

SYSTEM AND METHOD FOR A VARIABLE
HOME POSITION DISPENSE SYSTEM

5 RELATED APPLICATIONS

 The present application claims under 35 U.S.C. § 119(e) the benefit of and priority to United States Provisional Patent Application 60/630,384, entitled "System and Method for a Variable Home Position Dispense System" by Laverdiere et al., filed November 23, 2004, which is hereby fully incorporated by reference herein.

10 TECHNICAL FIELD

 Embodiments of the present invention generally relate to pumping systems and more particularly to dispense pumps. Even more particularly, embodiments of the present invention provide systems and method for reducing the hold-up volume for a dispense pump.

15 BACKGROUND

 Dispense systems for semiconductor manufacturing applications are designed to dispense a precise amount of fluid on a wafer. In one-phase systems, fluid is dispensed to a wafer from a dispense pump through a filter. In two-phase systems, fluid is filtered in a filtering phase before entering a dispense pump. The fluid is then dispensed directly to the wafer in a dispense phase.

20 In either case, the dispense pump typically has a chamber storing a particular volume of fluid and a movable diaphragm to push fluid from the chamber. Prior to dispense, the diaphragm is typically positioned so that the maximum volume of the chamber is utilized regardless of the volume of fluid required for a dispense operation. Thus, for example, in a 10mL dispense pump, the chamber will store 10.5mL or 11mL of fluid even if each dispense only requires 3mL of fluid (a 10mL dispense pump will have a slightly larger chamber to ensure there is enough fluid to complete the maximum anticipated dispense of 10mL). For each dispense cycle, the chamber will be filled to its maximum capacity (e.g., 10.5mL or 11mL,

depending on the pump). This means that for a 3mL dispense there is at least 7.5mL "hold-up" volume (e.g., in a pump having a 10.5mL chamber) of fluid that is not used for a dispense.

5 In two-phase dispense systems the hold-up volume increases because the two-phase systems utilize a feed pump that has a hold-up volume. If the feed pump also has a 10.5mL capacity, but only needs to provide 3mL of fluid to the dispense pump for each dispense operation, the feed pump will
10 also have a 7.5mL unused hold-up volume, leading, in this example, to a 15mL of unused hold-up volume for the dispense system as a whole.

 The hold-up volume presents several issues. One issue is that extra chemical waste is generated. When the dispense
15 system is initially primed, excess fluid than what is used for the dispense operations is required to fill the extra volume at the dispense pump and/or feed pump. The hold-up volume also generates waste when flushing out the dispense system. The problem of chemical waste is exacerbated as hold-up volume
20 increases.

 A second issue with a hold-up volume is that fluid stagnation takes place. Chemicals have the opportunity to gel, crystallize, degas, separate etc. Again, these problems are made worse with a larger hold-up volume especially in low
25 dispense volume applications. Stagnation of fluid can have deleterious effect on a dispense operation.

 Systems with large hold-up volumes present further shortcomings with respect to testing new chemicals in a semiconductor manufacturing process. Because many
30 semiconductor manufacturing process chemicals are expensive (e.g., thousands of dollars a liter), new chemicals are tested on wafers in small batches. Because semiconductor manufacturers do not wish to waste the hold-up volume of fluid and associated cost by running test dispenses using a multi-
35 stage pump, they have resorted to dispensing small amounts of test chemicals using a syringe, for example. This is an

inaccurate, time consuming and potentially dangerous process that is not representative of the actual dispense process.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide a system and method of fluid pumping that eliminates, or at least substantially reduces, the shortcomings of prior art pumping systems and methods. One embodiment of the present invention can include a pumping system comprising a dispense pump having a dispense diaphragm movable in a dispense chamber, and a pump controller coupled to the dispense pump. The pump controller, according to one embodiment, is operable to control the dispense pump to move the dispense diaphragm in the dispense chamber to reach a dispense pump home position to partially fill the dispense pump. The available volume corresponding to the dispense pump home position is less than the maximum available volume of the dispense pump and is the greatest available volume for the dispense pump in a dispense cycle. The dispense pump home position is selected based on one or more parameters for a dispense operation.

Another embodiment of the present invention includes a multi-stage pumping system comprising a feed pump that has a feed diaphragm movable within a feed chamber, a dispense pump downstream of the feed pump that has a dispense diaphragm movable within a dispense chamber and a pump controller coupled to the feed pump and the dispense pump to control the feed pump and the dispense pump.

The dispense pump can have a maximum available volume that is the maximum volume of fluid that the dispense pump can hold in the dispense chamber. The controller can control the dispense pump to move the dispense diaphragm in the dispense chamber to reach a dispense pump home position to partially fill the dispense pump. The available volume for holding fluid at the dispense pump corresponding to the dispense pump home position is less than the maximum available volume of the dispense pump and is the greatest available volume for the dispense pump in a dispense cycle. By reducing the amount of fluid held by the dispense pump to the amount required by the

dispense pump in a particular dispense cycle (or some other reduced amount from the maximum available volume), the hold-up volume of fluid is reduced.

5 Another embodiment of the present invention includes a method for reducing the hold-up volume of a pump that comprises asserting pressure on the process fluid, partially filling a dispense pump to a dispense pump home position for a dispense cycle, and dispensing a dispense volume of the process fluid from the dispense pump to a wafer. The
10 dispense pump has an available volume corresponding to the dispense pump home position that is less than the maximum available volume of the dispense pump and is the greatest available volume at the dispense pump for the dispense cycle. The available volume corresponding to the dispense pump home
15 position of the dispense pump is at least the dispense volume.

Another embodiment of the present invention includes a computer program product for controlling a pump. The computer program product comprises software instructions stored on a computer readable medium that are executable by a processor.
20 The set of computer instructions can comprise instructions executable to direct a dispense pump to move a dispense diaphragm to reach a dispense pump home position to partially fill the dispense pump, and direct the dispense pump to dispense a dispense volume of the process fluid from the
25 dispense pump. The available volume of the dispense pump corresponding to the dispense pump home position is less than the maximum available volume of the dispense pump and is the greatest available volume for the dispense pump in a dispense cycle.

30 Embodiments of the present invention provide an advantage over prior art pump systems and methods by reducing the hold-up volume of the pump (single stage or multi-stage), thereby reducing stagnation of the process fluid.

Embodiments of the present invention provide another
35 advantage by reducing the waste of unused process fluids in small volume and test dispenses.

Embodiments of the present invention provide yet another advantage by providing for more efficient flushing of stagnant fluid.

5 Embodiments of the present invention provide yet another advantage by optimizing the effective range of a pump diaphragm.

