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(54) **SINGLE WAFER DRYER AND DRYING METHODS**

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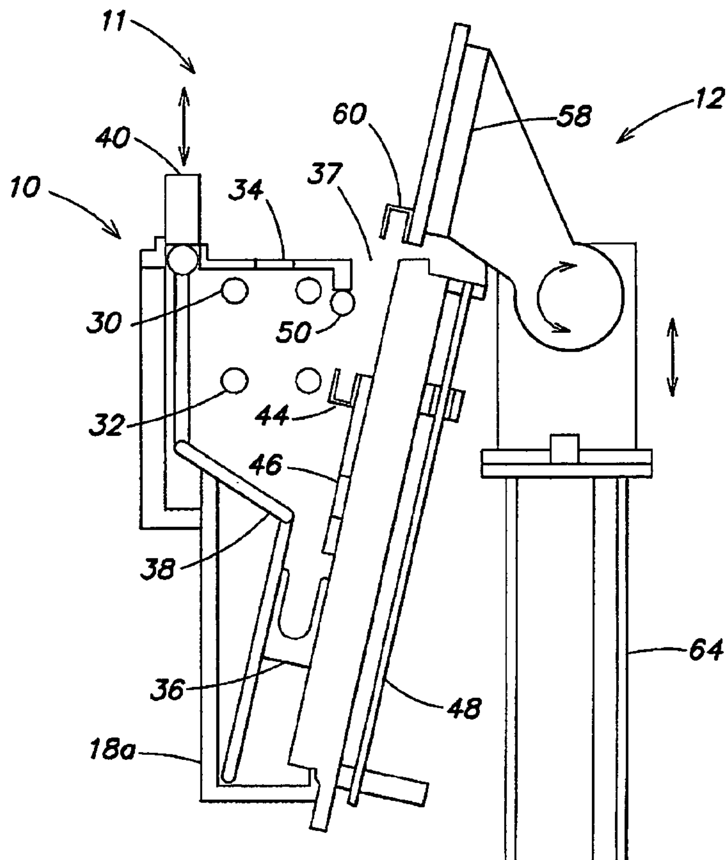
Publication Classification

(51) **Int. Cl.**[7] **B08B 3/00**

(52) **U.S. Cl.** **134/103.2**

(57) **ABSTRACT**

In a first aspect, a module is provided that is adapted to process a wafer. The module includes a processing portion having one or more features such as (1) a rotatable wafer support for rotating an input wafer from a first orientation wherein the wafer is in line with a load port to a second orientation wherein the wafer is in line with an unload port; (2) a catcher adapted to contact and travel passively with a wafer as it is unloaded from the processing portion; (3) an enclosed output portion adapted to create a laminar air flow from one side thereof to the other; (4) an output portion having a plurality of wafer receivers; (5) submerged fluid nozzles; and/or (6) drying gas flow deflectors, etc. Other aspects include methods of wafer processing.



