CUSTOMIZABLE DISPENSE SYSTEM WITH SMART CONTROLLER

TECHNICAL FIELD

[0001] This disclosure relates generally to liquid dispensing in semiconductor manufacturing processes and, more particularly, to a new dispense system having a smart controller for controlling customizable pump operations to meet the diverse needs in the field of semiconductor manufacturing.

BACKGROUND OF THE INVENTION

[0002] There are many applications for which precise control over the amount and/or rate at which a fluid is dispensed by a pumping apparatus is necessary. In semiconductor manufacturing processes, for example, it is important to control the amount and rate at which photochemicals, such as photoresist chemicals, are applied to a semiconductor wafer. A semiconductor manufacturing process refers to a process used to create integrated circuits that are present in everyday electrical and electronic devices. It includes a sequence of photographic and chemical processing steps during which electronic circuits are gradually created on a wafer made of pure semiconducting material. The coatings applied to semiconductor wafers during processing typically require a certain flatness and/or even thickness across the surface of the wafer that is measured in angstroms. The rates at which processing chemicals are applied (i.e., dispensed) onto the wafer have to be controlled carefully to ensure that the processing liquid is applied uniformly.

[0003] Photochemicals used in the semiconductor industry can be very expensive. Therefore, it is highly desirable to ensure that a minimum but adequate amount of chemical is used and that the chemical is not damaged by the pumping apparatus. Unfortunately, these desirable qualities can be extremely difficult to achieve in today's pumping systems because of the many interrelated obstacles. For example, due to incoming supply issues, pressure can vary from system to system. Due to fluid dynamics and properties, pressure needs vary from fluid to fluid (e.g., a fluid with higher viscosity requires more pressure). Because these obstacles are interrelated, sometimes solving one may cause many more problems and/or make

the matter worse. What is more, different applications have different needs. A pump system that meets the needs of a particular application may not be suitable for a different application.

SUMMARY OF THE INVENTION

[0004] In semiconductor manufacturing, various pumps may be used to mix chemicals as well as dispensing the mixture of chemicals onto wafers. High performance pumps, such as the Entegris IntelliGen Mini photolithography rolling edge diaphragm pump, can be used to mix and dispense the chemicals directly (Entegris and IntelliGen are trademarks of Entegris, Inc. of Chaska, Minnesota). These chemicals may vary from application to application and different applications may have different needs. Thus, a pump system used in dispensing the chemicals must consider a plurality of factors, including size, cost, performance (both speed and accuracy), reliability, adaptability, and so on.

[0005] Embodiments disclosed herein can address these needs with a customizable dispense system that is built on modular architecture and that includes a single main controller for controlling components in this versatile, "plug-and-play" dispense system. Within this disclosure, the term "customizable" refers to the fact that embodiments of a dispense system disclosed herein can be easily changed, modified, or otherwise altered to suit various needs. Such a change, modification, or alteration may occur dynamically whenever such a need arises. For example, one embodiment of a customizable dispense system disclosed herein may initially be built with a pneumatic to pneumatic configuration. Pneumatically driven pumps (pneumatic pumps) are generally less expensive than motor-driven pumps (motor pumps) and can provide positive pressure filtration and good throughput, which makes this pneumatic to pneumatic configuration ideal for handling applications such as those for non-critical layers. The pneumatic to pneumatic configuration can be easily changed, modified, or otherwise altered to a motor to motor configuration for critical layer applications. In some embodiments, the single main controller is configured with the necessary intelligence, and hence is referred to herein as a "smart" controller, to automatically recognize a change in the customizable dispense system and operate according to a new configuration and/or a new application.

[0005a] According to a first aspect of the present invention, there is provided a customizable dispense system, comprising: a smart controller configured to operate a plurality of pumps in semiconductor manufacturing processes that are sensitive to defects in printed patterns, the plurality of pumps including at least one pneumatic pump and at least one motor pump; and a plurality of lines connecting the smart controller with a track and a variety of devices, including pump heads for the at least one pneumatic pump and the at least one motor pump, wherein the smart controller is configured to, upon switching one of the plurality of lines from communicating with a first pump to communicating with a second pump, automatically recognize the second pump and automatically apply a control scheme corresponding to the second pump.

[0005b] According to a second aspect of the present invention, there is provided a customizable dispense system, comprising: a set of feed pumps for directing chemicals used in semiconductor manufacturing processes; a set of dispense pumps for dispensing the chemicals; and a smart controller configured to operate the set of feed pumps and the set of dispense pumps, wherein the set of feed pumps and the set of dispense pumps comprise one or more integrated pumps, each of the one or more integrated pumps comprising two or more pneumatic pumps physically combined as a unit, wherein the two or more pneumatic pumps in the unit operate independent of one another, and wherein the two or more pneumatic pumps in the unit are independently controlled by the smart controller; wherein the smart controller is further configured to, upon switching from communicating with a first pump to communicating with a second pump, automatically recognize the second pump and automatically apply a control scheme corresponding to the second pump.

[0005c] According to a third aspect of the present invention, there is provided a customizable dispense system, comprising: a set of feed pumps for directing chemicals used in semiconductor manufacturing processes; a set of dispense pumps for dispensing the chemicals; a smart controller configured to operate the set of feed pumps and the set of dispense pumps, wherein the set of feed pumps and the set of dispense pumps comprise one or more integrated pumps, each of the one or more integrated pumps comprising two or more pneumatic pumps physically combined as a unit, wherein the two or more pneumatic pumps in the unit operate independent of one another, wherein the two or more pneumatic pumps in the unit are independently controlled by the smart controller, and wherein the smart controller is further configured to, upon interfacing with a newly connected pump, automatically recognize the newly connected pump and automatically apply a control scheme corresponding to the

newly connected pump, wherein the newly connected pump is a motor pump or a pneumatic pump.

[0005d] According to a fourth aspect of the present invention, there is provided a filtration method, comprising: at a controller of a dispense system having a feed pump and a dispense pump, determining an upstream pressure for fluid upstream from a filter positioned between the feed pump and the dispense pump; setting a feed stage fluid pressure to the upstream pressure; setting a dispense stage fluid pressure to a filtration pressure setpoint; opening valves to allow the fluid flowing from a feed side to a dispense side through the filter, wherein the feed stage fluid pressure and the dispense stage fluid pressure cause a differential pressure across the filter, thereby moving the fluid from the feed side to the dispense side through the filter at a target rate; and determining an end of filtration based on a change in fluid pressure at the dispense side.

[0006] In some embodiments, the smart controller of a customizable dispense system disclosed herein can be configured to operate a plurality of pumps in semiconductor

manufacturing processes that are sensitive to defects in printed patterns. The plurality of pumps may include at least one pneumatic pump and at least one motor pump. The customizable dispense system may further comprise a plurality of lines connecting the smart controller with a track and a variety of devices. In some embodiments, the variety of devices may include filters with radio-frequency identification tags, sensors, and pump heads.

[0007] In some embodiments, the smart controller is further configured to, upon switching one of the plurality of lines from communicating with a first pump to a second pump, automatically recognize the second pump and apply a control scheme corresponding to the second pump in order to precisely and accurately control the second pump without downtime or with minimal, if any, downtime.

[0008] In some embodiments, the switching may occur between motor pumps, between pneumatic pumps, or between a mixture of pneumatic pumps and motor pumps. For example, a user may unplug pneumatic pumps and plug in motor pumps to take over certain functions of those pneumatic pumps. Example functions may include chemical feed and dispense. In some embodiments, no physical disconnection/connection may be necessary and the switching is done entirely via software.

[0009] In some embodiments, the smart controller may be configured to, upon interfacing with a newly connected pump, automatically recognize the newly connected pump and apply a control scheme corresponding to the newly connected pump, which may be a motor pump or a pneumatic pump. The smart controller may comprise an onboard database storing information associated with a plurality of pumps.

[0010] In some embodiments, the smart controller may be configured to control one or more integrated pumps. In some embodiments, an integrated pump may comprise two or more pneumatic pumps physically combined as a unit. The two or more pneumatic pumps in the unit may operate independent of one another. In some embodiments, the smart controller may be further configured to independently control the two or more pneumatic pumps in the unit.

