~~LIQUID~~ FLUID DELIVERY SYSTEM

[0001] The present application claims priority from U.S. Provisional Patent Application Serial No. 62/318,202, filed April 4, 2016, entitled "LIQUID DELIVERY SYSTEM" by Chris Melcer et al., which is incorporated by reference herein in its entirety.

Technical Field of the Invention

[0002] The present invention is directed to liquid chemical delivery systems, and more particularly to a modular tubeless liquid chemical delivery systems having a substantially reduced footprint.

Background of the Invention

[0003] Liquid delivery and distribution systems are used in a variety of applications, including the manufacture of semiconductor devices, the manufacture of pharmaceutical compounds, etc. For example, semiconductor wafers are subjected to various liquid treatment processes such as etching, cleaning, polishing, drying and material deposition during their manufacturing process. Semiconductor substrate processing generally requires that liquid chemicals must be delivered in precise amounts on demand, be free of bubbles, be of a uniform thickness on the usable part of the substrate and minimize chemical waste due to cost and environmental concerns.

[0004] Various types of liquid delivery systems are used to deliver liquid chemicals from supply sources to processes using various types of active components such as flow controllers, pressure transducers, flow measurement sensors, pressure regulators, valves, etc. In many of these applications, the size of the liquid chemical distribution system can dramatically affect costs. For example, in the manufacture of semiconductor devices, it is typical for the liquid distribution system or certain portions thereof to be housed in an ultra-clean environment, such as a clean room. Further, because many of the liquid used in the manufacture of semiconductors are toxic, highly reactive, or both, such liquid distribution systems frequently require specialized containment and venting equipment. For such systems, any decrease in the size of the fluid distribution system is advantageous.

Summary of the Invention

[0005] According to embodiments of the present invention, a modular system for enabling a distribution of liquid chemicals is provided. The system comprises a substrate block that includes at least two ports formed in a first major surface of the block and a fluid

CLAIMS

1. A fluid delivery system comprising:

a back plane;

a first substrate block mounted to an upper surface of the back plane, the first substrate block comprising:

an a first upper surface;

a first inlet substrate port in the first upper surface;

a first outlet second substrate port in the first upper surface;

a first substrate fluid passageway extending between the first inlet substrate port and the first outlet second substrate port;

each of the first outlet substrate port and the first inlet substrate port defined by a first substrate ring defining the second substrate port; and

for each of the first outlet substrate port and the first inlet substrate port, a first substrate seal channel formed in the first upper surface and surrounding the first substrate ring, an outer surface of the first substrate ring forming an inner surface of the first substrate seal channel;

a second substrate block mounted to the upper surface of the back plane, the second substrate block comprising:

a second upper surface;

a second inlet substrate port in the second upper surface;

a second outlet substrate port in the second upper surface;

a second substrate fluid passageway extending between the second inlet substrate port and the second outlet substrate port;

each of the second outlet substrate port and the second inlet substrate port defined by a second substrate ring; and

for each of the second outlet substrate port and the second inlet substrate port, a second substrate channel formed in the second upper surface and

surrounding the second substrate ring, an outer surface of the second substrate ring forming an inner surface of the second substrate channel;

an active component selected from the group consisting of a flow controller, a pressure transducer, a flow measurement sensor, a pressure regulator, a valve, and a flow meter, the active component comprising:

a lower surface;

a ~~first~~ component inlet port in the lower surface;

a component outlet port in the lower surface;

a component fluid passageway extending from the ~~first~~ component inlet port to the component outlet port;

each of the component inlet port and the component outlet port defined by a component ring ~~defining the first component port~~; and

for each of the component inlet port and the component outlet port, a component ~~seal~~ channel formed in the lower surface of the active component and surrounding the component ring, an outer surface of the component ring forming an inner surface of the component ~~seal~~ channel;