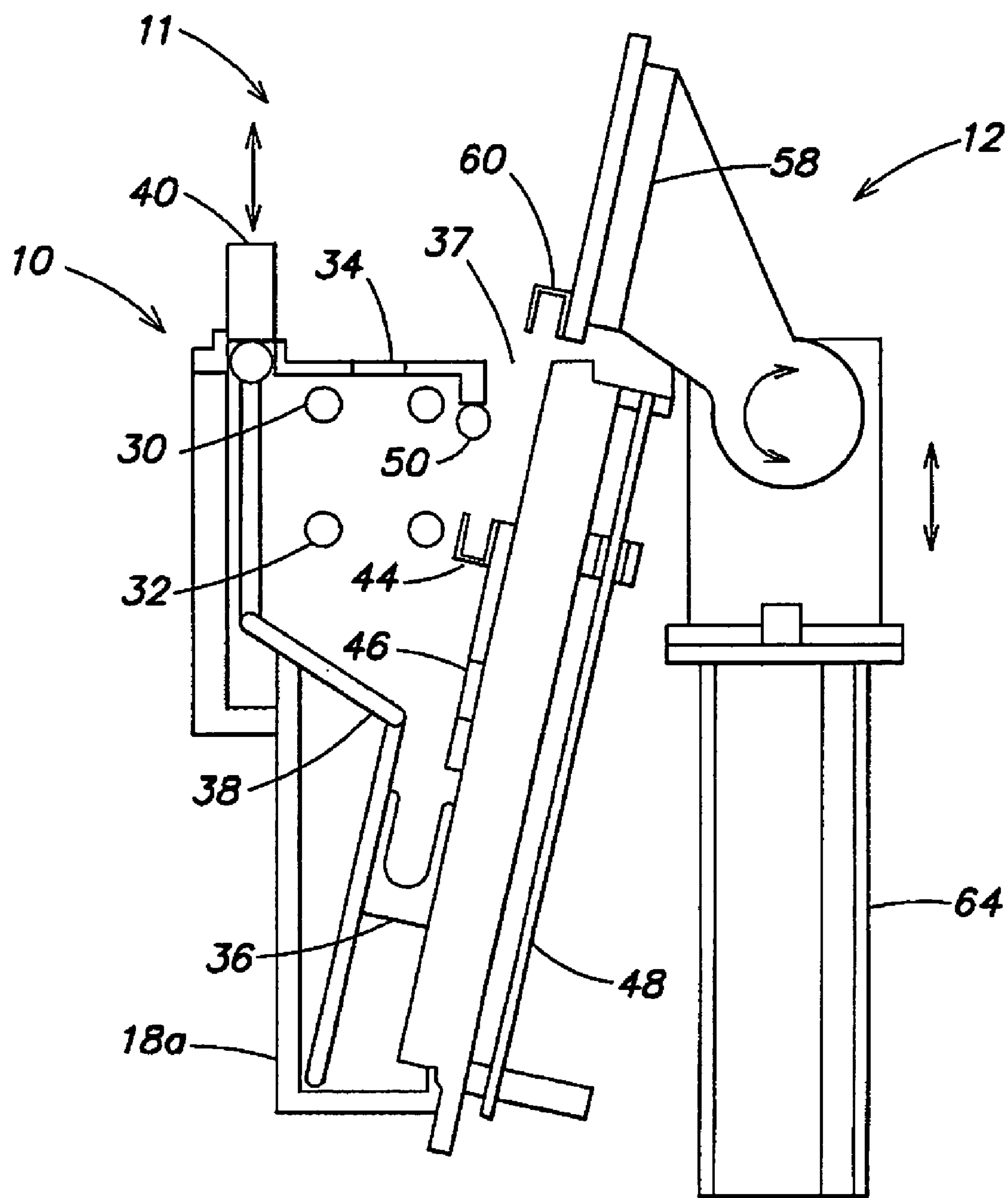


FIG. 1

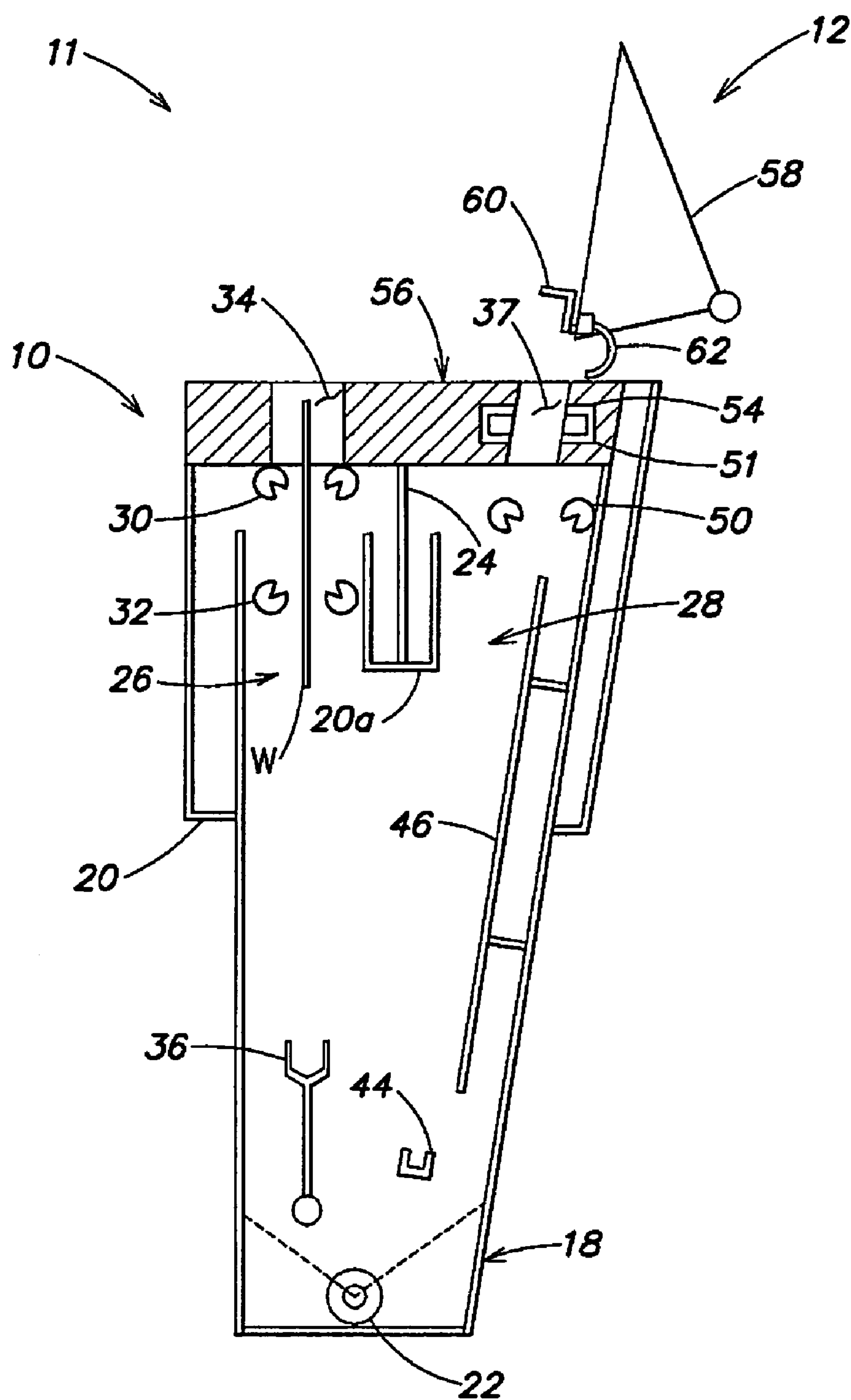


FIG. 2A

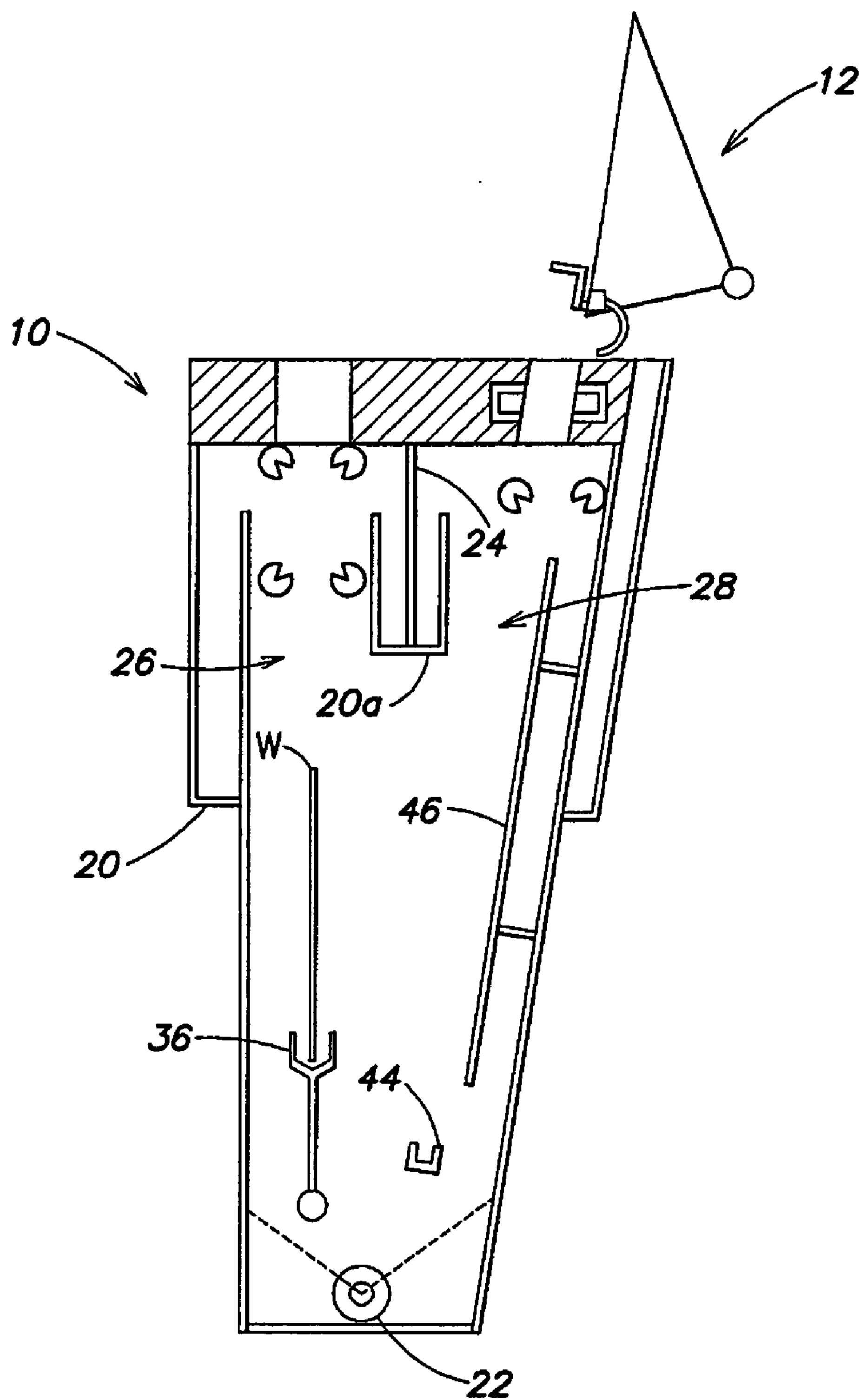


FIG. 2B

