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(54) **Title:** DIGITAL MICROFLUIDIC MIXED FLUID DROPLETS

(57) **Abstract:** In an example implementation according to aspects of the present disclosure, a non-transitory computer-readable medium comprises a set of instructions that when executed by a controller are to transmit first control signals from to cause a first droplet of fluid to be pulled onto a microfluidic electrode of a digital microfluidic (DMF) array from a first reservoir; transmit second control signals to cause a second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array from a second reservoir, wherein the first droplet of fluid and the second droplet of fluid are to be mixed on the microfluidic electrode responsive to mixing control signals to be transmitted by the controller and responsively yield a mixed fluid droplet; and transmit third control signals to cause the mixed fluid droplet to propagate to a feedhole.

WO 2022/071947 A1

DIGITAL MICROFLUIDIC MIXED FLUID DROPLETS

BACKGROUND

[0001] In the context of printing devices, such as fluid-based printing devices, printing fluids may contain solids that may be used for a number of different purposes. For example, colorants in the printing fluids may be used to form text, images, and/or objects on a print target, such as in the form of colors on a page of paper. In other examples, the solids may include components to provide a layer of protection on a print medium, such as polymers within a clear coat to provide a layer of protection on print media.

[0002] In yet other examples, the solids may include binder particles capable of absorbing electromagnetic radiation of desired wavelengths (e.g., ultraviolet (UV) light) and causing build material and/or a printing fluid to bind together. In yet other examples, the solids may include a combination of particles that make up agents or reagents to be used in the context of a biomedical test. In these and other contexts, the printing fluids may be ejected from the printing device via fluid ejection chambers, such as including nozzles and fluid actuators, to form droplets of printing fluid to be deposited on a medium or materials.

[0003] Printing devices may use, among other things, pressurized fluid lines and capillary forces of porous media to move printing fluids from reservoirs to the ejection chambers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0001] Many aspects of the disclosure can be better understood with reference to the following drawings. While several examples are described in connection with these drawings, the disclosure is not limited to the examples disclosed herein.

[0002] Figure 1 illustrates a block diagram illustrating an example non-transitory storage medium storing machine-readable instructions to mix fluids on a digital microfluidic (DMF) array;

[0003] Figures 2A-2B illustrate an example microfluidic electrode to mix fluids;

[0004] Figures 3A-3D illustrate an example DMF array to mix fluids;

[0005] Figure 4 illustrates a schematic cross-sectional diagram of an example fluid device to mix fluids on a DMF array;

[0006] Figure 5 illustrates an example diagram to uniformly mix fluids using a DMF array;

[0007] Figure 6 illustrates a flow diagram of an example process to mix fluids based on a modified property for a three-dimensional (3D) printing fluid;

[0008] Figure 7 illustrates a flow diagram of an example process to mix biological fluids in a fluid device, according to another example;

[0009] Figure 8 illustrates a block diagram illustrating a fluid ejection device to cause a fluid device to mix fluids on a DMF array.

DETAILED DESCRIPTION

[0010] In the context of printing devices, such as fluid-based printing devices, printing fluid may be transferred to fluid ejection chambers of the printing devices using pressurized fluid lines and capillary forces in porous media. At times, fluids may be mixed to provide a desired combination of fluids, such as for binders, absorbers, biological fluids, etc. The ability to mix the fluids is performed either by pre-mixing the fluids prior to introducing the fluid to the printing device (e.g., manufacturing mixed fluids), or by ejecting one fluid on top of the other on the print target and mixing after the fluids have exited from the ejection chambers.

[0011] Many mixed fluids have a short-shelf life and as a result, it may be impractical to obtain pre-mixed printing fluids. For example, a multi-part binding material may be combined in an order and at a time that better enables to binder properties of the multi-part binding material to be used. Therefore, some combination of fluids may be more efficiently used in printing if the mixing of the fluids is done at, or close to, the time of printing.

[0012] The use of sequential ejections of the multiple fluids from the ejection chamber to allow the fluids to be mixed on the printing media surface may lead to non-homogenous mixing of the fluids. For example, by ejecting one fluid first, the first fluid may absorb into the print target before the second fluid is ejected. Furthermore, using pressurized fluid lines to push each fluid to the ejection chambers provides limited control over the amount/ratio of each fluid that is ejected at a time. For example, modifying a property of a 3D printing material (e.g., opacity, ductility, etc.) may be achieved by homogenously combining fluids in specified ratios prior to coming into contact with the print target (e.g., powder bed). To ensure that the properties of the resultant 3D printing material are consistent throughout, the mixture of components in the droplet of fluid to be ejected should have the same proportions of components throughout. This may be difficult to achieve when using pressurized fluid lines to push each fluid to the ejection chambers. That is, it may be challenging to provide precise measures of fluid in a conventional pressurized fluid line so as to yield desired measures, ratios, and uniform mixtures, etc.

[0013] To further add to the complexity of this example, the presence of air in the fluid ejection chambers may lead to air bubbles or even failure of the fluid actuators upon activation. Additionally, solids in the printing fluid may settle in the fluid lines, the porous media, and/or the fluid ejection chambers. As a result, the fluid lines and/or the nozzles of the ejection chambers may be contaminated by other fluid remnants or clog, and the resulting ejected fluid may have undesirable solid concentrations (e.g., leading to lower quality print output, false negatives or positives for biomedical tests, and the like). Additionally, fluid delivery systems including pressurized fluid lines may introduce complexity and cost into the print system, such as using pumps, valves, and the like. There may be a desire, therefore, for alternative approaches for pre-mixing a plurality of fluids in a controlled order and at, or near, the time of printing.

[0014] A digital microfluidic (DMF) system may be employed for mixing printing fluids from multiple reservoirs and propagating the mixed fluid towards ejection chambers. DMF systems may enable separate droplets of fluid to be moved from multiple reservoirs toward a microfluidic electrode to be mixed together by activating a voltage to electrodes adjacent to a droplet and deactivating a voltage to an electrode under the droplet. Droplets from various fluid reservoirs may then move from the deactivated electrodes they are currently on to the activated, adjacent electrodes. By continuously varying the voltages of the electrodes, individual droplets may be maneuvered along a line of electrodes. Therefore, DMF systems may move printing fluid from the reservoirs towards a microfluidic electrode for mixing and then to ejection chambers without the use of pressure regulators, pumps, valves, and the like which may reduce the cost and complexity of implementing the fluid delivery system without compromising the performance of the system.

[0015] The use of a DMF system may provide increased flexibility and precision in how the fluids are delivered. As discuss above, fluid delivery systems that use pressure to move the printing fluids may result in pockets of air being pushed into the ejection chambers, creating inaccurate ratios of fluids being transferred and failure of the fluid actuators upon activation. DMF systems, on the other hand, enable the fluids to be pulled toward individual microfluidic electrodes and then to the ejection chambers using voltage variations. The voltage variations may allow the fluids to be moved. Therefore, air located in proximity to the ejection chamber would not be pulled into the ejection chamber with the mixed fluid. Additionally, the replacement of the pressure regulators and the like to move the fluid allows the DMF system to have more precision in the amounts and ratios of each fluid which is mixed and moved toward each ejection chamber. Furthermore, DMF systems allow there to be control in the order in which each of the different fluids from different reservoirs is mixed and moved toward the ejection chambers. In some examples, the mixed fluid may have a stability state for a threshold duration of time. For example, a biological fluid may begin to decompose after a threshold duration of time. In another example, a binder material may begin to harden after a threshold duration of time. Thus, precise mixtures of fluids can be created within the DMF system.

[0016] The use of DMF systems over other fluid delivery systems may enable an entire droplet of each printing fluid (e.g., binders, absorbers, biological fluids, etc.) to be moved along microfluidic electrodes at the time of printing. Therefore the use of DMF maintains the targeted ratios of the fluid composition and prevents clogging due to a buildup of fluid residues. In view of the foregoing, it should be appreciated that there may be a desire to use DMF systems to mix a combination of printing fluids and deliver the mixed printing fluid to ejection chambers.

[0017] In an example implementation according to aspects of the present disclosure, a non-transitory computer-readable medium comprises a set of instructions that when executed by a controller are to transmit first control signals from to cause a first droplet of fluid to be pulled onto a microfluidic electrode of a digital microfluidic (DMF) array from a first reservoir. The non-transitory computer-readable medium further comprise instructions that when executed by a controller are to transmit second control signals to cause a second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array from a second reservoir, wherein the first droplet of fluid and the second droplet of fluid are to be mixed on the microfluidic electrode responsive to mixing control signals to be transmitted by the controller and responsively yield a mixed fluid droplet. The non-transitory computer-readable medium further comprise instructions that when executed by a controller are to transmit third control signals to cause the mixed fluid droplet to propagate to a feedhole.

[0018] In another example described herein, a method is provided. The method may include determining a measured amount of a first droplet of fluid and a measured amount of a second droplet of fluid to be deposited onto a microfluidic electrode of a DMF array. The method may further include depositing a first droplet of fluid onto the microfluidic electrode of the DMF array from a first fluid reservoir based on the measured amount of the first droplet of fluid and depositing a second droplet of fluid onto the microfluidic electrode of the DMF array from a second fluid reservoir based on the measured amount of the second droplet of fluid. The method also includes mixing the first droplet of fluid and the second droplet of fluid on the microfluidic electrode to yield a mixed fluid droplet and propagating the mixed fluid droplet to a feedhole.

