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(71) **Applicant: AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH** [SG/SG]; 1 Fusionopolis Way, #20-10 Connexis, Singapore 138632 (SG).

(72) **Inventors: WANG, Wei;** c/o Singapore Institute of Manufacturing Technology, Fusionopolis 2, 4 Fusionopolis Way, F2 Supply Centre, Level 7, Room No. RM-L7-001, Kinesis Tower, Singapore 138635 (SG). **WANG, Zhiping;** c/o Singapore Institute of Manufacturing Technology, Fusionopolis 2, 4 Fusionopolis Way, F2 Supply Centre, Level 7, Room No. RM-L7-001, Kinesis Tower, Singapore 138635 (SG). **XIA, Huanming;** c/o Singapore Institute of Manufacturing Technology, Fusionopolis 2, 4 Fusionopolis Way, F2 Supply Centre, Level 7, Room No. RM-L7-001, Kinesis Tower, Singapore 138635 (SG).

(74) **Agent: VIERING, JENTSCHURA & PARTNER LLP;**  
P.O. Box 1088, Rochor Post Office, Rochor Road, Singa-  
pore 911833 (SG).

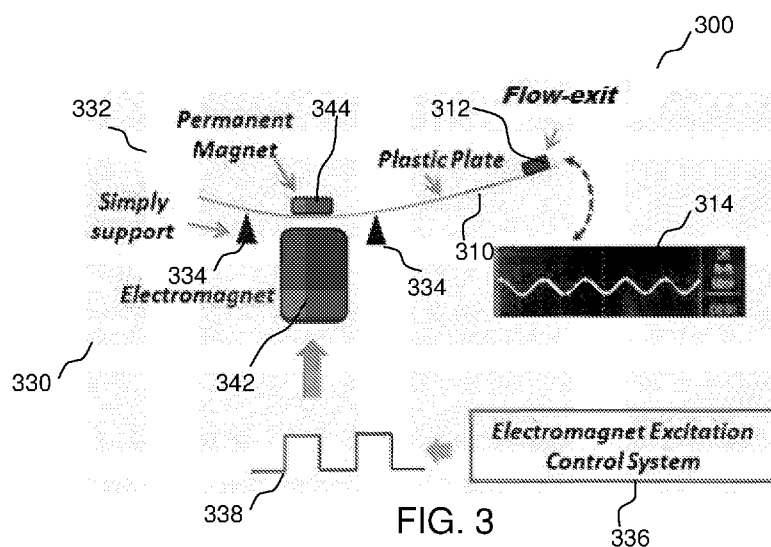
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**(54) Title:** APPARATUS AND METHOD FOR LIQUID DISPENSING



**(57) Abstract:** A liquid dispensing apparatus including a plate having a flow-exit at an end of the plate; and actuation unit including at least two support points for supporting the plate, wherein a first of the plate is received on the at least two support points, and an actuation mechanism adapted to deform a portion of the plate between the at least two support points to cause a deflection of the end of the plate to move the flow-exit. Also disclosed herein is an actuation unit, a plate and a method for liquid dispensing.

## APPARATUS AND METHOD FOR LIQUID DISPENSING

### Technical Field

[0001] Embodiments relate generally to apparatus and method for liquid  
5 dispensing.

### Background

[0002] Liquid dispensing on substrate may be categorized into contact and non-  
contact approaches. Liquid dispensing may include dispensing a stream of liquid,  
10 dispensing a discrete volume of liquid, droplet dispensing, droplet formation, droplet  
ejection etc.. In contact printing, capillary pins are utilized to draw liquids and transfer  
the liquid to a substrate through a physical contact of the pin with the surface of  
substrate. During non-contact liquid dispensing on substrate, mechanical actuations  
are usually employed to dispense the liquid through small flow-exit. Such actuation  
15 techniques include thermal actuation, acoustic actuation, piezoactuation, pneumatic  
actuation and electrostatic actuation.

[0003] In bio-medical applications, it is usually a requirement that the parts in  
contact with the liquid are maintained thoroughly clean and sterilized for each  
application. Ideally, it would be preferable if the used parts may be disposed after  
20 each application so that new sterilized parts may be used for the next application.  
However, the current techniques for liquid dispensing either require equipment that  
may be difficult to clean and sterilized after each application, or are too costly to be  
disposed after each application.

[0004] Example embodiments provide apparatus and method for liquid dispensing  
25 that seek to address at least some of the issues identified above.

**Summary**

[0005] According to various embodiments, there is provided a liquid dispensing apparatus including a plate having a flow-exit at an end of the plate; and an actuation unit including at least two support points for supporting the plate, wherein a first surface of the plate is received on the at least two support points, and an actuation mechanism adapted to deform a portion of the plate between the at least two support points to cause a deflection of the end of the plate to move the flow-exit.

[0006] According to various embodiments, there is provided an actuation unit for a liquid dispensing apparatus, the actuation unit including at least two support points adapted to receive a first surface of a plate for supporting the plate, and an actuation mechanism adapted to deform the plate, with the first surface of the plate received on the at least two support points, at a portion of the plate between the at least two support points to cause a deflection of an end of the plate to move a flow-exit at the end of the plate.

[0007] According to various embodiments, there is provided a plate for a liquid dispensing apparatus, the plate including a flow-exit at an end of the plate, wherein a first surface of the plate is adapted to be received on at least two support points for supporting the plate, and wherein the plate, with the first surface of the plate received on the at least two support points, is adapted to deform at a portion of the plate between the at least two support points to cause a deflection of the end of the plate to move the flow-exit.

[0008] According to various embodiments, there is provided a method for liquid dispensing, the method including deforming a portion of a plate between at least two support points to cause a deflection of an end of the plate to move a flow-exit at the

end of the plate, wherein the plate is supported on the at least two support points with a first surface of the plate received on the at least two support points.

### **Brief description of the drawings**

5    **[0009]**     In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments are described with reference to the following drawings, in which:

10           FIG. 1 shows a schematic block diagram of a liquid dispensing apparatus according to various embodiments;

              FIG. 2 shows a schematic diagram of a basic operation of a liquid dispensing apparatus according to various embodiments;

              FIG. 3 shows a schematic diagram of a liquid dispensing apparatus according  
15   to various embodiments;

              FIG. 4 shows simulation results of vibration of a simply supported bending plate according to various embodiments;

              FIG. 5 shows a photograph of precisely controlled liquid array generated and collected on a flat substrate via the liquid dispensing apparatus according to various  
20   embodiments;

              FIG. 6A shows a circular plate with flow-exits arranged around the circumference of the circular plate according to various embodiments; and

              FIG. 6B shows a rectangular plate with flow-exits lined across a breadth of an end of the plate according to various embodiments.

### **Detailed description**

[0010] Embodiments described below in context of the apparatus or device are analogously valid for the respective methods, and vice versa. Furthermore, it will be understood that the embodiments described below may be combined, for example, a part of one embodiment may be combined with a part of another embodiment.

[0011] It should be understood that the terms “on”, “over”, “top”, “bottom”, “down”, “side”, “back”, “left”, “right”, “front”, “lateral”, “side”, “up”, “down”, etc., when used in the following description are used for convenience and to aid understanding of relative positions or directions, and not intended to limit the orientation of any device, or structure or any part of any device or structure.