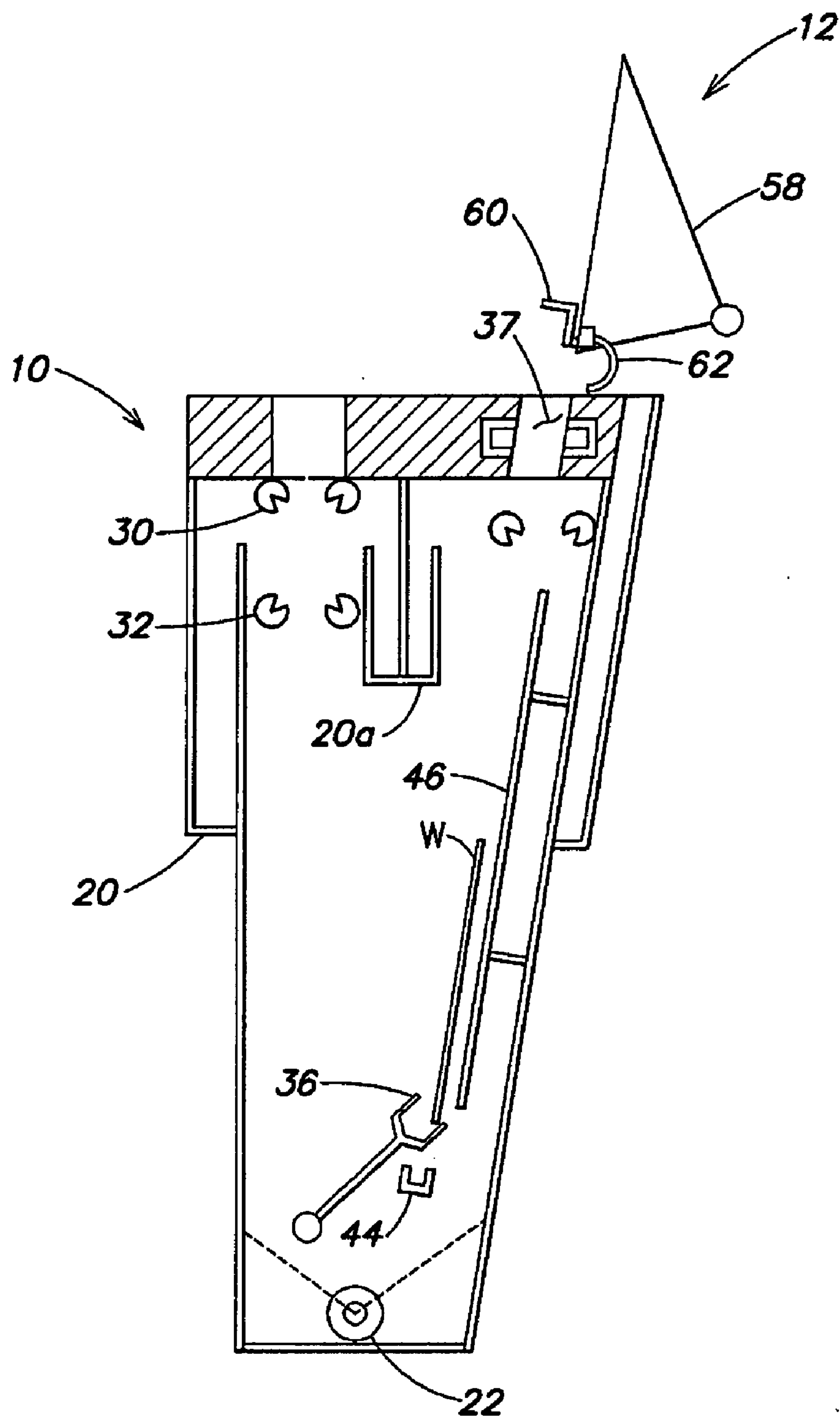


FIG. 2C

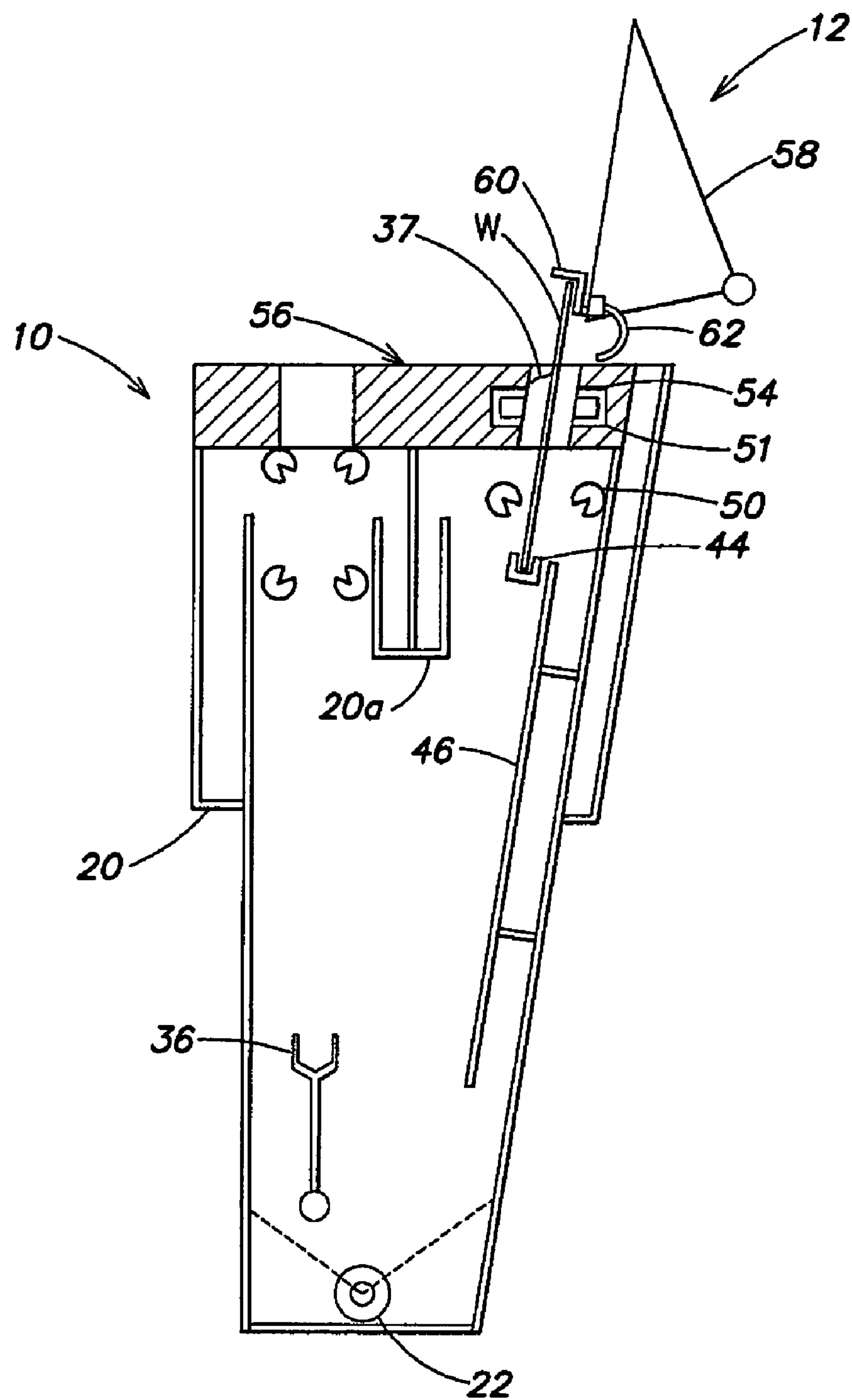


FIG. 2D

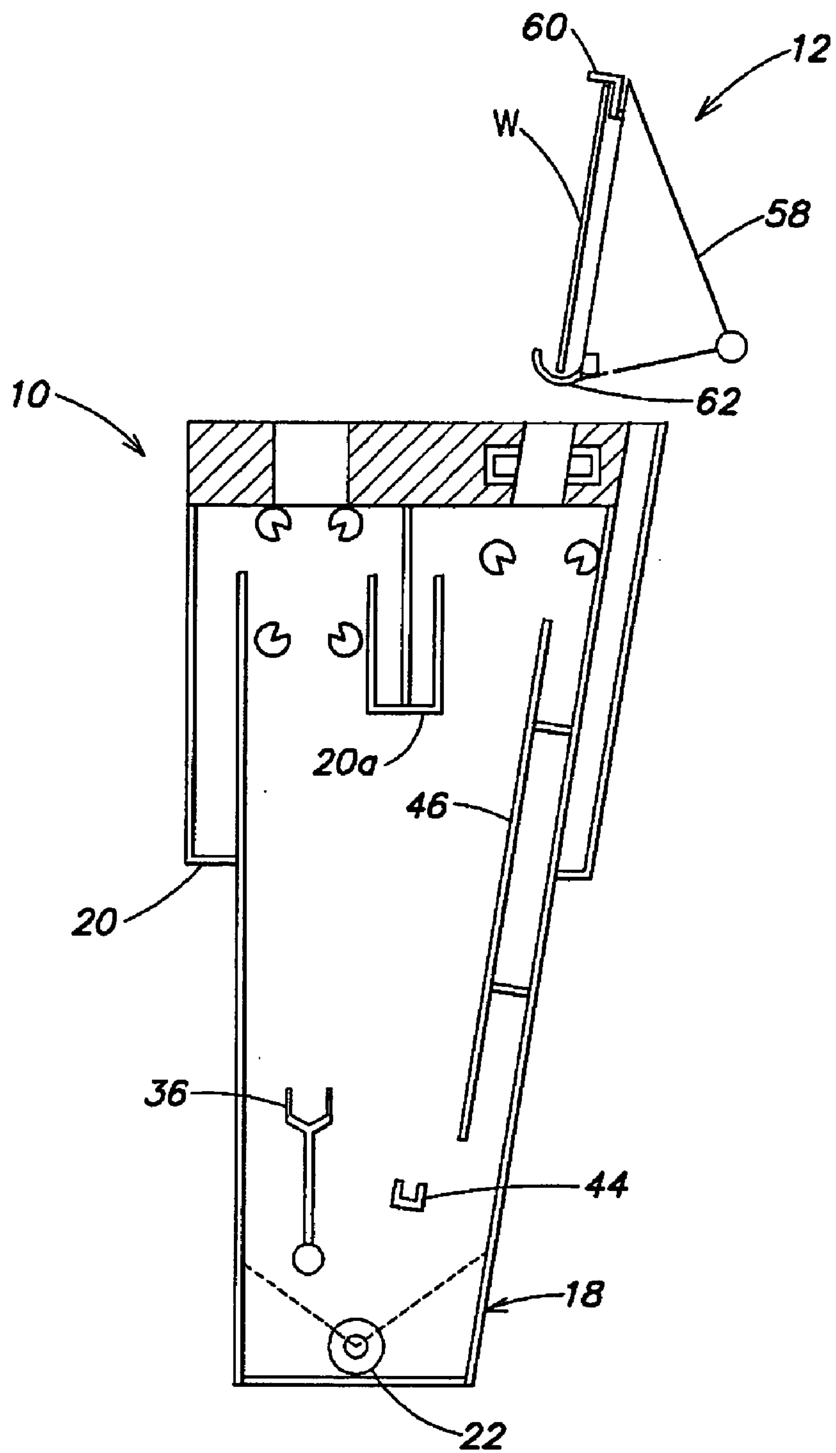


FIG. 2E

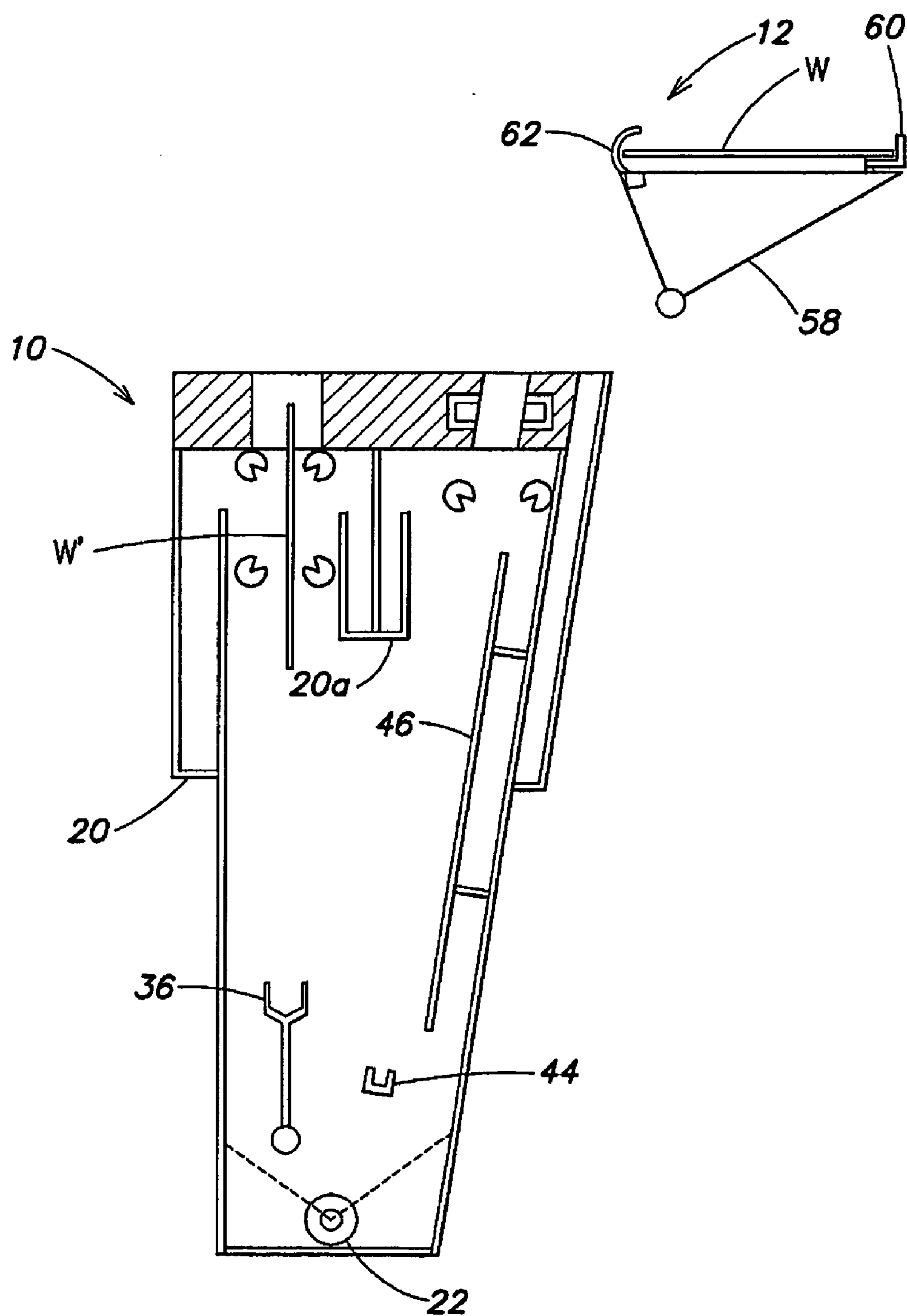