BRIEF DESCRIPTION OF THE FIGURES

10 A more complete understanding of the present invention 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:

FIGURE 1 is a diagrammatic representation of a pumping system;

15 FIGURE 2 is a diagrammatic representation of a multi-stage pump;

FIGURES 3A-3G provide diagrammatic representations of one embodiment of a multi-stage pump during various stages of operation

20 FIGURES 4A-4C are diagrammatic representations of home positions for pumps running various recipes;

FIGURE 5A-5K are diagrammatic representations of another embodiment of a multi-stage pump during various stages of a dispense cycle;

25 FIGURE 6 is a diagrammatic representation of a user interface; and

FIGURE 7 is a flow chart illustrating one embodiment of a method for reducing hold-up volume at a multi-stage pump;

30 FIGURE 8 is a diagrammatic representation of a single stage pump.

DETAILED DESCRIPTION

Preferred embodiments of the invention are illustrated in the FIGURES, like numerals being used to refer to like and corresponding parts of the various drawings.

35 Embodiments of the present invention provide a system and method for reducing the hold-up volume of a pump. More particularly, embodiments of the present invention provide a

system and method for determining a home position to reduce hold-up volume at a dispense pump and/or a feed pump. The home position for the diaphragm can be selected such that the volume of the chamber at the dispense pump and/or feed pump contains sufficient fluid to perform the various steps of a dispense cycle while minimizing the hold-up volume. Additionally, the home position of the diaphragm can be selected to optimize the effective range of positive displacement.

FIGURE 1 is a diagrammatic representation of a pumping system 10. The pumping system 10 can include a fluid source 15, a pump controller 20 and a multiple stage ("multi-stage") pump 100, which work together to dispense fluid onto a wafer 25. The operation of multi-stage pump 100 can be controlled by pump controller 20, which can be onboard multi-stage pump 100 or connected to multi-stage pump 100 via one or more communications links for communicating control signals, data or other information. Pump controller 20 can include a computer readable medium 27 (e.g., RAM, ROM, Flash memory, optical disk, magnetic drive or other computer readable medium) containing a set of control instructions 30 for controlling the operation of multi-stage pump 100. A processor 35 (e.g., CPU, ASIC, RISC or other processor) can execute the instructions. In the embodiment of FIGURE 1, controller 20 communicates with multi-stage pump 100 via communications links 40 and 45. Communications links 40 and 45 can be networks (e.g., Ethernet, wireless network, global area network, DeviceNet network or other network known or developed in the art), a bus (e.g., SCSI bus) or other communications link. Pump controller 20 can include appropriate interfaces (e.g., network interfaces, I/O interfaces, analog to digital converters and other components) to allow pump controller 20 to communicate with multi-stage pump 100. Pump controller 20 includes a variety of computer components known in the art including processors, memories, interfaces, display devices, peripherals or other computer components. Pump controller 20 controls various valves and

motors in multi-stage pump to cause multi-stage pump to accurately dispense fluids, including low viscosity fluids (i.e., less than 5 centipoises) or other fluids. It should be noted that while FIGURE 1 uses the example of a multi-stage pump, pumping system 10 can also use a single stage pump.

FIGURE 2 is a diagrammatic representation of a 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 the 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. Dispense stage portion 110 can further include a pressure sensor 112 that determines the pressure of fluid at dispense stage 110.

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 feed motor 175. Lead screw 170 couples to feed 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 175 rotates a nut that, in turn, rotates 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. According to other embodiments, feed stage 105 and dispense stage 110 can each include a variety of other pumps including pneumatically actuated pumps, hydraulic pumps or other pumps. One example of a multi-stage pump using a pneumatically actuated pump for the feed stage and a stepper motor driven dispense pump is

described in United States Patent Application No 11/051,576, which is hereby fully incorporated by reference herein.

Feed motor 175 and dispense motor 200 can be any suitable motor. According to one embodiment, dispense motor 200 is a
5 Permanent-Magnet Synchronous Motor ("PMSM") with a position sensor 203. The PMSM can be controlled by a digital signal processor ("DSP") utilizing Field-Oriented Control ("FOC") at motor 200, a controller onboard multi-stage pump 100 or a separate pump controller (e.g. as shown in FIGURE 1).

10 Position sensor 203 can be an encoder (e.g., a fine line rotary position encoder) for real time feedback of motor 200's position. The use of position sensor 203 gives accurate and repeatable control of the position of piston 192, which leads to accurate and repeatable control over fluid movements in
15 dispense chamber 185. For, example, using a 2000 line encoder, it is possible to accurately measure to and control 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.

20 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. According to one embodiment, these valves can be pneumatically actuated (i.e., gas driven) diaphragm valves that open or close depending on whether pressure or a vacuum
25 is asserted. However, in other embodiments of the present invention, any suitable valve can be used.

In operation, the dispense cycle multi-stage pump 100 can include a ready segment, dispense segment, fill segment, pre-filtration segment, filtration segment, vent segment, purge
30 segment and static purge segment. Additional segments can also be included to account for delays in valve openings and closings. In other embodiments the dispense cycle (i.e., the series of segments between when multi-stage pump 100 is ready to dispense to a wafer to when multi-stage pump 100 is again
35 ready to dispense to wafer after a previous dispense) may require more or fewer segments and various segments can be performed in different orders. During the feed segment, inlet

valve 125 is opened and feed stage pump 150 moves (e.g., pulls) feed stage diaphragm 160 to draw fluid into feed chamber 155. Once a sufficient amount of fluid has filled feed chamber 155, inlet valve 125 is closed. During the filtration segment, feed-stage pump 150 moves feed stage diaphragm 160 to displace fluid from feed chamber 155. Isolation valve 130 and barrier valve 135 are opened to allow fluid to flow through filter 120 to dispense chamber 185. Isolation valve 130, according to one embodiment, can be opened first (e.g., in the "pre-filtration segment") to allow pressure to build in filter 120 and then barrier valve 135 opened to allow fluid flow into dispense chamber 185. Furthermore, pump 150 can assert pressure on the fluid before pump 180 retracts, thereby also causing the pressure to build.

At the beginning of the vent segment, isolation valve 130 is opened, barrier valve 135 closed and vent valve 145 opened. In another embodiment, barrier valve 135 can remain open during the vent segment and close at the end of the vent segment. Feed-stage pump 150 applies pressure to the fluid to remove air bubbles from filter 120 through open vent valve 145 by forcing fluid out the vent. Feed-stage pump 150 can be controlled to cause venting to occur at a predefined rate, allowing for longer vent times and lower vent rates, thereby allowing for accurate control of the amount of vent waste.