[0012] FIG. 1 shows a schematic block diagram of a liquid dispensing apparatus 100 according to various embodiments. The liquid dispensing apparatus 100 may include a plate 110. The plate 110 may be in the form of a sheet or a panel with two surfaces, for example a first surface and a second surface opposite the first surface. The plate 110 may be in any shape, for example, rectangle, square, oval, circle, etc.. The plate 110 may have a flow-exit at an end of the plate 110. The flow-exit may be in the form of a nozzle. The flow-exit may be adapted to contain the liquid for subsequent liquid dispensing. According to various embodiments, liquid dispensing may include dispensing a stream of liquid, dispensing a discrete volume of liquid, droplet dispensing, droplet formation, droplet ejection etc..

[0013] The liquid dispensing apparatus 100 may further include an actuation unit 130. The actuation unit 130 may be operated to cause the flow-exit of the plate 110 to dispense liquid. According to various embodiments, to dispense liquid may include to dispense stream of liquid, to dispense discrete volume of liquid, to dispense liquid

droplets or to eject liquid droplets etc.. The actuation unit 130 may include at least two support points 134 for supporting the plate 110. A first surface of the plate 110 may be received on the at least two support points 134 of the actuation unit 130. In other words, the actuation unit 130 may include supporting means, for example the at least two support points 134, adapted to support the plate 110 at at least two locations on the first surface of the plate 110.

**[0014]** The actuation unit 130 may further include an actuation mechanism 132 adapted to deform a portion of the plate 110 between the at least two points 134 to cause a deflection of the end of the plate 110 to move the flow-exit. For example, the actuation mechanism 132 may be adapted to apply a force towards a second surface opposite the first surface of the plate 110 between the at least two support points 134 to deform the portion of the plate 110 between the at least two support points 134. Accordingly, the actuation mechanism 132 of the actuation unit 130 may be operated to generate the force, which may be directed towards the second surface of the plate 110 when the plate 110 is supported on the at least two support points 134 with the first surface of the plate 110 received on the at least two support points 134. The force may act on the second surface of the plate 110 within the portion of the plate 110 between the at least two support points 134 such that the portion of the plate 110 between the at least two support points 134 may be deformed. Deformation of the portion of the plate 110 between the at least two support points 134 may be achieved because the force generated by the actuation mechanism 132 may act on the second surface of the plate 110 between the at least two support points 134, while each of the at least two support points 134 may apply an opposing force on the first surface of the plate 110. Since the end of the plate 110 may be a free end that may move freely, the deformation of the portion of the plate 110 between the at least two support points

134 may cause a deflection of the end of the plate 110 such that the flow-exit on the end of the plate 110 may move in accordance to the deflection of the end of the plate 110.

[0015] According to various embodiments, liquid may be contained within the flow-exit via surface tension. Movement of the flow-exit due to the deflection of the end of the plate 110 as a result of the deformation of the portion of the plate 110, may cause the liquid to overcome the surface tension such that the liquid may be dispensed from the flow-exit. The liquid dispensed may be a stream of liquid, a discrete volume of liquid or a liquid droplet.

[0016] Therefore, with a single application of the force on the plate 110 between the at least two support points 134, the portion of the plate 110 between the at least two support points 134 may be deformed to cause a deflection of the end of the plate 110 for moving a single flow-exit to dispense liquid. In an embodiment in which the end of the plate 110 has multiple flow-exits, multiple streams of liquid may be formed simultaneously with a single application of the force. In another embodiment, multiple discrete volume of liquid may be simultaneously dispensed. In yet another embodiment, multiple droplets of liquid may be simultaneously dispensed.

[0017] As described above, a liquid dispensing apparatus 100 may include a plate 110 having a flow-exit at an end of the plate 110; and an actuation unit 130 including at least two support points 134 for supporting the plate 110, wherein a first surface of the plate 110 is received on the at least two support points 134, and an actuation mechanism 132 adapted to deform a portion of the plate 110 between the at least two support points 134 to cause a deflection of the end of the plate 110 to move the flow-exit. The actuation mechanism 132 may be further adapted to apply a force towards a second surface opposite the first surface of the plate 110 between the at least two

support points 134 to deform the portion of the plate 110 between the at least two support points 134.

[0018] According to various embodiments, the actuation mechanism 132 of the actuation unit 130 may be further adapted to periodically (typically in a frequency of a few Hertz such as 1-10 Hz to several thousand Hertz, such as 2000-5000 Hz) deform the portion of the plate 110 between the at least two support points 134 to cause a vibration at the end of the plate 110 to oscillate the flow-exit. For example, the actuation mechanism 132 may be adapted to periodically apply a force towards the second surface of the plate 110 between the at least two support points 134 to periodically deform the portion of the plate 110 between the at least two support points 134. Accordingly, when the force is applied periodically, for example repeatedly applied and removed, the portion of the plate 110 may be repeatedly deformed elastically. In other words, the portion of the plate 110 may repeatedly deform and return to its original shape. The repeated elastic deformation of the portion of the plate 110 may cause the end of the plate 110 to repeatedly be deflected from and returned to its original configuration. The repeated deflection and return of the end of the plate 110, i.e. the vibration of the end of the plate 110, may repeatedly displace and return the flow-exit from and to an initial position respectively to oscillate the flow-exit. During each cycle of the oscillation of the flow-exit, liquid may be dispensed. Thus, in an embodiment, multiple streams of liquid may continuously be dispensed from the oscillation of the flow-exit. In another embodiment, multiple discrete volume of liquid may continuously be dispensed from the oscillation of the flow-exit. In yet another embodiment, multiple droplets of liquid may continuously be dispensed from the oscillation of the flow-exit.

[0019] According to various embodiments, the actuation mechanism 132 may be adapted to deform the plate 110 in response to an excitation signal. Accordingly, the actuation mechanism 132 may be operated to deform the plate 110 based on the excitation signal received by the actuation mechanism 132. Advantageously, the liquid dispensing apparatus 100 may be easily operated by controlling the excitation signal sent to the actuation mechanism 132.

[0020] According to various embodiments, the excitation signal may include various types of signal depending on how liquid dispensing is desired. For example, the excitation signal may include a periodic signal or a pulse signal. A periodic signal may include periodic waveform such as square wave or sine wave. When the volume of liquid desired to be dispensed is larger than the volume of liquid dispensed in a single oscillation of the flow exit, the periodic signal may be used as the excitation signal to control the actuation mechanism 132 for periodic deformation of the plate 110 to vibrate the end of the plate 110 for periodically oscillating the flow-exit. Accordingly, liquid may be dispensed multiple times as the flow-exit oscillates periodically such that the desired volume of liquid may be accumulatively dispensed. When a one-time liquid dispensing is desired, a single pulse signal may be used as the excitation signal to control the actuation mechanism 132 for a one-time deformation the plate 110 to deflect the end of the plate 110 to move the flow-exit for performing a one-time liquid dispensing. Therefore, the amount of liquid desired to be dispensed may be accurately controlled with the excitation signal.

[0021] According to various embodiments, the actuation mechanism 132 of the actuation unit 130 may include a rotary cam mechanism. The rotary cam mechanism may transform rotary motion into linear motion to apply the force towards the second surface of the plate 110 between the at least two support points 134.