FIG. 2F

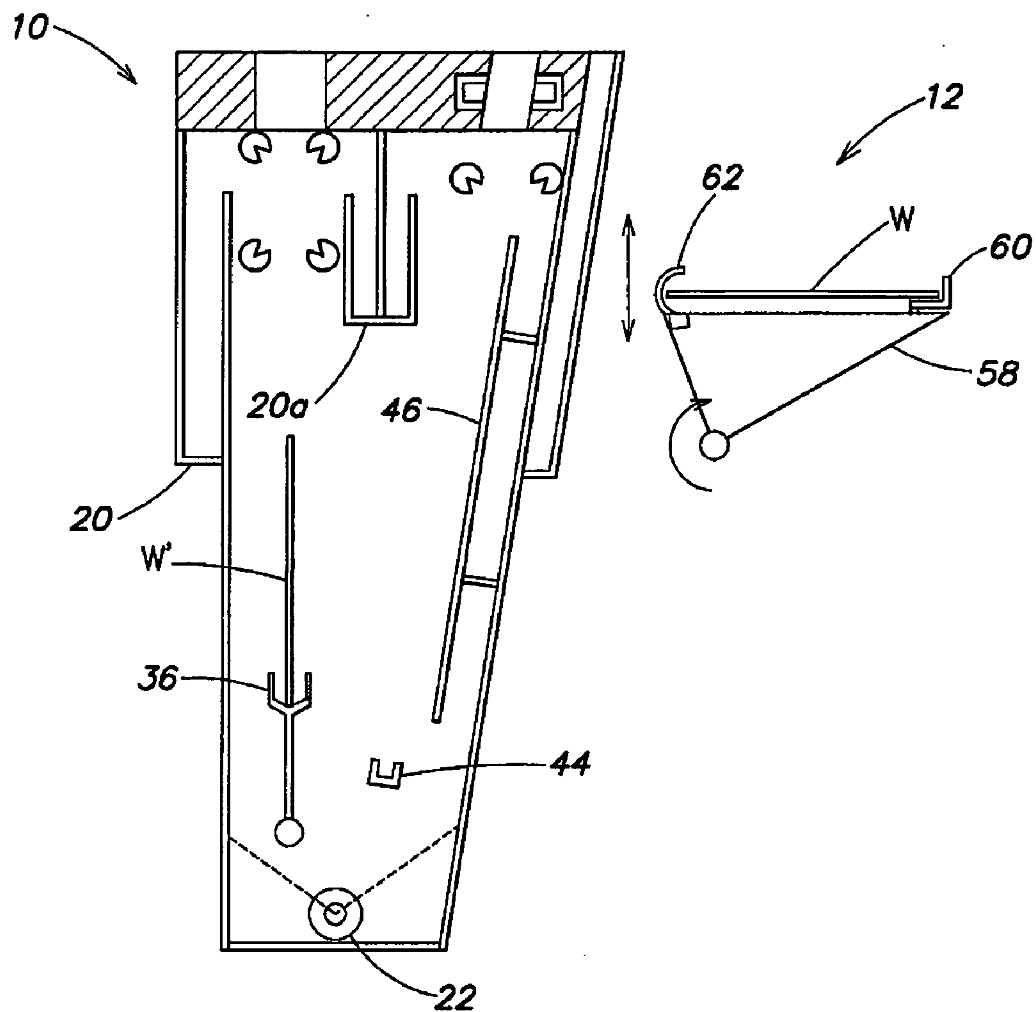


FIG. 2G

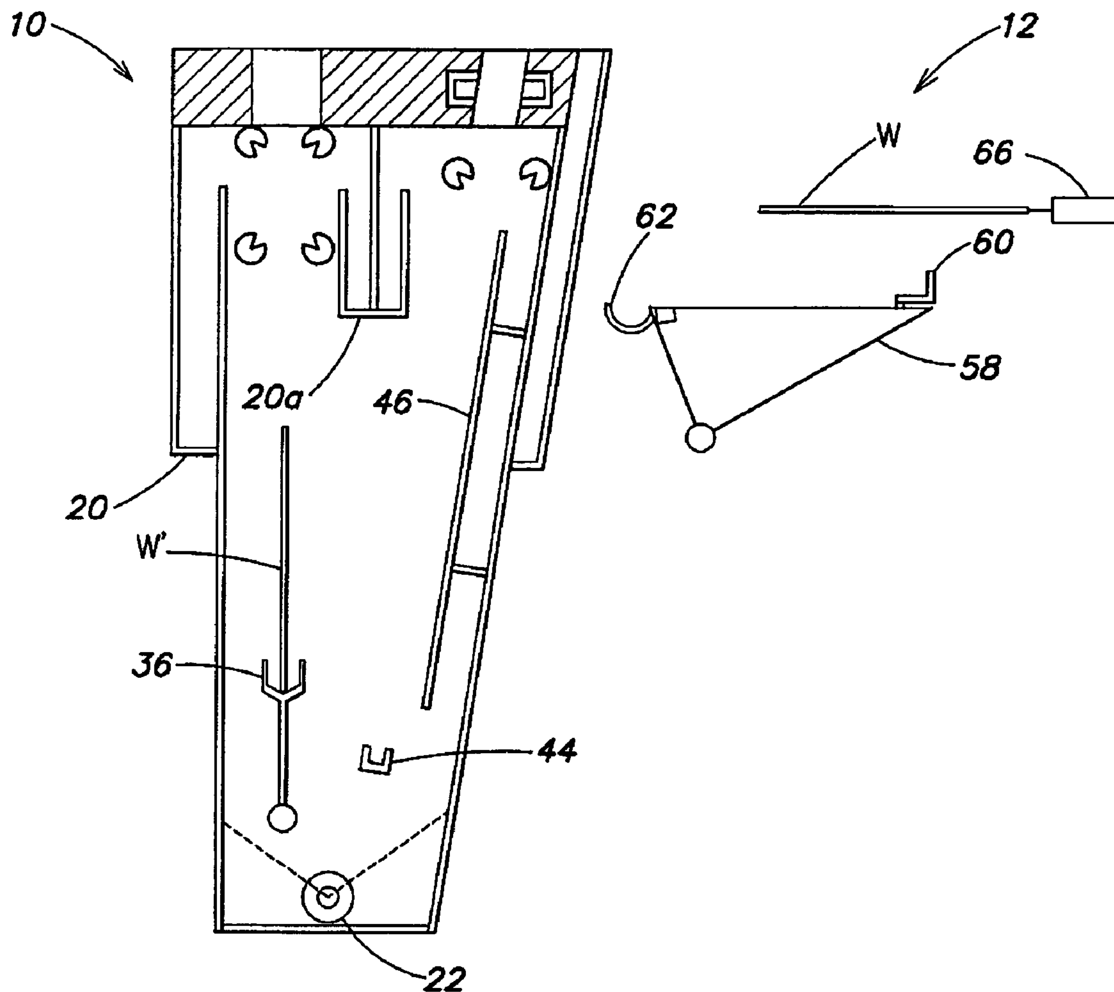


FIG. 2H

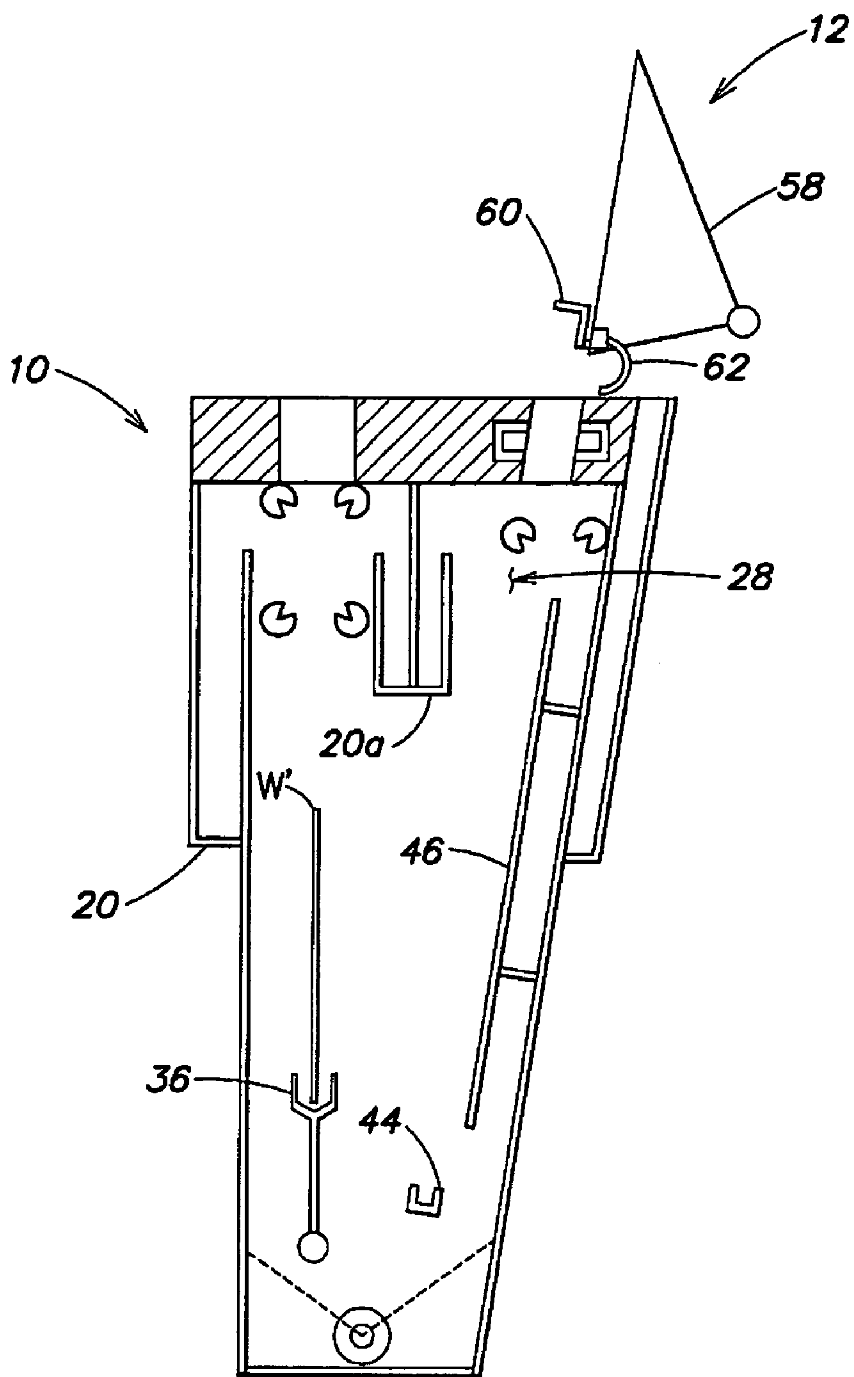