[0019] In yet another example described herein, another method is provided. The method may include applying a first voltage to a microfluidic electrode of a DMF array to pull a first droplet of fluid onto a microfluidic electrode of the DMF array from a first fluid reservoir based on a measured amount of the first droplet of fluid. The method further includes applying a second voltage to the microfluidic electrode of the DMF array to pull the second droplet of fluid onto the microfluidic electrode of the DMF array from a second fluid reservoir based on a measured amount of the second droplet of fluid, wherein the first droplet of fluid and the second droplet of fluid are combined on the microfluidic electrode of the DMF array to yield a combined fluid droplet.

[0020] Throughout this specification to one implementation, an implementation, one case, an example, and/or the like means that a particular feature, structure, characteristic, and/or the like described in relation to a particular implementation, case, and/or example is included in an implementation, case, and/or example of claimed subject matter. Thus, appearances of such phrases, for example, in various places throughout this specification are not necessarily intended to refer to the same implementation, case, and/or example or to any one particular implementation, case, and/or example. Furthermore, it is to be understood that particular features, structures, characteristics, and/or the like described are capable of being combined in various ways in different implementations, cases, and/or examples and, therefore, are within intended claim scope. In general, of course, as has always been the case for the specification of a patent application, these and other issues have a potential to vary in a particular context of usage. In other words, throughout the disclosure, particular context of description and/or usage provides helpful guidance regarding reasonable inferences to be drawn; however, likewise, “in this context” in general without further qualification refers to the context of the present disclosure.

[0021] Turning to Figure 1, a block diagram illustrating an example of non-transitory computer-readable medium storing instructions to mix fluids on a digital microfluidic (DMF) array. Non-transitory computer-readable medium 100 is non-transitory in the sense that is does not encompass a transitory signal but instead is made up of a memory component configured to store the relevant instructions. Examples of non-transitory computer-readable medium 100 include any type of volatile or non-volatile memory, including random access memory (RAM), read-only memory (ROM), electrically programmable read-only memory (EPROM), and the like, integrated memory, such as a hard drive, solid state drive, and the like, and portable media such as a CDs, DVDs, or portable flash drives. In another example, non-transitory computer-readable medium 100 may have program instructions stored thereon, which may be part of an application or applications already installed thereon. Non-transitory computer-readable medium 100 may be accessible by components of an electronic device, such as a controller to enable functionality of a fluid device, which may access non-transitory computer-readable medium 100 to seek instructions stored therein. For example, non-transitory computer-readable medium 100 may instruct a controller to enable functionality of a printing device, such as a two-dimensional (2D) printer and/or a three-dimensional (3D) printer. Non-transitory computer-readable medium 100 may be implemented to control a device capable of transferring fluids to a fluid ejection device. For instance, non-transitory computer-readable medium 100 include instructions 102 that when executed by a controller are to cause transmission of first control signals to cause a first droplet of fluid to be pulled onto a microfluidic electrode of a DMF array from a first reservoir.

[0022] The first control signals transmitted by the controller may indicate a voltage for a microfluidic electrode in a DMF array. The voltage may enable the first droplet of fluid to be pulled onto the microfluidic electrode of the DMF array. The first control signals may further indicate a variation of voltages of additional microfluidic electrodes to enable the first droplet of fluid to be moved across the DMF array by attracting the first droplet of fluid from one microfluidic electrode to another on the DMF array. In some examples, the control signaling may be communicated by using wireless signaling or wireline signaling.

[0023] The first fluid reservoir may include a container capable of storing printing fluid. The printing fluid may include any fluid capable of being dispensed by the fluid ejection chamber onto a media, such as paper, a layer of powder-based build material, reactive devices (such as lab-on-a-chip device), etc. In some examples, the printing fluid may include a material for printing, such as biological fluids, absorbers, binders, ink, toner, powders, colorants, varnishes, finishes, gloss enhancers, fusing agents, inhibiting agents, and/or other such materials which may be utilized in the printing process. In other examples, printing fluids may include one of a plurality of fluid colorants, such as pigments. In other examples, the first printing fluid comprises a first part of a multi-part binder fluid (e.g., an epoxy) or a first part of a multi-part absorber fluid. In yet another example, the printing fluid may include a first part of a multi-part biological fluid.

[0024] The machine-readable instructions include instructions 104 that when executed by a controller are to transmit second control signals to cause a second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array from a second reservoir. The first droplet of fluid and the second droplet of fluid are to be mixed on the microfluidic electrode responsive to mixing control signals to be transmitted by the controller and yield a mixed fluid droplet.

[0025] The second control signals indicate a microfluidic electrode of a DMF array through which a current is to be pulsed across. By pulsing the current across one of the microfluidic electrodes, an electrical potential is to be formed. The electrical potential attracts the second droplet of printing fluid. Based on this attraction, the second droplet of printing fluid is moved from the second reservoir to the microfluidic electrode. Additional control signaling may also indicate that certain microfluidic electrode(s) (e.g., microfluidic electrode(s) already receiving the current pulses) are to cease to receive current pulses.

[0026] For example, once the first droplet of fluid has moved to the first microelectrode, the control signaling may pass a second current across a second microelectrode of the DMF array. This second current would form an electric potential across the surface of the second microelectrode. In this example, the first droplet of fluid would now be attracted to the second microfluidic electrode and therefore, move from the first microfluidic electrode to the second microfluidic electrode in the DMF array. Using the alteration of voltage currents between microfluidic electrodes of DMF array, the first droplet of fluid and the second droplet of fluid are guided toward each other to be mixed on the same microfluidic electrode on the DMF array. This then yields the mixed droplet of fluid. In other examples, printing fluids may include one of a plurality of fluid colorants, such as pigments.

[0027] The machine-readable instructions include instructions 106 that when executed by a controller are to transmit third control signals to cause the mixed fluid droplet to propagate to a feedhole. The feedhole may allow the mixed droplet of fluid to be fed into a fluid ejection chamber. The fluid ejection chamber may be a device capable of receiving the mixed droplet of fluid from DMF array and ejecting printing fluids. For instance, the fluid ejection chamber may include an enclosure into which printing fluid may be propagated for storing and ejecting. The enclosure may include an actuator and an orifice. In the context of a thermal actuator, current pulses may cause the printing fluid to heat. A portion of the fluid may then be vaporized which in turn causes droplets of the fluid to be ejected via the orifices. In some examples, there may be additional instructions that when executed by the controller are to transmit additional control signals (e.g., fourth control signals) to cause the mixed fluid droplet to be ejected from the feedhole onto a print target, onto a sample, into a test tube, etc.

[0028] It should be noted that as used herein, the fluid ejection chamber may refer to a thermal inkjet (TIJ) or piezo inkjet (PIJ) ejection chamber, by way of non-limiting example. Thus, for example, a fluid device of a 3D printer may be used to eject an agent that may cause a build material to fuse together as part of an additive printing process. The agent may or may not include colorants, such as pigments.

Instead, the agent may include an additive agent to be used in the formation of a 3D object.

[0029] For example, the first printing fluid may comprise a first part of a multi-part binder fluid and the second printing fluid may comprise a second part of a multi-part binder fluid. In this example, each of the first part and the second part of the multi-part binder fluid may be combined to form the multi-part binder fluid. In another example, the first printing fluid may comprise a first part of a multi-part biological fluid and the second printing fluid may comprise a second part of a multi-part biological fluid. In this example, each of the first part and the second part of the multi-part biological fluid may be combined to form the multi-part biological fluid. Advantageously, this allows the multi-part binder/absorbers/biological fluids to be pre-mixed at the time the fluids are propagated to the feedhole. This ensures that the multi-part fluids are uniformly mixed in a more efficient order and time.

[0030] It should also be noted other fluid reservoirs may be included, such as in addition to the first fluid reservoir and the second fluid reservoir. Thus, in other examples, different variations of multi-part fluids may be lined up and sent for ejection in desired orders. For example, a mixed biological fluid may be first mixed on the microfluidic electrodes of the DMF array and ejected from the ejection chamber. Once the biological mixed fluid has been ejected from the fluid, a capping fluid may be mixed on the microfluidic electrodes of the DMF array and used to cap the ejection chamber.

[0031] In some examples, a measured amount of the first droplet of fluid to be pulled onto the microfluidic electrode of the DMF array is determined by the controller. The first control signals may be modified to cause the measured amount of the first droplet of fluid to be pulled onto the microfluidic electrode of the DMF array. Furthermore, a measured amount of the second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array may also be determined. In this example, the second control signals may also be modified to cause the measured amount of the second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array.

[0032] The measured amount of the first droplet of fluid and the measured amount of the second droplet of fluid may be determined based on a modified voxel property of the mixed fluid droplet. The voxel property may indicate data about a location in 3D coordinate space, such as data indicating a targeted opacity and/or ductility of the material in the location in 3D coordinate space. The opacity property may refer to a measured amount (or lack thereof) of translucence characteristics of the material. For example, a shielding material may have an opacity property which allows for little translucence of the material. This enables the material to block radiation from passing though the material. The ductility property may refer to an ability of the material to be deformed without fracture. For example, an example plastic material may have a higher ductility property to allow the plastic material to be bent into a desired shape. On the other hand, an example metal material may have a low ductility property which ensures that the material is not easily deformed.