~~a seal ring~~ first and second seal rings, each of the first and second seal rings comprising:

an interior sleeve defining a sleeve fluid passageway extending along a longitudinal axis;

an outer ring connected to and surrounding the interior sleeve so that: (1) an annular upper sleeve groove is formed between an upper portion of the outer ring and an upper portion of the interior sleeve; and (2) an annular lower sleeve groove is formed between a lower portion of the outer ring and a lower portion of the interior sleeve;

the active component mounted to and bridging the first and second substrate blocks so that: (1) the ~~second~~ first outlet substrate port and the ~~first~~ component inlet port are aligned~~;~~ and ~~(2)~~ the first seal ring nests in each of the first substrate ~~seal~~ channel of the first outlet substrate port and the component ~~seal~~ channel of the component inlet port, ~~and~~ the first seal ring fluidly ~~seals~~ sealing the first substrate fluid passageway and the component fluid passageway; (2) the second inlet substrate port and the component outlet port are aligned and the second seal ring

nests in each of the second substrate channel of the second inlet port and the component channel of the component outlet port, the second seal ring fluidly sealing the second substrate fluid passageway and the component fluid passageway; and (3) the active component is spaced and isolated from the back plane.

2. The fluid delivery system of claim 1 wherein the first substrate ring extends into the annular lower sleeve groove of the first seal ring and the component ring extends into the annular upper sleeve groove of the first seal ring; and wherein the upper portion of the outer ring of the first seal ring extends into the ~~annular~~ component channel and the lower portion of the outer ring of the first seal ring extends into the first ~~annular~~ substrate channel.

3. The fluid delivery system of claim 2 further comprising:

the first upper surface of the first substrate block and the lower surface of the active component forming a horizontal interface;

the first seal ring sized so that: (1) the outer ring of the first seal ring is horizontally compressed within each of the component ~~seal~~ channel and the first substrate ~~seal~~ channel; and (2) the outer ring of the first seal ring is under no vertical compression.

4. The fluid delivery system of claim 3 further comprising:

the first seal ring further comprising a web connecting the interior sleeve and outer ring, the web disposed between the component ring and the first substrate ring;

the first seal ring sized so that the web is under no vertical compression.

5. The fluid delivery system of claim 1 further comprising:

the first seal ring being bilaterally symmetric about a central plane and the sleeve fluid passageway extending along a central axis;

the upper portion of the interior sleeve having an outer surface comprising an outwardly sloped portion; and

the lower portion of the interior sleeve having an outer surface comprising an outwardly sloped portion.

6. The fluid delivery system of claim 5 wherein the interior sleeve of the first seal ~~sleeve~~ ring has no horizontal surface.

7. The fluid delivery system of claim 5 further comprising:

the upper portion of the interior sleeve having an inner surface comprising an inwardly sloped portion;

the lower portion of the interior sleeve having an inner surface comprising an inwardly sloped portion.

8. The fluid delivery system of claim 5 wherein the first seal ring is sized so that the component ring exerts an interference force on the outwardly sloped portion of the upper portion of the interior sleeve and the first substrate ring exerts an interference force on the outwardly sloped portion of the lower portion of the interior sleeve.

9. The fluid delivery system of claim 1 further comprising:

the upper portion of the interior sleeve of the first seal ring having an outer surface comprising an outwardly sloped portion;

the lower portion of the interior sleeve of the first seal ring having an outer surface comprising an outwardly sloped portion;

the component ring comprising an inner surface having an inwardly sloped portion that mates with the outwardly sloped portion of the upper portion of the interior sleeve of the first seal ~~sleeve~~ ring; and

the first substrate ring comprising an inner surface having an inwardly sloped portion that mates with the outwardly sloped portion of the lower portion of the interior sleeve of the first seal ~~sleeve~~ ring.

10. The fluid delivery system of claim 1 further comprising a plurality of fasteners extending through a base of the ~~activate~~ active component and into ~~to~~ the first substrate block to mount the active component to the first substrate block.

11. The fluid delivery system of claim 1 ~~further comprising:~~ wherein the first substrate block is attached to the back plane, the first substrate block remaining fixed to the back plane when the active component is removed.

~~a plurality of the substrate blocks mounted to a back plane; and~~

~~a plurality of the active components mounted to the plurality of substrate blocks to form one or more fluid pathways for processing semiconductors, each of the plurality of the active~~

~~components fluidly coupled to the first substrate port of a first one of the plurality of substrate blocks and the second substrate port of an adjacent one of the plurality of substrate blocks.~~

12. The fluid delivery system according to claim 1 wherein the first substrate block, the second substrate block, the first seal ring, and the second seal ring are formed of fluoropolymers.

