

CLAIMS

1. A spectrometer configured to determine an identity of analyte particles in solution, the spectrometer comprising:
 - a circular-shaped or partially-center-symmetric electrode configured to be placed in an AC electric field;
 - a controller configured to switch at least one property of the AC electric field from a first condition to a second condition, wherein when the AC electric field is in the first condition, the analyte particles are trapped in a first AC kinetic trap on the electrode and wherein when the AC electric field is in the second condition, the analyte particles trapped in a second AC kinetic trap on the electrode;
 - a detector configured to determine at least one motion characteristic of the analyte particles from the first AC kinetic trap to the second AC kinetic trap in response to switching the at least one property of the AC electric field; and
 - at least one processor programmed to determine an identity of the analyte particles based, at least in part, on the determined at least one motion characteristic.
2. The spectrometer of claim 1, wherein the at least one property comprises the frequency of the AC electric field.
3. The spectrometer of claim 1 or 2, wherein the at least one property comprises the amplitude of the AC electric field.
4. The spectrometer of any of the preceding claims, wherein the first AC kinetic trap is an electroosmosis trap and the second AC kinetic trap is a dielectrophoresis trap.
5. The spectrometer of claim 4, wherein the electroosmosis trap is located at a center of the electrode and the dielectrophoresis trap is located at an edge of the electrode.
6. The spectrometer of any of the preceding claims, wherein determining an identity of the analyte particles comprises:
 - comparing the determined at least one motion characteristic to each of a plurality of stored analyte particle motion characteristics; and

determining the identity of the analyte particles based, at least, in part on the comparisons.

7. The spectrometer of any of the preceding claims, wherein the detector is an optical detector.
8. The spectrometer of any of the preceding claims, further comprising:
a filtering stage configured to filter the analyte particles from other components in the solution to produce a filtered solution, and
wherein the electrode is arranged to trap the analyte particles in the filtered solution.
9. The spectrometer of claim 8, wherein the other components in the solution are blood cells.
10. The spectrometer of any of the preceding claims, wherein the analyte particles are viruses or bacteria.
11. The spectrometer of any of the preceding claims, wherein the electrode is configured to restrict motion of the analyte particles along the surface of the electrode.
12. The spectrometer of any of the preceding claims, wherein the at least one motion characteristic is a motion trajectory.
13. The spectrometer of any of the preceding claims, wherein the at least one motion characteristic is an amount of time that the analyte particles take to travel from the first AC kinetic trap to the second AC kinetic trap in response to the switching of the at least one property of the AC electric field.
14. A method of determining an identity of analyte particles in a solution, the method comprising:
placing a spiral-shaped or partially-center symmetric electrode in an AC electric field;

switching at least one property of the AC electric field from a first condition to a second condition, wherein when the AC electric field is in the first condition, the analyte particles are trapped in a first AC kinetic trap on the electrode and wherein when the AC electric field is in the second condition, the analyte particles trapped in a second AC kinetic trap on the electrode;

determining at least one motion characteristic of the analyte particles from the first AC kinetic trap to the second AC kinetic trap in response to switching the at least one property of the AC electric field; and

determining an identity of the analyte particles based, at least in part, on the determined at least one motion characteristic.

15. The method of claim 14, wherein switching the at least one property comprises switching the frequency of the AC electric field.

16. The method of claim 14 or 15, wherein switching the at least one property comprises switching the amplitude of the AC electric field.

17. The method of any of the claims 14-16, wherein determining an identity of the analyte particles comprises:

comparing the determined at least one motion characteristic to each of a plurality of stored analyte particle motion characteristics; and

determining the identity of the analyte particles based, at least, in part on the comparisons.

18. The method of any of claims 14-17, wherein determining at least one motion characteristic of the analyte particles comprises determining the at least one motion characteristic using an optical detector.

19. The method of any of claims 14-18, further comprising:

filtering the analyte particles from other components in the solution to produce a filtered solution, and

wherein determining at least one motion characteristic of the analyte particles from the first AC kinetic trap to the second AC kinetic trap in response to switching the at least one

property of the AC electric field comprises determining the at least one motion characteristic of the analyte particles in the filtered solution.