FIG. 2I

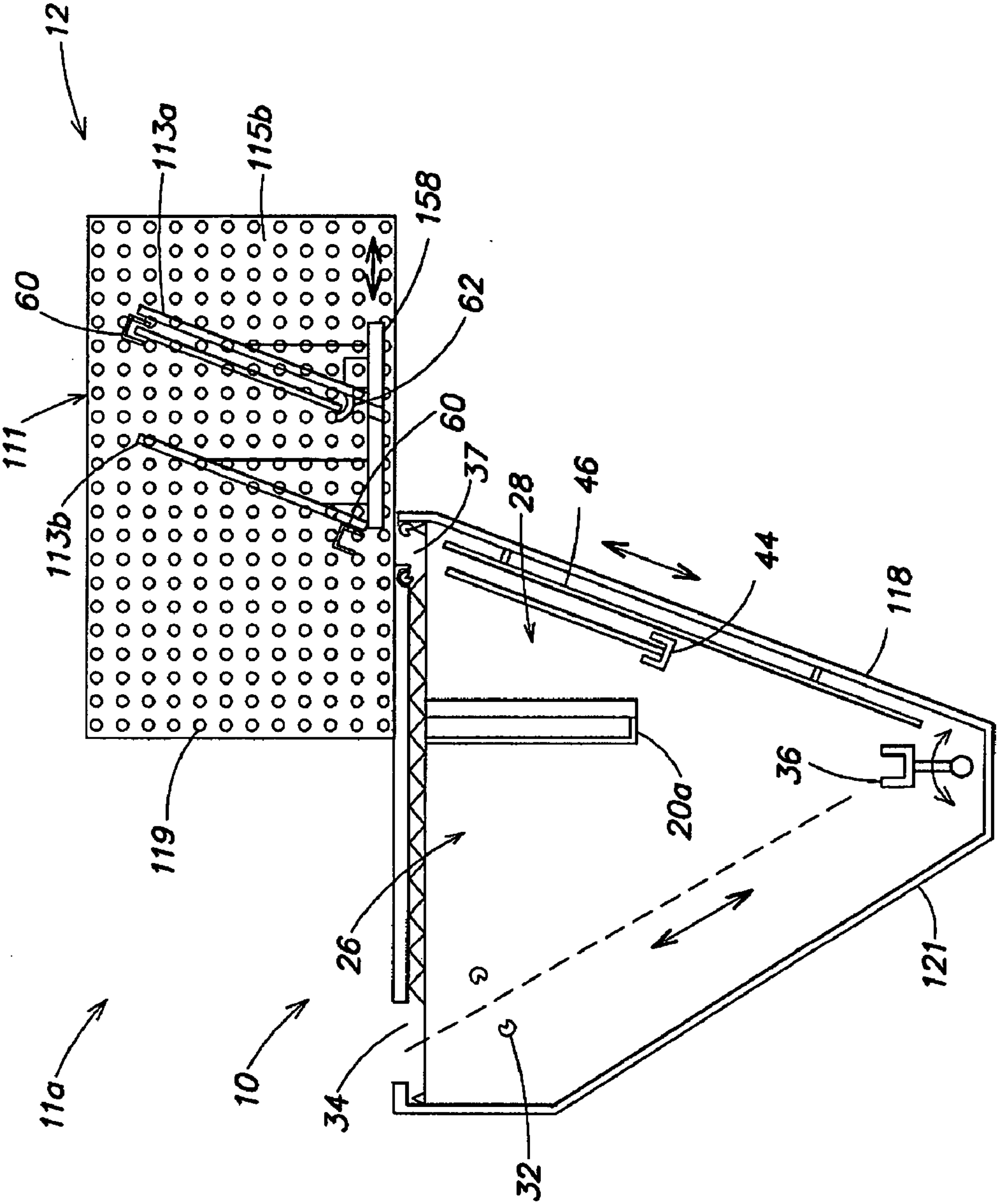


FIG. 3A

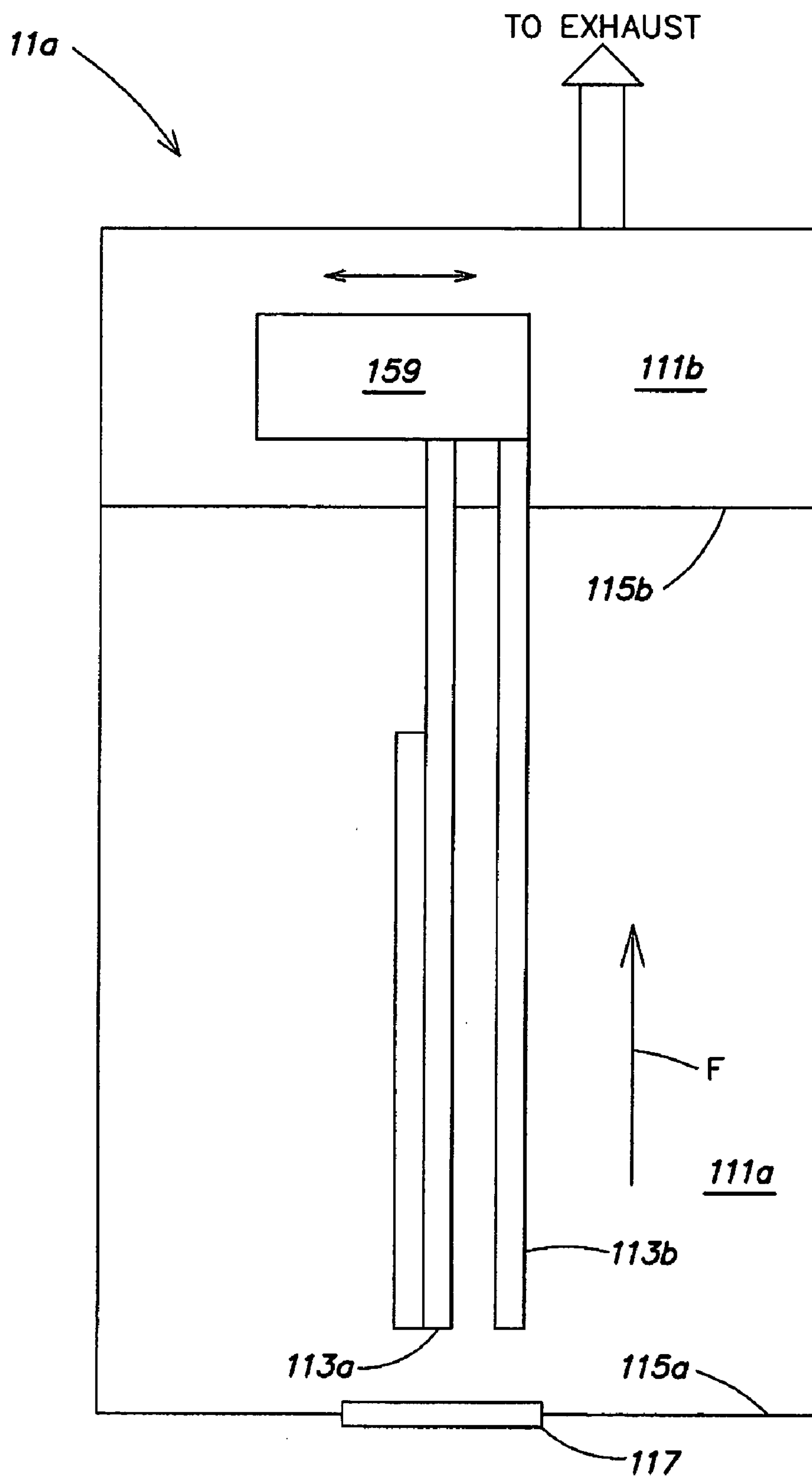


FIG. 3B

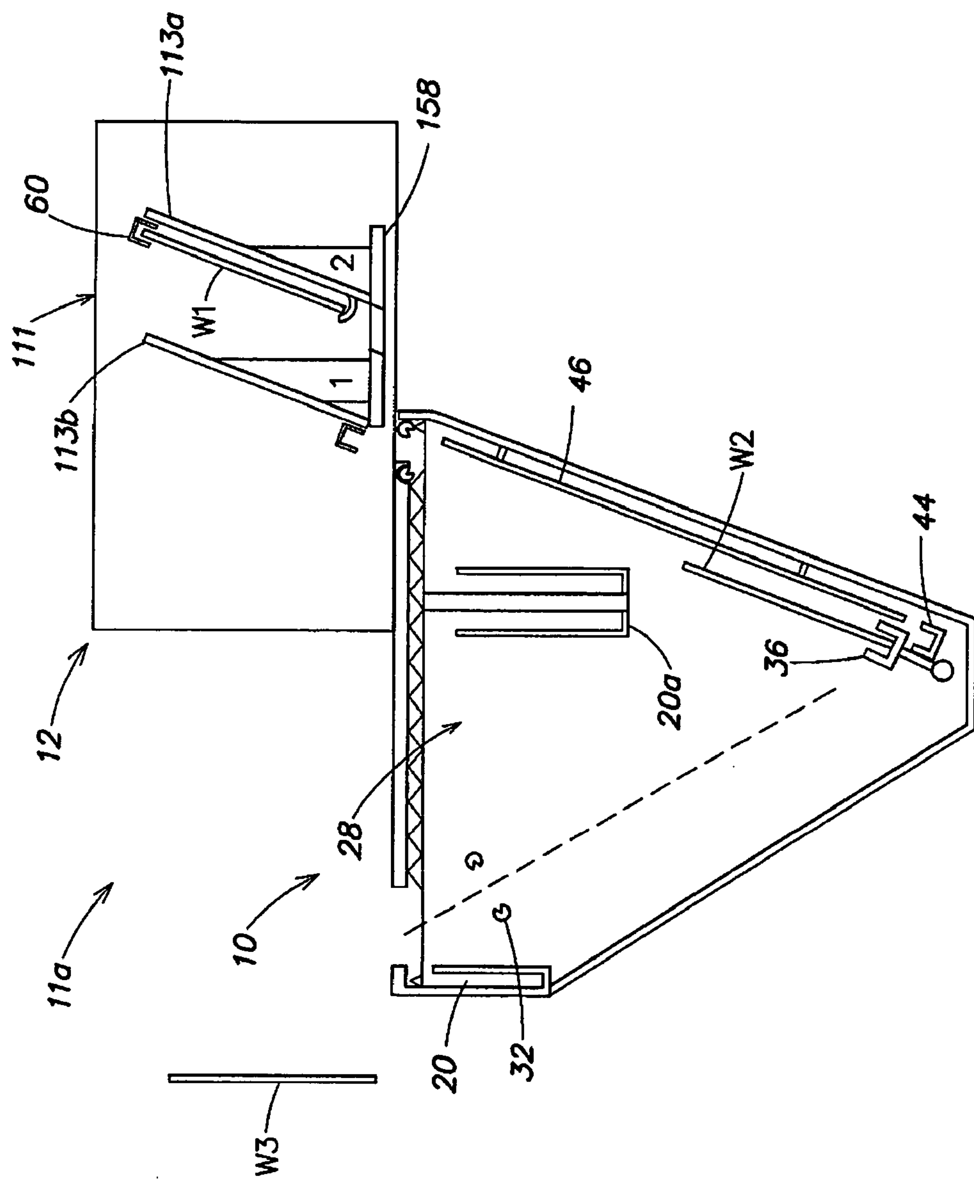


FIG. 4A