13~~12~~. A fluid delivery system comprising:

a back plane;

a first substrate block mounted to an upper surface of the back plane, the first substrate block comprising:

~~an~~ a first upper surface;

a first inlet substrate port in the first upper surface;

a ~~second~~ first outlet substrate port in the first upper surface; and~~;~~

a first substrate fluid passageway extending between the first inlet substrate port and the ~~second~~ first outlet substrate port;

a second substrate block mounted to the upper surface of the back plane, the second substrate block comprising:

a second upper surface;

a second inlet substrate port in the second upper surface;

a second outlet substrate port in the second upper surface;

a second substrate fluid passageway extending between the second inlet substrate port and the second outlet substrate port;

an active component selected from the group consisting of a flow controller, a pressure transducer, a flow measurement sensor, a pressure regulator, a valve, and a flow meter, the active component comprising:

a lower surface;

a ~~first~~ component inlet port in the lower surface;

a component outlet port in the lower surface; and

a component fluid passageway extending from the ~~first~~ component inlet port to the component outlet port;

~~a seal ring~~ first and second seal rings, each of the first and second seal rings having an interior sleeve and an outer ring;

the active component mounted to and bridging the first and second substrate blocks so that: (1) the ~~second~~ first outlet substrate port and the ~~first~~ component inlet port are aligned and a horizontal interface is formed between the first upper surface and the lower surface,~~;~~ ~~(2)~~ the first seal ring surrounds each of the ~~second~~ first outlet substrate port and the ~~first~~ component inlet port and fluidly seals the first substrate fluid passageway and the component fluid passageway, the first seal ring sized so that the outer ring of the first seal ring is horizontally compressed and under no vertical interference; (2) the second inlet substrate port and the component outlet port are aligned and a horizontal interface is formed between the second upper surface and the lower surface, and the second seal ring surrounds each of the second inlet substrate port and the component outlet port and fluidly seals the second substrate fluid passageway and the component fluid passageway, the second seal ring sized so that the outer ring of the second seal ring is horizontally compressed and under no vertical interference; and (3) the active component is spaced and isolated from the back plane.

14~~13~~. The fluid delivery system according to claim ~~12~~ 13 wherein the first seal ring further comprises a web extending radially inward from the outer ring; and wherein the web is under no vertical compression.

15~~14~~. The fluid delivery system according to claim ~~13~~ 14 further comprising:

the first substrate block comprising a first substrate ring defining the ~~second~~ first outlet substrate port and a substrate ~~seal~~ channel formed in the first upper surface and surrounding the first substrate ring;

the active component comprising a component ring defining the ~~first~~ component inlet port and a component ~~seal~~ channel formed in the lower surface and surrounding the component ring; and

the outer ring of the first seal ring extending into each of the substrate ~~seal~~ channel and the component ~~seal~~ channel, and wherein sidewalls of the substrate ~~seal~~ channel and the component ~~seal~~ channel horizontally compress the outer ring; and

the web disposed between the first substrate ring and the component ring.

16~~15~~. The fluid delivery system according to claim ~~12~~ 13 further comprising:

the first substrate block comprising a first substrate ring defining the ~~second~~ first outlet substrate port;

the active component comprising a component ring defining the ~~first~~ component inlet port;

the ~~seal ring comprising an~~ interior sleeve of the first seal ring comprising ~~having~~ an outer surface comprising an outwardly sloped lower portion and an outwardly sloped upper portion;

the component ring comprising an inner surface having an inwardly sloped portion that mates with and exerts a compression force on the outwardly sloped portion of the upper portion of the interior sleeve of the first seal ~~sleeve~~ ring; and

the first substrate ring comprising an inner surface having an inwardly sloped portion that mates with and exerts a compression force on the outwardly sloped portion of the lower portion of the interior sleeve of the first seal ~~sleeve~~ ring.