[0022] According to various embodiments, the rotary cam mechanism may be arranged above and between the at least two support points 134 such that the plate 110 may be sandwiched between the rotary cam mechanism and the at least two support points 134. In this arrangement, the first surface of the plate 110 may be received on the at least two support points 134 and the second surface of the plate 110 may be facing the rotary cam mechanism.

[0023] According to various embodiments, the rotary cam mechanism may include a rotary cam adapted to directly contact the second surface of the plate 110 for applying the force directly on the second surface of the plate 110. In this arrangement, the rotary cam may be a plate cam or a disc cam having an eccentric shape. The rotary cam may be rotated about an axis. Rotating the cam may slide a perimeter of the rotary cam against a point on the second surface of the plate 110. Due to the difference in the radial displacement of the perimeter of the eccentrically shaped rotary cam from the axis, a force may then be directly applied against the point on the second surface of the plate 110 as the rotary cam rotates.

[0024] According to various embodiments, the rotary cam may not be in direct contact with the plate 110. Instead, the cam may be in contact with an end of a lever, and the other end of the lever may be in contact with the plate 110. In this arrangement, rotating the cam may cause a reciprocating (back and forth) motion on the lever such that the lever may apply the force on the second surface of the plate 110.

[0025] According to various embodiments, the actuation mechanism 132 of the actuation unit 130 may include an electromagnet actuation mechanism. The electromagnet actuation mechanism may involve the use of electromagnetic forces to

move components of the electromagnet actuation mechanism to generate the force for applying on the second surface of the plate 110.

**[0026]** According to various embodiments, the electromagnet actuation mechanism may include an electromagnet. The electromagnet actuation mechanism may further include a permanent magnet spaced vertically apart from the electromagnet and movable relative towards the electromagnet. The electromagnet may be arranged between the at least two support points 134 and to face the first surface of the plate 110 received on the at least two support points 134. The permanent magnet may be arranged above the electromagnet and to face the second surface of the plate 110. Accordingly, the plate 110 may be sandwiched between the permanent magnet and the electromagnet. In other words, the plate 110 may separate the permanent magnet from the electromagnet as well as the at least two support points 134.

**[0027]** Further, the electromagnet may be operable to magnetically attract the permanent magnet for moving the permanent magnet relative towards the electromagnet to cause the permanent magnet to apply the force towards the second surface of the plate 110 between the at least two support points 134 for deforming the portion of the plate 110 between the at least two support points 134. Accordingly, when the electromagnet is energized to attract the permanent magnet, the permanent magnet may be attracted and moved towards the electromagnet. Since the plate 110 is adapted to separate the electromagnet from the permanent magnet, as the permanent magnet moves towards the electromagnet, the permanent magnet may move into the second surface of the plate 110. As a result, the permanent magnet may apply a force and push into the second surface of the plate 110 to deform the portion of the plate 110 between the at least two support points 134.

[0028] According to various embodiments, the arrangement of the electromagnet and the permanent magnet may be reversed. In this reversed arrangement, the electromagnet may be above the permanent magnet, and the electromagnet may be movable relative to the permanent magnet. Accordingly, the electromagnet may be the one that moves into the second surface of the plate 110 to apply a force and push into the second surface of the plate 110 to deform the portion of the plate 110 between the at least two support points 134.

[0029] According to various embodiments, the actuation mechanism 132 may further include a controller adapted to control the operation of the electromagnet actuation mechanism based on an excitation signal. The controller may control the voltage and current to energize the electromagnet in response to the excitation signal received so as to control the strength of the attractive force. The controller may also energized the electromagnet based on a periodic wave form received, such as square wave or sine wave at various frequency, to periodically apply the force towards the second surface of the plate 110 for periodic deformation of the portion of the plate 110 between the at least two support points 134.

[0030] According to various embodiments, the at least two support points 134 may be adapted to removably received the plate 110. Accordingly, the plate 110 may be simply received on the at least two support points 134 such that the plate 110 may be easily removed. For example, the plate 110 may be detachable from the at least two support points 134 after being placed on the at least two support points 134. The plate 110 may also be simply placed and supported on the at least two support points 134, which may be spaced apart so as to provide sufficient support for the plate 110. The plate 110 and the at least two support points 134 may also include snap and fit attachment means for detachably attaching the plate 110 to the at least two support

points 134. The plate 110 may further be simply clamped or attached using magnets. Advantageously, the plate 110 may be easily removed from the liquid dispensing apparatus 100 for cleaning and sterilizing of the plate 110 after each use of the plate 110. Being detachably received may also allow disposable plate to be used in the liquid dispensing apparatus 100.

**[0031]** According to various embodiments, the flow-exit may be integrally formed with the plate 110. Accordingly, the plate 110 and the flow-exit may be formed as one body. Advantageously, the plate 110 may be produced at low cost and the plate 110 may be produced as a disposable part.

**[0032]** According to various embodiments, the flow-exit may be a separate part attached to the plate 110.

**[0033]** According to various embodiments, the plate 110 may include a microfluidic channel in fluid connection with the flow-exit. The microfluidic channel may allow liquid to flow into the flow-exit such that the flow-exit may be filled with liquid for dispensing.

**[0034]** According to various embodiments, the microfluidic channel may be integrally formed with the plate 110. Accordingly, the plate 110 and the microfluidic channel may be formed as one body.

**[0035]** According to various embodiments, the microfluidic channel may be a separate part connected to the flow-exit of the plate 110.

**[0036]** According to various embodiments, the liquid dispensing apparatus 100 may include a liquid source adapted to supply liquid to the microfluidic channel.

**[0037]** According to various embodiments, the liquid source may include a liquid reservoir on the plate 110. The liquid reservoir may be adapted to store liquid. The liquid reservoir may be in fluid communication with the flow-exit via the microfluidic

channel such that liquid may flow from the liquid reservoir through the microfluidic channel to the flow-exit.

**[0038]** According to various embodiments, the liquid reservoir may be integrally formed with the plate 110.

5 **[0039]** According to various embodiments, the liquid reservoir may also be a separate part connected to the flow-exit of the plate 110.

**[0040]** According to various embodiments, liquid may be directed to the flow exit from the liquid source or the liquid reservoir via pressurized flow.

**[0041]** According to various embodiments, a distance between the end of the plate  
10 110 and a midpoint of a line joining the at least two support points 134 may be larger than twice of a distance between any one of the at least two support points 134 and the midpoint. Advantageously, when the distance measured from the end of the plate 110 to the midpoint between the at least two support points 134 is larger than twice the distance measured between any one of the at least two support points 134 and the  
15 midpoint (or the distance measured between the at least two support points 134), the deflection at the end of the plate 110 may be larger than the deformation experienced by the portion of the plate 110 between the at least two support points 134. Thus, the deflection at the end of the plate 110 may be an amplification of the deformation experienced by the portion of the plate 110 between the at least two support points  
20 134. When the force is periodically or cyclically applied to the plate 110, the vibration of the end of the plate 110 may be an amplification of the cyclic elastic deformation experienced by the portion of the plate 110 between the at least two support points 134. Advantageously, the amplification effect may allow a small force to be applied on the plate 110 for achieving the desired deflection or vibration to dispense liquid  
25 from the flow-exit at the end of the plate 110.