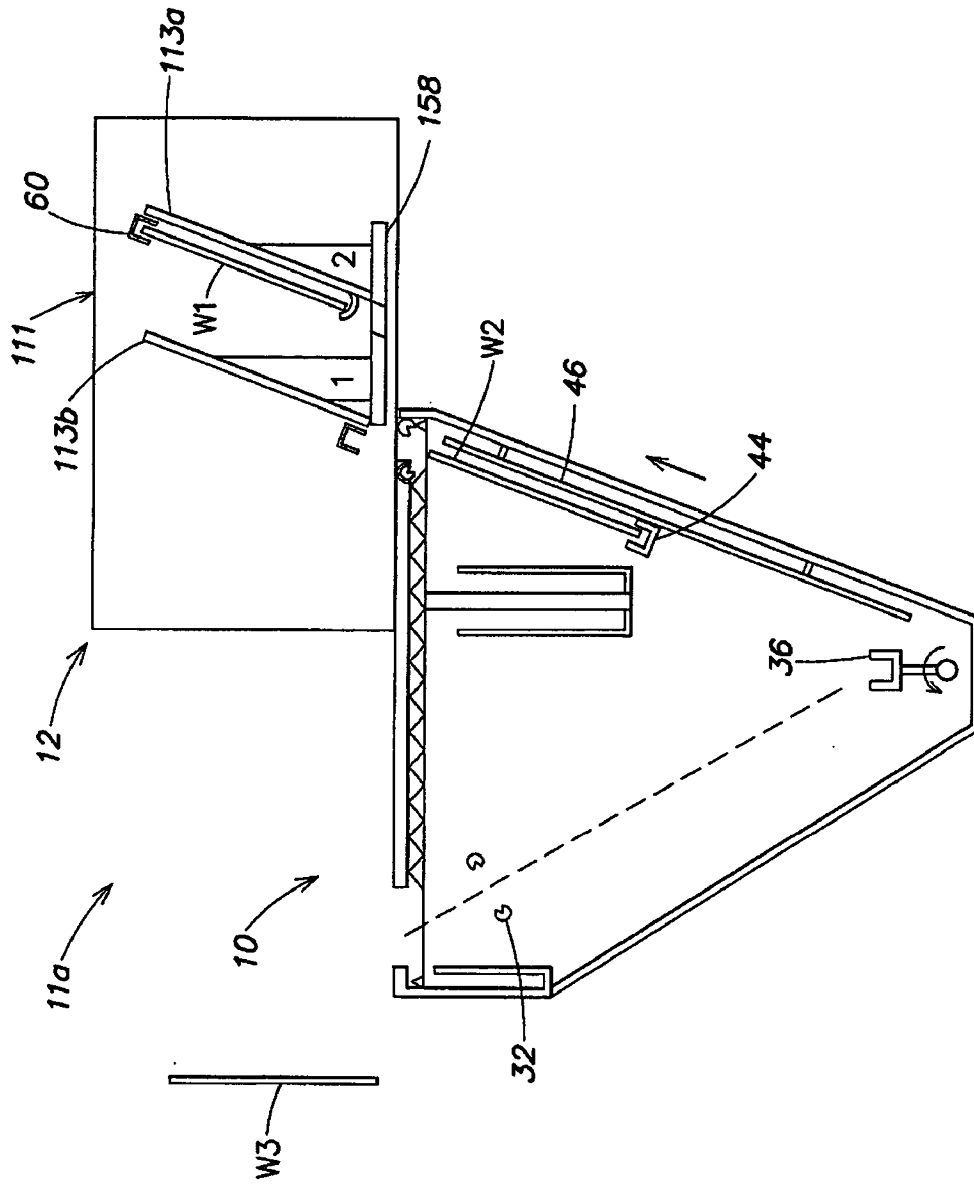


FIG. 4B

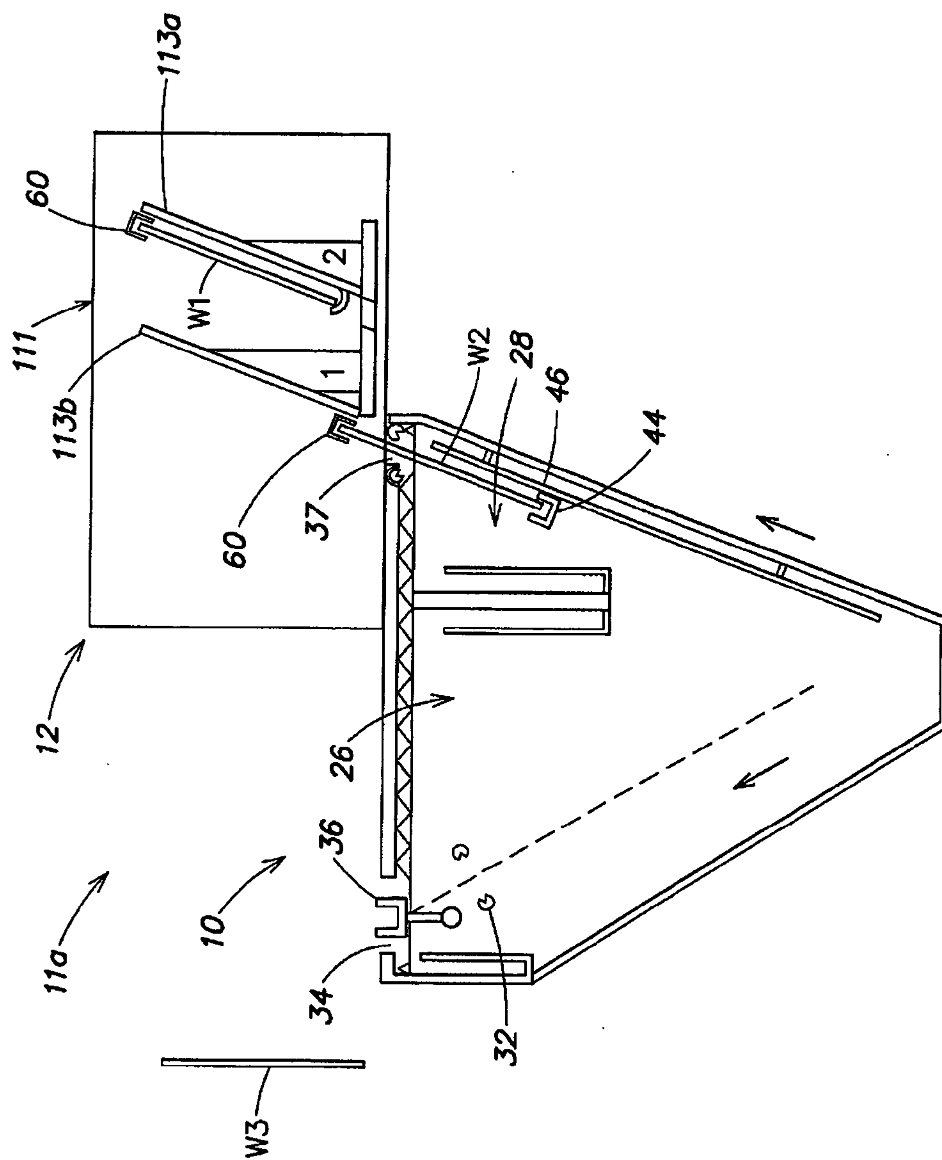


FIG. 4C

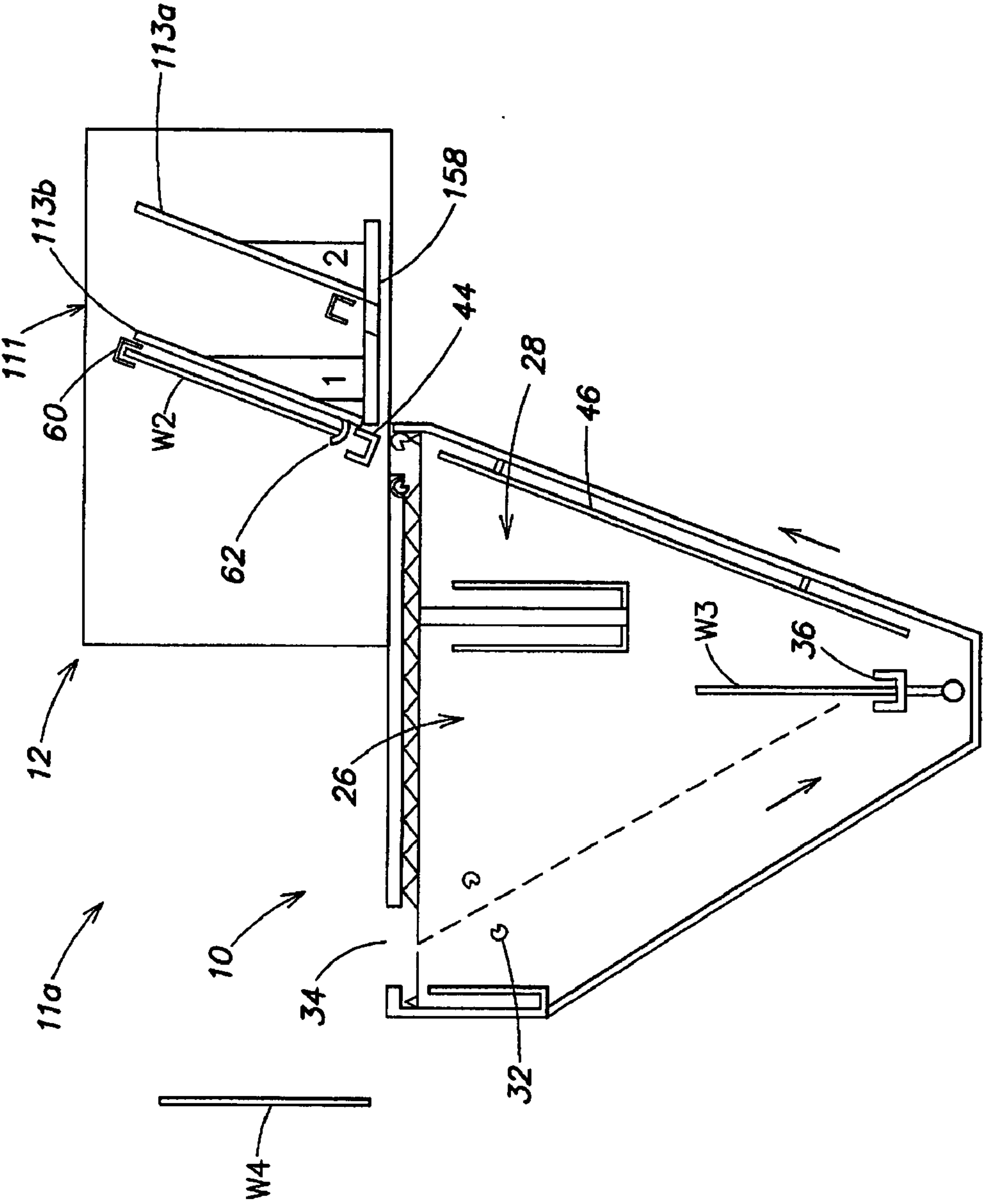


FIG. 4D