At the beginning of the purge segment, isolation valve 130 is closed, barrier valve 135, if it is open in the vent segment, is closed, vent valve 145 closed, and purge valve 140 opened. Dispense pump 180 applies pressure to the fluid in dispense chamber 185. The fluid can be routed out of multi-stage pump 100 or returned to the fluid supply or feed-pump 150. During the static purge segment, dispense pump 180 is stopped, but purge valve 140 remains open to relieve pressure built up during the purge segment. Any excess fluid removed during the purge or static purge segments can be routed out of multi-stage pump 100 (e.g., returned to the fluid source or discarded) or recycled to feed-stage pump 150. During the ready segment, all the valves can be closed.

During the dispense segment, outlet valve 147 opens and dispense pump 180 applies pressure to the fluid in dispense chamber 185. Because outlet valve 147 may react to controls more slowly than dispense pump 180, outlet valve 147 can be opened first and some predetermined period of time later dispense motor 200 started. This prevents dispense pump 180 from pushing fluid through a partially opened outlet valve 147. In other embodiments, the pump can be started before outlet valve 147 is opened or outlet valve 147 can be opened and dispense begun by dispense pump 180 simultaneously.

An additional suckback segment can be performed in which excess fluid in the dispense nozzle is removed by pulling the fluid back. During the suckback segment, outlet valve 147 can close and a secondary motor or vacuum can be used to suck excess fluid out of the outlet nozzle. Alternatively, outlet valve 147 can remain open and dispense motor 200 can be reversed to suck fluid back into the dispense chamber. The suckback segment helps prevent dripping of excess fluid onto the wafer.

FIGURES 3A-3G provide diagrammatic representations of multi-stage pump 100 during various segments of operation in which multi-stage pump 100 does not compensate for hold up volume. For the sake of example, it is assumed that dispense pump 180 and feed pump 150 each have a 20mL maximum available capacity, the dispense process dispenses 4mL of fluid, the vent segment vents .5mL of fluid and the purge segment (including static purge) purges 1mL of fluid and the suckback volume is 1mL. During the ready segment (FIGURE 3A), isolation valve 130 and barrier valve 135 are open while inlet valve 125, vent valve 145, purge valve 140 and outlet valve 147 are closed. Dispense pump 180 will be near its maximum volume (e.g., 19mL) (i.e., the maximum volume minus the 1mL purged from the previous cycle). During the dispense segment (FIGURE 3B), isolation valve 130, barrier valve 135, purge valve 140, vent valve 145 and inlet valve 125 are closed and outlet valve 147 is opened. Dispense pump 180 dispenses a predefined amount of fluid (e.g., 4mL). In this example, at

the end of the dispense segment, dispense pump 180 will have a volume of 15mL.

During the suckback segment (FIGURE 3C), some of the fluid (e.g., 1mL) dispensed during the dispense segment can be sucked back into dispense pump 180 to clear the dispense nozzle. This can be done, for example, by reversing the dispense motor. In other embodiments, the additional 1mL of fluid can be removed from the dispense nozzle by a vacuum or another pump. Using the example in which the 1mL is sucked back into dispense pump 180, after the suckback segment, dispense pump 180 will have a volume of 16mL.

In the feed segment (FIGURE 3D), outlet valve 147 is closed and inlet valve 125 is opened. Feed pump 150, in prior system, fills with fluid to its maximum capacity (e.g., 20mL). During the filtration segment, inlet valve 125 is closed and isolation valve 130 and barrier valve 135 opened. Feed pump 150 pushes fluid out of feed pump 150 through filter 120, causing fluid to enter dispense pump 180. In prior systems, dispense pump 180 is filled to its maximum capacity (e.g., 20mL) during this segment. During the dispense segment and continuing with the previous example, feed pump 150 will displace 4mL of fluid to cause dispense pump 180 to fill from 16mL (the volume at the end of the suckback segment) to 20mL (dispense pump 180's maximum volume). This will leave feed pump 150 with 16mL of volume.

During the vent segment (FIGURE 3F), barrier valve 135 can be closed or open and vent valve 145 is open. Feed pump 150 displaces a predefined amount of fluid (e.g., .5mL) to force excess fluid or gas bubbles accumulated at filter 120 out vent valve 145. Thus, at the end of the vent segment, in this example, feed pump 150 is at 15.5mL.

Dispense pump 180, during the purge segment (FIGURE 3G) can purge a small amount of fluid (e.g., 1mL) through open purge valve 140. The fluid can be sent to waste or re-circulated. At the end of the purge segment, multi-stage pump 100 is back to the ready segment, with the dispense pump at 19mL.

In the example of FIGURES 3A-3G, dispense pump 180 only uses 5mL of fluid, 4mL for the dispense segment (1mL of which is recovered in suckback) and 1mL for the purge segment.

Similarly, feed pump 150 only uses 4 to recharge dispense pump

180 in the filtration segment (4mL to recharge for the dispense segment minus 1mL recovered during suckback plus 1mL to recharge for the purge segment) and .5mL in the vent segment. Because both feed pump 150 and dispense pump 180 are filled to their maximum available volume (e.g., 20mL each) there is a relatively large hold-up volume. Feed pump 150, for example, has a hold-up volume of 15.5mL and dispense pump 180 has a hold-up volume of 15mL, for a combined hold-up volume of 30.5mL.

The hold-up volume is slightly reduced if fluid is not sucked back into the dispense pump during the suckback segment. In this case, the dispense pump 180 still uses 5mL of fluid, 4mL during the dispense segment and 1mL during the purge segment. However, feed pump 150, using the example above, must recharge the 1mL of fluid that is not recovered during suckback. Consequently feed pump 150 will have to recharge dispense pump 180 with 5mL of fluid during the filtration segment. In this case feed pump 150 will have a hold-up volume of 14.5mL and dispense pump 180 will have a hold up volume of 15mL.

Embodiments of the present invention reduce wasted fluid by reducing the hold-up volume. According to embodiments of the present invention, the home position of the feed and dispense pumps can be defined such that the fluid capacity of the dispense pump is sufficient to handle a given "recipe" (i.e., a set of factors affecting the dispense operation including, for example, a dispense rate, dispense time, purge volume, vent volume or other factors that affect the dispense operation), a given maximum recipe or a given set of recipes. The home position of a pump is the position of pump that has the greatest available volume for a given cycle. For example, the home position can be the diaphragm position that gives a greatest allowable volume during a dispense cycle. The

available volume corresponding to the home position of the pump will typically be less than the maximum available volume for the pump.