[0011] In some embodiments, a customizable dispense system may include a set of feed pumps and a set of dispense pumps. In some embodiments, a smart controller may

be configured to operate the set of feed pumps and the set of dispense pumps which may include one or more integrated pumps.

[0012] Software implementing embodiments disclosed herein may be implemented in suitable computer-executable instructions that may reside on one or more non-transitory computer readable medium. Within this disclosure, the term "computer-readable storage medium" encompasses all types of data storage medium that can be read by a processing unit such as a processor or a controller. Examples of computer-readable storage media can include random access memories, read-only memories, hard drives, data cartridges, floppy diskettes, flash memory drives, and the like.

[0013] Embodiments disclosed herein can provide many advantages. For example, instead of a fixed number of pumps, a customizable dispense system disclosed herein can support a variable number of different types of pumps over time. This mix and match flexibility may allow the system to be tailored to each particular application, reduce the cost of maintaining the system, and provide a way to easily upgrade to a new type of pumps and/or a new system setup.

[0014] These, and other, aspects of the disclosure will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following description, while indicating various embodiments of the disclosure and numerous specific details thereof, is given by way of illustration and not of limitation. Many substitutions, modifications, additions and/or rearrangements may be made within the scope of the disclosure without departing from the spirit thereof, and the disclosure includes all such substitutions, modifications, additions and/or rearrangements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The drawings accompanying and forming part of this specification are included to depict certain aspects of the disclosure. It should be noted that the features illustrated in the drawings are not necessarily drawn to scale. A more complete understanding of the disclosure and the advantages thereof may be acquired by referring to the following description, taken in conjunction with the accompanying drawings in which like reference numbers indicate like features and wherein:

[0016] FIGURE 1 depicts a diagrammatic representation of an example multiple stage pump ("multi-stage pump");

[0017] FIGURES 2 and 3 depict perspective views of an example multi-stage pump;

[0018] FIGURE 4 depicts a perspective view of an example single stage pump;

[0019] FIGURE 5 depicts a diagrammatic representation of one example embodiment of modular architecture for customizable dispense systems;

[0020] FIGURE 6 depicts a diagrammatic representation of one example embodiment of a customizable dispense system with a smart controller controlling pneumatic feed pumps and pneumatic dispense pumps;

[0021] FIGURE 7 depicts a diagrammatic representation of one example embodiment of a customizable dispense system with a smart controller controlling pneumatic feed pumps and motor dispense pumps;

[0022] FIGURE 8 depicts a diagrammatic representation of one example embodiment of a customizable dispense system with a smart controller controlling motor feed pumps and motor dispense pumps;

[0023] FIGURE 9 depicts a diagrammatic representation of one example embodiment of a customizable dispense system with a pneumatic to pneumatic configuration;

[0024] FIGURES 10-15 illustrate pump control and sequence operation of one example embodiment of a customizable dispense system;

[0025] FIGURES 16-17 depict diagrammatic representations of example embodiments of an integrated pump;

[0026] FIGURE 18 depicts a perspective top view of one example embodiment of an integrated pump; and

[0027] FIGURE 19 depicts an exploded view of a pneumatic pump in one example embodiment of an integrated pump.

DETAILED DESCRIPTION

[0028] The disclosure and various features and advantageous details thereof are explained more fully with reference to the exemplary, and therefore non-limiting, embodiments illustrated in the accompanying drawings and detailed in the following description. Descriptions of known programming techniques, computer software, hardware, operating platforms and protocols may be omitted so as not to unnecessarily obscure the disclosure in detail. It should be understood, however, that the detailed description and the specific examples, while indicating the preferred embodiments, are given by way of illustration only and not by way of limitation. Various substitutions, modifications, additions and/or rearrangements within the spirit and/or scope of the underlying inventive concept will become apparent to those skilled in the art from this disclosure.

[0029] FIGURE 1 depicts a diagrammatic representation of example multi-stage pump 100. Multi-stage pump 100 includes a feed stage portion 105 and a separate dispense stage portion 110. Located between feed stage portion 105 and dispense stage portion 110, from a fluid flow perspective, is filter 120 to filter impurities from a process fluid. A number of valves can control fluid flow through multi-stage pump 100 including, for example, inlet valve 125, isolation valve 130, barrier valve 135, purge valve 140, vent valve 145 and outlet valve 147. The valves of multi-stage pump 100 are opened or closed to allow or restrict fluid flow to various portions of multi-stage pump 100. These valves can be pneumatically actuated (i.e., gas driven) diaphragm valves that open or close depending on whether pressure or a vacuum is asserted.

[0030] Dispense stage portion 110 can further include a pressure sensor 112 that determines the pressure of fluid at dispense stage 110. The pressure determined by pressure sensor 112 can be used to control the speed of the various pumps as described below. Example pressure sensors include ceramic and polymer piezoresistive and capacitive pressure sensors, including those manufactured by Metallux AG, of Korb, Germany. The face of pressure sensor 112 that contacts the process fluid can be a perfluoropolymer. Pump 100 can include additional pressure sensors, such as a pressure sensor that determines the pressure of fluid at feed stage 105 and/or a pressure sensor to read pressure in feed chamber 155.

[0031] Feed stage 105 and dispense stage 110 can include rolling diaphragm pumps to pump fluid in multi-stage pump 100. Feed-stage pump 150 ("feed pump 150"), for example, includes a feed chamber 155 to collect fluid, a feed stage diaphragm 160 to move within feed chamber 155 and displace fluid, a piston 165 to move feed stage diaphragm 160, a lead screw 170 and a stepper motor 175. Lead screw 170 couples to stepper motor 175 through a nut, gear or other mechanism for imparting energy from the motor to lead screw 170. According to one embodiment, feed motor 170 rotates a nut that, in turn, actuates lead screw 170, causing piston 165 to actuate. Dispense-stage pump 180 ("dispense pump 180") can similarly include a dispense chamber 185, a dispense stage diaphragm 190, a piston 192, a lead screw 195, and a dispense motor 200. Feed stage 105 and dispense stage 110 can each include a variety of pumps including pneumatically actuated pumps, hydraulic pumps or other pumps. For example, a pneumatically actuated pump may be used for the feed stage and a stepper motor driven hydraulic pump may be used for the dispense stage.

[0032] In the example shown in FIGURE 1, multi-stage pump 100 implements a motor to motor configuration between the feed stage and the dispense stage. Feed motor 175 and dispense motor 200 can be any suitable motor. For example, dispense motor 200 can be a Permanent-Magnet Synchronous Motor ("PMSM"). The PMSM can be controlled by a digital signal processor ("DSP") utilizing Field-Oriented Control ("FOC") or other position/speed control scheme. In some embodiments, a smart controller in multi-stage pump 100 is configured to control dispense motor 200 utilizing the control scheme.

[0033] Dispense motor 200 can further include an encoder (e.g., a fine line rotary position encoder) for real time feedback of dispense motor 200's position. The use of a position sensor enables accurate and repeatable control of the position of piston 192, which leads to accurate and repeatable control over fluid movements in dispense chamber 185. For, example, using a 2000 line encoder, which may provide 8000 pulses to the DSP, it is possible to accurately measure to and control dispense motor 200's position at .045 degrees of rotation. In addition, a PMSM can run at low velocities with little or no vibration. Feed motor 175 can also be a PMSM or a stepper motor. For example, feed motor 175 can be an EAD Motors of Dover, N.H. stepper motor part no. L1LAB-005 and dispense motor 200 can be an EAD Motors brushless DC Motor part no. DA23DBBL-13E17A.

[0034] FIGURES 2 and 3 depict perspective views of an example of a pump assembly for multi-stage pump 100. Multi-stage pump 100 can include a dispense block 205 that defines various fluid flow paths through multi-stage pump 100. Dispense pump block 205 can be a unitary block of PTFE, modified PTFE or other material. Because these materials do not react with or are minimally reactive with many process fluids, the use of these materials allows flow passages and pump chambers to be machined directly into dispense block 205 with a minimum of additional hardware. Dispense block 205 consequently reduces the need for piping by providing a fluid manifold.