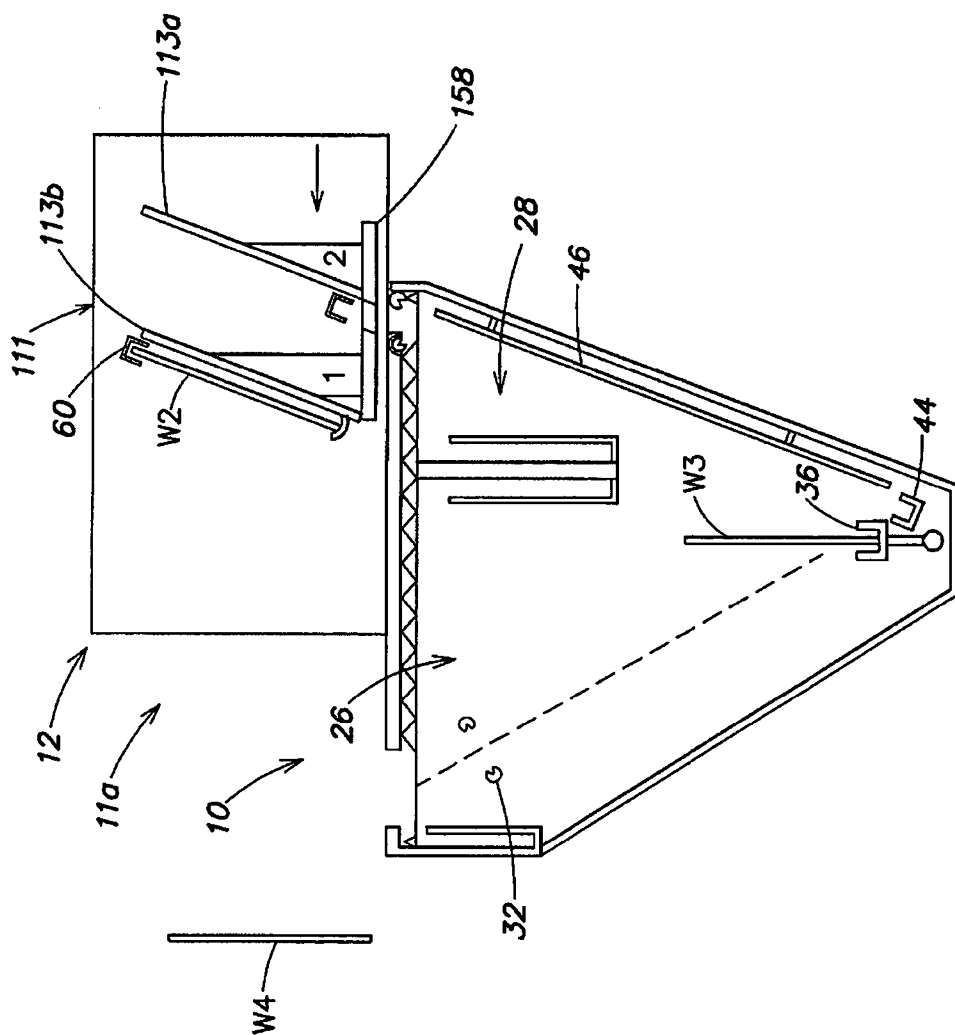


FIG. 4E

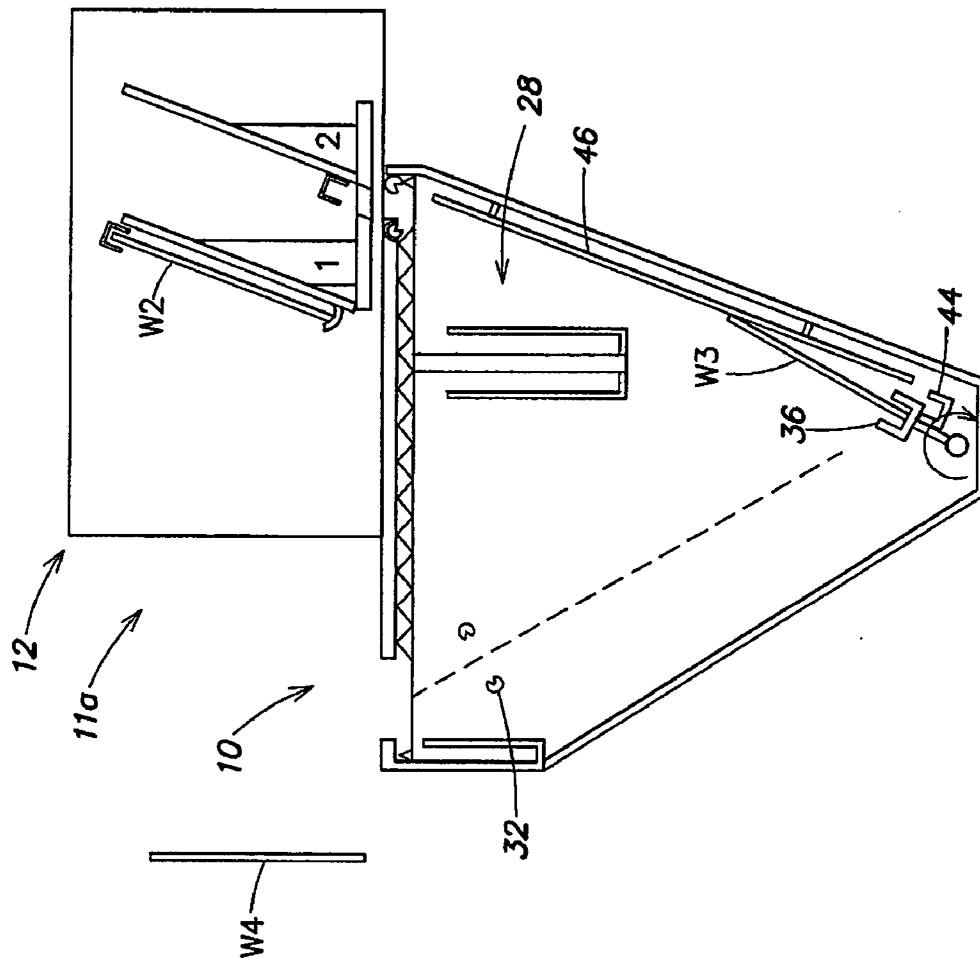


FIG. 4F

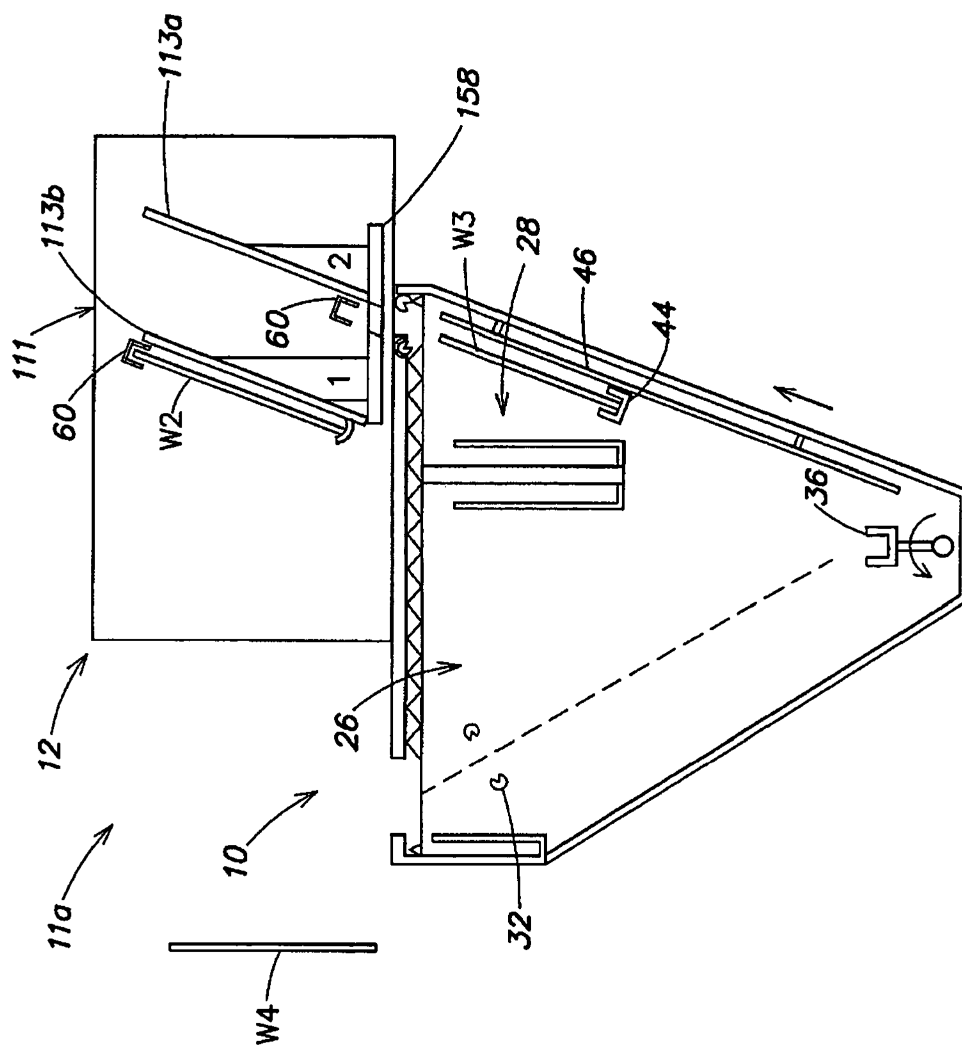


FIG. 4G

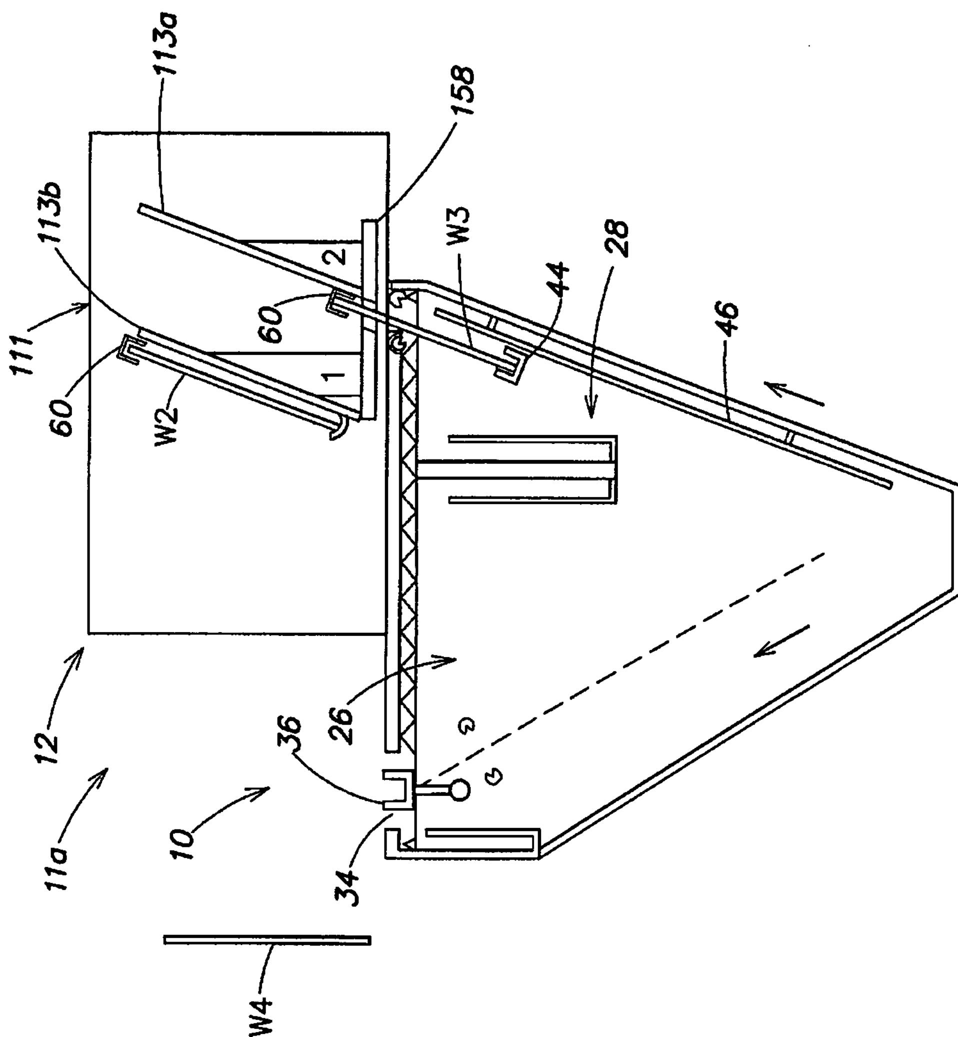