[0033] Figures 2A-2B illustrate an example microfluidic electrode to mix fluids, according to an example. As illustrated in Figure 2A and Figure 2B, substrate 200 may include first fluid reservoir 202 and second fluid reservoir 204. It should be noted that substrate 200 includes microfluidic electrodes 206A-206C. Figure 2B also includes first droplet of fluid 208A from first fluid reservoir 202, second droplet of fluid

208C from second fluid reservoir, and mixed droplet of fluid 208B. Although not illustrated in Figures 2A and 2B, substrate 200 includes a ground electrode, a driving electrode, and feedholes (illustrated in Figure 4). The surface of the ground electrode and driving electrode may be hydrophobic to prevent printing fluid from wetting the surfaces of the ground electrode and the driving electrode until activated.

[0034] The substrate 200 and the components included in the substrate 200 to mix the fluid may be an example of components used to perform the functions of the set of instructions 102-106 in the non-transitory computer-readable medium 100 from Figure 1. However, the substrate 200 and the components included in the substrate 200 to mix the fluid may differ in form or structure from the components used to perform the functions of the set of instructions 102-106 in the non-transitory computer-readable medium 100 from Figure 1.

[0035] In operation, the first fluid may be stored in first fluid reservoir 202 and the second fluid may be stored in second fluid reservoir 204, as illustrated in Figure 2A. Turning to Figure 2B, a voltage may be applied to microfluidic electrode 206A on the driving electrode to generate an electric potential between the ground electrode and the driving electrode. This electric potential attracts a first droplet of fluid 208A in first fluid reservoir 202 to move onto microfluidic electrode 206A. Once the first droplet of fluid 208A has moved to microfluidic electrode 206A, the voltage applied to microfluidic electrode 206A may be deactivated and applied to a next microfluidic electrode 206B along substrate 200.

[0036] Further, another voltage may be applied to microfluidic electrode 206C on the driving electrode to generate an electric potential between the ground electrode and the driving electrode. This electric potential attracts a second droplet of fluid

208C in second fluid reservoir 204 to move onto microfluidic electrode 206C. Once the second droplet of fluid 208C has moved to microfluidic electrode 206C, the voltage applied to microfluidic electrode 206C may be deactivated and applied to a next microfluidic electrode 206B along substrate 200.

[0037] Once both the first droplet of fluid 208A and the second droplet of fluid 208C are pulled toward microfluidic electrode 206B, the first droplet of fluid 208A and the second droplet of fluid 208C are mixed to form mixed droplet of fluid 208B. By varying the electric potential between the ground electrode and the driving electrode for each electric pad, the electrowetting is affected and each of the two droplets of printing fluid are moved along substrate 200 to form a homogenously mixed droplet of fluid. The homogenously mixed droplet of fluid may then be driven to the bottom of a feedhole next to a fluid ejection chamber.

[0038] It should be noted that a controlled amount of printing fluid is pulled from each of the first fluid reservoir 202 and the second fluid reservoir 204 to form the mixed droplet of fluid, instead the of a less controlled amount of each fluid being pushed to the ejection chamber using back pressure from a pressure regulator. The controlled amount may refer to a precise volume of fluid which is pulled from first fluid reservoir 202. The controlled amount may be determined based on known interaction between the fluid being pulled from the fluid reservoir and the voltage levels applied to the microfluidic electrode. The use of DMF techniques to move the printing fluids to feedhole for an ejection chamber allows more precision in the amount of each fluid that is moved toward the ejection chamber. Furthermore, the substitution of the pressure regulator to move the printing fluid decreases the air moved to the fluid ejection chamber which maintains the performance of the fluid device and lowers the cost and complexity of the fluid device.

[0039] Figures 3A-3D illustrate a fluid device to continuously mix printing fluids, according to an example. More specifically, Figures 3A-3D provide an example of how printing fluids, such as a multi-part binding fluid, may be continuously mixed in slots of an array of microelectrodes. While this example focuses on the multi-part binding fluid, it is to be understood that any multi-part fluids are contemplated by this discussion. Figures 3A-3D illustrate an example of how fluids are mixed using the components from Figure 2. For example, the first fluid reservoir in Figures 3A-3D may be an example of first fluid reservoir 202, the second fluid reservoir in Figures 3A-3D may be an example of second fluid reservoir 204, etc. However, the components included in Figures 3A-3D may differ in form or structure from the components included in Figure 2. Furthermore, the components used to perform the operations in Figure 2 (e.g., control signals, voltage potentials, microfluidic electrodes, etc.) may be used to perform the operations in Figures 3A-3D. Therefore, a repeated discussion of these components is not included.

[0040] Referring to Figure 3A, a first part of the multi-part binding fluid from part A and a second part of the multi-part binding fluid from part B enter an array of microelectrodes. As illustrated in Figure 3B, the first part of the multi-part binding fluid from part A and the second part of the multi-part binding fluid from part B are shifted along electronic pads of the microelectronic array by varying the voltages of each of the electronic pads (e.g., the first part of the multi-part binding fluid is moving down onto lower electronic pads and the second part of the multi-part binding fluid is moving up onto higher electronic pads).

[0041] Referring to Figure 3C, after being shift along the electronic pads of the microelectronic array, the first part of the multi-part binding fluid from part A and the second part of the multi-part binding fluid from part B are merged on the array of microelectrodes. As illustrated in Figure 3D, the droplets are continuously merged to provide a steady flow of mixed binding droplets. The continuous mixing of the multi-part binding fluids allows the binding material to be mixed in real-time at the location of the fluid dispensing. Maintaining a constant flow of a precisely mixed fluid can dramatically affect the quality of the content resulting from the dispense fluid. Of course, other types of printing fluids could be similarly mixed prior to being conveyed to an ejection chamber, consistent with the present disclosure.

[0042] Figure 4 illustrates a schematic cross-sectional diagram of an example fluid device to mix fluids on a DMF array. Fluid device 400 includes ground electrode 402, DMF array 404, first fluid channel 406A, second fluid channel 406B, feedhole 408, and fluid ejection chamber 410. Figure 4 may include different components of fluid device 400 in different examples. Fluid device 400 may perform operations similar to operations performed by non-transitory computer-readable medium 100 in Figure 1.

[0043] Ground electrode 402 may be used in conjunction with DMF array 404 to vary voltages of specified microfluidic electrodes an enable the printing fluid to travel along DMF array 404 toward feedhole 408. Fluid channels 406A and 406B may each carry different printing fluids towards and/or away from separate fluid reservoirs (not shown for simplicity). DMF array 404 may be supported by a substrate and may include an array of electric pads/electrical interconnects, as described previously in relation to Figures. 1-3D. As illustrated at feedhole 408, the two fluids from fluid channel 406A and fluid channel 406B are mixed on the microfluidic electrode near feedhole 408. Electrical interconnects may exchange control signals to combine two or more fluids and enable the delivery of the printing fluid toward fluid ejection chamber 410 via feedhole 408.

[0044] The droplet of mixed fluid may be drawn into feedhole 408 by capillary action. For example, a surface tension created in feedhole 408 may cause the droplet of mixed fluid to be drawn from the electric pad located below feedhole 408. Likewise, once the droplet of mixed fluid has been drawn into feedhole 408, the mixed fluid may continue to move toward fluid ejection chamber 410 due to the capillary action force. Once in fluid ejection chamber 410, the droplet of mixed fluid may then be ejected and caused to deposit on an external surface, such as a print target or biological sample (e.g., tissue sample). Advantageously, a controlled amount of fluid or droplets of fluid may be uniformly pre-mixed immediately before the droplet of mixed fluid is drawn into feedhole 408. This provides more control of the amount of each fluid used to form the mixed fluid, unlike previous techniques where a mixed fluid was either pre-mixed externally (e.g., at the manufacturer), or ejected from fluid ejection chamber 410 at separate times in which the mixed fluid is non-homogenously mixed on the surface of the media.

[0045] Figure 5 illustrates an example diagram of uniformly mixed fluids which are ejected onto a print target. Figure 5 includes a first droplet of fluid 502, a second droplet of fluid 504, a mixed droplet of fluid 506, and a print target 508. In this example, the mixed droplet of fluid 506 may not have a long shelf-life. For example, mixed droplet of fluid 506 may comprise an epoxy in which adhesive properties of the epoxy are activated once first droplet of fluid 502 is mixed with second droplet of fluid 504.

[0046] Still referring to Figure 5, the first droplet of fluid 502 and the second droplet of fluid are mixed prior to being ejected from an ejection chamber to the print target 508. Unlike previous techniques in which the first droplet of fluid 502 and the second droplet of fluid 504 are mixed on the print target 508 after being ejected from the ejection chamber to the print target 508, Figure 5 illustrates how the droplets of fluid may be pre-mixed prior to ejection. This allow for homogenous mixing of the fluids. Furthermore, the ability to pre-mix the fluids at the time of printing allows fluids to be mixed in a controlled order and time. Therefore, unlike prior techniques in which a pre-mixed fluid is bought, manufactured, etc. as a pre-mixed fluid, Figure 5 illustrates how a controlled amount of fluid may be combined with other controlled amounts of fluids in a controlled order and time.