[0035] Dispense block 205 can include various external inlets and outlets including, for example, inlet 210 through which the fluid is received, vent outlet 215 for venting fluid during the vent segment, and dispense outlet 220 through which fluid is dispensed during the dispense segment. Dispense block 205, in the example of FIGURE 2, does not include an external purge outlet as purged fluid is routed back to the feed chamber. In other implementations, however, fluid can be purged externally.

[0036] Dispense block 205 routes fluid to the feed pump, dispense pump and filter 120. A pump cover 225 can protect feed motor 175 and dispense motor 200 from damage, while piston housing 227 can provide protection for piston 165 and piston 192. In this example, valve plate 230 provides a valve housing for a system of valves (e.g., inlet valve 125, isolation valve 130, barrier valve 135, purge valve 140 and vent valve 145 of FIGURE 1) that can be configured to direct fluid flow to various components of multi-stage pump 100. According to one embodiment, each of inlet valve 125, isolation valve 130, barrier valve 135, purge valve 140, and vent valve 145 is partially integrated into valve plate 230 and is a diaphragm valve that is either opened or closed depending on whether pressure or vacuum is applied to the corresponding diaphragm.

[0037] Valve plate 230 includes a valve control inlet for each valve to apply pressure or vacuum to the corresponding diaphragm. For example, inlet 235 corresponds to barrier valve 135, inlet 240 to purge valve 140, inlet 245 to isolation valve 130, inlet 250 to vent valve 145, and inlet 255 to inlet valve 125. By the selective application of pressure or vacuum to the inlets, the corresponding valves are opened and closed. The valves can be opened and closed in various sequences which may vary from application to application. Valve plate 230 can be configured to reduce the hold-up

volume of the valves, eliminate volume variations due to vacuum fluctuations, reduce vacuum requirements and reduce stress on the valve diaphragm.

[0038] A valve control gas and vacuum are provided to valve plate 230 via valve control supply lines 260, which run from a valve control manifold (covered by manifold cover 263 or housing cover 225), through dispense block 205 to valve plate 230. Valve control gas supply inlet 265 provides a pressurized gas to the valve control manifold and vacuum inlet 270 provides vacuum (or low pressure) to the valve control manifold. The valve control manifold acts as a three way valve to route pressurized gas or vacuum to the appropriate inlets of valve plate 230 via supply lines 260 to actuate the corresponding valve(s).

[0039] In FIGURE 3, dispense block 205 is made transparent to show the fluid flow passages defined there through. Dispense block 205 defines various chambers and fluid flow passages for multi-stage pump 100. Feed chamber 155 and dispense chamber 185 can be machined directly into dispense block 205. Additionally, various flow passages can be machined into dispense block 205. A fluid flow passage runs from inlet 210 to the inlet valve. Fluid flow passage 280 runs from the inlet valve to feed chamber 155, to complete the path from inlet 210 to feed pump 150. Inlet valve 125 in valve housing 230 regulates flow between inlet 210 and feed pump 150. Flow passage 285 routes fluid from feed pump 150 to isolation valve 130 in valve plate 230. The output of isolation valve 130 is routed to filter 120 by another flow passage. Fluid flows from filter 120 through flow passages that connect filter 120 to the vent valve 145 and barrier valve 135. The output of vent valve 145 is routed to vent outlet 215 while the output of barrier valve 135 is routed to dispense pump 180 via flow passage 290. During the dispense segment, the dispense pump can output fluid to outlet 220 via flow passage 295 or, in the purge segment, to the purge valve through flow passage 300. During the purge segment, fluid can be returned to feed pump 150 through flow passage 305. Because the fluid flow passages can be formed directly in the PTFE (or other material) block, dispense block 205 can act as the piping for the process fluid between various components of multi-stage pump 100, obviating or reducing the need for additional tubing. In other cases, tubing can be inserted into dispense block 205 to define the fluid flow passages.

[0040] FIGURE 3 further shows supply lines 260 for providing pressure or vacuum to valve plate 230. Actuation of the valves is controlled by the valve control manifold 302 that

directs either pressure or vacuum to each supply line 260. Each supply line 260 can include a fitting (an example fitting is indicated at 318) with a small orifice (i.e., a restriction). The orifice in each supply line helps mitigate the effects of sharp pressure differences between the application of pressure and vacuum to the supply line. This allows the valves to open and close more smoothly and more slowly.

[0041] In addition to the examples shown in FIGURES 1-3, other multi-stage pump configurations, including pneumatic-to-motor and pneumatic to pneumatic, are also possible. Further, although described in terms of a multi-stage pump, embodiments disclosed herein can also be utilized in a single stage pump. FIGURE 4 depicts a perspective view of an example pump assembly for single stage pump 4000.

[0042] Pump 4000 can be similar to one stage, say the dispense stage, of multi-stage pump 100 described above. Pump 4000 can include a pneumatically actuated pump or a rolling diaphragm pump driven by a stepper motor, brushless DC motor, or other motor. Pump 4000 can include a dispense block 4005 that defines various fluid flow paths through pump 4000 and at least partially defines a pump chamber. Dispense pump block 4005 can be a unitary block of PTFE, modified PTFE or other material. Because these materials do not react with or are minimally reactive with many process fluids, the use of these materials allows flow passages and the pump chamber to be machined directly into dispense block 4005 with a minimum of additional hardware. Dispense block 4005 consequently reduces the need for piping by providing an integrated fluid manifold. A pressure sensor can be positioned to read the pressure in the pump chamber.

[0043] Dispense block 4005 can include various external inlets and outlets including, for example, inlet 4010 through which the fluid is received, purge/vent outlet 4015 for purging/venting fluid, and dispense outlet 4020 through which fluid is dispensed during the dispense segment. Dispense block 4005, in the example of FIGURE 4, includes external purge outlet 4010 as the pump only has one chamber. Appropriate fittings such as o-ring-less low profile fittings can be utilized to connect the external inlets and outlets of dispense block 4005 to fluid lines.

[0044] Dispense block 4005 routes fluid from the inlet to an inlet valve (e.g., at least partially defined by valve plate 4030), from the inlet valve to the pump chamber, from the pump chamber to a vent/purge valve and from the pump chamber to outlet 4020. A pump cover 4025 can protect a pump motor from damage, while piston housing 4027

can provide protection for a piston. The cover/housing can be formed of polyethylene or other polymer. Valve plate 4030 provides a valve housing for a system of valves (e.g., an inlet valve, and a purge/vent valve) that can be configured to direct fluid flow to various components of pump 4000. Valve plate 4030 and the corresponding valves can be formed similarly to the manner described in conjunction with valve plate 230, discussed above. The purge valve can be the same size as, smaller than, or larger than the inlet valve. Using a smaller purge valve, however, can reduce the holdup volume returned to the chamber as described above. Each of the inlet valve and the purge/vent valve can be partially integrated into valve plate 4030 and can be a diaphragm valve that is either opened or closed depending on whether pressure or vacuum is applied to the corresponding diaphragm. In some implementations, some of the valves may be external to dispense block 4005 or arranged in additional valve plates. As an example, a sheet of PTFE can be sandwiched between valve plate 4030 and dispense block 4005 to form the diaphragms of the various valves. Valve plate 4030 includes a valve control inlet (not shown) for each valve to apply pressure or vacuum to the corresponding diaphragm.

[0045] In some embodiments, instead of a fixed number of pumps, a customizable system may support a variable number of pumps over time. The customizable dispense system employs a flexible, modular architecture. Embodiments of a customizable dispense system may also support different types of pumps, including pneumatic and motor, at any given time. For example, in a multi-stage pump system, the first stage pump may be driven pneumatically and the second stage pump may be driven by a motor. This mix and match flexibility allows the system to be customized for each particular application. FIGURE 5 depicts a diagrammatic representation of one example embodiment of modular architecture 500 for customizable dispense systems.