[0042] According to various embodiments, the plate 110 may include a plurality of flow-exits. Advantageously, with a plurality of flow-exits, multiple streams of liquid, or multiple discrete volume of liquid, or multiple liquid droplets may be formed simultaneously with a single application of force of the plate 110 to cause a  
5 single deflection of the end of the plate 110.

[0043] According to various embodiments, the plate 110 may be rectangular in shape and the flow-exit or the plurality of flow-exits may be on one extreme end of the rectangular plate 110.

[0044] According to various embodiments, the plate 110 may be circular in shape  
10 and the plurality of flow-exit may be distributed around the circumference of the circular plate 110.

[0045] According to various embodiments, the plate 110 may be made of a material selected from the group consisting of plastic, copper, aluminium or stainless steel. Advantageously, the material may be made of low cost material and may be  
15 deformable. Further, by making use of non magnetic material for the plate 110, an electromagnet actuation mechanism may be used for the actuation unit 130.

[0046] According to various embodiments, the at least two support points 134 may include at least two separate points on two separate support structures respectively. For example, the actuation unit 130 may include two separate support  
20 structures. Each of the two separate support structures may provide one support point.

[0047] According to various embodiments, the at least two support points 134 may include at least two separate points on a support structure. For example, the actuation unit 130 may include one support structure which contain both the at least two support points 134. Accordingly, the one support structure may be a ring-shaped  
25 support structure. The ring-shaped support structure may contain both the at least two

support points 134 for receiving the first surface of the plate 110. In an implementation, the ring-shaped support structure may be suitable for supporting a circular plate with a plurality of flow-exits distributed along the circumference of the circular plate.

5   **[0048]**   According to various embodiments, there may be provided an actuation unit 130 for a liquid dispensing apparatus 100. The actuation unit 130 may include at least two support points 134 adapted to receive a first surface of a plate 110 for supporting the plate 110, and an actuation mechanism 132 adapted to deform the plate 110, with the first surface of the plate 110 received on the at least two support points  
10   134, at a portion of the plate 110 between the at least two support points 134 to cause a deflection of an end of the plate 110 to move a flow-exit at the end of the plate 110. The actuation mechanism 132 may be further adapted to apply a force between the at least two support points 134 towards a second surface opposite the first surface of the plate 110 to deform the portion of the plate 110 between the at least two support  
15   points 134.

**[0049]**   According to various embodiments, the actuation unit 130 may be further adapted to apply the force perpendicularly towards the second surface of the plate 110.

**[0050]**   According to various embodiments, there may be provided a plate 110 for  
20   a liquid dispensing apparatus 100, the plate 110 may include a flow-exit at an end of the plate 110. The flow-exit may be in the form of a nozzle. A first surface of the plate 110 may be adapted to be received on at least two support points 134 for supporting the plate 110. The plate 110 , with the first surface of the plate 110 received on the at least two support points 134, may be adapted to deform at a portion of the plate 110  
25   between the at least two support points 134 to cause a deflection of the end of the

plate 110 to move the flow-exit. The plate 110 may be adapted to be deformed at the portion of the plate 110 between the at least two support points 134 by a force applied between the at least two support points 134 towards a second surface opposite the first surface of the plate 110.

5   **[0051]**     According to various embodiments, there may be provided a method for liquid dispensing. The method may include deforming a portion of a plate 110 between at least two support points 134 to cause a deflection of an end of the plate 110 to move a flow-exit at the end of the plate 110, wherein the plate 110 is supported on the at least two support points 134 with a first surface of the plate 110 received on  
10   the at least two support points 134. Deforming the portion of the plate 110 may include applying a force between the at least two support points 134 towards a second surface opposite the first surface of the plate 110.

**[0052]**     According to various embodiments, the method may further include placing the plate 110 on the at least two support points 134.

15   **[0053]**     According to various embodiments, the at least two support points 134 may be on a supporting structure or supporting structures of an actuation unit 130 of a liquid dispensing apparatus 100. Accordingly, the method may further include operating the actuation unit 130 of the liquid dispensing apparatus 100 for applying the force between the at least two support points 134 towards the second surface of  
20   the plate 110.

**[0054]**     FIG. 2 shows a schematic diagram of a basic operation of a liquid dispensing apparatus 200 according to various embodiments. As shown in FIG. 2, liquid dispensing may be achieved through vibration of a plastic plate 210 bent mechanically by a force. Advantageously, the plastic plate 210 may be low in cost to  
25   be manufactured. The plastic plate 210 may be simply attached to the liquid

dispensing apparatus 200, for example by magnet based clamping. As shown in FIG. 2, the rectangular plate 210 may be supported at two points 234 towards one end along the longer side. An amplified vibration may be simply achieved at the other end of the plate 210 by exciting the plate 210 at the middle of two supports 234 to achieve low energy actuation. In FIG. 2, the amplitude of the vibration at the other end of the plate 210 is represented by  $\Delta D$ , and the amplitude of the excitation of the plate 210 at the middle of the two supports 234 is represented by  $\Delta d$ . In FIG. 2, it is shown that  $\Delta D \gg \Delta d$ . In other words, the amplitude of the vibration at the other end of the plate 210 is greater than the amplitude of the excitation of the plate 210 at the middle of the two supports 234. Accordingly, an amplified vibration may be obtained at one end of a rectangular plate 210 by exciting the plate 210 at the middle of two supports 234 towards the other end of the plate 210.

**[0055]** FIG. 3 shows a schematic diagram of a liquid dispensing apparatus 300 according to various embodiments. The liquid dispensing apparatus 300 may include an electromagnet 342, a permanent magnet 344, a rectangular plastic plate (in other words a plate) 310 integrated with flow-exits 312 and an electromagnet excitation control system (in other words a controller) 336. The flow-exits 312 may be nozzles. The electromagnet 342 and the permanent magnet 344 may be part of an actuation mechanism 332 of an actuation unit 330 of the liquid dispensing apparatus 300.

**[0056]** The rectangular plastic plate 310 may be a thin plate, for example with a thickness of approximately 1mm. The rectangular thin plastic plate 310 may sit on simple supports 334, for example at least two support points of the actuation unit 330 of the liquid dispensing apparatus 300, above the electromagnet 342. When the electromagnet 342 is excited with a periodic waveform such as square wave or sine wave at low frequency, a periodic force may be applied on the top of the clamped

plastic plate 310 due to the interaction between the permanent magnet 344 and electromagnet 342. Such force may be set by controlling the driven voltage of the electromagnet 342 via the electromagnet excitation control system 336.

[0057] The excitation from the periodic clamping force due to the interaction of  
5 electromagnet 342 and permanent magnet 344 may result in a forced vibration of the plastic plate 310 at the same frequency as the electromagnet driven signal 338 as shown in FIG. 3. Such vibration at the free end of the plastic plate 310 (the end away from the clamping end) may be verified by a laser vibrometer system (i.e. Polytec OFV-5000 Vibrometer) as shown as the sine waveform 314 in FIG. 3. The amplified  
10 vibration may also be verified by simulation as shown in FIG. 4. With the amplified up down movement of the free end of the plastic plate 310, liquid may be dispensed from the flow-exits 312 located at the free end of the plastic plate 310. Multiple flow-exits 312 may be arranged in an array format to dispense multiple streams of liquid, or multiple discrete volume of liquid, or multiple liquid droplets simultaneously. Since  
15 the vibration of plastic plate 310 may follow the electromagnet excitation signal 338, the liquid dispensing may be generated driven by the electromagnet excitation signal 338.