~~16. A method of processing semiconductors with a fluid delivery system, the method comprising:~~

~~a) fluidly coupling a component inlet port in a lower surface of an active component to an outlet substrate port in an upper surface of a first substrate block to form a first fluid connection, the first substrate block comprising a first inlet substrate port and a first substrate fluid passageway extending between the first inlet substrate port and the first outlet substrate port; and~~

~~b) fluidly coupling a component outlet port in the lower surface of the active component to a second inlet substrate port in an upper surface of a second substrate block to form a second fluid connection, the second substrate block comprising a second outlet substrate port and a second substrate fluid passageway extending between the second inlet substrate port and the second outlet substrate port, the active component comprising a component fluid passageway extending from the component inlet port to the component outlet port, thereby forming the fluid delivery system; and~~

~~c) flowing a fluid through the fluid delivery system to process the semiconductors; and~~

wherein the first fluid connection comprises a first seal ring nesting in each of a substrate seal channel in the upper surface of the first substrate block and a component seal channel in the lower surface of the active component, the seal ring fluidly sealing the first substrate fluid passageway and the component fluid passageway.

17. The method of claim 16 wherein the active component is selected from the group consisting of a flow controller, a pressure transducer, a flow measurement sensor, a pressure regulator, a valve, and a flow meter, the active component comprising:

18. The method of claim 17 further comprising:

the seal ring having an outer ring having an upper portion that is disposed within the component seal channel and a lower portion disposed within the substrate seal channel; and

wherein a horizontal interface is formed between the upper surface of the first substrate block and the lower surface of the active component, and wherein the seal ring is sized so that the outer ring of the seal ring is horizontally compressed and under no vertical interference.

19. The method of claim 18 further comprising:

the seal ring further comprising a web extending radially inward from the outer ring; and

wherein the web is under no vertical compression.

20. The method according to claim 19 further comprising:

the first substrate block comprising a first substrate ring defining the first outlet substrate port;

the active component comprising a component ring defining the inlet component port;

the seal ring comprising an interior sleeve comprising having an outer surface comprising an outwardly sloped lower portion and an outwardly sloped upper portion;

the component ring comprising an inner surface having an inwardly sloped portion that mates with and exerts a compression force on the outwardly sloped portion of the upper portion of the interior sleeve of the sleeve ring; and

the first substrate ring comprising an inner surface having an inwardly sloped portion that mates with and exerts a compression force on the outwardly sloped portion of the lower portion of the interior sleeve of the sleeve ring.

21. A liquid delivery system comprising:

a substrate block including a first substrate port and a second substrate port formed in an upper surface and a first liquid passageway that extends in a first direction and fluidly connects the first substrate port to the second substrate port;

a first active component having a lower surface with an active component port fluidly connected to the first substrate port; and

a removable seal assembly surrounding the fluidly connected substrate and active component ports and sized to fit inside corresponding channels formed in the upper surface of the substrate block and the lower surface of the first active component and around the fluidly connected substrate and active component ports for sealing the fluid connection between the substrate block and the first active component, the seal assembly including:

a cylindrical inner sleeve having conically shaped upper and lower portions surrounding an interior liquid pathway and sized to fit within the corresponding inner channels in the surfaces of the substrate block and active component so that liquid flowing between the substrate and active component ports passes through the interior liquid pathway, said inner sleeve being tapered toward the top and bottom by having a sloped outer portion that is sloped away from the interior pathway at an angle relative to the vertical axis of the inner sleeve at both the top and bottom of the inner sleeve; and

an annular outer ring connected to the outer portion of the inner sleeve and having a larger diameter than the inner sleeve, the outer ring extending in a vertical direction toward both the top and bottom of the seal assembly.

22. The liquid delivery system of claim 21 wherein the corresponding channels formed around the substrate and active component ports comprise a port opening having a sloped surface that will mate with the sloped outer portion of the inner sleeve when the seal assembly is installed.

~~23. The liquid delivery system of claim 22 wherein the corresponding channels formed around the substrate and active component ports further comprise a circular groove having a larger diameter than the port opening into which the circular outer ring of the seal assembly will be inserted when the seal assembly is installed.~~

~~24. The liquid delivery system of claim 23 wherein the outer ring has a width that is larger than the width of the corresponding circular groove formed around the fluidly connected substrate and active component ports.~~

~~25. The liquid delivery system of claim 24 wherein the outer ring, when installed, is compressed in the horizontal direction but not in the vertical direction.~~