[0046] As illustrated in FIGURE 5, different application may have different needs, perhaps depending upon the chemicals used, the level of quality/performance desired the cost involved in achieving the level of quality/performance desired, and so on. For example, where the cost of chemicals is high and the end product is sensitive to defects, the system may utilize a motor to motor configuration, an example of which is shown in FIGURE 8, for the best possible filtration control with the lowest possible defects. Since this motor to motor configuration can be inherently expensive, in some cases, a pneumatic to motor configuration may be utilized to reduce the cost of

the system while retaining a desirable level of throughput and the ability to monitor and control the dispense rate and volume. An example of a pneumatic to motor configuration is shown in FIGURE 7. In some cases, a pneumatic to pneumatic configuration may be desirable, particularly if the cost relative to the dispense volume is a concern and/or where high quality performance is not needed or required. An example of a pneumatic to pneumatic configuration is shown in FIGURE 6. In embodiments disclosed herein, modular architecture 500 includes a smart controller that allows for mixing and matching, sometimes dynamically and on-the-fly, pneumatic and motor pumps. In this way, embodiments of a customizable dispense system disclosed herein may capture the whole spectrum of performance levels for many different applications to meet the diverse needs in the field of semiconductor manufacturing.

[0047] This flexible, modular architecture may provide a dispense system disclosed herein with many advantages. For example, an owner of the system may start with a pneumatic to pneumatic set up. Over time, the owner's needs may change and/or after an evaluation, the pneumatic to pneumatic set up may need an upgrade. One or more of the pneumatic pumps may be readily swapped out and replaced with motor driven pump(s) and/or replacement pneumatic pump(s). The owner would not have to replace the entire dispense system.

[0048] This type of plug-n-play modification to the dispense system is possible due at least in part to a versatile, smart controller operable to control various types of pumps automatically and dynamically. For example, one may unplug a first pump, plug in a second pump, plumb the line, and begin or resume the operation. Upon interfacing with the pump head of the second pump, the controller is operable to automatically recognize the second pump and apply a control scheme corresponding to the second pump. In some embodiments, the switching from one pump to another may be done entirely via software, without having to physically unplugging and plugging in pumps. For example, a user may want to take Pump A and Pump B off-line and designate Pump C and Pump D to take over and function as new Pump A and new Pump B.

[0049] In some embodiments, electronically readable tags or code may be utilized to provide a wide variety of information to the smart controller. In some embodiments, the smart controller may connect to various devices identifiable via electronically readable tags which may or may not be directly affixed on or embedded in those

devices/packages. For example, the smart controller may be connected to a smart filter via one of its many ports and information about the smart filter may be provided to the smart controller via an electronically readable tag associated with the smart filter. As another example, the smart controller may be connected to a pack or package and information about the content contained therein may be provided to the smart controller via an electronically readable tag associated with the pack or package. The pack may contain a chemical or substance necessary for a particular application. Other devices/packages can be connected to the smart controller in a similar manner.

[0050] In semiconductor manufacturing, different applications often have different requirements for chemical layer thickness and coating area. Correspondingly, a wide array of dispense volumes and rates may be required. Meeting such requirements involves many different size pumps for all the different track sizes as each pump must be able to contain all of the fluid required for an individual dispense. These tracks and pumps may rely on discrete lines for communication, which means each input line and each output line would require a physical wire or cabling. The complexity of wiring adds another layer of challenge to the already complicated fluidic connections in the dispense system.

[0051] One way to address these challenges is to provide an input/output (I/O) interface device that can provide serial communications between individual pump controllers and tracks. In this way, individual pump controllers for the same type of pumps can communicate with different tracks through the I/O interface device. More specifically, the I/O interface device can take a signal from a track at the front end and serially communicate that signal to a pump controller at the back end in a format that can be understood by the pump controller.

[0052] Embodiments of a smart controller disclosed herein can provide another viable solution. In some embodiments, the smart controller may comprise a plurality of communication ports for physical connections to a track and a variety of devices. In some embodiments, the smart controller may have 24 communication ports for motor pumps, pneumatic pumps, filters, sensors, etc., each of which may be plugged into any one of the 24 ports and be automatically recognized by the smart controller, utilizing an onboard database. The communication lines between the smart

controller and the devices may be software configurable. In some embodiments, each type of device may be assigned to a particular port of the smart controller.

[0053] In some embodiments, the smart controller may comprise different types of interfaces to communicate serial, parallel, or analog signals/data to and from various devices, including a track, pumps, valves, sensors, tag readers, pump heads, and other components. In some embodiments, the interface to the track may utilize a proprietary protocol or an industry standard protocol. As another example, an interface to the track may be a Controller Area Network (CAN) interface with DeviceNet, an industry standard Ethernet, or some other industry standard protocol. For example, the smart controller may utilize the Transmission Control Protocol/Internet Protocol (TCP/IP) to communicate with the track. Other interfaces of the smart controller may be used to communicate with a variety of devices, including individual pump heads, in one or more protocols. In some embodiments, the variety of devices may include CAN devices. In some embodiments, the interfaces to the variety of devices may include stripped down simple proprietary interfaces.

[0054] In many tracks, Ethernet and DeviceNet or something similar may be utilized to control the I/O signals of the pumps. For example, a track would send a DeviceNet command to a DeviceNet parallel I/O board to set some signals and those signals would go through connectors and cables to a special pump interface module. This kind of connection architecture requires delicate and complicated hardware arrangement in addition to software programming.

[0055] In some embodiments, the smart controller may implement a proprietary communications protocol for interfacing/communicating with the pumps. In some embodiments, the smart controller may implement a track interface to take the place of a parallel I/O that is normally used to trigger the pump and get basic status. In some embodiments, pumps may be implemented as the same parallel device type and the smart controller may be operable to interpret the protocol directly. This would eliminate the need for parallel signals on the pump as well as the track hardware board and cabling while providing virtually the same programming functions that many tracks currently use. Following the above example, the track could send the same DeviceNet command to the pump through the smart controller and not require additional hardware. Those skilled in the art will appreciate that this

is just one possible example. In some embodiments, an existing Entegris Networking Protocol may be used to communicate to the smart controller or pumps.

[0056] In some prior dispense systems, a master controller may be connected to multiple pumps and each pump may have a dedicated pump controller coupled thereto. The functionality of this type of dedicated pump controller may be categorized into two levels: high and low. High level control functions may include functions required to run a dispense pump. Low level control functions may include simple functions such as moving a motor from Point A to Point B. These pump controllers have a lot of processing power. Unfortunately, prior dispense systems do not utilize the processing powers of such pump controllers in an efficient manner. For example, in a dispense system with multiple pumps, say 30-40, there may be up to three pumps that are operating at the same time and the rest of the pumps sit idle. This inefficiency can be costly.

[0057] Another drawback of a prior dispense system is in its fixed architecture that cannot be readily modified. The master controller is generally programmed with a control scheme corresponding to the type of pump controllers connected thereto. Since the control scheme is specific to the type of pumps, if a pneumatic pump is pulled out and replaced with a motor pump, the master controller will not recognize the motor pump, nor will the master controller know how to control the motor pump.

[0058] Embodiments of a smart controller disclosed herein can take the high level functionality out of the pump controllers so they can share the processing power smartly in order to reduce idle time and corresponding cost. The low level functionality stays at the pump head. The distinction between high level functions and low level functions may be software configurable to customize the dispense system for a particular implementation. For example, in some embodiments, the smart controller may send a simple 'DISPENSE' command to a pump head and the pump head has sufficient intelligence to execute the command and report to the smart controller when the task is complete. As another example, the smart controller may give the pump controller (at or local to the pump) a generic command "DISPENSE RECIPE 4" and the pump controller having been configured to dispense this particular recipe, performs the task as instructed. In some embodiments, the pump head may have only rudimentary or basic functions sufficient to drive a pump

coupled thereto and the smart controller may provide specific instructions to the pump head in order to perform the task at hand.

[0059] In some embodiments, the operation of a pump is controlled by the smart controller using information about a filter that is connected to the pump. In some embodiments, the filter is a removable filter disposed in a fluid flow path between a pump inlet and a pump outlet. The removable filter may implement a quick change or quick connect mechanism to connect to the pump. In some embodiments, the smart controller is configured to receive filter information, receive process fluid information such as a chemical type, access a library of operating routines (control schemes) based on the filter information and the process fluid information to select an operating routine for the pump and operate the pump according to the selected operating routine. The selected operating routine can include a priming routine, a dispense cycle, selected segments of a dispense cycle or some other routine.