[0058] According to various embodiments as shown above, on-demand liquid dispensing may be achieved by an electromagnetic system.

20 [0059] FIG. 4 shows simulation results 401 of the vibration of a simply supported bending plate 410 to verify that the amplified vibration at the free end 416 of the bending plate 410. As shown the maximum displacement of the free end 416 of the plate 410 is approximately 300 $\mu$ m while the displacement of a portion 418 of the plate 410 in the middle of the two simple support may be less than 50  $\mu$ m. Accordingly,

the simulation results have verified the amplified vibration at the free end 416 of the plate 410.

[0060] FIG. 5 shows a photograph 501 of precisely controlled liquid array 506 generated and collected on a flat substrate 508 via the liquid dispensing apparatus according to various embodiments. To obtain the precisely controlled liquid array 506 shown, the flat substrate 508 may be manually moved as the end of the plate of the liquid dispensing apparatus vibrates.

[0061] According to various embodiments, the plate 110, 210, 310, 410 of FIGs. 1 to 4 may be made of plastic. Advantageously, the liquid dispensing chips (in other words the plates) may be manufactured to be disposable parts and produced at low cost because the plates and flow-exits may be plastic molding parts. The plates and the flow-exits may be molded as one body or produced separately.

[0062] According to various embodiments, the plastic plate 110, 210, 310, 410 of FIGs. 1 to 4 may be replaced by non-magnetic metal plates, such as copper plate, aluminum plate or stainless plate. The flow-exit may also be made from other non-magnetic materials, such as stainless steel.

[0063] According to various embodiments, multiple flow-exits may be integrated into the elastic plate. The multiple flow-exits may be integrated such that a layout of the multiple flow-exits may define a pattern for patterning and printing to be achieved. Accordingly, high throughput patterning and printing may be achieved with the multiple flow-exits. For example, as shown in plates 610 and 611 in FIG. 6A and 6B.

[0064] According to various embodiments, other excitation methods may be applied at the middle of the two supporting points to generate the same effect. For

example as shown in FIG. 6B, the actuation of the elastic plate 611 may be done by a rotary cam 690 instead of electromagnet actuation mechanism.

[0065] FIG. 6A shows a circular plate 610 with flow-exits 612 arranged around the circumference of the circular plate 610. The circular plate 610 may be supported by at least two support points 634. The at least two support points 634 may be on a ring-shape support structure supporting the circular plate 610. Applying a force on a portion 618 of the plate 610 may cause an end 616 of the plate 610 to deflect. Periodic application of the force on the portion 618 of the plate 610 may cause the end 616 of the plate 610 to vibrate. The embodiment as shown in FIG. 6A is an example of high throughput liquid dispensing/printing through the integration of multiple flow-exits into an elastic plate.

[0066] FIG. 6B shows a rectangular plate 611 with flow-exits 613 lined across a breadth of an end 617 of the plate 611. The rectangular plate 611 may be supported by at least two support points 635. The at least two support points 635 may be on two separate support structures respectively. The rotary cam 690 may periodically apply a force on a portion 619 of the plate 611 as the rotary cam rotates. The force may cause the end 617 of the plate 611 to deflect. Periodic application of the force on the portion 619 of the plate 611 may cause the end 617 of the plate 611 to vibrate. FIG. 6B is an example of high throughput liquid dispensing/printing through the actuation by a rotary cam on a multiple- flow-exits integrated plate.

[0067] According to various embodiments, there may be provided an on-demand liquid dispensing system (in other words a liquid dispensing apparatus) including an elastic plate. A force may be applied on one end of the elastic plate to deform the plate and obtain an amplified displacement at the free end of the elastic plate. The on-demand liquid dispensing system may further include a control to vary the force to

deform the elastic plate to obtain controlled movement of the free end of the plate. The on-demand liquid dispensing system may further include one or more flow-exits integrated into the free end of the elastic plate.

[0068] According to various embodiments, the elastic plate may be under simply  
5 support.

[0069] According to various embodiments, the elastic plate with flow-exits may be easily detachable from the rest part of the system.

[0070] According to various embodiments, the force applied on one end of the elastic plate may be a clamping force generated by placing the plate in between a  
10 permanent magnet and an electromagnet.

[0071] According to various embodiments, an air gap between the elastic plate and the electromagnet may exist to allow the deformation of the elastic plate due to electromagnet force exerted.

[0072] According to various embodiments, an electromagnet control may be  
15 utilized to vary the clamping force applied to the elastic plate and thus control the movement of the far end of the elastic plate.

[0073] According to various embodiments, the actuation of the elastic plate may be done by a rotary cam.

[0074] According to various embodiments, the displacement of the far end of the  
20 elastic plate may be amplified when the length of the plate is extended.

[0075] According to various embodiments, the use of a permanent and an electromagnet to simply clamp the elastic plate in between of the two may facilitate easy detachment of the elastic plate from the rest part of the system.

[0076] According to various embodiments, microfluidic channel may be  
25 integrated into the elastic plate.

[0077] According to various embodiments, the flow-exits integrated into the elastic plate may be arranged at certain layout for a printing pattern at a single cycle of liquid dispensing.

[0078] Various embodiments may provide simple and low cost liquid dispensing apparatus and method which may allow easy and quick change of liquid dispensing parts contacting with liquid; low cost liquid dispensing parts (contacting with liquid); and low energy mechanical actuation mechanism.

[0079] The low cost liquid dispensing parts may lead to disposable liquid dispensing parts to avoid contamination during liquid dispensing. This may be achieved as various embodiments may allow the liquid dispensing parts to be physically detachable from the mechanical actuation parts.

[0080] The simple liquid dispensing apparatus and methods may also provide the following advantages. For example, the plastic bending plate may be easily detachable from the rest of the apparatus or system. Quick replacement of the liquid dispensing chip or plate may also be achieved. Standard sterilization process may be utilized to prepare liquid dispensing chips for biological or pharmaceutical applications.

[0081] Further, the liquid dispensing may be achieved by the vibration of a bending plate driven by an electromagnet actuation system. Thus, the liquid dispensing interval may be simply controlled by the electromagnet actuation signal. Accordingly, various embodiments may provide a precision liquid dispensing apparatus.

[0082] In addition, the vibration of the flow-exit mounted at the far end of the bending plate may be much larger than the plate bending displacement at the

clamping center (where permanent magnet may be sited) due to the amplification effect of the cantilever-like supporting of the bending plate.

[0083] Advantageously, various embodiments may be useful in many engineering and scientific applications, such as single cell printing, protein & DNA microarray, deposition of reagents on diagnostic strips, drug screening and so on. The concept of low cost disposable chip or plate may be very suitable for pharmaceutical and biochemical printing (i.e. bio-microarray printing) which required less contamination during production. Other applications may be surface patterning of functional materials for organic thin-film transistors, organic light emitting diodes, organic solar cells, sensors and so on.