[0047] Figure 6 illustrates a flow diagram of an example process to mix fluids based on a modified property for a 3D printing fluid. Method 600 may be used by a fluid device, such as fluid device 400. Method 600 includes applying a first voltage to a microfluidic electrode of a DMF array to pull the first droplet of fluid onto the microfluidic electrode of the DMF array from a first fluid reservoir based on the measured amount of the first droplet of fluid, at 601. Method 600 further includes applying a second voltage to the microfluidic electrode of the DMF array to pull the second droplet of fluid onto the microfluidic electrode of the DMF array from a second fluid reservoir based on the measured amount of the second droplet of fluid, wherein the first droplet of fluid and the second droplet of fluid are combined on the microfluidic electrode of the DMF array to yield a combined fluid droplet, at 602.

[0048] Figure 7 illustrates a flow diagram of an example process to mix biological fluids in a fluid device, according to another example. Method 700 may be used by a fluid device, such as fluid device 400. Method 700 may include determining a measured amount of a first part of a multi-part biological fluid and a measured amount of a second part of a multi-part biological fluid to be deposited onto a microfluidic electrode of a DMF array, at 701. Method 700 may also include depositing a first part of multi-part biological fluid droplet onto the microfluidic electrode of the DMF array from a first fluid reservoir based on the measured amount of the first part of multi-part biological fluid, at 702.

[0049] Still referring to Figure 7, method 700 includes depositing a second part of multi-part biological fluid droplet onto the microfluidic electrode of the DMF array from a second fluid reservoir based on the measured amount of the second part of multi-part biological fluid, at 703. Method 700 further includes mixing the first part of the multi-part biological fluid droplet and the second part of the multi-part biological fluid droplet to yield a mixed biological fluid droplet, at 704. Method 700 then includes propagating the mixed biological fluid droplet to a feedhole, at 705. Although not shown in Figure 7 for clarity, method 700 may further include ejecting the mixed biological fluid droplet from the feedhole onto a print target. In other examples, the mixed biological fluid droplet may be ejected from the feedhole into a test tube, onto a sample, etc.

[0050] Figure 8 illustrates a block diagram illustrating a system to cause a fluid device to mix fluids on a DMF array. Figure 8 illustrates fluid ejection device 800, which is representative of any system or visual representation of systems in which the various applications, services, scenarios, and processes disclosed herein may be implemented.

[0051] Fluid ejection device 800 may be implemented as a single apparatus, system, or device or may be implemented in a distributed manner as multiple apparatuses, systems, or devices. Fluid ejection device 800 includes, but is not limited to, controller 802, storage system 804, program instructions 806, communication interface system 808, and DMF fluid device 810. DMF fluid device 810 comprises fluid reservoirs 812A-812B, DMF array 814, microfluidic electrodes 816, and fluid ejection chamber 818. Controller 802 is operatively coupled with storage system 804, communication interface system 808, DMF fluid device 810.

[0052] DMF fluid device 810 and components 812-818 may be examples of components from Figures 1-4. For example, first fluid reservoir 812A may be an example of first fluid reservoir 202, second fluid reservoir 812B may be example of second fluid reservoir 204, DMF array 814 may be an example of DMF array 404, microfluidics electrodes 816 may be an example of microfluidics electrodes 206A-206C, and fluid ejection chamber 818 may be an example of fluid ejection chamber 410. Therefore, a repeated discussion of these components is not included. DMF fluid device 810 may perform operations similar to operations performed by non-transitory computer-readable medium 100 in Figure 1, as directed by program instructions 806 when executed by controller 802.

[0053] Controller 802 executes program instructions 806 from storage system 804. Program instructions 806 are representative of the processes discussed with respect to the preceding Figures 1-7, including program instructions 102-106, method 600, and method 700. When executed by controller 802, program instructions 806 direct controller 802 to operate as described herein for at least the various processes, operational scenarios, and sequences discussed in the foregoing examples. Fluid ejection device 800 may optionally include additional devices, features, or functionality not discussed for purposes of brevity.

[0054] Referring still to Figure 8, controller 802 may comprise a micro-processor and other circuitry that retrieves and executes program instructions 806 from storage system 804. Controller 802 may be implemented within a single processing device but may also be distributed across multiple processing devices or sub-systems that cooperate in executing program instructions. Examples of controller 802 include general purpose central processing units, graphical processing units, application specific processors, and logic devices, as well as any other type of processing device, combination, or variation.

[0055] Storage system 804 may comprise any computer readable storage media readable by controller 802 and capable of storing program instructions 806 and may correspond to non-transitory computer-readable medium 100 discussed in Figure 1. Storage system 804 may include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. Examples of storage media include random access memory, read only memory, magnetic disks, optical disks, flash memory, virtual memory and non-virtual memory, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or other suitable storage media, except for propagated signals. Storage system 804 may be implemented as a single storage device but may also be implemented across multiple storage devices or sub-systems co-located or distributed relative to each other. Storage system 804 may comprise additional elements, such as a controller, capable of communicating with controller 802 or possibly other systems.

[0056] Program instructions 806 may be implemented in program instructions and among other functions may, when executed by controller 802, direct DMF fluid device 810 to operate as described with respect to the various operational scenarios, sequences, and processes illustrated herein. Program instructions 806 may include program instructions for implementing method 600 and method 700.

[0057] The program instructions 806 may include various components or modules that cooperate or otherwise interact to carry out the various processes and operational scenarios described herein. The various components or modules may be embodied in compiled or interpreted instructions, or in some other variation or combination of instructions. The various components or modules may be executed in a synchronous or asynchronous manner, serially or in parallel, in a single threaded environment or multi-threaded, or in accordance with any other suitable execution paradigm, variation, or combination thereof. Program instructions 806 may include additional processes, programs, or components, such as operating system software, virtual machine software, or other application software, in addition to or that include program instructions 102-106. Program instructions 806 may also comprise firmware or some other form of machine-readable processing instructions executable by controller 802.

[0058] In general, program instructions 806 may, when loaded into controller 802 and executed, transform a suitable apparatus, system, or device (of which fluid ejection device 800 is representative) overall from a general-purpose computing system into a special-purpose computing system. Indeed, encoding program instructions 806 on storage system 804 may transform the physical structure of storage system 804. The specific transformation of the physical structure may depend on various factors in different examples of this description. Such factors may include, but are not limited to, the technology used to implement the storage media of storage system 804 and whether the computer-storage media are characterized as primary or secondary storage, as well as other factors.

[0059] If the computer readable storage media are implemented as semiconductor-based memory, program instructions 806 may transform the physical state of the semiconductor memory when the program instructions are encoded therein, such as by transforming the state of transistors, capacitors, or other discrete circuit elements constituting the semiconductor memory. A similar transformation may occur with respect to magnetic or optical media. Other transformations of physical media are possible without departing from the scope of the present description, with the foregoing examples provided only to facilitate the present discussion.

[0060] Communication interface system 808 may include communication connections and devices that allow for communication with other computing systems (not shown) over communication networks (not shown). Examples of connections and devices that together allow for inter-system communication may include network interface cards, antennas, power amplifiers, RF circuitry, transceivers, and other communication circuitry. The connections and devices may communicate over communication media to exchange communications with other computing systems or networks of systems, such as metal, glass, air, or any other suitable communication media. The aforementioned media, connections, and devices are well known and need not be discussed at length here.

[0061] Communication between fluid ejection device 800 and other computing systems (not shown), may occur over a communication network or networks and in accordance with various communication protocols, combinations of protocols, or variations thereof. Examples include intranets, internets, the Internet, local area networks, wide area networks, wireless networks, wired networks, virtual networks, software defined networks, data center buses, computing backplanes, or any other type of network, combination of network, or variation thereof. The aforementioned communication networks and protocols are well known and need not be discussed at length here.

[0062] In the preceding description, various aspects of claimed subject matter have been described. For purposes of explanation, specifics, such as amounts, systems and/or configurations, as examples, were set forth. In other instances, well-known features were omitted and/or simplified so as not to obscure claimed subject matter. While certain features have been illustrated and/or described herein, many modifications, substitutions, changes and/or equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all modifications and/or changes as fall within claimed subject matter.

[0063] It is appreciated that examples described may include various components and features. It is also appreciated that numerous specific details are set forth to provide a thorough understanding of the examples. However, it is appreciated that the examples may be practiced without limitations to these specific details. In other instances, well known methods and structures may not be described in detail to avoid unnecessarily obscuring the description of the examples. Also, the examples may be used in combination with each other.

[0064] Reference in the specification to “an example” or similar language means that a particular feature, structure, or characteristic described in connection with the example is included in an example, but not necessarily in other examples. The various instances of the phrase “in one example” or similar phrases in various places in the specification are not necessarily all referring to the same example.

What is claimed is:

1. A non-transitory computer-readable medium comprising a set of instructions that when executed by a controller are to:

transmit first control signals from to cause a first droplet of fluid to be pulled onto a microfluidic electrode of a digital microfluidic (DMF) array from a first reservoir;

transmit second control signals to cause a second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array from a second reservoir, wherein the first droplet of fluid and the second droplet of fluid are to be mixed on the microfluidic electrode responsive to mixing control signals to be transmitted by the controller and responsively yield a mixed fluid droplet; and

transmit third control signals to cause the mixed fluid droplet to propagate to a feedhole.