Using the example above, given the recipe in which the dispense segment uses 4mL of fluid, the purge segment 1mL, the vent segment .5mL and the suckback segment recovers 1mL of fluid, the maximum volume required by the dispense pump is:

$$V_{DMax} = V_D + V_P + e_1 \quad [EQN 1]$$

V_{DMax} = maximum volume required by dispense pump

V_D = volume dispensed during dispense segment

V_P = volume purged during purge segment

e_1 = an error volume applied to dispense pump

and the maximum volume required by feed pump 150 is:

$$V_{FMax} = V_D + V_P + V_V - V_{suckback} + e_2 \quad [EQN 2]$$

V_{FMax} = maximum volume required by dispense pump

V_D = volume dispensed during dispense segment

V_P = volume purged during purge segment

V_V = volume vented during vent segment

$V_{suckback}$ = volume recovered during suckback

e_2 = error volume applied to feed pump

Assuming no error volumes are applied and using the example above, $V_{DMax} = 4 + 1 = 5\text{mL}$ and $V_F \text{ max} = 4 + 1 + .5 - 1 = 4.5\text{mL}$. In cases in which dispense pump 180 does not recover fluid during suckback, the $V_{suckback}$ term can be set to 0 or dropped. e_1 and e_2 can be zero, a predefined volume (e.g., 1mL), calculated volumes or other error factor. e_1 and e_2 can have the same value or different values (assumed to be zero in the previous example).

Returning to FIGURES 3A-3G, and using the example of $V_{Dmax} = 5\text{mL}$ and $V_{Fmax} = 4.5\text{mL}$, during the ready segment (FIGURE 3A), dispense pump 180 will have a volume of 4mL and feed pump 150 will have a volume of 0mL. Dispense pump 180, during the dispense segment (FIGURE 3B), dispenses 4mL of fluid and recovers 1mL during the suckback segment (FIGURE 3C). During the feed segment (FIGURE 3D), feed pump 150 recharges to 4.5mL. During the filtration segment (FIGURE 3E), feed pump 150 can displace 4mL of fluid causing dispense pump 180 to fill to 5mL of fluid. Additionally, during the vent segment, feed pump 150 can vent .5mL of fluid (FIGURE 3F). Dispense

pump 180, during the purge segment (FIGURE 3G) can purge 1mL of fluid to return to the ready segment. In this example, there is no hold-up volume as all the fluid in the feed segment and dispense segment is moved.

5 For a pump that is used with several different dispense recipes, the home position, of the dispense pump and feed pump can be selected as the home position that can handle the largest recipe. Table 1, below, provides example recipes for a multi-stage pump.

10 **Table 1**

	RECIPE 2	RECIPE 3
Name:	Main Dispense 1	Main Dispense 2
Dispense Rate	1.5mL/sec	1mL/sec
Dispense Time	2 sec	2.5 sec
Resulting Volume	3mL	2.5mL
Purge	.5mL	.5mL
Vent	.25mL	.25mL
Predispen se Rate	1mL/sec	.5mL/sec
Predispen se Volume	1mL	.5mL

In the above examples, it is assumed that no fluid is recovered during suckback. It is also assumed that there is a pre-dispense cycle in which a small amount of fluid is dispensed from the dispense chamber. The pre-dispense cycle can be used, for example, to force some fluid through the dispense nozzle to clean the nozzle. According to one embodiment the dispense pump is not recharged between a pre-dispense and a main dispense. In this case:

$$V_D = V_{DPre} + V_{DMain}$$

[EQN. 3]

V_{DPre} = amount of pre-dispense dispense
 V_{DMain} = amount of main dispense

Accordingly, the home position of the dispense diaphragm
5 can be set for a volume of 4.5mL (3+1+.5) and the home
position of the feed pump can be set to 4.75mL (3+1+.5+.25).
With these home positions, dispense pump 180 and feed pump 150
will have sufficient capacity for Recipe 1 or Recipe 2.

According to another embodiment, the home position of the
10 dispense pump or feed pump can change based on the active
recipe or a user-defined position. If a user adjusts a recipe
to change the maximum volume required by the pump or the pump
adjusts for a new active recipe in a dispense operation, say
by changing Recipe 2 to require 4mL of fluid, the dispense
15 pump (or feed pump) can be adjusted manually or automatically.
For example, the dispense pump diaphragm position can move to
change the capacity of the dispense pump from 3mL to 4mL and
the extra 1mL of fluid can be added to the dispense pump. If
the user specifies a lower volume recipe, say changing Recipe
20 2 to only require 2.5mL of fluid, the dispense pump can wait
until a dispense is executed and refill to the new lower
required capacity.

The home position of the feed pump or dispense pump can
also be adjusted to compensate for other issues such as to
25 optimize the effective range of a particular pump. The
maximum and minimum ranges for a particular pump diaphragm
(e.g., a rolling edge diaphragm, a flat diaphragm or other
diaphragm known in the art) can become nonlinear with
displacement volume or force to drive the diaphragm because
30 the diaphragm can begin to stretch or compress for example.
The home position of a pump can be set to a stressed position
for a large fluid capacity or to a lower stress position where
the larger fluid capacity is not required. To address issues
of stress, the home position of the diaphragm can be adjusted
35 to position the diaphragm in an effective range.

As an example, dispense pump 180 that has a 10mL capacity
may have an effective range between 2 and 8mL. The effective
range can be defined as the linear region of a dispense pump

where the diaphragm does not experience significant loading. FIGURES 4A-C provide diagrammatic representations of three examples of setting the home position of a dispense diaphragm (e.g., dispense diaphragm 190 of FIGURE 2) for a 10mL pump having a 6mL effective range between 2mL and 8mL. It should be noted that in these examples, 0mL indicates a diaphragm position that would cause the dispense pump to have a 10mL available capacity and a 10mL position would cause the dispense pump to have a 0mL capacity. In other words, the 0mL-10mL scale refers to the displaced volume.

FIGURE 4A provides a diagrammatic representation of the home positions for a pump that runs recipes having a $V_{DMax} = 3\text{mL}$ maximum volume and a $V_{Dmax} = 1.5\text{mL}$ maximum volume for a pump that has a 6mL non-stressed effective range (e.g., between 8mL and 2mL). In this example, the diaphragm of the dispense pump can be set so that the volume of the dispense pump is 5mL (represented at 205). This provides sufficient volume for the 3mL dispense process while not requiring use of 0mL to 2mL or 8mL to 10mL region that causes stress. In this example, the 2mL volume of the lower-volume less effective region (i.e., the less effective region in which the pump has a lower available volume) is added to the largest V_{DMax} for the pump such that the home position is $3\text{mL} + 2\text{mL} = 5\text{mL}$. Thus, the home position can account for the non-stressed effective region of the pump.

