Directing Motion of Droplets Using Differential Wetting

BACKGROUND

[0001] This application claims from United States provisional App. Ser. No. 62/811,018, filed February 27, 2019, titled Directing Motion of Droplets Using Differential Wetting, and United States provisional App. Ser. No. 62/636,268, filed Feb. 28, 2018, titled Manufacturing Methods for Electrowetting Microfluidic Chip. These applications are incorporated by reference.

[0002] This application relates to controlling and manipulating a liquid or gas in a device that is small, typically milliliter to sub-microliter scale.

SUMMARY

[0002a] In an aspect, the present disclosure refers to a system for processing a sample, comprising: an array comprising (i) a first plurality of electrodes, (ii) a second plurality of electrodes, (iii) a liquid coating filling in gaps between adjacent electrodes of said first plurality of electrodes and said second plurality of electrodes, (iv) a dielectric disposed over said first plurality of electrodes, said second plurality of electrodes, and said liquid coating filling in gaps between said adjacent electrodes, and (v) a liquid layer disposed over said dielectric, wherein said liquid layer is configured to support a droplet on a surface of said liquid layer, wherein said droplet comprises said sample, wherein said liquid layer comprises a liquid that has a wetting affinity characteristic for said dielectric, wherein said liquid is immiscible with said droplet, and wherein said first plurality of electrodes and said second plurality of electrodes are configured to supply an electric field to induce said droplet to motion along a surface of said liquid layer; and a controller operatively coupled to said first plurality of electrodes and said second plurality of electrodes, wherein said controller is configured to direct at least a subset of said first plurality of electrodes and said second plurality of electrodes to supply said electric field to alter a wetting characteristic of said surface of said liquid layer, to thereby induce said droplet to motion along said surface of said liquid layer.

[0002b] In another aspect, the present disclosure refers to a method for processing a sample, comprising: (a) providing an array comprising: (i) a first plurality of electrodes, (ii) a second plurality of electrodes, (iii) a liquid coating filling in gaps between adjacent electrodes of said first plurality of electrodes and said second plurality of electrodes, (iv) a dielectric disposed over said first plurality of electrodes, said second plurality of electrodes, and said liquid coating filling in gaps between said adjacent electrodes, and (v) a liquid layer disposed over said dielectric, wherein said liquid layer is configured to support a droplet on a surface of said liquid layer, wherein said droplet comprises said sample, wherein said liquid layer comprises a liquid that has a wetting affinity characteristic for said dielectric, and wherein said liquid is immiscible with said droplet; (b)

introducing said droplet comprising said sample on said surface of said liquid layer disposed over said dielectric; and (c) directing at least a subset of said first plurality of electrodes and said second plurality of electrodes to supply an electric field to alter a wetting characteristic of said surface of said liquid layer, to thereby induce said droplet to motion along said surface of said liquid layer.

[0003] In general, in a first example, the present disclosure features apparatus for controlling motion of liquid droplets. A set of electrode pads is arranged in an array or in paths defining one or more tracks over which liquid droplets may be induced to move over a sequence of the electrode pads. A surface over the electrode pads is dielectric, smooth to within 2μm, has a slide angle for a 5μl droplet of the liquid of no more than 5 degrees, and has a wetting affinity to the liquid that can be altered by application of voltage to the electrode pads. A control is designed to alter the wetting characteristic of portions of the surface over respective electrode pads to effect induced motion of the droplets over the tracks, the wetting characteristic to be altered by controlling charging and discharging of the electrode pads in a desired sequence.

[0004] In general, in a second example, the present disclosure features apparatus for controlling motion of liquid droplets. A smooth, hydrophobic surface has portions with a wetting affinity to the liquid that can be varied in a controlled manner. The varying-wettability portions are arranged in an array or in paths defining one or more tracks over which liquid droplets may be induced to move over a sequence of the varying-wettability portions. A control is designed to vary the wetting characteristic of varying-wettability portions of the surface to effect induced motion of the droplets over the tracks. The apparatus is designed with the smooth hydrophobic surface open, with no overlying or facing electrode or plate above the droplets.

[0005] In general, in a third example, the present disclosure features apparatus for controlling motion of liquid droplets. A solid surface is textured to hold a thin layer of a second liquid that is immiscible with the liquid of the droplets, an upper surface of the second liquid forming a liquid-liquid surface that is slippery with respect to the liquid droplets, having a slide angle for a 5μl droplet of the droplet liquid of no more than 5 degrees, and having a wetting affinity to the droplet liquid that can be varied under control, the varying-wettability portions being arranged in an array or in paths defining one or more tracks over which the liquid droplets may be induced to move over a sequence of the varying-wettability portions. A control is designed to vary the wetting characteristic of varying-wettability portions of the liquid-liquid surface to effect induced motion of the droplets over the tracks.