[0060] FIGURE 6 depicts a diagrammatic representation of one example embodiment of customizable dispense system 600 with smart controller 610 controlling pneumatic feed pumps 630 at feed stage 601 and pneumatic dispense pumps 640 at dispense stage 602. In this example, controller 610 is communicatively linked to track 620, pneumatic feed pumps 630, filters 650, and dispense pumps 640. In this example, electronic regulator 635 is employed to regulate pneumatically actuated feed pumps 630 and electronic regulator 645 is employed to regulate pneumatically actuated dispense pumps 640.

[0061] FIGURE 7 depicts a diagrammatic representation of one example embodiment of customizable dispense system 700 with smart controller 610 controlling pneumatic feed pumps 630 at feed stage 601 and motor-driven dispense pumps 740 at dispense stage 602. Following the above example, controller 610 is communicatively linked to track 620, pneumatic feed pumps 630, filters 650, and dispense pumps 740. In dispense system 700, electronic regulator 635 is employed to regulate pneumatically actuated feed pumps 630. In this example, smart controller 610 can be configured to control dispense pumps 740 without an electronic regulator. In some embodiments, customizable dispense system 700 may nevertheless include an electronic regulator as a standard component. This allows for mixing and matching different types of pumps for dispense pumps 740, if desired, with one or more pneumatic pumps in dispense pumps 740 connected to the electronic regulator.

[0062] FIGURE 8 depicts a diagrammatic representation of one example embodiment of customizable dispense system 800 with smart controller 610 controlling motor-driven feed pumps 830 at feed stage 601 and motor-driven dispense pumps 740 at dispense stage 602. Following the above example, controller 610 is communicatively linked to track 620, feed pumps 830, filters 650, and dispense pumps 740. Smart controller 610 can control motor-driven feed pumps 830 and motor-driven dispense pumps 740 in a manner similar to multi-stage pump 100 described above. In some embodiments, customizable dispense system 800 may comprise an electronic regulator for feed stage 601 and an electronic regulator for feed stage 602 as standard components. This allows for mixing and matching different types of pumps for feed pumps 830 and dispense pumps 740, if desired, with one or more pneumatic pumps in feed pumps 830 connected to the electronic regulator at feed stage 601 and one or more pneumatic pumps in dispense pumps 740 connected to the electronic regulator at feed stage 602.

[0063] FIGURES 6-8 exemplify the flexibility and versatile of smart controller 610 which can handle pneumatic feed pumps 630 at feed stage 601, pneumatic dispense pumps 640 at dispense stage 602, motor-driven dispense pumps 740 at dispense stage 602, and motor-driven feed pumps 830 at feed stage 601, as well as various filters 650. Smart controller 610 provides a plug and play interface with multiple physical interfaces (ports) for connection to track 620 and various devices. The same connection line can be used to communicate with different types of pumps. This reduces/simplifies wiring for the underlying customizable dispense system.

[0064] The smart controller may provide proprietary or internally standardized communication lines to communicate with a variety of devices, including pneumatic pumps, motor pumps, filters, etc. In communicating with these devices, the smart controller may identify each type of device upon connection, look up a corresponding control scheme, and proceed accordingly. For example, to switch from communicating with one pump to another, the smart controller may access an internal or local database for information, including a control scheme associated with the newly connected pump, and apply the control scheme accordingly.

[0065] In some embodiments, the smart controller may connect to filters having electronically readable filter information tags containing filter information. Some examples of electronically readable filter information tags may implement the Radio-

frequency identification (RFID) technology. These filters may be of a removable type implementing a quick change or quick connect mechanism. In some embodiments, the filter information tags can be an active or passive RFID tags, bar code or other optically readable code.

[0066] Radio-frequency identification (RFID) generally has two parts: readers and tags. Using radio waves, some RFID tags can be read from several meters away and beyond the line of sight of an RFID reader. In some embodiments, the range of suitable RFID tags is intentionally shortened to reduce cross talk of adjacent pumps reading each other's tags. As an example, in one embodiment, the range of RFID tags is reduced to about an inch. Other ranges are also possible, depending upon the distance and/or arrangement of RFID reader(s) and tag(s). FIGURE 10 shows example filters 950a with RFID tags 952a and example filters 950b with RFID tags 952b. In some embodiments, RFID tags may be directly affixed on or embedded with the filters. In some embodiments, RFID tags may not need to be physically attached to the filters. RFID technology is known to those skilled in the art and thus is not further described herein.

[0067] Examples of filter information may include, but are not limited to, part number, design style, membrane type, retention rating, generation of the filter, configuration of the filter membrane, lot number, serial number, a device flow, membrane thickness, membrane bubble point, particle quality, filter manufacturer quality information or other information. The design style indicates the type of pump for which the filter is designed, the capacity/size of the filter, amount of membrane material in the filter or other information about the design of the filter. The membrane type indicates the material and/or thickness of the membrane. The retention rating indicates the size of particles that can be removed with a particular efficiency by the membrane. The generation of the filter indicates whether the filter is a first, second, third or other generation of the filter design. The configuration of the filter membrane indicates whether the filter is pleated, the type of pleating or other information regarding the design of the membrane. The serial number provides the serial number of the individual filter. The lot number can specify the manufacturing lot of the filter or membrane. The device flow indicates the flow rate the filter can handle while still producing good dispenses. The device flow can be determined during manufacture for the individual filter. The membrane bubble point provides another measure of the flow rates/pressure the filter can handle and still produce good dispenses. The

membrane bubble point can also be determined during manufacture for the individual filter. The above examples are provided by way of explanation are not limiting of the information that can be contained in the filter information.

[0068] The part number contained in the filter information can convey a variety of information. For example, each letter in the example part number format "Aabcdefgh" can convey a different piece of information. Table 1 below provides an example of information conveyed by the part number:

TABLE 1

Letter	Information	Examples
A	Connectology	
a	Design Style --Indicates the type of pump for which the filter is designed.	For IntelliGen Pump Filters: P=wide body pump (IntelliGen1 or IntelliGen2) 2 or M= IntelliGen3 or IntelliGen Mini Pump
b	Membrane Type-Type of Membrane Used in Filter	A = thin UPE U = thick UPE S = asymmetric nylon and UPE or other combination) M = PCM (chemically modified UPE) N = nylon
c	Retention Rating	G = 0.2um V = 0.1um Z = 0.05um Y = 30nm X = 20nm T = 10nm F = 5nm K= 3nm
d	Generation-generation of filter	0=V1 2=V2
e	RFID	R=RFID
f	Pleat-Type of Pleating Used in Filter	0 = Standard M = M pleat
g	Where O-Ring is Located	0=OM K=Karlez E=EPDM R=O-ringless

h	How Many Filters in a Box	1=1 per box 3=3 per box

[0069] Using the example of Table 1, the part number A2AT2RMR1 for an Impact pump filter would indicate that the connectology of the filter, the filter is designed for an IntelliGen2 Pump (Impact and IntelliGen are trademarks of Entegris, Inc. of Chaska, Minn.), the membrane is thin UPE, has a retention rating of 10nm, the filter is a version 2 filter, the filter includes an RFID tag, the filter membrane has an M-pleat, the filter is O-ringless and there is one filter per box. The use of a part number to convey information, however, is provided by way of example and filter information can be conveyed in other manners.

[0070] Other suitable filters may also be connected to the smart controller for various purposes. For example, an earlier version of a smart filter may need to be swapped out and replaced with a newer version. This may be done as simple as pulling the old smart filter out and plugging in the replacement in its place. A set of rules can be applied to the filter information to determine if the filter is appropriate. The rules for determining whether a filter is appropriate can depend on the filter information and other factors, such as the process fluid, environmental properties, required cycle time or other factors. For example, a rule may be applied such that, if the process fluid has a certain viscosity, a filter will only be considered appropriate if it has a specific part number or certain part number and bubble point. Thus, the rules applied can depend on multiple pieces of filter information and other information. If the filter is not an appropriate filter, a corresponding action can be taken. Otherwise, operation of the pump can proceed.