FIGURE 4B provides a diagrammatic representation of a second example. In this second example, the dispense pump runs an 8mL maximum volume dispense process and a 3mL maximum volume dispense process. In this case, some of the less effective region must be used. Therefore, the diaphragm home position can be set to provide a maximum allowable volume of 8mL (represented at 210) for both processes (i.e., can be set at a position to allow for 8mL of fluid). In this case, the smaller volume dispense process will occur entirely within the effective range.

In the example of FIGURE 4B, the home position is selected to utilize the lower-volume less effective region

(i.e., the less-effective region that occurs when the pump is closer to empty). In other embodiments, the home position can be in the higher-volume less effective region. However, this will mean that part of the lower volume dispense will occur in the less-effective region and, in the example of FIGURE 4B, there will be some hold-up volume.

In the third example of FIGURE 4C, the dispense pump runs a 9mL maximum volume dispense process and a 4mL maximum volume dispense process. Again, a portion of the process will occur in the less effective range. The dispense diaphragm, in this example, can be set to a home position of to provide a maximum allowable volume of 9mL (e.g., represented at 215). If, as described above, the same home position is used for each recipe, a portion of the 4mL dispense process will occur in the less effective range. According to other embodiments, the home position can reset for the smaller dispense process into the effective region.

In the above examples, there is some hold-up volume for the smaller volume dispense processes to prevent use of the less effective region in the pump. The pump can be setup so that the pump only uses the less effective region for larger volume dispense process where flow precision is less critical. These features make it possible to optimize the combination of (i) low volume with higher precision and (ii) high volume with lower precision. The effective range can then be balanced with the desired hold-up volume.

As discussed in conjunction with FIGURE 2, dispense pump 180 can include a dispense motor 200 with a position sensor 203 (e.g., a rotary encoder). Position sensor 203 can provide feedback of the position of lead screw 195 and, hence, the position of lead screw 195 will correspond to a particular available volume in dispense chamber 185 as the lead screw displaces diaphragm. Consequently, the pump controller can select a position for the lead screw such that the volume in the dispense chamber is at least V_{DMax} .

According to another embodiment, the home position can be user selected or user programmed. For example, using a

graphical user interface or other interface, a user can program a user selected volume that is sufficient to carry out the various dispense processes or active dispense process by the multi-stage pump. According to one embodiment, if the user selected volume is less than $V_{\text{Dispense}} + V_{\text{Purge}}$, an error can be returned. The pump controller (e.g., pump controller 20) can add an error volume to the user specified volume. For example, if the user selects 5cc as the user specified volume, pump controller 20 can add 1cc to account for errors. Thus, pump controller will select a home position for dispense pump 180 that has corresponding available volume of 6cc.

This can be converted into a corresponding lead screw position that can be stored at pump controller 20 or an onboard controller. Using the feedback from position sensor 203, dispense pump 180 can be accurately controlled such that at the end of the filtration cycle, dispense pump 180 is at its home position (i.e., its position having the greatest available volume for the dispense cycle). It should be noted that feed pump 150 can be controlled in a similar manner using a position sensor.

According to another embodiment, dispense pump 180 and/or feed pump 150 can be driven by a stepper motor without a position sensor. Each step or count of a stepper motor will correspond to a particular displacement of the diaphragm. Using the example of FIGURE 2, each count of dispense motor 200 will displace dispense diaphragm 190 a particular amount and therefore displace a particular amount of fluid from dispense chamber 185. If $C_{\text{fullstroked}}$ is the counts to displace dispense diaphragm from the position in which dispense chamber 185 has its maximum volume (e.g., 20mL) to 0mL (i.e., the number of counts to move dispense diaphragm 190 through its maximum range of motion), C_p is the number of counts to displace V_p and C_D is the number of counts to displace V_D , then the home position of stepper motor 200 can be:

$$C_{\text{HomeD}} = C_{\text{fullstroked}} - (C_p + C_D + C_{e1}) \quad [\text{EQN 3}]$$

where C_{e1} is a number of counts corresponding to an error volume.

Similarly, if $C_{fullstrokeF}$ is the counts to displace feed diaphragm 160 from the position in which dispense chamber 155 has its maximum volume (e.g., 20mL) to 0mL (i.e., the number of counts to move dispense diaphragm 160 through its maximum range of motion), C_s is the number of counts at the feed motor 175 corresponding to $V_{suckback}$ recovered at dispense pump 180 and C_v is the number of counts at feed motor 175 to displace V_v , the home position of feed motor 175 can be:

$$C_{HomeF} = C_{fullstrokeF} - (C_p + C_d - C_s + C_{e2}) \quad [EQN\ 4]$$

where C_{e2} is a number of counts corresponding to an error volume.

FIGURES 5A-5K provide diagrammatic representations of various segments for a multi-stage pump 500 according to another embodiment of the present invention. Multi-stage pump 500, according to one embodiment, includes a feed stage pump 501 ("feed pump 501"), a dispense stage pump 502 ("dispense pump 502"), a filter 504, an inlet valve 506 and an outlet valve 508. Inlet valve 506 and outlet valve 508 can be three-way valves. As will be described below, this allows inlet valve 506 to be used both as an inlet valve and isolation valve and outlet valve 508 to be used as an outlet valve and purge valve.

Feed pump 501 and dispense pump 502 can be motor driven pumps (e.g., stepper motors, brushless DC motors or other motor). Shown at 510 and 512, respectively, are the motor positions for the feed pump 501 and dispense pump 502. The motor positions are indicated by the corresponding amount of fluid available in the feed chamber or dispense chamber of the respective pump. In the example of FIGURES 5A-5K, each pump has a maximum available volume of 20 cc. For each segment, the fluid movement is depicted by the arrows.

FIGURE 5A is a diagrammatic representation of multi-stage pump 500 at the ready segment. In this example, feed pump 501 has a motor position that provides for 7 cc of available volume and dispense pump 502 has a motor position that provides for 6 cc of available volume. During the dispense segment (depicted in FIGURE 5B), the motor of dispense pump

502 moves to displace 5.5cc of fluid through outlet valve 508. The dispense pump recovers .5cc of fluid during the suckback segment (depicted in FIGURE 5C). During the purge segment (shown in FIGURE 5D), dispense pump 502 displaces 1cc of fluid through outlet valve 508. During the purge segment, the motor of dispense pump 502 can be driven to a hard stop (i.e., to 0cc of available volume). This can ensure that the motor is backed the appropriate number of steps in subsequent segments.

