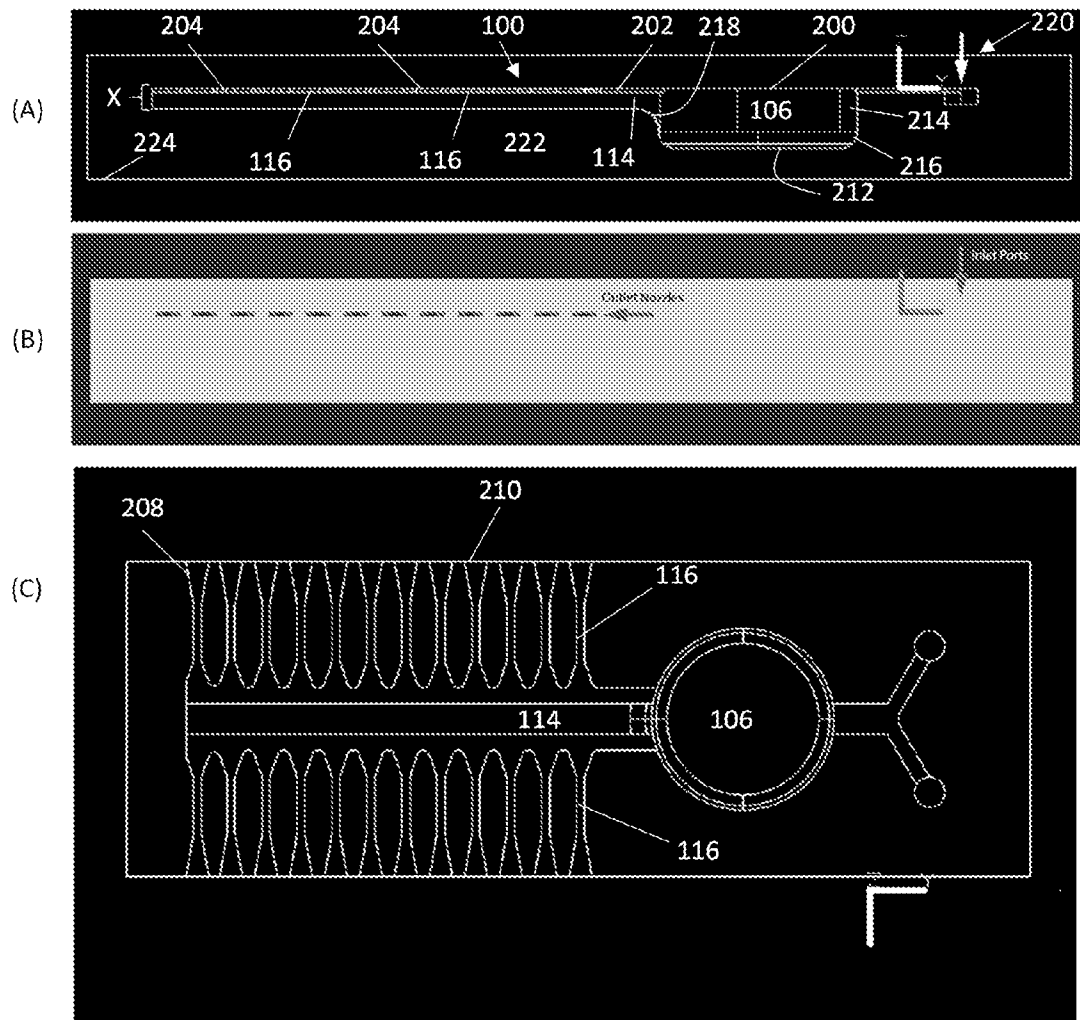
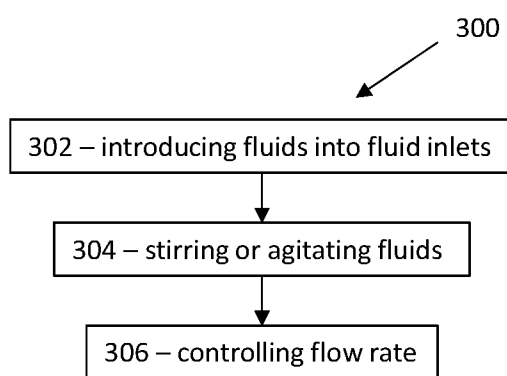


Figure 2

**Figure 3**

INTERNATIONAL SEARCH REPORT		International application No. PCT/SG2021/050642
A. CLASSIFICATION OF SUBJECT MATTER B01L 3/00 (2006.01) B01F 33/30 (2021.01) B01J 19/00 (2006.01) B01F 27/00 (2021.01) According to International Patent Classification (IPC)		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) B01L, B01F, B01J Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Database(s): FAMPAT. Keyword(s): droplet generation, mix, stir, homogeneous mixture, side channel, transverse, microfluidics, and related terms.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/0119570 A1 (SUGIURA, S., ET AL.) 16 May 2013 Abstract; Figures 1-8; Paragraphs [0001], [0044]-[0069], [0077]-[0108]	1-30
A	RYU, K. S., ET AL., Micro Magnetic Stir-bar Mixer Integrated with Parylene Microfluidic Channels. <i>Lab Chip</i> , 14 October 2004, Vol. 4, No. 6, pages 608-613 [Retrieved on 2022-01-19] <DOI: 10.1039/B403305A> Abstract, Figures 1-6 and corresponding paragraphs	
A	US 2008/0080302 A1 (TAKAHASHI, K.) 3 April 2008 Abstract, Figures 1-8 and corresponding paragraphs	
☐ Further documents are listed in the continuation of Box C.		☒ See patent family annex.
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INTERNATIONAL SEARCH REPORT Information on patent family members		International application No. PCT/SG2021/050642	
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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