2. The non-transitory computer-readable medium of claim 1 wherein the set of instructions when executed by the controller are to transmit fourth control signals to cause the mixed fluid droplet to be ejected from the feedhole onto a print target.

3. The non-transitory computer-readable medium of claim 1 wherein the first droplet of fluid comprises a first part of a multi-part binding material and wherein the second droplet of fluid comprises a second part of the multi-part binding material.

4. The non-transitory computer-readable medium of claim 1 wherein the first droplet of fluid comprises a first part of a multi-part absorbing material and wherein the second droplet of fluid comprises a second part of the multi-part absorbing material.

5. The non-transitory computer-readable medium of claim 1 wherein the first droplet of fluid comprises a first component of a multi-part biological material and the second droplet of fluid comprises a second part of the multi-part biological material.

6. The non-transitory computer-readable medium of claim 1 wherein the set of instructions when executed by the controller are to:

determine a measured amount of the first droplet of fluid to be pulled onto the microfluidic electrode of the DMF array;

modify the first control signals to cause the measured amount of the first droplet of fluid to be pulled onto the microfluidic electrode of the DMF array;

determine a measured amount of the second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array; and

modify the second control signals to cause the measured amount of the second droplet of fluid to be pulled onto the microfluidic electrode of the DMF array.

7. The non-transitory computer-readable medium of claim 6 wherein the measured amount of the first droplet of fluid and the measured amount of the second droplet of fluid are determined based on a modified voxel property of the mixed fluid droplet.

8. The non-transitory computer-readable medium of claim 7 wherein the modified voxel property comprises a modified ductility property of the mixed fluid droplet.

9. The non-transitory computer-readable medium of claim 7 wherein the modified voxel property comprises a modified opacity property of the mixed fluid droplet.

10. A method comprising:

determining a measured amount of a first droplet of fluid and a measured amount of a second droplet of fluid to be deposited onto a microfluidic electrode of a digital microfluidic (DMF) array;

depositing a first droplet of fluid onto the microfluidic electrode of the DMF array from a first fluid reservoir based on the measured amount of the first droplet of fluid;

depositing a second droplet of fluid onto the microfluidic electrode of the DMF array from a second fluid reservoir based on the measured amount of the second droplet of fluid;

mixing the first droplet of fluid and the second droplet of fluid on the microfluidic electrode to yield a mixed fluid droplet; and

propagating the mixed fluid droplet to a feedhole.

11. The method of claim 10 further comprising ejecting the mixed fluid droplet from the feedhole onto a biological sample.

12. The method of claim 10 wherein the mixed droplet of fluid comprises a fluid having a state of stability for a threshold duration of time.

13. The method of claim 10 wherein the first droplet of fluid comprises a first component of a multi-part biological material and the second fluid comprises a second part of the multi-part biological material.

14. The method of claim 10 wherein the measured amount of the first droplet of fluid and the measured amount of the second droplet of fluid are deposited in an order based on a modified voxel property of the mixed fluid droplet.

15. A method comprising:

applying a first voltage to a microfluidic electrode of a digital microfluidic (DMF) array to pull a first droplet of fluid onto the microfluidic electrode of the DMF array from a first fluid reservoir based on a measured amount of the first droplet of fluid; and

applying a second voltage to the microfluidic electrode of the DMF array to pull a second droplet of fluid onto the microfluidic electrode of the DMF array from a second fluid reservoir based on a measured amount of the second droplet of fluid, wherein the first droplet of fluid and the second droplet of fluid are combined on the microfluidic electrode of the DMF array to yield a combined fluid droplet.

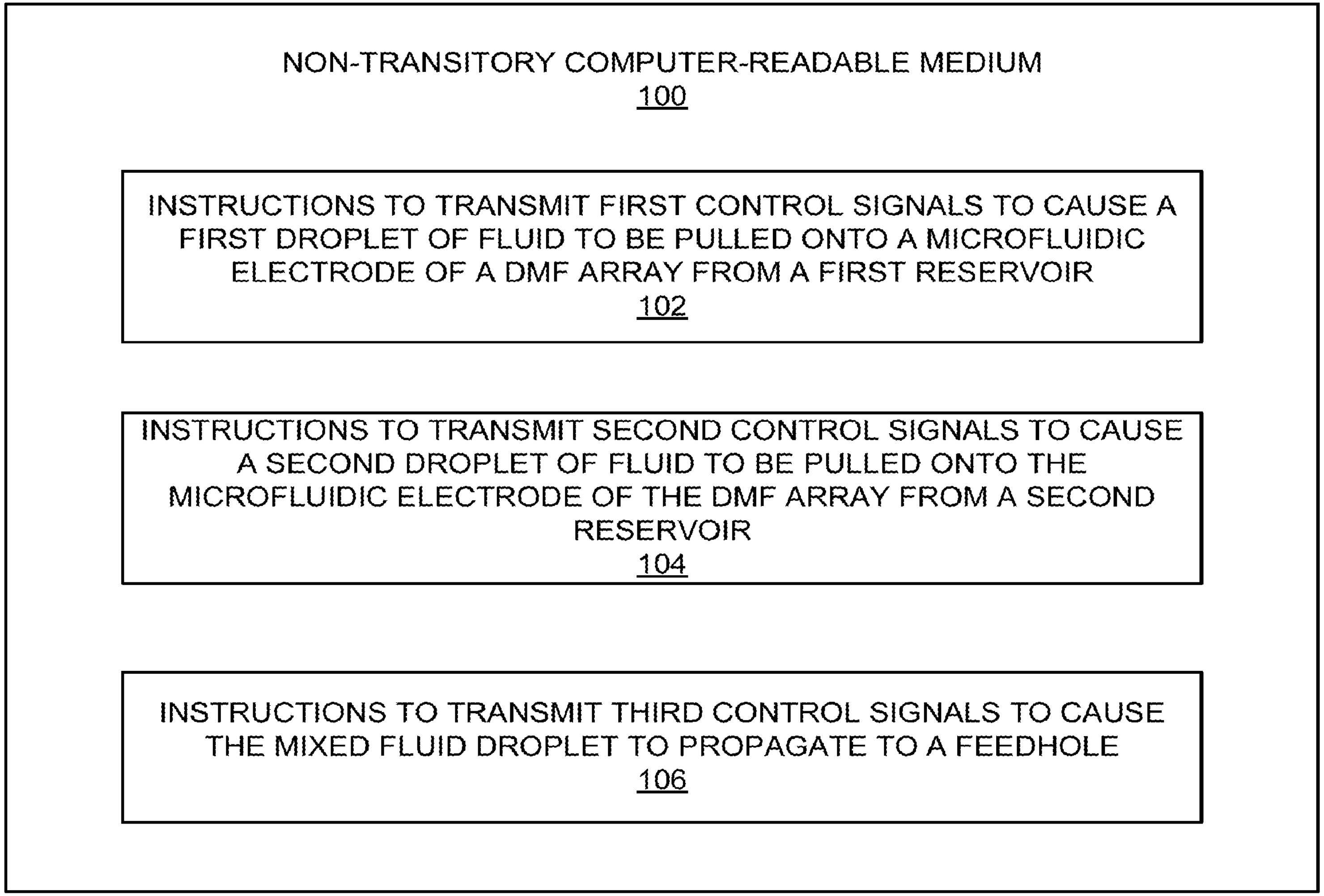
NON-TRANSITORY COMPUTER-READABLE MEDIUM
100
INSTRUCTIONS TO TRANSMIT FIRST CONTROL SIGNALS TO CAUSE A FIRST DROPLET OF FLUID TO BE PULLED ONTO A MICROFLUIDIC ELECTRODE OF A DMF ARRAY FROM A FIRST RESERVOIR
102
INSTRUCTIONS TO TRANSMIT SECOND CONTROL SIGNALS TO CAUSE A SECOND DROPLET OF FLUID TO BE PULLED ONTO THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY FROM A SECOND RESERVOIR
104
INSTRUCTIONS TO TRANSMIT THIRD CONTROL SIGNALS TO CAUSE THE MIXED FLUID DROPLET TO PROPAGATE TO A FEEDHOLE
106