[0071] Smart filters may play an important role in various semiconductor manufacturing processes that are sensitive to defects in printed patterns, especially those processes involving very small, microscopic or submicron feature sizes. Some existing dispense systems filter at a negative pressure. Some existing dispense systems are able to monitor and perhaps passively maintain the pressure needed for the filtration. However, prior dispense systems are not known to have the ability to accurately and precisely control the pressure needed for the filtration.

[0072] Some embodiments disclosed herein may control and maintain a positive pressure in a pump head at the inlet of the pump on the dispense side to reduce defect-causing bubbles. For a motor pump, this positive pressure can be controlled by motor

movements and by a feedback loop to a pressure transducer. For example, to provide a 5 psi positive pressure, an upstream electronic regulator may be set to provide 10 psi in the first stage and a downstream electronic regulator may be set to provide 5 psi in the second stage. This pressure differential pushes the fluid across the filter to the dispense side.

[0073] In a pneumatic pump set up, a pressure transducer is placed in the fluid path to detect the actual fluid pressure. Based on information from the smart filters, the smart controller can infer what the actual filtration rate is for a particular filter and control that filtration rate accordingly. This allows a user to set a desired filtration rate, in addition to setting the downstream pressure. The upstream pressure can be adjusted to get the desired target rate across the filter.

[0074] As an example, a filtration rate for a pneumatic to pneumatic pump set up can be calculated as follows:

- A user enters the viscosity of a chemical (FV) for a pneumatic dispense pump.
- The user enters a desired filtration pressure setpoint (FP) for an RFID filter fluidly connected to the pump. In some cases, FP may be set to 4 psi. In some cases, FP may be set to from about 2 psi to about 10 psi.
- The user enters a desired filtration rate (FR) for filtering the chemical. FR may be set to from about 0.2 cc per sec. to about 1 cc per sec. and perhaps higher in some cases.
- The controller gets a filter flow rate (FLR) from an RFID tag off of a filter. The information provided by the RFID tag may include the type of filter and the current flow rate of the fluid flowing through the filter.
- The controller has a resistance constant (FC) stored in the firmware.
- The controller calculates a filter resistance (R), where R = FC / FLR.
- At this point, the controller has all the information needed to calculate the upstream pressure (UFP), where UFR = (R*FR*FV) + FP. UFP is needed to obtain the filtration rate desired by the user.
- The controller sets the first stage fluid pressure to UFP and sets the second stage fluid pressure to FP.
- The isolate and barrier valves open.
- Filtration occurs at the given filtration rate.
- When filtration is complete, the 1st stage fluid pressure will raise from FP to UFP.
- The raising pressure signals the end of filtration.

[0075] As a specific example, a user may desire a filtration rate of 1.5 cc per sec. and a downstream pressure of 4 psi on the dispense pump for filtering a fluid having a viscosity of 3 Centipoise (cps). Suppose R = 1.55, UFR = 10.98 psi. If the pressure regulator for the feed pump is set at 10.98 psi and the pressure regulator for the dispense pump is set at 4 psi, the movement of fluid is caused by the differential pressure across the filter which in this example causes the fluid to move from the feed side to the dispense side at a flow rate of 1.5 cc per sec through the filter. That flow rate will continue until it does not need any more fluid. At that time, the dispense pump diaphragm will bottom out and the pressure regulator for the dispense pump will no longer be able to maintain the 4 psi setpoint. The pressure at the second stage then begins to drift towards the 10.98 psi setpoint. Once that drift begins to occur, it signifies the end of filtration and the dispense pump can move away from filtration and go to the next step in the cycle. One reason that this is possible is because a pressure transducer is placed in the fluid path. If the pressure transducer is only placed in the pneumatic path, a change in the fluid pressure may not be detected.

[0076] FIGURE 9 depicts a diagrammatic representation of one example embodiment of customizable dispense system 900 with a pneumatic to pneumatic pump set up for feed stage 901 and dispense stage 902. In this example, feed pump 930a and feed pump 930b are physically combined as a unit, but each operates independently from one another, is independently controlled by an embodiment of a smart controller disclosed herein (see FIGURE 6), and has fluidic connections with respective sets of bottles 970a, 970b containing chemicals for a particular dispense application. Advantageously, this configuration can provide cost savings and high throughput due to simultaneous dispense. Likewise, dispense pump 940a and dispense pump 940b are physically combined as a unit, but each operates independently from one another, is independently controlled by the smart controller, and has fluidic connections with respective filters 950a, 950b, purge lines, and dispensing (outlet) valves leading to dispensing points. In some embodiments, the outlet valves may include stop/suckback valves (SSBVs). The outlet valves which may be connected to airborne molecular contamination or other molecular or chemical monitoring/detection devices. A control amount of fluid containing processing chemicals is applied (dispensed) onto a wafer through a dispense nozzle at a dispense point. The rates at which processing chemicals are applied to the wafer must be controlled in order to ensure that the processing liquid is applied uniformly.

The thickness of the coating across the surface of the wafer is typically measured in angstroms.

[0077] The dispense nozzle is generally at atmosphere. Preferably, the level of pressure at the dispense nozzle remains undisturbed – no high pressure, no vacuum, no spikes. Placing the pressure transducer in the fluid path in a pneumatic to pneumatic set up may ensure that the inlet of the dispense pump has a positive pressure and that the positive pressure is accurately controlled at all time, without having to make any assumptions. A pressure transducer is a type of sensor that can generate a signal as a function of the pressure imposed. Many suitable pressure transducers may be used in this set up. In some embodiments, the positive pressure may be in the range of 0 to about 12 psi. In some embodiments, the positive pressure may be in the range of about 2 to 10 psi.

[0078] FIGURES 10-15 illustrate pump control and sequence operation of one example embodiment of customizable dispense system 1000 with a pneumatic to pneumatic pump configuration for feed stage 901 and dispense stage 902. In this example embodiment, customizable dispense system 1000 may comprise various valves, including inlet valves, isolate valves, vent valves, barrier valves, purge valves, and outlet valves, which have similar functions as respective valves described above with reference to multi-stage pump 100. Further, in this example, electronic regulator 935 is utilized to independently regulate pneumatic actuation of feed pumps 930a, 930b and electronic regulator 945 is utilized to independent regulate pneumatic actuation of dispense pumps 940a, 940b. In this example embodiment, customizable dispense system 1000 may further comprise smart filter 950a with RFID tag 952a, smart filter 950b with RFID tag 952b, PCB 961, and PCB 962. Since, in this example, two pumps are physically combined as a unit, a printed circuit board (PCB) is coupled to the unit and the smart controller to run, per an instruction from the smart controller, one of the pumps or both pumps at the same time.

[0079] FIGURE 11 illustrates example fill and dispense sequence 1100 where chemicals are drawn from bottles 970a into feed pump 930a. For the sake of simplicity, feed pump 930b and dispense pump 940b and components/connections associated therewith are not shown in FIGURES 11-15. Feed pump 930b and dispense pump 940b can have the same or similar pump control and sequence operation described herein with reference to respective feed pump 930a and dispense pump 940a.

[0080] Filter 950a can have tag 952a. In operation, a tag reader (not shown) can read filter information from tag 952a and communicates the filter information to the smart controller (see FIGURE 6). The smart controller can process the filter information and apply rules to the filter information to determine whether and how to operate feed pump 930a and dispense pump 940a, including controlling the fill pressure, monitoring a fluid pressure profile, and generating alarm(s) for excursion(s). Additionally, the smart controller can adjust the operation of customizable dispense system 1000 during a dispense cycle based on the filter information obtained from tag 952a.

[0081] The smart controller can also use the filter information to correlate good or bad operations to filter characteristics. During operation, the smart controller can track a variety of operational data for customizable dispense system 1000. The information tracked by the smart controller can include any operational parameters made available to the smart controller and any information calculated by the smart controller. Some non-limiting examples of operational data may include pressure, parameters related to valve operations, motor positions, motor speeds, hydraulic pressure or other parameters (such as temperature if the pump includes temperature sensors). This information can be used to determine whether a dispense is/was a good dispense. This can be done after the dispense has occurred or in real time during the dispense cycle.