~~26. The liquid delivery system of claim 21 wherein the outer ring has a height defined as the distance the outer ring extends in a vertical direction toward both the top and bottom of the seal assembly from a central horizontal axis and in which the height of the outer ring is less than the depth of the corresponding channels formed around the substrate and active component ports.~~

~~27. The liquid delivery system of claim 21 wherein the sloped outer portion of the inner sleeve is compressed in a vertical direction when the seal assembly is installed.~~

~~28. The liquid delivery system of claim 25 wherein the sloped outer portion of the inner sleeve is compressed in a vertical direction when the seal assembly is installed.~~

~~29. The liquid delivery system of claim 21 wherein the inner sleeve further comprises an sloped inner portion that slopes away from the sloped outer portion and toward the interior liquid pathway at an angle relative to the vertical axis of the inner sleeve at both the top and bottom of the inner sleeve.~~

~~30. The liquid delivery system of claim 26 wherein the slope of the sloped inner portion is at a greater angle relative to the vertical axis than the slope of the sloped outer portion.~~

~~31. The liquid delivery system of claim 21 wherein the inner sleeve has an axial height from the horizontal axis of the seal assembly to the upper or lower edge of the inner sleeve and in which the ratio of the axial height to the thickness of the inner sleeve wall is in the range from about 0.5 to 2.5.~~

32. The liquid delivery system of claim 21 wherein the removable seal assembly is symmetrical above and below a central horizontal plane.

33. The liquid delivery system of claim 21 wherein the removable seal assembly is symmetrical about a central vertical plane.

34. The liquid delivery system of claim 21 wherein the removable seal assembly comprises a polymer or fluoropolymer.

35. The liquid delivery system of claim **Error! Reference source not found.** in which the removable seal assembly comprises a compressible material.

36. A removable seal assembly for sealing around a fluid connection formed when two substrates, each having a fluid flow pathway open to a first substrate face, are connected via a face-to-face interface, the removable seal assembly comprising:

a cylindrical inner sleeve having conically shaped upper and lower portions surrounding an interior fluid pathway and sized to fit within corresponding channels in the substrate faces so that fluid flowing between the fluidly connected substrates passes through the interior fluid pathway, said inner sleeve being tapered toward the top and bottom by having a sloped outer portion that is sloped away from the interior pathway at an angle relative to the vertical axis of the inner sleeve at both the top and bottom of the inner sleeve; and

an annular outer ring connected to the outer portion of the inner sleeve and having a larger diameter than the inner sleeve, the outer ring extending in a vertical direction toward both the top and bottom of the seal assembly and sized to fit within corresponding cylindrical grooves formed in the substrate faces and surrounding the fluid connection between the substrates.

37. The removable seal assembly of claim 36 wherein the inner sleeve has an axial height from the horizontal axis of the seal assembly to the upper or lower edge of the inner sleeve and in which the ratio of the axial height to the thickness of the inner sleeve wall is in the range from about 0.5 to 2.5.

38. The removable seal assembly of claim 36 wherein the removable seal assembly is symmetrical above and below a central horizontal plane.

39. The removable seal assembly of claim 36 wherein the removable seal assembly is symmetrical about a central vertical plane.

40. The removable seal assembly of claim 36 wherein the removable seal assembly comprises a polymer or fluoropolymer.

41. The removable seal assembly of claim 36 wherein the removable seal assembly comprises a compressible material.

42. A method of manufacturing semiconductor devices, the method comprising controlled delivery of a liquid from a supply source using a modular liquid delivery system, the liquid delivery system comprising:

a substrate block including a first substrate port and a second substrate port formed in an upper surface and a first liquid passageway that extends in a first direction and fluidly connects the first substrate port to the second substrate port;

a first active component having a lower surface with an active component port fluidly connected to the first substrate port; and

a removable seal assembly surrounding the fluidly connected substrate and active component ports and sized to fit inside corresponding channels formed in the upper surface of the substrate block and the lower surface of the first active component and around the fluidly connected substrate and active component ports for sealing the fluid connection between the substrate block and the first active component, the seal assembly including:

a cylindrical inner sleeve having conically shaped upper and lower portions surrounding an interior liquid pathway and sized to fit within the corresponding inner channels in the surfaces of the substrate block and active component so that liquid flowing between the substrate and active component ports passes through the interior liquid pathway, said inner sleeve being tapered toward the top and bottom by having a sloped outer portion that is sloped away from the interior pathway at an angle relative to the vertical axis of the inner sleeve at both the top and bottom of the inner sleeve; and

a circular outer ring connected to the outer portion of the inner sleeve and having a larger diameter than the inner sleeve, the outer ring extending in a vertical direction toward both the top and bottom of the seal assembly.