[0006] In general, in a fourth example, the present disclosure features apparatus for controlling motion of liquid droplets. A set of electrode pads is arranged in an array or in paths defining one or more tracks over which liquid droplets may be induced to move over a sequence of the electrode pads. A surface over the electrode pads is dielectric, smooth to within 1μm, the smooth surface being formed as a thin layer of a second liquid that is immiscible with the liquid of the droplets, an upper surface of the second liquid forming a liquid-liquid surface that is hydrophobic, having a slide angle for a 5μl droplet of the liquid of no more than 5 degrees, and having portions whose wetting affinity to the liquid that can be individually varied in a controlled manner by application of voltage to respective electrode pads, the varying-wettability portions being arranged in an array or in paths defining one or more tracks over which liquid droplets may be induced to move over a sequence of the varying-wettability portions. The second liquid is laid as a thin layer on a surface of an underlying solid substrate that is textured to hold the second liquid stable against gravity. A control is designed to alter the wetting characteristic of varying-wettability portions of the surface over respective electrode pads to effect induced motion of the droplets over the tracks, the wetting characteristic to be altered by controlling charging and discharging of the electrode pads in a desired sequence. The apparatus is designed with the smooth hydrophobic surface open, with no overlying or facing electrode or plate above the droplets.

[0007] In general, in a fifth example, the present disclosure features a method. A liquid droplet is introduced onto a surface over a set of electrode pads arranged in an array or in paths defining one or more tracks over which the liquid droplet may be induced to move over a sequence of the electrode pads. The surface is dielectric, hydrophobic, smooth to within 2μm, and has a slide angle for a 5μl droplet of the liquid of no more than 5 degrees, and has a wetting affinity to the liquid that can be altered by application of voltage to the electrode pads. The varying-wettability portions are arranged in an array or in paths defining one or more tracks over which liquid droplets may be induced to move over a sequence of the varying-wettability portions. The wetting characteristic of portions of the surface over respective electrode pads is controlled to effect induced motion of the droplet over the tracks, the wetting characteristic to be altered by controlling charging and discharging of the electrode pads in a desired sequence. The surface is designed with the smooth hydrophobic surface open, with no overlying or facing electrode or plate above the droplets.

[0008] Examples of the present disclosure may include one or more of the following features. The motive voltage may be less than 100V, less than 80V, less than 50V, less than 40V, less than 30V, or less than 20V. The electrodes may be printed on a substrate using printed circuit board technology, or manufactured using thin-film transistor (TFT), active matrix, or passive matrix backplane technology. Various levels of smoothing may be preferred, from 5μm, 2μm, 1μm, 500nm, 200nm, or 100nm. The surface may be smoothed to within 1μm by polishing. The surface may be smoothed to within 1μm by applying a coating, the coating applied by at least one of spin coating, spray coating, dip coating, or vapor deposition. The surface coating may be of a material that is both dielectric and hydrophobic. The surface may be smoothed to within 1μm by application of a sheet of a polymer stretched to remove wrinkles. The slide angle may be imparted to the surface by patterning or texturing to induce hydrophobicity. The slide angle of a 5μl droplet may be no more than 5º, 3º, 2º, or 1º. A set of

CLAIMS

1. A system for processing a sample, comprising:

an array comprising (i) a first plurality of electrodes, (ii) a second plurality of electrodes, (iii) a liquid coating filling in gaps between adjacent electrodes of said first plurality of electrodes and said second plurality of electrodes, (iv) a dielectric disposed over said first plurality of electrodes, said second plurality of electrodes, and said liquid coating filling in gaps between said adjacent electrodes, and (v) a liquid layer disposed over said dielectric, wherein said liquid layer is configured to support a droplet on a surface of said liquid layer, wherein said droplet comprises said sample, wherein said liquid layer comprises a liquid that has a wetting affinity characteristic for said dielectric, wherein said liquid is immiscible with said droplet, and wherein said first plurality of electrodes and said second plurality of electrodes are configured to supply an electric field to induce said droplet to motion along a surface of said liquid layer; and

a controller operatively coupled to said first plurality of electrodes and said second plurality of electrodes, wherein said controller is configured to direct at least a subset of said first plurality of electrodes and said second plurality of electrodes to supply said electric field to alter a wetting characteristic of said surface of said liquid layer, to thereby induce said droplet to motion along said surface of said liquid layer.