[0084] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

## Claims

1. A liquid dispensing apparatus comprising  
a plate having a flow-exit at an end of the plate; and  
an actuation unit comprising  
at least two support points for supporting the plate, wherein a first surface of the plate is received on the at least two support points, and  
an actuation mechanism adapted to deform a portion of the plate between the at least two support points to cause a deflection of the end of the plate to move the flow-exit.
2. The apparatus of claim 1, wherein the actuation mechanism is further adapted to periodically deform the portion of the plate between the at least two support points to cause a vibration at the end of the plate to oscillate the flow-exit.
3. The apparatus of claim 1, wherein the actuation mechanism is further adapted to deform the plate in response to an excitation signal.
4. The apparatus of claim 3, wherein the excitation signal comprises a periodic signal or a pulse signal.
5. The apparatus of claim 1 or 2, wherein the actuation mechanism is further adapted to apply a force towards a second surface opposite the first surface of the plate between the at least two support points to deform the portion of the plate between the at least two support points.

6. The apparatus of claim 5, wherein the actuation mechanism comprises a rotary cam mechanism.

7. The apparatus of claim 6, wherein the rotary cam mechanism comprises a rotary cam adapted to directly contact the second surface of the plate for applying the force directly on the second surface of the plate.

8. The apparatus of claim 5, wherein the actuation mechanism comprises an electromagnet actuation mechanism.

9. The apparatus of claim 8, wherein the electromagnet actuation mechanism comprises:

an electromagnet; and

a permanent magnet spaced apart from the electromagnet and movable relative towards the electromagnet,

wherein the electromagnet is arranged between the at least two support points and to face the first surface of the plate received on the at least two support points, and the permanent magnet is arranged to face the second surface of the plate, and

wherein the electromagnet is operable to magnetically attract the permanent magnet for moving the permanent magnet relative towards the electromagnet to cause the permanent magnet to apply the force towards the second surface of the plate between the at least two support points for deforming the portion of the plate between the at least two support points.

10. The apparatus of claims 8 or 9, wherein the actuation mechanism further comprises a controller adapted to control the operation of the electromagnet actuation mechanism based on an excitation signal.
11. The apparatus of any one of claims 1 to 10, wherein the at least two support points are adapted to removably received the plate.
12. The apparatus of any one of claims 1 to 11, wherein the flow-exit is integrally formed with the plate.
13. The apparatus of any one of claims 1 to 12, wherein the plate comprises a microfluidic channel in fluid connection with the flow-exit.
14. The apparatus of claim 13, further comprising a liquid source adapted to supply liquid to the microfluidic channel.
15. The apparatus of any one of claims 1 to 14, wherein a distance between the end of the plate and a midpoint of a line joining the at least two support points is larger than twice of a distance between any one of the at least two support points and the midpoint.

16. The apparatus of any one of claims 1 to 15, wherein the at least two support points comprise at least two separate points on two separate support structures respectively.

17. The apparatus of any one of claims 1 to 15, wherein the at least two support points comprise at least two separate points on a support structure.

18. An actuation unit for a liquid dispensing apparatus, the actuation unit comprising:

at least two support points adapted to receive a first surface of a plate for supporting the plate, and

an actuation mechanism adapted to deform the plate, with the first surface of the plate received on the at least two support points, at a portion of the plate between the at least two support points to cause a deflection of an end of the plate to move a flow-exit at the end of the plate.

19. A plate for a liquid dispensing apparatus, the plate comprising:

a flow-exit at an end of the plate,

wherein a first surface of the plate is adapted to be received on at least two support points for supporting the plate, and

wherein the plate, with the first surface of the plate received on the at least two support points, is adapted to deform at a portion of the plate between the at least two support points to cause a deflection of the end of the plate to move the flow-exit.

20. A method for liquid dispensing, the method comprising:

deforming a portion of a plate between at least two support points to cause a deflection of an end of the plate to move a flow-exit at the end of the plate, wherein the plate is supported on the at least two support points with a first surface of the plate received on the at least two support points.

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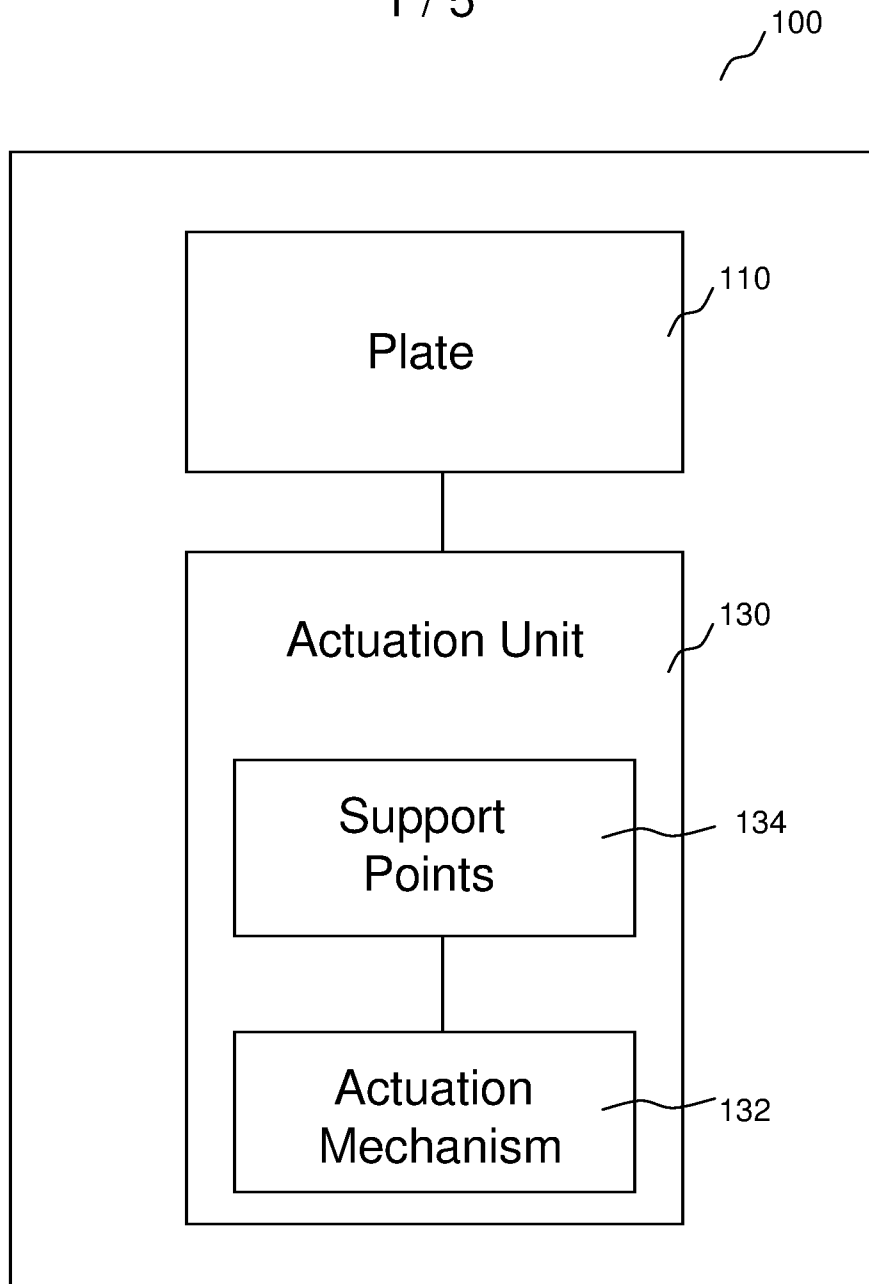