In the vent segment (shown in FIGURE 5E), feed pump 501 can push a small amount of fluid through filter 502. During the dispense pump delay segment (shown in FIGURE 5F), feed pump 501 can begin pushing fluid to dispense pump 502 before dispense pump 502 recharges. This slightly pressurizes fluid to help fill dispense pump 502 and prevents negative pressure in filter 504. Excess fluid can be purged through outlet valve 508.

During the filtration segment (shown in FIGURE 5G), outlet valve 508 is closed and fluid fills dispense pump 502. In the example shown, 6cc of fluid is moved by feed pump 501 to dispense pump 502. Feed pump 501 can continue to assert pressure on the fluid after the dispense motor has stopped (e.g., as shown in the feed delay segment of FIGURE 5H). In the example of FIGURE 5H, there is approximately .5 cc of fluid left in feed pump 501. According to one embodiment, feed pump 501 can be driven to a hard stop (e.g., with 0cc of available volume), as shown in FIGURE 5I. During the feed segment (depicted in FIGURE 5J), feed pump 501 is recharged with fluid and multi-stage pump 500 returns to the ready segment (shown in FIGURE 5K and 5A).

In the example of FIGURE 5A-5K the purge segment occurs immediately after the suckback segment to bring dispense pump 502 to a hardstop, rather than after the vent segment as in the embodiment of FIGURE 2. The dispense volume is 5.5 cc, the suckback volume .5cc and purge volume 1 cc. Based on the sequence of segments, the largest volume required by dispense pump 502 is:

$$V_{DMax} = V_{Dispesne} + V_{Purge} - V_{Suckback} + e_1 \quad [EQN \ 5]$$

If dispense pump 502 utilizes a stepper motor, a specific number of counts will result in a displacement of V_{DMax} . By backing the motor from a hardstop position (e.g., 0 counts) the number of counts corresponding to V_{DMax} , dispense pump will have an available volume of V_{DMax} .

For feed pump 501, V_{Vent} is .5 cc, and there is an additional error volume of .5 cc to bring feed pump 501 to a hardstop. According to EQN 2:

$$V_{FMax}=5.5+1+.5-.5+.5$$

In this example, V_{FMax} is 7cc. If feed pump 501 uses a stepper motor, the stepper motor, during the recharge segment can be backed from the hardstop position the number of counts corresponding to 7cc. In this example, feed pump 501 utilized 7 cc of a maximum 20cc and feed pump 502 utilized 6 cc of a maximum 20cc, thereby saving 27cc of hold-up volume.

FIGURE 6 is a diagrammatic representation illustrating a user interface 600 for entering a user defined volume. In the example of FIGURE 6, a user, at field 602, can enter a user defined volume, here 10.000mL. An error volume can be added to this (e.g., 1mL), such that the home position of the dispense pump has a corresponding available volume of 11mL. While FIGURE 6 only depicts setting a user selected volume for the dispense pump, the user, in other embodiments, can also select a volume for the feed pump.

FIGURE 7 is a diagrammatic representation of one embodiment of a method for controlling a pump to reduce the hold-up volume. Embodiments of the present invention can be implemented, for example, as software programming executable by a computer processor to control the feed pump and dispense pump.

At step 702, the user enters one or more parameters for a dispense operation, which may include multiple dispense cycles, including, for example, the dispense volume, purge volume, vent volume, user specified volumes for the dispense pump volume and/or feed pump and other parameters. The parameters can include parameters for various recipes for different dispense cycles. The pump controller (e.g., pump

controller 20 of FIGURE 1) can determine the home position of the dispense pump based on a user specified volume, dispense volume, purge volume or other parameter associated with the dispense cycle. Additionally, the choice of home position can be based on the effective range of motion of the dispense diaphragm. Similarly, the pump controller can determine the feed pump home position.

During a feed segment, the feed pump can be controlled to fill with a process fluid. According to one embodiment, the feed pump can be filled to its maximum capacity. According to another embodiment, the feed pump can be filled to a feed pump home position (step 704). During the vent segment the feed pump can be further controlled to vent fluid having a vent volume (step 706).

During the filtration segment, the feed pump is controlled to assert pressure on the process fluid to fill the dispense pump until the dispense pump reaches its home position. The dispense diaphragm in the dispense pump is moved until the dispense pump reaches the home position to partially fill the dispense pump (i.e., to fill the dispense pump to an available volume that is less than the maximum available volume of the dispense pump) (step 708). If the dispense pump uses a stepper motor, the dispense diaphragm can first be brought to a hard stop and the stepper motor reversed a number of counts corresponding to the dispense pump home position. If the dispense pump uses a position sensor (e.g., a rotary encoder), the position of the diaphragm can be controlled using feedback from the position sensor.

The dispense pump can then be directed purge a small amount of fluid (step 710). The dispense pump can be further controlled to dispense a predefined amount of fluid (e.g., the dispense volume) (step 712). The dispense pump can be further controlled to suckback a small amount of fluid or fluid can be removed from a dispense nozzle by another pump, vacuum or other suitable mechanism. It should be noted that steps of FIGURE 7 can be performed in a different order and repeated as needed or desired.

While primarily discussed in terms of a multi-stage pump, embodiments of the present invention can also be utilized in single stage pumps. FIGURE 8 is a diagrammatic representation of one embodiment of a single stage pump 800. Single stage pump 800 includes a dispense pump 802 and filter 820 between dispense pump 802 and the dispense nozzle 804 to filter impurities from the process fluid. A number of valves can control fluid flow through single stage pump 800 including, for example, purge valve 840 and outlet valve 847.

Dispense pump 802 can include, for example, a dispense chamber 855 to collect fluid, a diaphragm 860 to move within dispense chamber 855 and displace fluid, a piston 865 to move dispense stage diaphragm 860, a lead screw 870 and a dispense motor 875. Lead screw 870 couples to motor 875 through a nut, gear or other mechanism for imparting energy from the motor to lead screw 870. According to one embodiment, feed motor 875 rotates a nut that, in turn, rotates lead screw 870, causing piston 865 to actuate. According to other embodiments, dispense pump 802 can include a variety of other pumps including pneumatically actuated pumps, hydraulic pumps or other pumps.

Dispense motor 875 can be any suitable motor. According to one embodiment, dispense motor 875 is a PMSM with a position sensor 880. The PMSM can be controlled by a DSP FOC at motor 875, a controller onboard pump 800 or a separate pump controller (e.g. as shown in FIGURE 1). Position sensor 880 can be an encoder (e.g., a fine line rotary position encoder) for real time feedback of motor 875's position. The use of position sensor 880 gives accurate and repeatable control of the position of dispense pump 802.

