CLAIMS

1. A microfluidic device comprising:

a substrate having at least one electrode configured to be connected to a voltage source; a cover having at least one electrode configured to be connected to the voltage source;

and at least one spacing element,

wherein the substrate and the cover are substantially parallel to one another and joined together by the spacing element so as to define an enclosure configured to hold a liquid, wherein the substrate has a droplet actuation surface that defines, in part, the enclosure,

the droplet actuation surface having an inner dielectric layer and an outer hydrophobic layer,

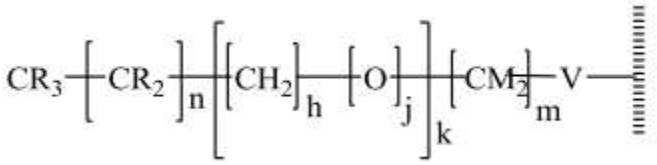
wherein the inner dielectric layer comprises a first layer of dielectric material and a second layer of dielectric material, wherein the first layer of dielectric material comprises an oxide,

wherein the first layer of dielectric material and the second layer of dielectric material are comprised of different materials;

wherein the outer hydrophobic layer comprises self-associating molecules covalently bonded to the first layer of dielectric material of the inner dielectric layer, to thereby form a densely packed hydrophobic monolayer thereon, and

wherein, when the at least one electrode of the substrate and the at least one electrode of the cover are connected to opposing terminals of the voltage source, the substrate is capable of applying an electrowetting force to aqueous droplets in contact with the droplet actuation surface of the substrate.

2. The microfluidic apparatus of claim 1, wherein the molecules of the hydrophobic monolayer each comprise a surface modifying ligand and a linking group that links the surface modifying ligand to the surface of the inner dielectric layer, wherein the droplet actuation surface has a structure of Formula II:



Formula II:

wherein  is a surface of the dielectric layer;

V is -P(O)(OY)W- or -Si(OZ)$_2$W-;

W is -O-, -S-, or -NH- and connects to the surface;

Z is a bond to an adjacent silicon atom attached to the surface or is a bond to the surface;

Y is a bond to an adjacent phosphorus atom attached to the surface or is a bond to the surface;

R is hydrogen or fluorine;

M is hydrogen or fluorine;

h is independently an integer of 2 or 3;

j is 1;

k is 0 or 1;

m is 0 or an integer of 1 to 20

n is 0 or an integer of 1 to 20;

the sum of $(n + [(h + j)\cdot k] + m)$ is an integer of 11 to 25;

when k is 1, then m is at least 2 and M is hydrogen; and

when k is 0 and R is fluorine, then m is at least 2 and M is hydrogen.

3. The microfluidic device of claim 2, wherein V is $-Si(OZ)_2W-$.

4. The microfluidic device of claim 2 or 3, wherein n is an integer of 1 to 20, and wherein R is hydrogen.

5. The microfluidic device of claim 4, wherein m is 2, and wherein M is hydrogen.

6. The microfluidic device of any one of claims 2 to 5, wherein n is an integer of 1 to 20, and wherein R is fluorine.

7. The microfluidic device of claim 6, wherein m is 2, and wherein M is hydrogen.

8. The microfluidic device of claim 2, wherein k is 0.

9. The microfluidic device of claim 2, wherein the sum of $(n + [(h + j)\cdot k] + m)$ is an integer of 13 to 19.

10. The microfluidic device of claim 1, wherein the oxide is a metal oxide.

11. The microfluidic device of claim 10, wherein the second layer of dielectric material is selected from the group consisting of silicon dioxide and silicon nitride.

12. The microfluidic device of claim 1, wherein the first layer of dielectric material comprises first and second sublayers of dielectric materials, wherein the first sublayer is covalently bonded to the hydrophobic layer.

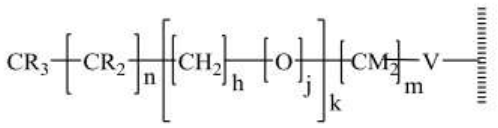
13. The microfluidic device of claim 1, wherein the inner dielectric layer of the droplet actuation surface of the substrate has a thickness of about 40 nanometers to about 120 nanometers.

14. The microfluidic device of claim 1, wherein the substrate further comprises a photoresponsive layer having a first side that contacts the inner dielectric layer and a second side that contacts the at least one electrode.

15. The microfluidic device of claim 1, wherein the substrate comprises a plurality of electrodes, each electrode configured to be connected to one or more AC voltage source(s), and wherein each electrode of the plurality is connectable to one of the one or more AC voltage source(s) via a transistor switch.

16. The microfluidic device of claim 1, wherein the cover has an inward-facing surface that defines, in part, the enclosure, the inward-facing surface of the cover having an inner layer and an outer hydrophobic layer, wherein the outer hydrophobic layer of the cover comprises molecules covalently bonded to a surface of the inner layer of the cover, to thereby form a densely packed hydrophobic monolayer thereon.

17. The microfluidic device of claim 16, wherein the molecules of the hydrophobic monolayer of the cover each comprise a surface modifying ligand and a linking group that links the surface modifying ligand to the surface of the inner layer of the cover, wherein the inward-facing surface of the cover has a structure of Formula II:



Formula II:

wherein  is a surface of the inner layer; V

is -P(O)(OY)W- or -Si(OZ)$_2$W-;

W is -O-, -S-, or -NH- and connects to the surface of the inner layer;

Z is a bond to an adjacent silicon atom attached to the surface of the inner layer or is a bond to the surface of the inner layer;

Y is a bond to an adjacent phosphorus atom attached to the surface of the inner layer or is a bond to the surface of the inner layer;

R is hydrogen or fluorine;

M is hydrogen or fluorine;

h is independently an integer of 2 or 3;

j is 1;

k is 0 or 1;

m is 0 or an integer of 1 to 20

n is 0 or an integer of 1 to 20;

the sum of (n + [(h + j)·k] + m) is an integer of 11 to 25;

when k is 1, then m is at least 2 and M is hydrogen; and

when k is 0 and R is fluorine, then m is at least 2 and M is hydrogen.