FIG. 1

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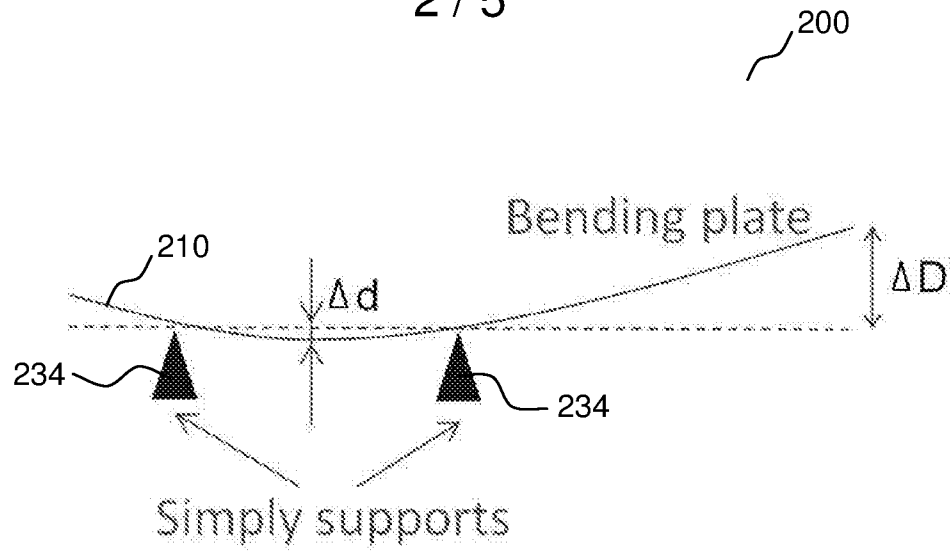


FIG. 2

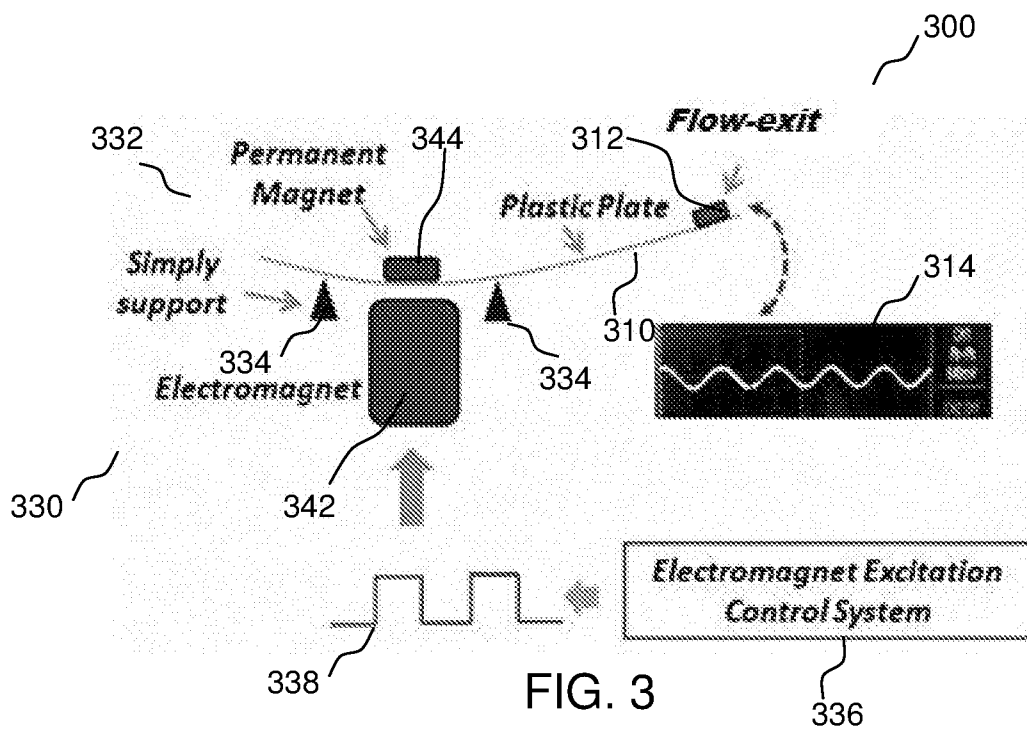


FIG. 3

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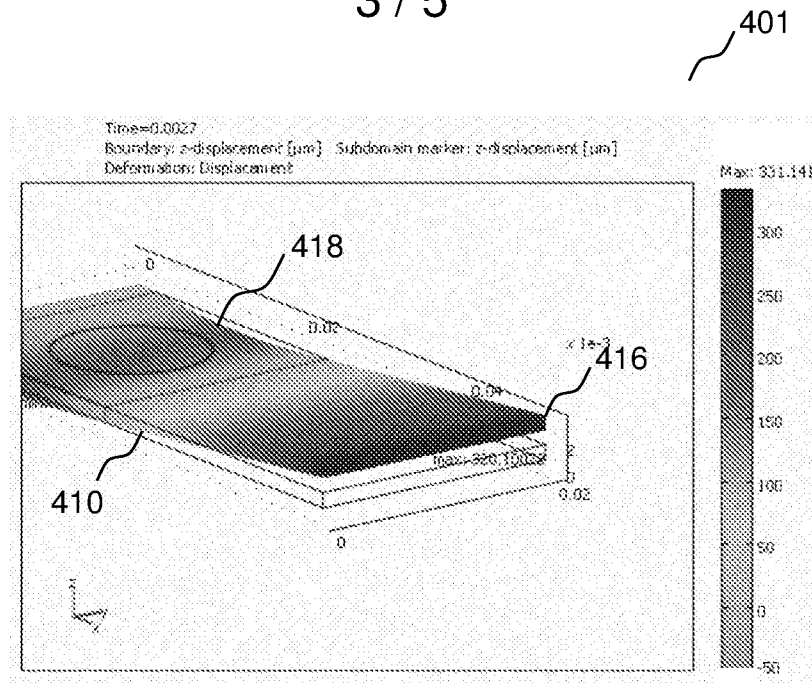