FIGURE 1

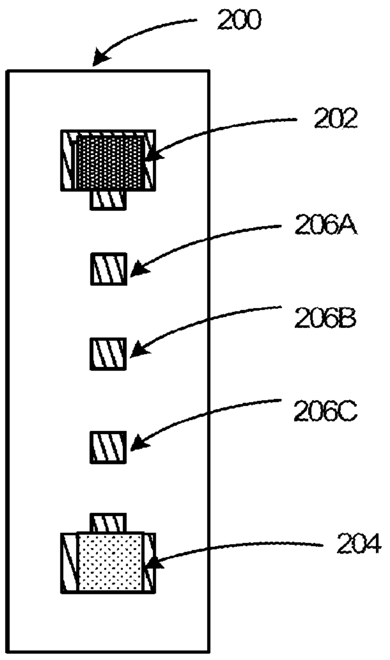

FIGURE 2A

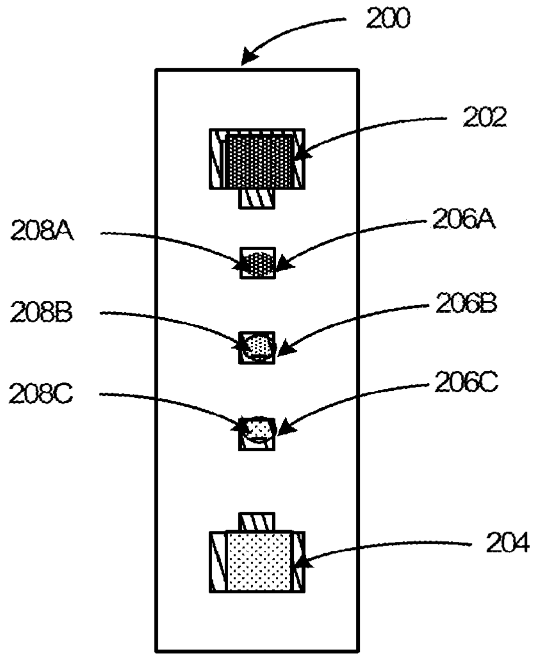

FIGURE 2B

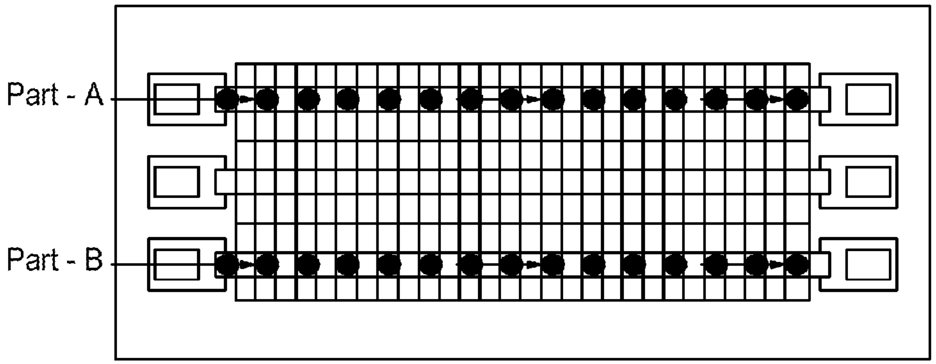

FIGURE 3A

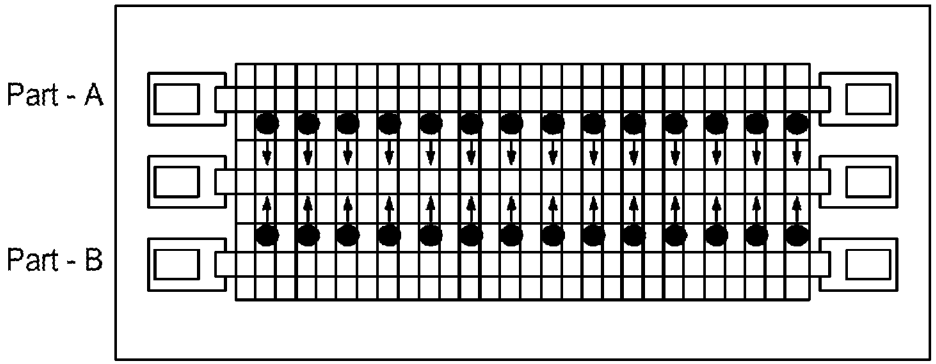

FIGURE 3B

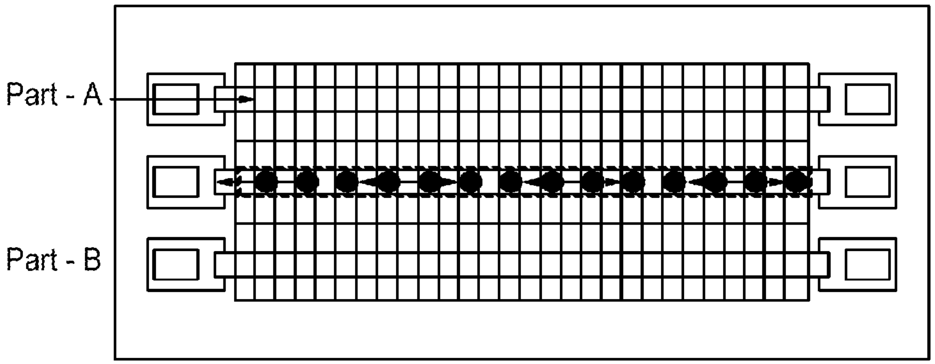

FIGURE 3C

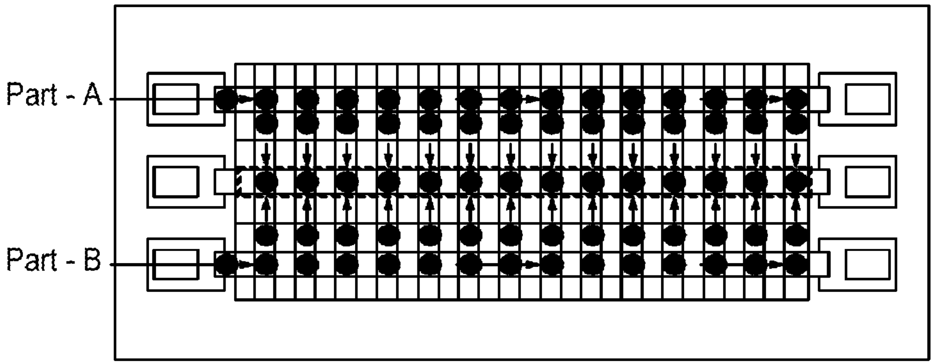

FIGURE 3D

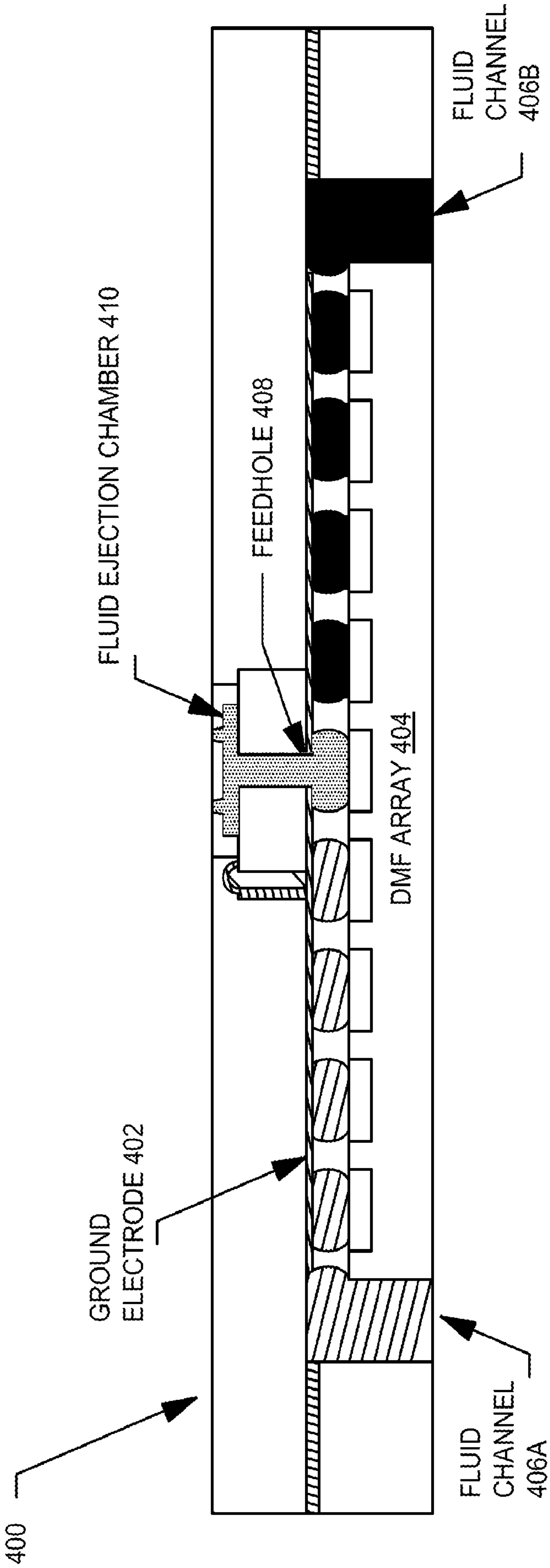
400
GROUND ELECTRODE 402
FLUID EJECTION CHAMBER 410
FEEDHOLE 408
DMF ARRAY 404
FLUID CHANNEL 406A
FLUID CHANNEL 406B