20. The method of any of claims 14-19, wherein determining the at least one motion characteristic comprises determining a motion trajectory.

21. The method of any of claims 14-20, wherein determining the at least one motion characteristic comprises determining an amount of time that the analyte particles take to travel from the first AC kinetic trap to the second AC kinetic trap in response to the switching of the at least one property of the AC electric field.

22. An apparatus, comprising
at least one electrode configured to be placed in an AC electric field; and
a controller configured to control at least one characteristic of the AC electric field to identify, based on dynamics of induced motion, analyte particles in a solution located adjacent to the at least one electrode.

23. In a microfluidic device including a microfluidic chamber adapted for filtering and analyzing analytes from entities to be eliminated from analysis, said device comprising dielectrophoresis (DEP) and/or electroosmosis (EO) electrodes, a method for highly selective filtration, the method comprising:

compiling data including a Clausius-Mossotti (CM) factor as a function of frequency and conductivity for said analytes and said entities to be eliminated;

for each entity to be eliminated,

identifying, based on the data, a frequency and conductivity having a largest difference for said CM factor for said analyte and said CM factor for said entity to be eliminated;

filtering said entity to be eliminated by introducing a solution of the identified conductivity and by imposing an electric field of the identified frequency so as to separate said entity to be eliminated;

wherein separation for each entity to be eliminated is used to achieve said highly selective filtration.

24. The method of claim 23, further comprising employing electroosmosis.
25. The method of claim 23 or 24, further comprising, communicating diagnostic information concerning said analyte identities and concentrations to a smartphone or other network-connected device.
26. The method of any of claims 23-25, wherein the analytes comprise antibodies and/or viruses.
27. The method of any of claims 23-26, further comprising storing in a database, information concerning said analyte identities and concentrations for purposes of diagnosing and tracking said analytes, and quantifying response of analytes to antibodies.
28. The method of any of claims 23-27, wherein the microfluidic device is adapted for use inline for detection of analytes and/or toxins.
29. The method of any of claims 23-27, wherein the microfluidic device is adapted for detection of sulfur-reducing bacteria or other bacteria which change their response to the electric field based on response to chemicals.
30. The method of any of claims 23-27, wherein the microfluidic device is adapted for use in capturing and/or separating analytes from samples made in a bioreactor.
31. A device for capture, separation, and/or filtering of analytes in a fluid sample containing said analytes and entities to be eliminated, the device comprising:
- a pump configured to force said fluid sample past a dielectrophoresis (DEP) filter or an electroosmosis (EO) filter, said filter comprising electrodes adapted to produce a force or motion on said analytes that is different than the force on said entities to be eliminated;
 - a concentrating electrode adapted to attract said analytes after filtration and hold them while said pump replaces said solution with a buffer solution;

a microwire field effect transistor (FET) comprising a source, a drain, and a microwire connecting the source and the drain, wherein the source, the drain, and the microwire are disposed on an insulating substrate formed on a semiconducting bottom gate layer; and secondary electrodes arranged adjacent to said microwire FET and being adapted to attract said analytes to contact said microwire.

32. The device of claim 31, wherein said secondary electrodes are selected from the group consisting of interdigitating circular electrodes and strip electrodes disposed parallel to said microwire and resting on said insulating substrate.

33. The device of claim 31 or 32, further comprising a component configured to employ electroosmosis.

34. The device of any of claims 31-33, further comprising a network interface configured to communicate information concerning said analyte identities and concentrations to a smartphone or other network-connected device.

35. The device of any of claims 31-34, wherein the analytes comprise antibodies and/or viruses.

36. The device of any of claims 31-35, further comprising a database configured to store information concerning said analyte identities and concentrations for purposes of diagnosing and tracking said analytes, and quantifying response of analytes to antibodies or an applied electric field.

37. The device of any of claims 31-36, wherein the device is adapted for use inline in an IV or in a streamlined inline process or as a smart sensor for detection or separation of analytes and/or toxins.

38. The device of any of claims 31-36, wherein the device is adapted for detection of sulfur-reducing bacteria or any bacteria and or other analytes which respond to chemicals.