The valves of single stage pump 800 are opened or closed to allow or restrict fluid flow to various portions of single stage pump 800. According to one embodiment, 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. However, in other embodiments of the present invention, any suitable valve can be used.

In operation, the dispense cycle of single stage pump 100 can include a ready segment, filtration/dispense segment, vent/purge segment and static purge segment. Additional segments can also be included to account for delays in valve openings and closings. In other embodiments the dispense cycle (i.e., the series of segments between when single stage pump 800 is ready to dispense to a wafer to when single stage pump 800 is again ready to dispense to wafer after a previous dispense) may require more or fewer segments and various segments can be performed in different orders.

During the feed segment, inlet valve 825 is opened and dispense pump 802 moves (e.g., pulls) diaphragm 860 to draw fluid into dispense chamber 855. Once a sufficient amount of fluid has filled dispense chamber 855, inlet valve 825 is closed. During the dispense/filtration segment, pump 802 moves diaphragm 860 to displace fluid from dispense chamber 855. Outlet valve 847 is opened to allow fluid to flow through filter 820 out nozzle 804. Outlet valve 847 can be opened before, after or simultaneous to pump 802 beginning dispense.

At the beginning of the purge/vent segment, purge valve 840 is opened and outlet valve 847 closed. Dispense pump 802 applies pressure to the fluid to move fluid through open purge valve 840. The fluid can be routed out of single stage pump 800 or returned to the fluid supply or dispense pump 802. During the static purge segment, dispense pump 802 is stopped, but purge valve 140 remains open to relieve pressure built up during the purge segment.

An additional suckback segment can be performed in which excess fluid in the dispense nozzle is removed by pulling the fluid back. During the suckback segment, outlet valve 847 can close and a secondary motor or vacuum can be used to suck excess fluid out of the outlet nozzle 804. Alternatively, outlet valve 847 can remain open and dispense motor 875 can be reversed to suck fluid back into the dispense chamber. The suckback segment helps prevent dripping of excess fluid onto the wafer.

It should be noted that other segments of a dispense cycle can also be performed and the single stage pump is not limited to performing the segments described above in the order described above. For example, if dispense motor 875 is
5 a stepper motor, a segment can be added to bring the motor to a hard stop before the feed segment. Moreover, the combined segments (e.g., purge/vent) can be performed as separate segments. According to other embodiments, the pump may not perform the suckback segment. Additionally, the single stage
10 pump can have different configurations. For example, the single stage pump may not include a filter or rather than having a purge valve, can have a check valve for outlet valve 147.

According to one embodiment of the present invention,
15 during the fill segment, dispense pump 802 can be filled to home position such that dispense chamber 855 has sufficient volume to perform each of the segments of the dispense cycle. In the example given above, the available volume corresponding to the home position would be at least the dispense volume
20 plus the purge volume (i.e., the volume released during the purge/vent segment and static purge segment). Any suckback volume recovered into dispense chamber 855 can be subtracted from the dispense volume and purge volume. As with the multi-stage pump, the home position can be determined based on one
25 or more recipes or a user specified volume. The available volume corresponding to the dispense pump home position is less than the maximum available volume of the dispense pump and is the greatest available volume for the dispense pump in a dispense cycle.

30 While the present invention has been described with reference to particular embodiments, it should be understood that the embodiments are illustrative and that the scope of the invention is not limited to these embodiments. Many variations, modifications, additions and improvements to the
35 embodiments described above are possible. It is contemplated that these variations, modifications, additions and

improvements fall within the scope of the invention as detailed in the following claims.

WHAT IS CLAIMED IS:

1. A pumping system comprising:

a dispense pump, wherein the dispense pump has a maximum available volume, the dispense pump further comprising
5 a dispense diaphragm movable within a dispense chamber; and
a pump controller coupled to the dispense pump, the pump controller operable to:

control the dispense pump to move the dispense diaphragm in the dispense chamber to reach a dispense pump
10 home position to partially fill the dispense pump, wherein an available volume corresponding to the dispense pump home position is less than the maximum available volume of the dispense pump and is the greatest available volume for the dispense pump in a dispense cycle and wherein the dispense
15 pump home position is selected based on one or more parameters for the dispense operation;

control the dispense pump to dispense the process fluid from the dispense pump.

20 2. The system of Claim 1, further comprising:

a filter downstream of the dispense pump;
an inlet valve upstream of the dispense pump;
a purge valve downstream of the filter; and
an outlet valve downstream of the filter.

25 3. The system of Claim 1, further comprising:

a filter downstream of the feed pump and upstream of the dispense pump;
an inlet valve upstream of the feed pump;
30 an isolation valve between the feed pump and the filter;
a barrier valve between the filter and the dispense pump;
a purge valve downstream of the dispense pump; and
an outlet valve downstream of the dispense pump.

35 4. The system of Claim 1, wherein the controller is

further operable to control the dispense pump to purge a purge volume of fluid and wherein the available volume corresponding

to the dispense pump home position is at least a dispense volume plus the purge volume.

5 5. The system of Claim 1, wherein the dispense pump further comprises a dispense motor to move the dispense diaphragm and wherein the controller is further operable to:

 control the dispense pump to move the dispense diaphragm to a hard stop prior to partially filling the dispense pump;

10 control the dispense pump to move the dispense diaphragm from the hard stop position to the dispense pump home position by reversing the stepper motor a corresponding number of steps.

15 6. The system of Claim 1, wherein the dispense pump further comprises:

 a dispense motor to move the dispense diaphragm;

 a position sensor to indicate the position of the dispense motor.

20

 7. The system of Claim 6, wherein the position sensor is a linear encoder.

 8. The system of Claim 6, wherein the position sensor is a rotary encoder.

25

 9. The system of Claim 6, wherein the controller is further operable to control the dispense motor to move the dispense diaphragm from a first position to the dispense pump home position.

30

 10. The system of Claim 9, wherein the controller is further operable to stop the dispense diaphragm at the home position based on feedback from the position sensor.

35

11. The system of Claim 1, further comprising:
a feed pump comprising a feed diaphragm movable
within a feed chamber; and
wherein the pump controller is connected to the feed
5 pump and operable to control the feed pump to assert a
pressure on the process fluid to provide the process fluid to
the dispense pump.

12. The system of Claim 11, wherein the controller is
10 further operable to control the feed pump to move the feed
diaphragm to a feed pump home position to partially fill the
feed pump.

13. The system of Claim 12, wherein the controller is
15 further operable to control the feed pump to vent a vent
volume of fluid.