FIGURE 4

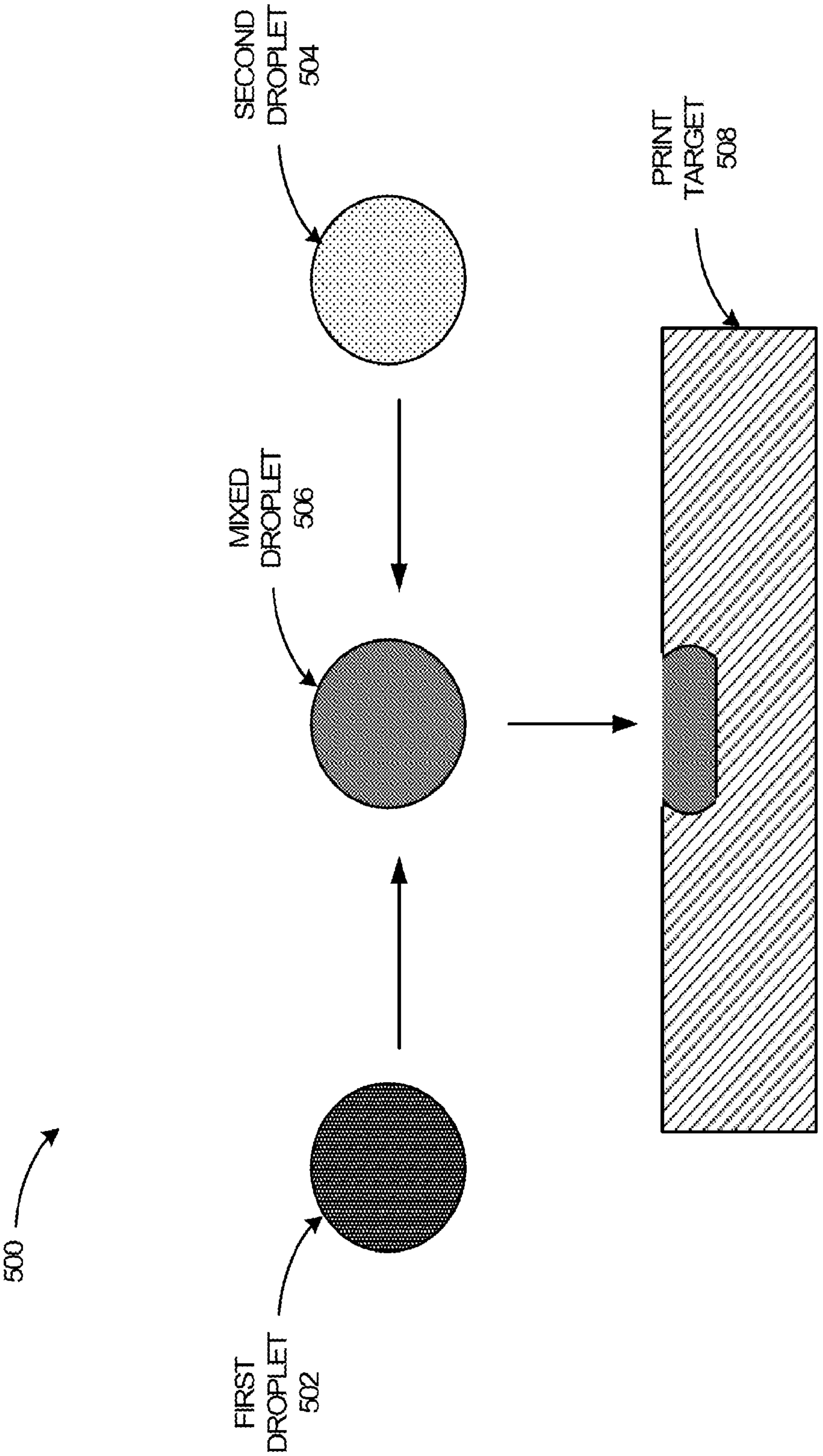
500
FIRST DROPLET 502
SECOND DROPLET 504
MIXED DROPLET 506
PRINT TARGET 508

FIGURE 5

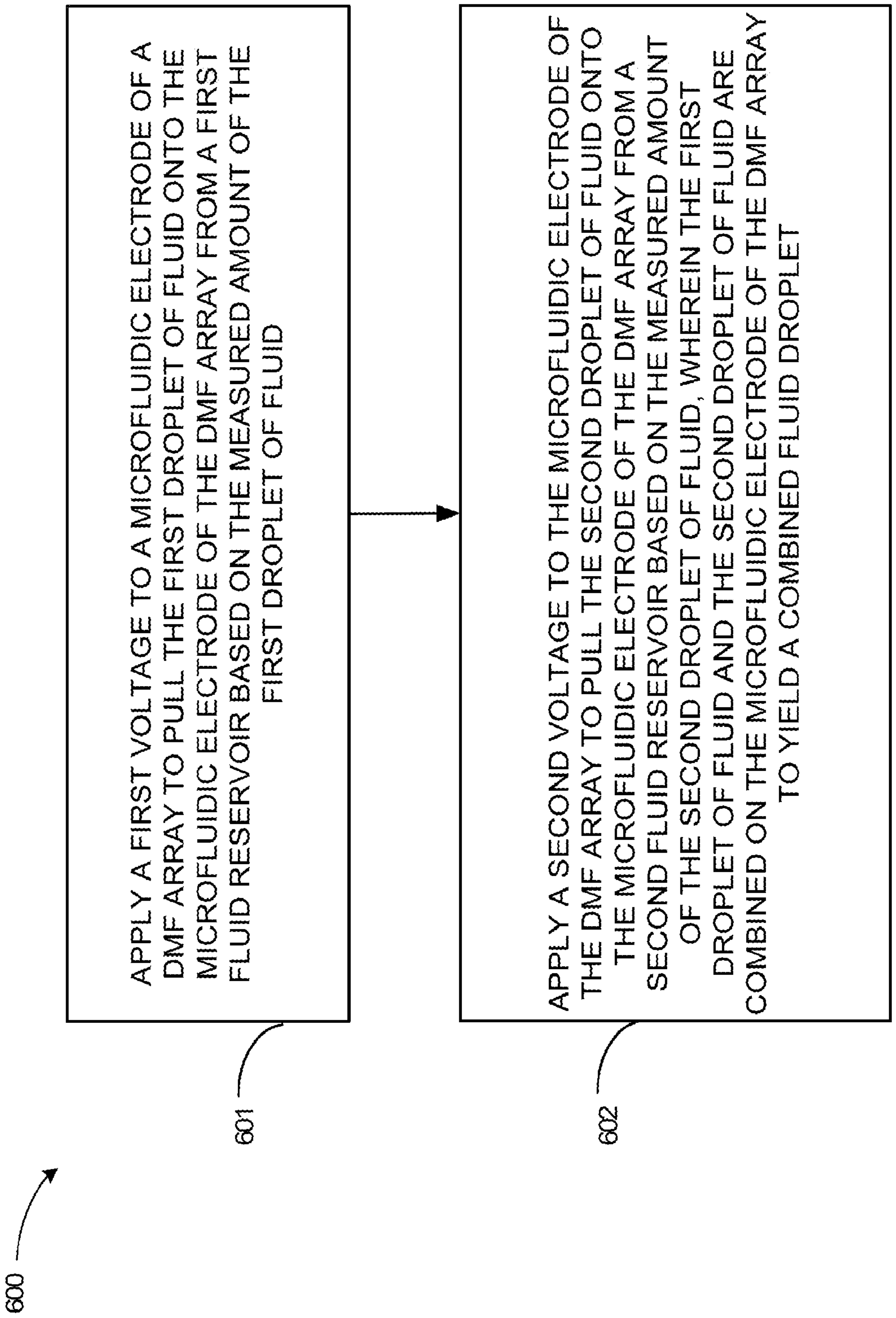
600
601
APPLY A FIRST VOLTAGE TO A MICROFLUIDIC ELECTRODE OF A DMF ARRAY TO PULL THE FIRST DROPLET OF FLUID ONTO THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY FROM A FIRST FLUID RESERVOIR BASED ON THE MEASURED AMOUNT OF THE FIRST DROPLET OF FLUID
602
APPLY A SECOND VOLTAGE TO THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY TO PULL THE SECOND DROPLET OF FLUID ONTO THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY FROM A SECOND FLUID RESERVOIR BASED ON THE MEASURED AMOUNT OF THE SECOND DROPLET OF FLUID, WHEREIN THE FIRST DROPLET OF FLUID AND THE SECOND DROPLET OF FLUID ARE COMBINED ON THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY TO YIELD A COMBINED FLUID DROPLET