18. The microfluidic device of claim 17, wherein the molecules of the hydrophobic monolayer of the cover are the same as the molecules of the hydrophobic monolayer of the droplet actuation surface of the substrate.

19. The microfluidic device of claim 1, wherein the at least one spacing element defines one or more microchannels and a plurality of chambers within the enclosure, wherein each chamber opens off of at least one microchannel.

20. The microfluidic device of any one of claims 1-19, wherein the substrate having the droplet actuation surface comprises a first section of the device and wherein the device further comprises a second section having a dielectrophoresis (DEP) configuration.

21. The microfluidic device of claim 20, wherein the microfluidic device having the first section comprising the substrate having the droplet actuation surface and the second section comprising the DEP configuration is monolithic.

22. A system for transporting micro-objects, biological products, and/or reagents that are compatible with and/or soluble in aqueous media, the system comprising:

a microfluidic device having an enclosure comprising a base and a microfluidic circuit structure, wherein the base comprises a hydrophobic monolayer covalently bonded to at least a portion of an upper surface of the base;

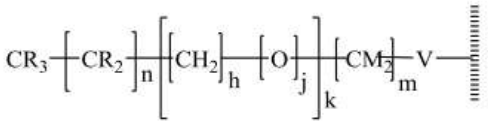
a first fluidic medium that is immiscible with aqueous media; and

at least one aqueous droplet;

wherein the microfluidic device is a microfluidic device according

to any one of claims 1 to 21.

23. The system of claim 22, wherein the hydrophobic monolayer has a surface modifying ligand and a linking group that links the surface modifying ligand to the surface, wherein the hydrophobic surface has a structure of Formula II:



Formula II

wherein  is the surface;

V is -P(O)(OY)W- or -Si(OZ)2W-;

W is -O-, -S-, or -NH- and connects to the surface;

Z is a bond to an adjacent silicon atom attached to the surface or is a bond to the surface;

Y is a bond to an adjacent phosphorus atom attached to the surface or is a bond to the surface;

R is hydrogen or fluorine;

M is hydrogen or fluorine;

h is independently an integer of 2 or 3; j

is 1;

k is 0 or 1;

m is 0 or an integer of 1 to 20

n is 0 or an integer of 1 to 20;

the sum of (n + [(h + j)·k] + m) is an integer of 11 to 25;

when k is 1, then m is at least 2 and M is hydrogen; and

when k is 0 and R is fluorine, then m is at least 2 and M is hydrogen.

24. The system of claim 22 or 23, wherein the microfluidic device is a microfluidic device according to any one of claims 1 to 21.

25. The system of any one of claims 22 to 24, wherein the first fluidic medium comprises one or more acyclic organic or organosilicon compounds.

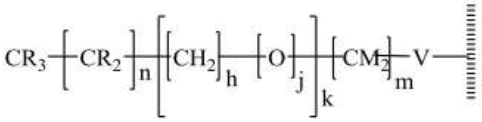
26. A kit for transporting micro-objects, biological products, and/or reagents that are compatible with and/or soluble in aqueous media, the kit comprising:

a microfluidic device having an enclosure comprising a base and a microfluidic circuit structure, wherein the base comprises a hydrophobic monolayer covalently bonded to at least a portion of an upper surface of the base; and

a first fluidic medium that is immiscible with aqueous media;

wherein the microfluidic device is a microfluidic device according to any one of claims 1 to 21.

27. The kit of claim 26, wherein the hydrophobic monolayer has a surface modifying ligand and a linking group that links the surface modifying ligand to the surface, wherein the hydrophobic surface has a structure of Formula II:



Formula II

wherein  is the surface;

V is -P(O)(OY)W- or -Si(OZ)2W-;

W is -O-, -S-, or -NH- and connects to the surface;

Z is a bond to an adjacent silicon atom attached to the surface or is a bond to the surface;

Y is a bond to an adjacent phosphorus atom attached to the surface or is a bond to the surface;

R is hydrogen or fluorine;

M is hydrogen or fluorine;

h is independently an integer of 2 or 3;

j is 1;

k is 0 or 1;

m is 0 or an integer of 1 to 20

n is 0 or an integer of 1 to 20;

the sum of $(n + [(h + j)\cdot k] + m)$ is an integer of 11 to 25;

when k is 1, then m is at least 2 and M is hydrogen; and

when k is 0 and R is fluorine, then m is at least 2 and M is hydrogen.

28. The kit of claim 26, wherein the base comprises a conductive substrate.

29. The kit of any one of claims 26 to 28, wherein the first fluidic medium comprises one or more acyclic organic or organosilicon compounds.

30. The kit of any one of claims 26 to 29, further comprising a non-ionic surfactant.

31. A process of operating the microfluidic device of any one of claims 1 to 21, the process comprising:

filling the enclosure, or a portion thereof, with a first liquid medium;

applying an AC voltage potential between the at least one electrode of the substrate and the at least one electrode of the cover;

introducing a first droplet of liquid into the enclosure, wherein the first droplet is immiscible in the first liquid medium; and

moving the first droplet to a desired location within the enclosure by applying an electrowetting force to the first droplet.

32. The process of claim 31, wherein the applied AC voltage potential is between about 25 and 35 ppV.

33. The process of claim 31, wherein the applied AC voltage potential has a frequency of about 1 to 100 kHz.