2. The system of claim 1, wherein said electric field is between a subset of electrodes of said first plurality of electrodes, a subset of electrodes of said second plurality of electrodes, or between said first plurality of electrodes and said second plurality of electrodes.

3. The system of claim 1, wherein said second plurality of electrodes has a thickness of less than 10 μm.

4. The system of claim 1, wherein said surface of said liquid layer comprises one or more paths, wherein a path of said one or more paths comprises one or more tracks for motion of said droplet.

5. The system of claim 1, wherein said surface of said liquid layer is configured to support an additional droplet comprising an additional sample or a chemical sample.

6. The system of claim 1, further comprising a light source operatively coupled to said controller, wherein said controller is configured to alter said wetting characteristic of said surface of said liquid layer by directing said light source to apply light to said array.

7. The system of claim 1, further comprising one or more dispensers configured to dispense or remove said droplet to or from said surface.

8. The system of claim 1, wherein said dielectric comprises a polymeric material.

9. The system of claim 8, wherein said polymeric material is removable.

10. The system of claim 1, wherein said first plurality of electrodes and said second plurality of electrodes are coplanar.

11. The system of claim 1, wherein said first plurality of electrodes and said second plurality of electrodes are non-coplanar.

12. The system of claim 1, wherein said array further comprises one or more stations, wherein said one or more stations are selected from the group consisting of a mixing station, a temperature control station, a magnetic field station, an acoustic field station, a nucleic acid delivery station, an optical inspection station, an optical manipulation station, a droplet input station and a droplet output station.

13. The system of claim 1, wherein said dielectric has a thickness of at least 25 nanometers or at most 100 μm.

14. The system of claim 1, wherein said liquid layer comprises an upper surface, and wherein said upper surface of said liquid layer, said droplet, and a gas form a liquid-liquid-gas interface.

15. The system of claim 1, wherein said liquid layer and said dielectric form an electrical barrier between (1) said first plurality of electrodes and said second plurality of electrodes, and (2) said droplet.

16. The system of claim 1, wherein said liquid coating comprises a photoresist, epoxy, potting compound, liquid polymer, or other dielectric.

17. The system of claim 1, wherein said droplet comprises a biological sample.

18. The system of claim 1, wherein said electric field induces said droplet to motion in at least two directions along said surface of said liquid layer.

19. A method for processing a sample, comprising:

(a) providing an array comprising: (i) a first plurality of electrodes, (ii) a second plurality of electrodes, (iii) a liquid coating filling in gaps between adjacent electrodes of said first plurality of electrodes and said second plurality of electrodes, (iv) a dielectric disposed over said first plurality of electrodes, said second plurality of electrodes, and said liquid coating filling in gaps between said adjacent electrodes, and (v) a liquid layer disposed over said dielectric, wherein said liquid layer is configured to support a droplet on a surface of said liquid layer, wherein said droplet comprises said sample, wherein said liquid layer comprises a liquid that has a wetting affinity characteristic for said dielectric, and wherein said liquid is immiscible with said droplet;

(b) introducing said droplet comprising said sample on said surface of said liquid layer disposed over said dielectric; and

(c) directing at least a subset of said first plurality of electrodes and said second plurality of electrodes to supply an electric field to alter a wetting characteristic of said surface of said liquid layer, to thereby induce said droplet to motion along said surface of said liquid layer.

20. The method of claim 19, wherein altering said wetting characteristic comprises controlling charging and discharging of one or more electrodes of said first plurality of electrodes and said second plurality of electrodes in sequence.

21. The method of claim 19, wherein altering said wetting characteristic comprises applying light to said array.

22. The method of claim 19, further comprising, during or subsequent to (b), subjecting said droplet to heating, cooling, a magnetic field, a light field, acoustic energy, or mixing to manipulate said sample.

23. The method of claim 19, wherein said sample comprises a nucleic acid or a protein, and wherein subsequent to (c), said nucleic acid or protein is processed within said droplet.

24. The method of claim 19, further comprising, during or subsequent to (b), introducing an additional droplet comprising one or more additional samples over said surface.

25. The method of claim 24, further comprising merging said droplet and said additional droplet.

26. The method of claim 19, further comprising splitting said droplet.

27. The method of claim 19, further comprising replenishing said liquid layer.

28. The method of claim 19, wherein said dielectric comprises a polymeric material.

29. The method of claim 19, wherein said liquid layer and said dielectric form an electrical barrier between (1) said first plurality of electrodes and said second plurality of electrodes, and (2) said droplet.

30. The method of claim 19, wherein said liquid coating comprises a photoresist, epoxy, potting compound, liquid polymer, or other dielectric.