39. A method for selective functionalization of a microwire field effect transistor (FET) array, wherein each FET in the microwire FET array includes a source, a drain, and a microwire connecting the source and the drain, the method comprising:

- (a) coating said microwire FET array with a passivating layer;
- (b) applying an electric field of sufficient intensity to sources and drains of a subset of the FETs in said FET array so as to overcome a breakdown voltage of said passivating layer, thereby removing said passivating layer from said subset of said FET array;
- (c) introducing a solution containing a functionalizing element onto said microwire FET array, allowing said solution to contact the microwires of the FETs in said subset while all microwires of the FETs not in said subset remain protected by said passivating layer, and flushing said solution; and
- (d) repeating acts (b) and (c) for each subset of FETs in said FET array requiring a different functional layer;

wherein a set of differently functionalized FET microwires are obtained without requiring micropositioning.

40. A method for selective functionalization of a microwire field effect transistor (FET) array in contact with individually addressable dielectrophoresis (DEP) electrodes, wherein each FET in the microwire FET array includes a source, a drain, and a microwire connecting the source and the drain, the method comprising:

- (a) activating a subset of said DEP/EO electrodes;
- (b) introducing a solution containing a functionalizing element onto said array so as to allow said solution to contact the microwires of the FETs in contact with said subset;
- (c) flushing said solution; and
- (d) repeating acts (b) and (c) for each subset of FETs of said FET array requiring a different functional layer;

wherein a set of differently functionalized FET microwires are obtained without requiring micropositioning.

41. A method of analyte detection, the method comprising:

- providing a test sample including an analyte together with a waste product;
- providing at least one reference solution;

transporting said test sample through a plurality of microfluidic channels;
generating dielectrophoretic forces on said test sample as said test sample is transported through said plurality of microfluidic channels;
separating said waste product from said analyte by said dielectrophoretic forces;
directing said waste product away from said analyte;
directing said analyte to a condensing area;
condensing said analyte in a localized area;
flushing said analyte with said reference solution to remove substantially all of remaining waste product from said condensed analyte; and
detecting low amounts of analyte using a microfluidic sensor.

42. The method of claim 41, further comprising: manipulating using dielectrophoresis, said analyte to said microfluidic sensor to overcome a diffusion limitation and enable analyte contact with said microfluidic sensor surface for detection.

43. The method of claim 41 or 42, further comprising:
introducing a pharmaceutical or other substance which pierces, intersects or modifies membranes of an alive analyte component in said reference solution at a predetermined frequency, wherein the pharmaceutical or other substance does not pierce membranes of other analyte components or dead analyte components; and
differentiating said alive component from other analyte components and dead analyte components through dielectrophoretic forces.

44. The method of any of claims 41-43, further comprising using a change of a Clausius-Mossotti factor, $CM(\omega)$, upon a change of a medium permittivity, ϵ_m , for analyte capture and release.

45. The method of claim 44, wherein said capture includes:
applying an electric field causing a first dielectrophoretic force to said analyte to facilitate analyte capture;
changing said Clausius-Mossotti factor by said flushing; and

causing a second dielectrophoretic force under said electric field acting on said analyte with said changed Clausius-Mossotti factor to facilitate release of said analyte.

46. The method of claim 45, further comprising adjusting a pH or conductivity of said test sample for control of voltage and frequency dependence for said Clausius-Mossotti factor cross-over frequency.

47. The method of claim 45, further comprising inducing change of said Clausius-Mossotti factor cross-over frequency for said analyte by adding or mixing an additional fluid.

48. The method of claim 45, further comprising tuning said electric field to said analyte such that said analyte is isolated by said dielectrophoretic force.

49. The method of claim 41, wherein separating said waste product from said analyte comprises:

providing a microfluidic assembly including a plurality of microfluidic channels forming an array, each of said micro fluidic channels including:

electrodes for establishing dielectrophoretic forces on said test sample separating said portions of said test sample into said analyte and said waste product; and

adjacent microchannels for receiving said waste product attracted by a dielectrophoretic force, removing said waste product from said analyte;

transporting said analyte to said condenser area; and

localizing said analyte at said condenser area by a condenser electrode.