FIGURE 6

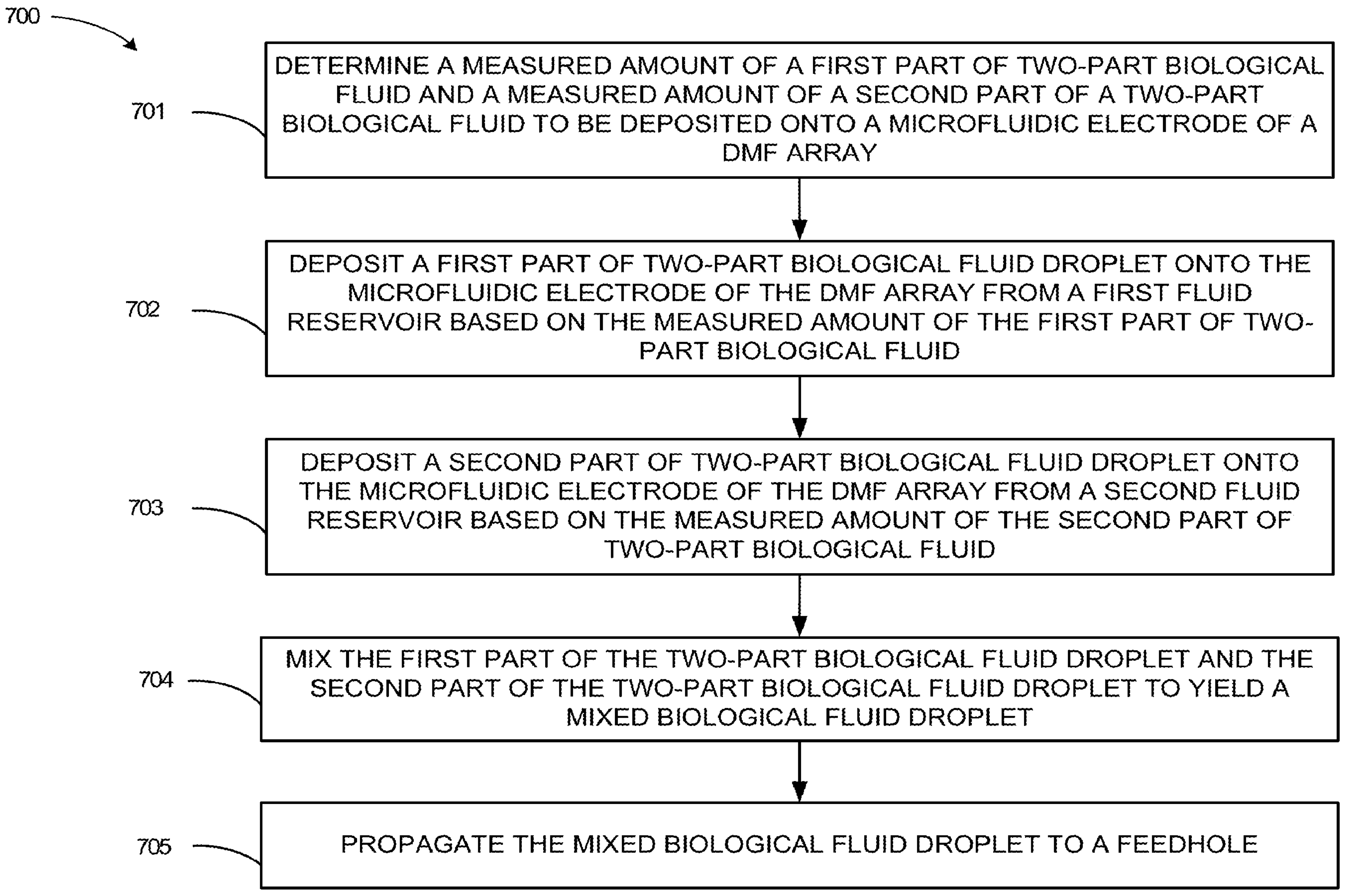
700
701
DETERMINE A MEASURED AMOUNT OF A FIRST PART OF TWO-PART BIOLOGICAL FLUID AND A MEASURED AMOUNT OF A SECOND PART OF A TWO-PART BIOLOGICAL FLUID TO BE DEPOSITED ONTO A MICROFLUIDIC ELECTRODE OF A DMF ARRAY
702
DEPOSIT A FIRST PART OF TWO-PART BIOLOGICAL FLUID DROPLET ONTO THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY FROM A FIRST FLUID RESERVOIR BASED ON THE MEASURED AMOUNT OF THE FIRST PART OF TWO-PART BIOLOGICAL FLUID
703
DEPOSIT A SECOND PART OF TWO-PART BIOLOGICAL FLUID DROPLET ONTO THE MICROFLUIDIC ELECTRODE OF THE DMF ARRAY FROM A SECOND FLUID RESERVOIR BASED ON THE MEASURED AMOUNT OF THE SECOND PART OF TWO-PART BIOLOGICAL FLUID
704
MIX THE FIRST PART OF THE TWO-PART BIOLOGICAL FLUID DROPLET AND THE SECOND PART OF THE TWO-PART BIOLOGICAL FLUID DROPLET TO YIELD A MIXED BIOLOGICAL FLUID DROPLET
705
PROPAGATE THE MIXED BIOLOGICAL FLUID DROPLET TO A FEEDHOLE

FIGURE 7

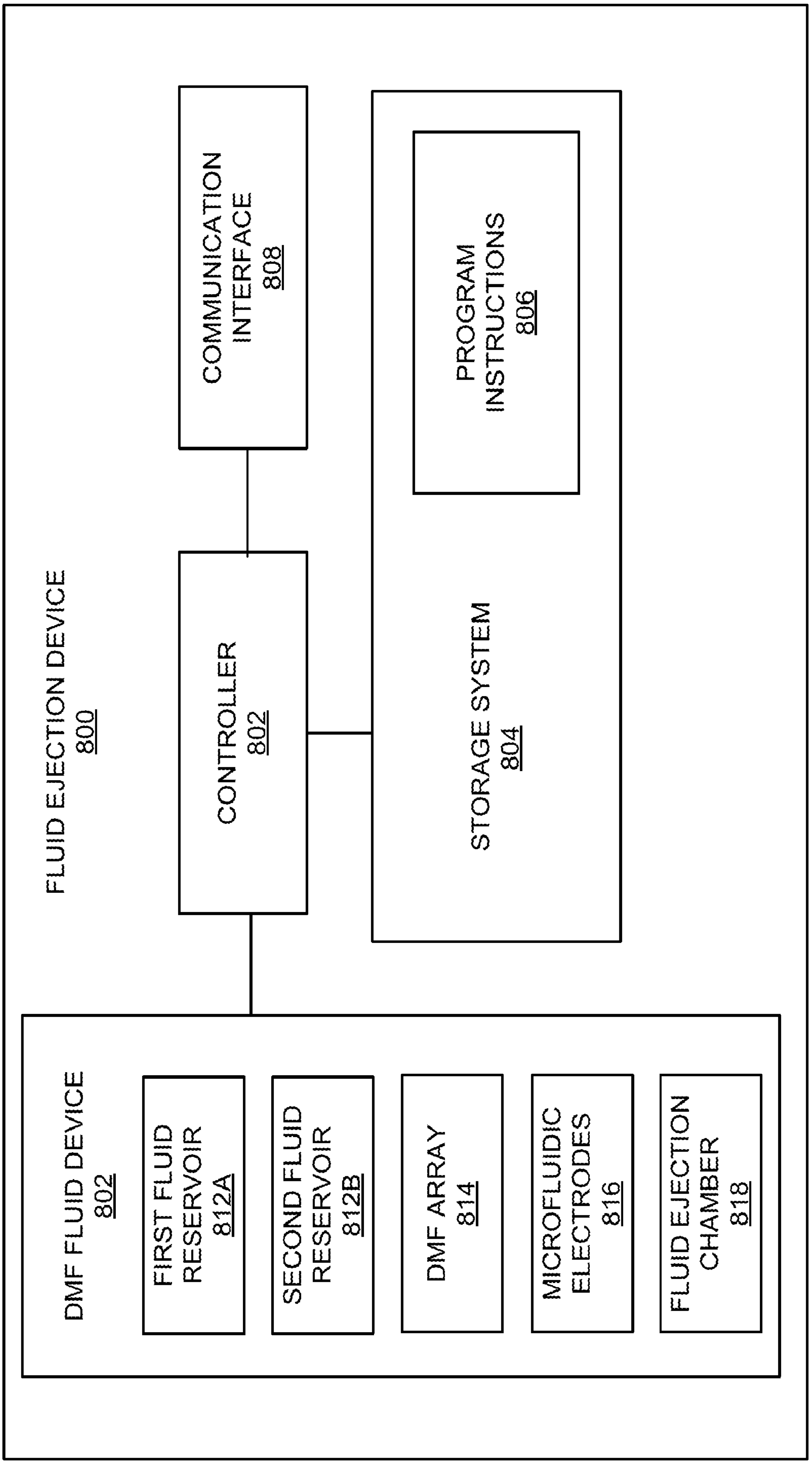
FLUID EJECTION DEVICE
800
COMMUNICATION
INTERFACE
808
CONTROLLER
802
PROGRAM
INSTRUCTIONS
806
STORAGE SYSTEM
804
DMF FLUID DEVICE
802
FIRST FLUID
RESERVOIR
812A
SECOND FLUID
RESERVOIR
812B
DMF ARRAY
814
MICROFLUIDIC
ELECTRODES
816
FLUID EJECTION
CHAMBER
818

FIGURE 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2020/053593

A. CLASSIFICATION OF SUBJECT MATTER

G01N 35/10 *(2006.01)*
B01L 3/00 *(2006.01)*
B81B 7/04 *(2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N 35/10, B01L 3/00, B81B 7/04

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)

PatSearch (RUPTO Internal), USPTO, PAJ, Espacenet, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/170268 A1 (DH TECHNOLOGIES DEVELOPMENT PTE. LTD.) 12.11.2015, paragraphs [0004]-[0009], [0017]-[0019], [0057], [0064]-[0065], [0073]	1-2, 5-6, 10-13, 15
Y		3, 4
A		7-9, 14
Y	WO 2018/026962 A1 (3DEO,INC.) 08.02.2018, paragraphs [0101], [0112]	3, 4
A	WO 2020/072986 A1 (VELO3D, INC) 09.04.2020	1-15
A	WO 2019/094049 A1 (HEWLETT-PAKCARD DEVELOPMENT COMPANY, L.P.) 16.05.2019	1-15

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"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
"&" document member of the same patent family

Date of the actual completion of the international search

29 April 2021 (29.04.2021)

Date of mailing of the international search report

03 June 2021 (03.06.2021)

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