[0082] The operational data can be correlated to the filter information so that the effect of the various filter parameters on dispense quality can be identified. As an example, the smart controller can record the lot number of a filter so that operational data of customizable dispense system 1000 can be correlated to that lot. This information can be used to identify whether a particular lot of filters produced better or worse results compared to another lot of filters of the same design. Similarly, the serial number can be used to track operational data versus individual filter to help determine if an individual filter was the cause of bad coatings. As yet another example, operational data can be correlated to membrane bubble points to determine if filters having the same part number but different membrane bubble points had different dispense results. Recording information from tag 952a and tracking information about dispenses can optimize selection and even manufacture of filters.

[0083] FIGURE 12 illustrates example filtration sequence 1200. As discussed above, smart filters may play an important role in various semiconductor manufacturing processes. As a specific example, suppose the first stage fluid pressure setpoint is set to 10 psi and the second stage fluid pressure setpoint is set to 8 psi, the delta between the two setpoints is 2 psi. This delta in pressure (ΔP) pulls the fluid across the filter. The filter is a sealed type, so there is no loss in pressure when the fluid is pushed across it. Depending upon the flow rate and the resistance of the filter, pressures in the two stages eventually reach equilibrium over time and filtration ends. Previously, when that end actually occurs is not precisely known in a pneumatic to pneumatic set up. In some embodiments, a pressure transducer can be positioned in the fluid path to provide timely and accurate information to the pump, so it can move on to the next step without having to wait unnecessarily. Using the set up shown on FIGURE 10 as an example, the fluid diaphragm on the dispense side eventually bottoms out and no more fluid can go into the pump. Meanwhile, the bottle drawer at the feed stage continues to try to push the fluid through to the dispense side, causing the fluid pressure at the dispense side to rise, eventually ramp up to 10 psi, signaling the end of filtration. In a pneumatic to pneumatic set up, this pressure is detected by the pressure transducer placed in the fluid path. Again, the flow rate is controlled via coordination with the dispense stage. At the dispense stage, downstream pressure can be controlled so that the lowest defects could be produced. Further, the end-of-filtration sensing can enable the best possible throughput for the underlying customizable dispense system as the system does not have to wait a predetermined time period and can go ahead and proceed to get ready for the next dispensing cycle.

[0084] In a mix and match system, the bottle drawer may utilize motor pump(s) to pull the fluid(s) from the bottle(s). A negative pressure may be applied (via an upstream electronic regulator) to pull the fluid(s) from the bottle(s) into the fluid reservoir in the first stage. Using a motor pump may have the benefit of a finer level of controls with respect to rate of the fluid and pressure. In some embodiments, a pneumatic pump may be utilized at a lower cost. Thus, in some embodiments, the positive pressure control scheme described above is not limited to a pneumatic to pneumatic set up and may be implemented in a motor to motor set up or a motor to pneumatic set up. The bottle could also be pressurized, and the feed stage used to control the rate at which chemical fills, and also determine when the fill is complete.

[0085] In addition to the dispense cycle, the smart controller may be configured to perform other operations. For example, when a new filter is connected to a pump, the filter should be primed so that the filter membrane is fully wetted prior to running a dispense cycle. An example priming routine may be as follows. First, fluid is introduced into the dispense chamber. The filter can be vented for a period of time to remove air bubbles from the upstream portion of the filter. Next, a recirculating purge segment may occur. An example recirculating purge sequence 1300 is shown in FIGURE 13. Recirculating purge can remove the bubbles without chemical waste, in addition to being important for priming the filter in an efficient manner. In a purge-to-vent segment that follows, the isolate and purge valves are opened and the barrier valve is closed. The fluid is directed out of the dispense chamber and through the vent. This can be followed by a filtration segment, a vent segment, and a purge segment, after which the filter can be pressurized and the barrier valve and vent valve can be closed, while the isolate valve is opened and fluid at the feed stage is pressurized. A forward flush segment may occur in which fluid is run through the filter to the dispense chamber and purged out the purge valve. A purge-to-vent segment may occur again. The priming routine can be repeated as needed or desired.

[0086] The pumps in a customizable dispense system may be primed based on the type of filter and process fluid used. Thus, while the foregoing provides an example priming routine, other priming routines can be used as would be understood by those of ordinary skill in the art. A suitable priming routine can involve any number of different steps and to ensure that the filter membrane is fully wetted. Some non-limiting examples of sequences of segments that can be used in a priming routine include, but are not limited to: I) a fill segment, a vent segment; ii) a fill segment, a purge-to-vent segment, a filtration segment, a vent segment, a purge-to-inlet segment; iii) a dispense segment, a fill segment, a filtration segment and a purge segment. FIGURE 14 illustrates example fill segment 1400 in which customizable dispense system 1000 is ready for the next dispense. FIGURE 15 illustrates example vent segment 1500 in which customizable dispense system 1000 automatically vents to remove bubbles when they are detected through pressure monitoring, thus preventing gas from redissolving under pressure. Additional or alternative segments can be used in priming routines as needed or desired.

[0087] As discuss above, in some embodiments, a customizable dispense system may include one or more units of physically connected pumps. With the help of a PCB, the smart controller can communicate with these pumps via a single line/port/physical interface per unit. However, since the pumps are not physically integrated, each of the pumps still requires a full set of tubing and parts. In some embodiments, a customizable dispense system disclosed herein may include integrated pumps with simplified wiring/tubing requirements.

[0088] FIGURE 16 depicts a diagrammatic representation of one example embodiment of integrated pump 1600 with two pneumatic pumps physically integrated as a unit. In integrated pump 1600, two pneumatic pumps (Pump 1, Pump 2) share fluid plate 1610 which is sandwiched between front plate 1611 and end late 1612. As a non-limiting example, the fluid plate may be made out of a polymeric material such as polytetrafluoroethylene (PTFE) or some other suitable material. As a specific example, a fluid plate may be 4" tall, 4" wide, and ¼" thick. Both sides of the fluid plate may be machined or otherwise shaped to create a dish, recess, or concave surface. In this example, each of the pneumatic pumps has an end plate that couples to one side of the fluid plate to form a cavity or space for holding a fluid therein. Diaphragms 1621, 1622 may be independently pneumatically actuated to direct fluids 1601, 1602 in or out of integrated pump 1600. A fittings plate may be sandwiched between the end plates to provide fluidic connections between the fluid spaces and fittings. As a non-limiting example, the end plates may be made out of metal. Other suitable materials such as plastic may also be used. Referring to FIGURE 6, suppose feed pumps 630 comprise a plurality of integrated pumps 1600, each unit of which has a single control board connected thereto. Customizable dispense system 600 in this example can readily increase its operation capacity and capabilities without having to rewire each of feed pumps 630.

[0089] FIGURE 17 depicts a diagrammatic representation of one example embodiment of integrated pump 1700 with four pneumatic pumps (Pump 1 for Fluid 1701, Pump 2 for Fluid 1702, Pump 3 for Fluid 1703, Pump 4 for Fluid 1704) physically integrated as a unit. The smart controller can control these pumps via a single line/port/interface. Each pump has a fluid side and a pneumatic side. These pumps share certain parts, including center plate 1710, front plate 1711, end plate 1712, fluid plate 1721, and fluid plate 1722. In some embodiments, they can also share a fittings plate and fittings, including fluid fittings and pneumatic fittings.

[0090] FIGURE 18 depicts a perspective top view of one example embodiment of integrated pump 1800. In this example, Pump 1 and Pump 2 of integrated pump 1800 share fluid plate 810, front plate 1811, end plate 1812, fittings plate 1860, fluid fittings 1885, and pneumatic fittings 1895.