50. The method of claim 41, wherein detecting low amounts of analyte using a microfluidic sensor includes using an electric field at predetermined flow conditions to immobilize said analyte on a nanowire or nanoribbon sensor surface.

51. The method of claim 41, further comprising superpositioning or tuning of frequency components, waveform shapes, and waveform tunings, or any combination thereof, to maximize separation, differentiation, capture, or release of said analyte.

52. The method of claim 41, wherein said dielectrophoretic forces include at least two opposing forces.
53. An apparatus for analyte detection comprising:
a first chamber configured to store a reference solution;
a pump configured to pump a test sample and said reference solution;
at least one injection chamber configured to introduce said reference solution and said test sample to a microfluidic separator;
said microfluidic separator separating said product to be analyzed from microscaled components, said microfluidic separator including at least one microfluidic channel, said microfluidic channel including:
electrodes for producing a force on said test sample when said test sample is pumped through said at least one microfluidic channel to separate said product to be analyzed from said microscaled components; and
at least one channel for transporting said microscaled components away from said product to be analyzed.
54. The apparatus of claim 53, wherein said electrodes produce a dielectrophoretic force on said test sample.
55. The apparatus of claim 53, wherein said electrodes produce a differentiating force on said test sample.
56. The apparatus of any of claims 53-55, further comprising a second chamber configured to store said microscaled components when separated from said product to be analyzed by said at least one microfluidic channel.
57. The apparatus of any of claims 53-56, further comprising:
a condenser for capturing said product to be analyzed once said product has passed through said at least one microfluidic channel and is substantially separated from said microscaled components; and
a sensor for detecting said product to be analyzed.

58. A filtration system for analyte detection comprising:
microchannels for fluid transport;
a dielectrophoretic separator for separating said fluid into constituent components;
a dielectrophoretic condenser for condensing at least one constituent component of said fluid;
a dielectrophoretic transport module; and
a field effect based sensor, nanowire sensor, nanoribbon sensor, or ion sensitive field effect transistor, or any combination thereof, for detecting said at least one constituent component of said fluid.
59. The filtration system of claim 58, wherein said dielectrophoretic separator includes a parallel multichannel structure having a plurality of microfluidic channels in multiple stacked layers, and branched with waste channels.
60. A fluidic device that captures and/or separates analytes from unwanted components in a fluid at an efficiency greater than 80% or 90% or at approximately 100% in less than 1 minute, less than 30 seconds, less than 15 seconds, or less than 1 second.
61. The fluidic device of claim 60, wherein said analyte is a pathogen.
62. The fluidic device of claim 60, wherein said analyte is bacteria, viruses, blood components, or proteins.
63. The fluidic device of claim 60, wherein the device is used for detection of the said analyte.
64. The fluidic device of any of claims 60-63, wherein the device is configured for use as a point-of-care diagnostic device.
65. The fluidic device of any of claims 60-64, wherein said fluid is blood.

66. The fluidic device of any of claims 60-64, wherein said fluid is water, a drug, a protein matrix, or a microbiome sample.

67. The fluidic device of any of claims 60-64, wherein said fluid is urine, another body fluid, or a protein or cell matrix.

68. The device of claim 60, where the analytes are separated from the unwanted components in the fluid by a force arising from an AC electric field in the fluid as the fluid transverses one or more channels.

69. The device of claim 68, wherein the AC electric field has a frequency between 300 Hz and 400MHz.

70. The device of claim 68 or 69, where the one or more channels are less than or approximately 100 μ m.

71. The fluidic device of any of claims 68-70, where the one or more channels have at least one electrode on a wall of a chamber for delivering force to either the analyte, the fluid, or both as they traverse the channels.

72. A fluidic device that separates particles from unwanted components in a fluid by a force on the particles and/or the unwanted components in the fluid arising from an AC electric field in the fluid as the fluid transverses a channel where the frequency of the AC field has at least two independent frequencies.

73. A fluidic device that separates particles from unwanted components in a fluid by a force on the particles and/or the unwanted components in the fluid arising from an AC electric field in the fluid as the fluid transverses one or more channels,

wherein the AC electric field is applied by a plurality of electrodes for delivering force to the particles or the unwanted components as the fluid traverses the one or more channels,

and wherein the electrodes are configured as an arc, a ring, or a circle,

and wherein the arc, ring, or circle has approximately a constant radius of curvature.