14. The system of Claim 13, wherein an available volume
of the feed pump when the feed diaphragm is at the feed pump
20 home position is at least equal to a dispense volume, the vent
volume and a purge volume.

15. The system of Claim 1, wherein the available volume
of the dispense pump corresponding to the dispense pump home
25 position is at least equal to a user specified volume.

16. The system of Claim 15, wherein the controller is
further operable to:
receive a user specified volume; and
30 add an error volume to the user specified
volume to determine the available volume of the dispense pump
corresponding to the dispense pump home position.

17. The system of Claim 1, further comprising:
35 a feed pump comprising a feed diaphragm movable
within a feed chamber; and

wherein the pump controller is connected to the feed pump and operable to:

control the feed pump to assert a pressure on the process fluid to provide the process fluid to the dispense pump;

5 receive a user specified volume for the feed pump;

add an error volume to the user specified volume to determine the available volume of the feed pump corresponding to the feed pump home position.

10 18. The system of Claim 1, wherein the dispense pump home position is selected to utilize the effective region of the dispense diaphragm.

15 19. A method for reducing hold-up volume of a process fluid in a pump system comprising:

providing a process fluid to a dispense pump;

selecting a dispense pump home position for the dispense pump based on one or more parameters for the dispense operation;

20 partially filling a dispense pump to a dispense pump home position for a dispense cycle, wherein the dispense pump has an available volume corresponding to the dispense pump home position that is less than the maximum available volume of the dispense pump and is the greatest available volume at the
25 dispense pump for the dispense cycle;

dispensing the process fluid from the dispense pump to a wafer, wherein a dispense volume of process fluid is dispensed from the dispense pump with at least a portion of the dispense volume being dispensed to the wafer, and wherein the available
30 volume corresponding to the dispense pump home position of the dispense pump is at least the dispense volume.

20. The method of Claim 19, further comprising purging a purge volume of fluid from the dispense pump.

35

21. The method of Claim 20, wherein the available volume of the dispense pump corresponding to the dispense pump home

position is at least the dispense volume plus the purge volume.

5 22. The method of Claim 21, wherein purging occurs in the dispense cycle prior to dispensing.

 23. The method of Claim 19, wherein purging occurs in the dispense cycle subsequent to dispensing.

10 24. The method of Claim 19, further comprising:
 partially filling a feed pump to a feed pump home position, wherein the feed pump has an available volume corresponding to the feed pump home position that is less than the maximum available volume of the feed pump and the greatest
15 available volume for the feed pump during the dispense cycle and wherein the available volume corresponding to the feed pump home position is at least the dispense volume.

 25. The method of Claim 24, further comprising venting a
20 vent volume of process fluid, wherein the available volume corresponding to the feed pump home position is at least the vent volume plus the dispense volume.

 26. The method of Claim 25, further comprising purging a
25 purge volume of process fluid from the dispense pump, wherein the available volume corresponding to the feed pump home position is at least the vent volume plus the dispense volume plus the purge volume.

30 27. The method of Claim 26, further comprising sucking back a suckback volume of process fluid at the dispense pump, wherein the available volume at the feed pump corresponding to the feed pump home position is at least the vent volume plus the dispense volume plus the purge volume minus the suckback
35 volume.

28. The method of Claim 19, further comprising selecting the dispense pump home position based on the effective range of the dispense diaphragm.

5 29. A computer program product comprising a set of computer instructions stored on a computer readable medium, the computer instructions comprising instructions executable by a processor to:

10 receive one or more parameters for a dispense operation;
 select a dispense pump home position for a dispense pump based on the one or more parameters;
 direct a dispense pump to move a dispense diaphragm to reach the dispense pump home position to
15 partially fill the dispense pump with a process fluid, wherein an available volume corresponding to the dispense pump home position is less than the maximum available volume of the dispense pump and is the greatest available volume for the dispense pump in a dispense cycle;
20 direct the dispense pump to dispense the process fluid from the dispense pump.

25 30. The computer program product of Claim 29, wherein the set of computer instructions further comprise instructions executable to direct the dispense pump to purge a purge volume of fluid, wherein the available volume of the dispense pump corresponding to the dispense pump home position is at least a dispense volume plus the purge volume.

30 31. The computer program product of Claim 29, wherein the set of computer instructions further comprise instructions executable to:

 direct the dispense pump to move the dispense diaphragm to a hard stop prior to partially filling the
35 dispense pump;

 direct the dispense pump to move the dispense diaphragm from the hard stop position to the dispense pump

home position by reversing the stepper motor a corresponding number of steps.

5 32. The computer program product of Claim 29, wherein the set of computer instructions further comprise instructions executable to control the dispense motor to move the dispense diaphragm from a first position to the dispense diaphragm home position.

10 33. The computer program product of Claim 32, wherein the set of computer instructions further comprise instructions executable to:

 receive feedback from a position sensor at the dispense pump; and

15 stop the dispense diaphragm at the home position based on the feedback from the position sensor.

 34. The computer program product of Claim 29, wherein the set of computer instructions further comprise instructions executable to:

20 direct a feed pump to assert pressure on the process fluid to provide the process fluid to the dispense pump;

 direct the feed pump to move a feed diaphragm to a feed stage home position to partially fill the feed pump.

25 35. The computer program product of Claim 34, wherein the set of computer instructions further comprise instructions executable to direct the feed pump to vent a vent volume of fluid.

30 36. The computer program product of Claim 35, wherein an available volume of the feed pump when the feed diaphragm is at the feed stage home position is at least equal to the dispense volume plus the vent volume plus a purge volume.

35 37. The computer program product of Claim 29, wherein the available volume of the dispense pump when the dispense

diaphragm is at the dispense pump home position is at least equal to a user specified dispense pump volume.

5 38. The computer program product of Claim 37, wherein the one or more parameters for the dispense operation include user specified dispense pump volume and wherein the set of computer instructions further comprise instructions executable to:

10 add an error volume to the user specified dispense pump volume to determine the available volume corresponding to the dispense diaphragm home position.

15 39. The computer program product of Claim 29, wherein an available volume of the feed pump when the feed pump is at the feed pump home position is at least equal to a user specified feed pump volume.

20 40. The computer program product of Claim 38, wherein the one or more parameters for the dispense operation include the user specified feed pump volume and wherein the set of computer instructions further comprise instructions executable to:

25 add an error volume to the user specified feed pump volume to determine the available volume corresponding to the dispense diaphragm home position.

30 41. The computer program product of Claim 29, wherein the set of computer instructions further comprise instructions executable to select the dispense pump home position to utilize the effective range of the dispense diaphragm.