43. A liquid delivery system comprising:

a substrate block including a first substrate port and a second substrate port formed in a first surface and a first liquid passageway that extends in a first direction and fluidly connects the first substrate port to the second substrate port;

a first active component fluidly connected to the first substrate port and a second active component, which is distinct from the first active component, fluidly connected to the second substrate port; and

wherein the first liquid passageway has no dead volume or areas for liquid entrapment.

44. The liquid delivery system of claim 43 wherein the first liquid passageway is formed so that liquid flow sweeps through the entire volume of the liquid passageway.

45. The liquid delivery system of claim 43 wherein the entire volume of the first liquid passageway is in line with the fluid flow.

46. The liquid delivery system of claim 43 in which the substrate block comprises a polymer or fluoropolymer.

47. The liquid delivery system of claim 43 in which the substrate block comprises polypropylene, PTFE, modified PTFE, or PFA.

48. The liquid delivery system of claim 43 in which the substrate block comprises a third and a fourth substrate port formed in the first surface and a second liquid passageway fluidly connecting the third substrate port to the fourth substrate port.

49. The liquid delivery system of claim 43 in which the substrate block is formed by machining a smooth groove in an upper surface of a first substrate layer and a matching smooth groove in a bottom surface of a second substrate layer, positioning the second substrate layer on the first substrate layer so that the matching grooves form a liquid passageway and bonding the two layers together.

50. The liquid delivery system of claim 49 further comprising drilling a first port and a second port through the second layer at either end of the formed groove.

~~51. The liquid delivery system of claim 43 in which bonding the two substrate layers comprises fusion bonding two polymer or fluoropolymer layers together by the application of heat and pressure.~~

~~52. The liquid delivery system of claim 43 in which the substrate block is formed by molding a polymer or fluoropolymer.~~

~~53. The liquid delivery system of claim 52 in which molding comprises compression molding, isostatic molding, or melt-processing.~~

~~54. The liquid delivery system of claim 52 in which molding comprises injection molding.~~

~~55. The liquid delivery system of claim 43 in which the substrate block is formed by sintering a fluoropolymer in a mold.~~

~~56. The liquid delivery system of claim 43 in which the substrate block is formed by sintering two separate substrate layers in molds and then fusion bonding the layers together.~~

~~57. The liquid delivery system of claim 43 in which the first active component is a component selected from the group of a flow controllers, a pressure transducers, a flow measurement sensor, a pressure regulator, and a valve.~~

~~58. The liquid delivery system of claim 43 in which the liquid delivery system has a footprint having a ratio of free space to system components that is no more than 30%.~~

~~59. The liquid delivery system of claim 43 in which the liquid delivery system has a plurality of active components mounted so that the space between active components is less than 20 mm.~~

~~60. The liquid delivery system of claim 59 in which the plurality of active components comprises two or more components selected from the group of flow controllers, pressure transducers, flow measurement sensors, pressure regulators, and valves.~~

~~61. A system for enabling a distribution of liquid chemicals, comprising:~~

~~a substrate block including a first substrate port and a second substrate port formed in a first surface and a first liquid passageway that extends in a first direction and fluidly connects the first substrate port to the second substrate port;~~

~~wherein the first substrate port is adapted to be fluidly connected to a first active component and the second substrate port is adapted to be fluidly connected to a second active component that is distinct from the first active component; and wherein the first liquid passageway is a smooth passageway having no dead volume or areas for entrapment of liquid.~~

~~62. A system for enabling a distribution of liquid chemicals, comprising:~~

~~a substrate block including a first substrate port and a second substrate port formed in a first surface and a first liquid passageway that extends in a first direction and fluidly connects the first substrate port to the second substrate port;~~