74. The fluidic device of claim 73, wherein the fluidic device separates the particles with an efficiency greater than 80% or 90% or at approximately 100% in less than 1 minute, less than 30 seconds, less than 15 seconds, or less than one second.

75. The fluidic device of claim 73 or 74, wherein the one or more channels are less than or approximately 100 μm .

76. The fluidic device of claim any of claims 73-75, wherein the electrodes are configured as a plurality of concentric arcs, rings, or circles, electrically connected to a voltage source such that when voltage is applied to at least one electrode, said arcs, rings, or circles alternate in voltage potential, wherein a first set of arcs, rings, or circles is configured to be held at a first voltage potential and a second set of arcs, rings, or circles is configured to be held at a second voltage potential, said first voltage potential being different from said second voltage potential in magnitude, phase, polarity, or any combination thereof.

77. The fluidic device of claim 76, wherein the plurality of concentric rings or concentric arcs extend radially outwards from a center point.

78. The fluidic device of any of claims 73-77, wherein said fluid is water, a drug, a protein matrix, or a microbiome sample.

79. The fluidic device of claim 78, wherein the device is used for detection of an analyte in said water, a drug, a protein matrix, or a microbiome sample.

80. In a microfluidic device adapted for filtering and analyzing microorganisms from an entity to be eliminated, said device comprising dielectrophoresis (DEP) and/or electroosmosis (EO) electrodes, a method for highly selective filtration, the method comprising:

identifying a frequency and conductivity having a difference for a Clausius-Mossotti (CM) factor for said microorganisms and a CM factor for said entity to be eliminated; and

filtering said entity to be eliminated by introducing a solution of the identified conductivity and by imposing an electric field having the identified frequency so as to separate said entity to be eliminated from said microorganisms.

81. A detection method comprising:
transporting a test sample including an analyte and a waste product through a plurality of microfluidic channels;
generating dielectrophoretic forces on said test sample as said test sample is transported through said plurality of microfluidic channels to separate said waste product from said analyte;
directing said waste product away from said analyte;
condensing said analyte;
flushing said condensed analyte with a reference solution to remove substantially all remaining waste product from said condensed analyte; and
analyzing, with a microfluidic sensor, the condensed analyte to detect the analyte.

82. A filtration system for analyte detection comprising:
a dielectrophoretic separator comprising at least one channel, wherein the dielectrophoretic separator is configured to separate constituent components of a fluid using dielectrophoresis as the fluid flows through the at least one channel;
a dielectrophoretic condenser configured to condense at least one constituent component separated from said fluid by said dielectrophoretic separator;
a dielectrophoretic transport module configured to transport the condensed at least one constituent component; and
a field effect based sensor, nanowire sensor, nanoribbon sensor, or ion sensitive field effect transistor, or any combination thereof, configured to receive the condensed at least one constituent component from the dielectrophoretic transport module and detect said at least one constituent component.

83. A method of detecting the presence of an analyte in a sample, the method comprising:
monitoring a change in a noise levels or a change in a noise spectrum of a detected signal between a first signal when the analyte is not in close proximity to a sensor and a second signal when the analyte is in close proximity to the sensor.

84. The method of claim 83, wherein a surface of the surface is coated with a substance sensitive to the analyte or a family of analytes in which the analyte is included.
85. A method of modulating a gate of an Ion-Sensitive Field Effect Transistor or a capacitive sensor, the method comprising bringing an analyte particle in contact with an electrode edge.
86. A method of signal modulation, the method comprising performing signal modulation based on analyte contact with an electrode edge.
87. A device, comprising:
An electrode configured to be placed in an AC electric field, the electrode configured to operate as a virtual valve by preventing, using an AC kinetic trap, an analyte in solution flowing past the electrode from continuing past the electrode.
88. An apparatus, comprising:
at least one electrode configured to be placed in an AC electric field; and
a controller configured to control at least one characteristic of the AC electric field to identify, without the use of labels, analyte particles in a solution located adjacent to the at least one electrode.