[0091] FIGURE 19 depicts an exploded view of one example embodiment of integrated pump 1900. For the sake of simplicity, only one pneumatic pump is shown. Pneumatic pumps of integrated pump 1900 may share certain parts as described above with reference to FIGURES 16-18. In this example, integrated pump 1900 comprises fluid plate 1910, valve plate 1911, end plate 1912, diaphragm 1922 sandwiched between valve plate 1911 and fluid plate 1910, o-rings 1980 positioned between diaphragm 1922 and valve plate 1911, and fasteners 1990 holding together fluid plate 1910, valve plate 1911, end plate 1912, and diaphragm 1922. O-rings 1980 may be partially seated. Diaphragm 1922 may be made of a sheet of elastomeric material, PTFE, modified PTFE, a composite material of different layer types or other suitable material that is preferably non-reactive with the process fluid. In one embodiment, diaphragm 1922 can be approximately .013 inches thick. Fluids may be directed into and out of integrated pump 1900 through fluid fittings 1985 which may connect to fluid channels through top support plate 1970 and fittings plate 1960. Diaphragm 1922 may be pneumatically actuated via pneumatic fittings 1995. The displacement volume of the fluid in the cavity (fluid side) may vary with the amount of pressure/vacuum applied to diaphragm 1922. This pressure may be measured via pressure nut 1950.

[0092] As those skilled in the art can appreciate, the number of pumps as well as the type of pumps that can be combined in this way is not limited to what is shown in the drawings accompanying this disclosure. For example, motor driven pumps may also be combined: by forming two or more bore holes – one for each pump – in a single block, by bolting together two or more rolling diaphragm pumps with a single control board, etc. In some cases, practical considerations such as complexity involved in combining the pumps and benefits that may be provided by such a combination may influence the number of pumps to be combined. For example, using two separate pumps in a dispense system may cost X and combining two pumps may cost a fraction of X. Combining four pumps, however, may increase that fraction of X. As the number of pumps to be combined continues to increase, so does the challenges, which diminishes the value in combining them. There may be a point where that

fraction of X is sufficiently close to X so as to render negligible the saving from combining the pumps.

[0093] Combining pumps that may be operated independently can provide many advantages. For example, the integrated pumps may require a smaller foot print than the total foot print of separate pumps. Additionally, the integrated pumps may simplify wiring/cabling, thereby reducing the installation/configuration/maintenance time. Furthermore, the integrated pumps may reduce the cost of the overall system, at least due to the sharing of materials in each unit of the integrated pumps.

[0094] Although embodiments of a modular, flexible, smart, cost-effective, and high-performance dispense system have been described in this disclosure, one of ordinary skill in the art can appreciate that various modifications and changes can be made without departing from the spirit and scope of the specific embodiments disclosed herein. Those skilled in the art will appreciate that features and aspects disclosed herein may be independently implemented or in various combinations. Accordingly, the specification and figures disclosed herein, including in the accompanying appendices, are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of this disclosure. Therefore, the scope of the present disclosure should be determined by the following claims and their legal equivalents.

WHAT IS CLAIMED IS:

1. A customizable dispense system, comprising:

a smart controller configured to operate a plurality of pumps in semiconductor manufacturing processes that are sensitive to defects in printed patterns, the plurality of pumps including at least one pneumatic pump and at least one motor pump; and

a plurality of lines connecting the smart controller with a track and a variety of devices, including pump heads for the at least one pneumatic pump and the at least one motor pump, wherein the smart controller is configured to, upon switching one of the plurality of lines from communicating with a first pump to communicating with a second pump, automatically recognize the second pump and automatically apply a control scheme corresponding to the second pump.

2. A customizable dispense system according to Claim 1, wherein the first pump is a pneumatic pump and the second pump is a motor pump.

3. A customizable dispense system according to Claim 1, wherein both the first pump and the second pump are motor pumps.

4. A customizable dispense system according to Claim 1, wherein both the first pump and the second pump are pneumatic pumps.

5. A customizable dispense system according to Claim 1, wherein the smart controller is further configured to, upon interfacing with a newly connected pump, automatically recognize the newly connected pump and apply a control scheme corresponding to the newly connected pump, wherein the newly connected pump is a motor pump or a pneumatic pump.

6. A customizable dispense system according to Claim 1, wherein the smart controller comprises an onboard database storing information associated with the plurality of pumps.

7. A customizable dispense system according to Claim 1, wherein the variety of devices includes filters with radio-frequency identification tags.

8. A customizable dispense system according to Claim 1, wherein the plurality of pumps comprises one or more integrated pumps, wherein each of the one or more integrated pumps comprises two or more pneumatic pumps physically combined as a unit, wherein the two or more pneumatic pumps in the unit operate independent of one another, and wherein the two or more pneumatic pumps in the unit are independently controlled by the smart controller.

9. A customizable dispense system according to Claim 8, wherein the one or more integrated pumps function as feed pumps.

10. A customizable dispense system according to Claim 8, wherein the one or more integrated pumps function as dispense pumps.

11. A customizable dispense system according to Claim 1, wherein the switching is due to physical disconnection of the first pump and physical connection of the second pump.

12. A customizable dispense system according to Claim 1, wherein the switching is due to an instruction received at the smart controller.

13. A customizable dispense system, comprising:

a set of feed pumps for directing chemicals used in semiconductor manufacturing processes;

a set of dispense pumps for dispensing the chemicals; and

a smart controller configured to operate the set of feed pumps and the set of dispense pumps, wherein the set of feed pumps and the set of dispense pumps comprise one or more integrated pumps, each of the one or more integrated pumps comprising two or more pneumatic pumps physically combined as a unit, wherein the two or more pneumatic pumps in the unit operate independent of one another, and wherein the two or more pneumatic pumps in the unit are independently controlled by the smart controller;

wherein the smart controller is further configured to, upon switching from communicating with a first pump to communicating with a second pump, automatically recognize the second pump and automatically apply a control scheme corresponding to the second pump.

14. A customizable dispense system according to Claim 13, wherein the first pump is a pneumatic pump and the second pump is a motor pump.

15. A customizable dispense system according to Claim 13, wherein both the first pump and the second pump are motor pumps.

16. A customizable dispense system according to Claim 13, wherein both the first pump and the second pump are pneumatic pumps.

17. A customizable dispense system according to Claim 13, wherein the smart controller is further configured to, upon interfacing with a newly connected pump, automatically recognize the newly connected pump and apply a control scheme corresponding to the newly connected pump, wherein the newly connected pump is a motor pump or a pneumatic pump.

18. A customizable dispense system, comprising:

a set of feed pumps for directing chemicals used in semiconductor manufacturing processes;

a set of dispense pumps for dispensing the chemicals;

a smart controller configured to operate the set of feed pumps and the set of dispense pumps, wherein the set of feed pumps and the set of dispense pumps comprise one or more integrated pumps, each of the one or more integrated pumps comprising two or more pneumatic pumps physically combined as a unit, wherein the two or more pneumatic pumps in the unit operate independent of one another, wherein the two or more pneumatic pumps in the unit are independently controlled by the smart controller, and wherein the smart controller is further configured to, upon interfacing with a newly connected pump, automatically recognize the newly connected pump and automatically apply a control scheme corresponding to the newly connected pump, wherein the newly connected pump is a motor pump or a pneumatic pump.

19. A customizable dispense system according to Claim 18, wherein the smart controller is further configured to, upon switching from communicating with a first pump to a second pump, automatically recognize the second pump and apply a control scheme corresponding to the second pump.

20. A customizable dispense system according to Claim 19, wherein the first pump is a pneumatic pump and the second pump is a motor pump.

21. A customizable dispense system according to Claim 19, wherein both the first pump and the second pump are motor pumps.

22. A customizable dispense system according to Claim 19, wherein both the first pump and the second pump are pneumatic pumps.

23. A customizable dispense system according to Claim 19, wherein the switching is due to physical disconnection of the first pump and physical connection of the second pump.

24. A customizable dispense system according to Claim 19, wherein the switching is due to an instruction received at the smart controller.

25. A filtration method, comprising:

at a controller of a dispense system having a feed pump and a dispense pump, determining an upstream pressure for fluid upstream from a filter positioned between the feed pump and the dispense pump;

setting a feed stage fluid pressure to the upstream pressure;

setting a dispense stage fluid pressure to a filtration pressure setpoint;

opening valves to allow the fluid flowing from a feed side to a dispense side through the filter, wherein the feed stage fluid pressure and the dispense stage fluid pressure cause a differential pressure across the filter, thereby moving the fluid from the feed side to the dispense side through the filter at a target rate; and

determining an end of filtration based on a change in fluid pressure at the dispense side.