~~wherein the first substrate port is adapted to be fluidly connected to a first active component and the second substrate port is adapted to be fluidly connected to a second active component that is distinct from the first active component; and wherein the entire volume of the first liquid passageway is in line with the fluid flow.~~

~~63. The liquid delivery system of any of the preceding claims wherein the first liquid passageway is formed so that liquid flow sweeps through the entire volume of the liquid passageway.~~

~~64. The liquid delivery system of any of the preceding claims wherein the entire volume of the first liquid passageway is in line with the fluid flow.~~

~~65. The liquid delivery system of any of the preceding claims in which the substrate block comprises a polymer or fluoropolymer.~~

~~66. The liquid delivery system of any of the preceding claims in which the substrate block comprises polypropylene, PTFE, modified PTFE, or PFA.~~

~~67. The liquid delivery system of any of the preceding claims in which the substrate block comprises a third and a fourth substrate port formed in the first surface and a second liquid passageway fluidly connecting the third substrate port to the fourth substrate port.~~

~~68. The liquid delivery system of any of the preceding claims in which the substrate block is formed by machining a smooth groove in an upper surface of a first substrate layer and a matching smooth groove in a bottom surface of a second substrate layer, positioning the second~~

substrate layer on the first substrate layer so that the matching grooves form a liquid passageway and bonding the two layers together.

69. The liquid delivery system of any of the preceding claims in which bonding the two substrate layers comprises fusion bonding two polymer or fluoropolymer layers together by the application of heat and pressure.

70. The liquid delivery system of any of the preceding claims in which the substrate block is formed by molding a polymer or fluoropolymer, wherein the molding comprises compression molding, isostatic molding, melt-processing, or injection molding.

71. The liquid delivery system of any of the preceding claims in which the substrate block is formed by sintering a fluoropolymer in a mold.

72. The liquid delivery system of any of the preceding claims in which the substrate block is formed by sintering two separate substrate layers in molds and then fusion bonding the layers together.

73. The liquid delivery system of any of the preceding claims in which the active components comprise one or more components selected from the group of flow controllers, pressure transducers, flow measurement sensors, pressure regulators, and valves.

74. The liquid delivery system of any of the preceding claims in which the liquid delivery system has a footprint having a ratio of free space to system components that is no more than 30%, no more than 20%, no more than 10%, or no more than 5% free space.

75. The liquid delivery system of any of the preceding claims in which the liquid delivery system has a plurality of active components mounted so that the space between active components is less than 20 mm, such as less than 10 mm, less than 5 mm, approximately 1 mm, or even less than 1 mm.

76. A liquid delivery system comprising:

a substrate block including a first substrate port and a second substrate port formed in a first surface and a first liquid passageway that extends in a first direction and fluidly connects the first substrate port to the second substrate port;

~~a first active component having a lower surface fluidly connected to the first substrate port; and~~

~~a seal assembly sealing the fluid connection, the seal assembly including a primary seal comprising a removable seal insert, and a secondary seal comprising a tongue and groove structure formed in the first surface of the substrate block and in the lower surface of the active component.~~

~~77. The liquid delivery system of claim 76 in which the seal insert comprises a polymer or fluoropolymer.~~

~~78. The liquid delivery system of any one of claims 76-77 in which the seal assembly comprises a seal ring that, when installed, is compressed in the horizontal direction but not in the vertical direction.~~

~~79. The liquid delivery system of any one of claims 76-78, in which the secondary tongue and groove structure is a circular groove in one of the upper surface of the substrate block or the lower surface of the active component and a corresponding circular tongue extending from the other of either the upper surface of the substrate block or the lower surface of the active component.~~

~~80. The liquid delivery system of any one of claims 76-79 in which the tongue and groove structure comprises a circular structure having a larger diameter than the insert seal.~~

~~81. The liquid delivery system of any one of claims 76-80 in which the tongue and groove structure comprises at least two concentric circular tongue and groove structures.~~

~~82. The liquid delivery system of any one of claims 76-81 in which the seal comprises a conical center section through which liquid flows when the seal is in place.~~

~~83. The liquid delivery system of claim 82 in which the ratio of the height of the cone in the conical center section to the thickness of the seal wall in the conical center section is from about 0.5 to 2.5, such as about 1.0 to 2.0, 1.1 to 1.8, or 1.1 to 1.6.~~