FIG. 4

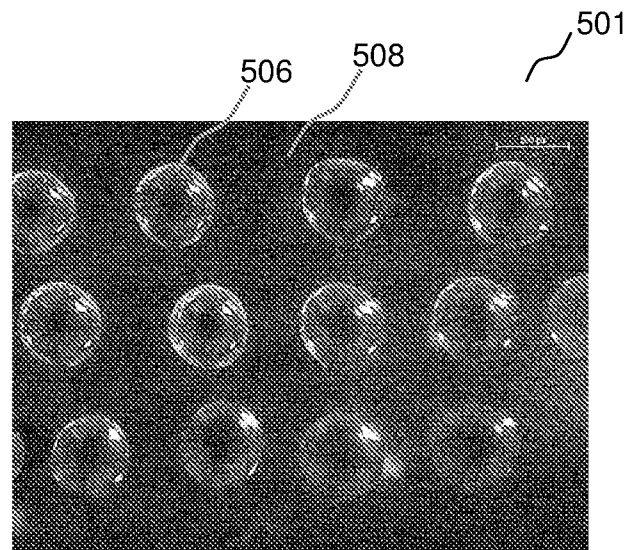


FIG. 5

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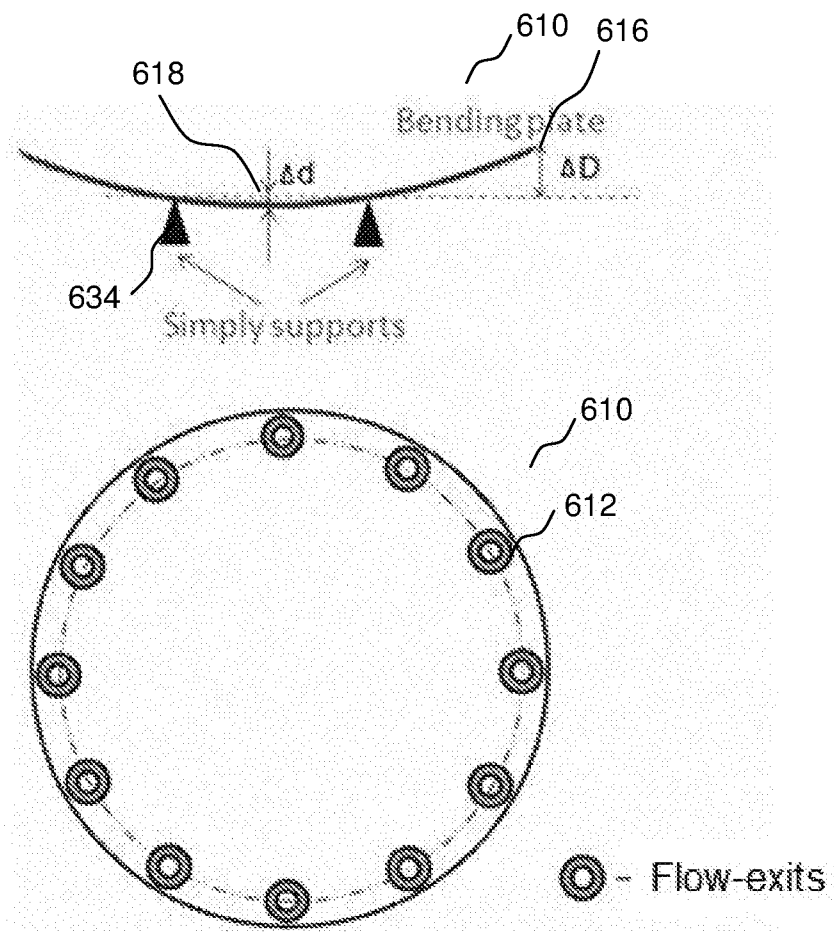


FIG. 6A

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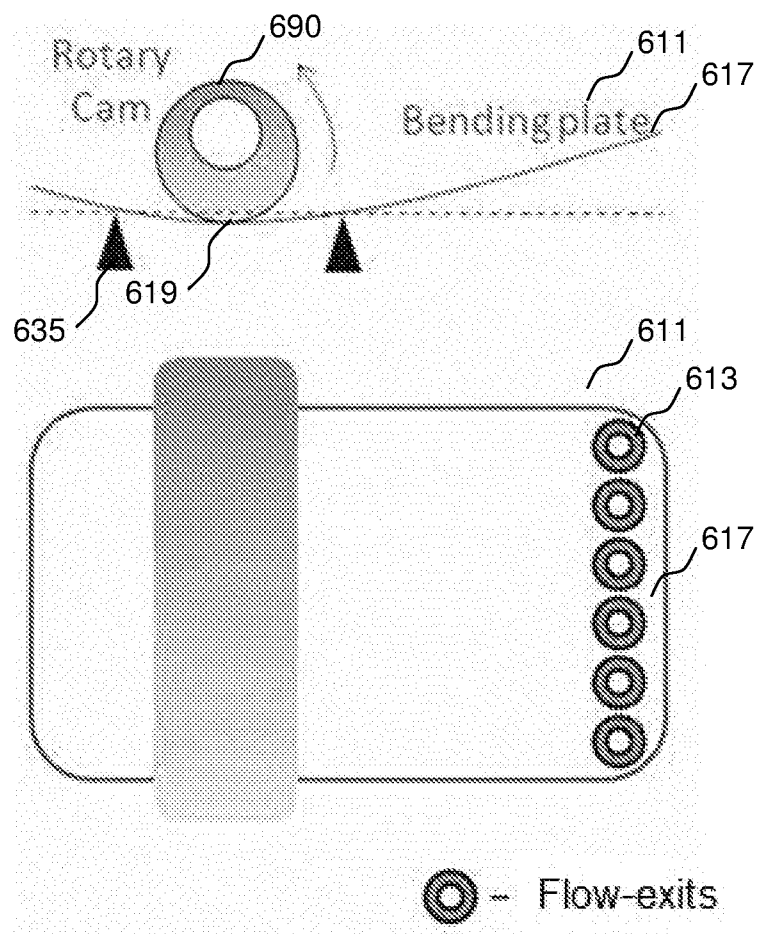


FIG. 6B

# INTERNATIONAL SEARCH REPORT

International application No.

**PCT/SG2016/050109**

## A. CLASSIFICATION OF SUBJECT MATTER

**B01L 3/00 (2006.01) G01N 35/00 (2006.01)**

According to International Patent Classification (IPC)

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01L, G01N

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)

Databases: EPODOC, WPI, FAMPAT

Keywords: liquid, fluid, droplet, dispensing, formation, vibrate, oscillate, deform, deflect, bend, actuate, plate, flow-exit, nozzle, orifice 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. |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 6629646 B1 (IVRI, Y.) 7 October 2003<br>see column 1 line 62-66, column 6 line 1-21, Figure 9 and 10                           | 1-20                  |
| X         | US 2779623 A (EISENKRAFT, B.J.) 29 January 1957<br>see Figure 2 and 4                                                             | 18                    |
| X         | US 2646261 A (POIROT, E.M.) 21 July 1953<br>see Figure 1                                                                          | 18                    |
| X         | US 2505423 A (MORGAN, H.W.) 25 April 1950<br>see Figure 2                                                                         | 18                    |
| A         | US 2011/0284378 A1 (SHINODA, M.) 24 November 2011<br>see [0001], [0051]-[0053], [0085]-[0086], [0100], [0116], Figure 2, 3 and 13 |                       |

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

\*Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

29/04/2016

(day/month/year)

Date of mailing of the international search report

09/05/2016

(day/month/year)

Name and mailing address of the ISA/SG

**Intellectual Property Office of Singapore**  
 51 Bras Basah Road  
#01-01 Manulife Centre  
Singapore 189554

Email: pct@ipos.gov.sg

Authorized officer

Zhuo Mingkun (Dr)

IPOS Customer Service Tel. No.: (+65) 6339 8616

**INTERNATIONAL SEARCH REPORT**

International application No.

**PCT/SG2016/050109****C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
| A         | US 4336544 A (DONALD, D.K. ET AL.) 22 June 1982<br>see whole document              |                       |

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/SG2016/050109**

*Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.*

| Patent document<br>cited in search report | Publication date | Patent family<br>member(s)                                                                                                                                                                         | Publication date                                                                                                                                       |
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