FIG. 4H

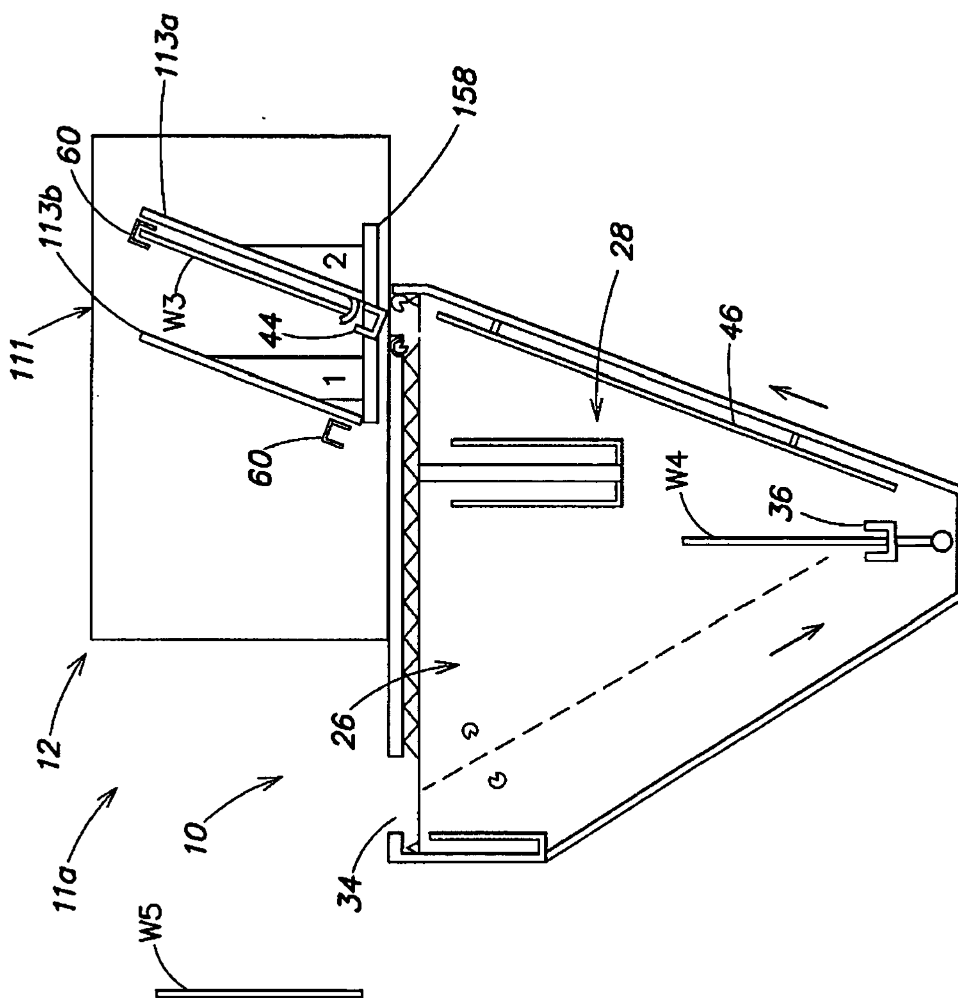


FIG. 4I

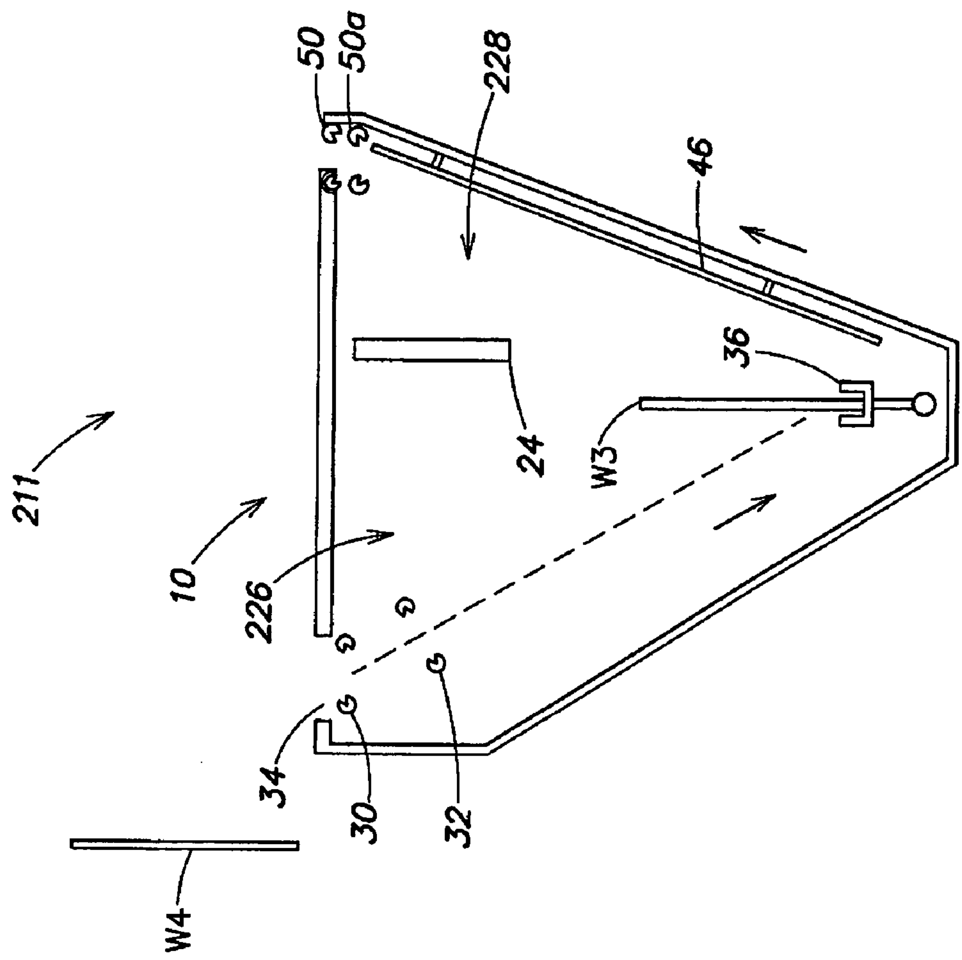


FIG. 5

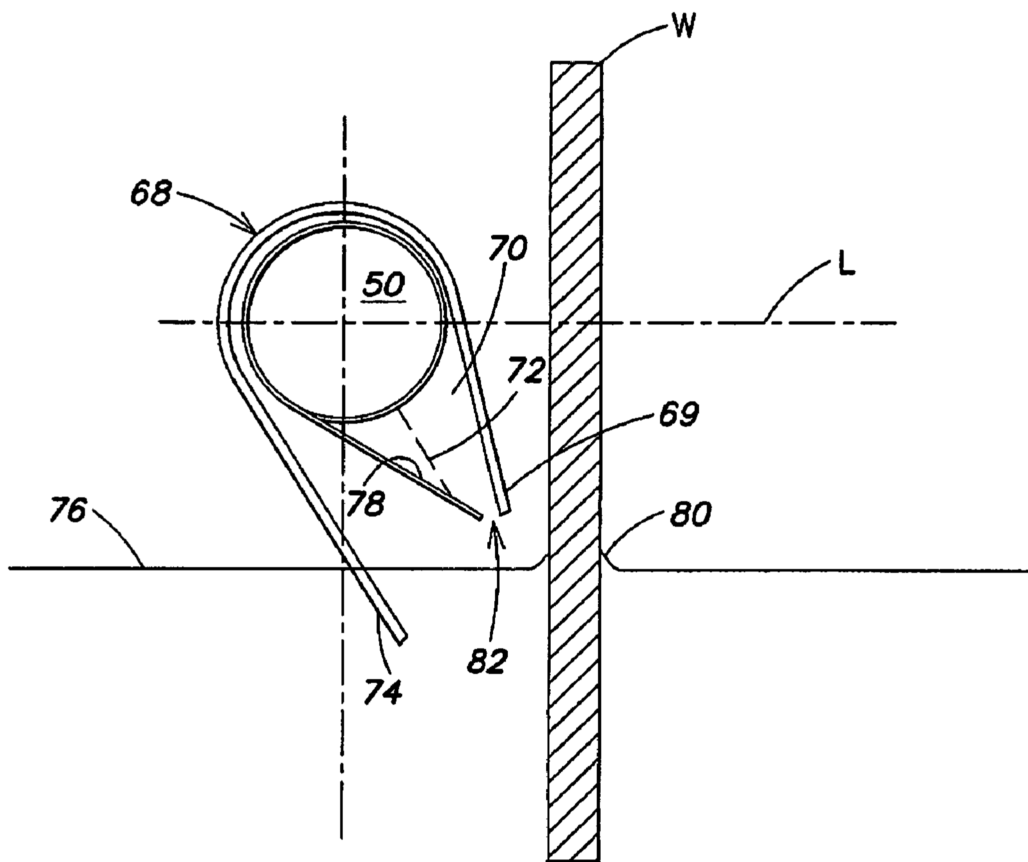


FIG. 6

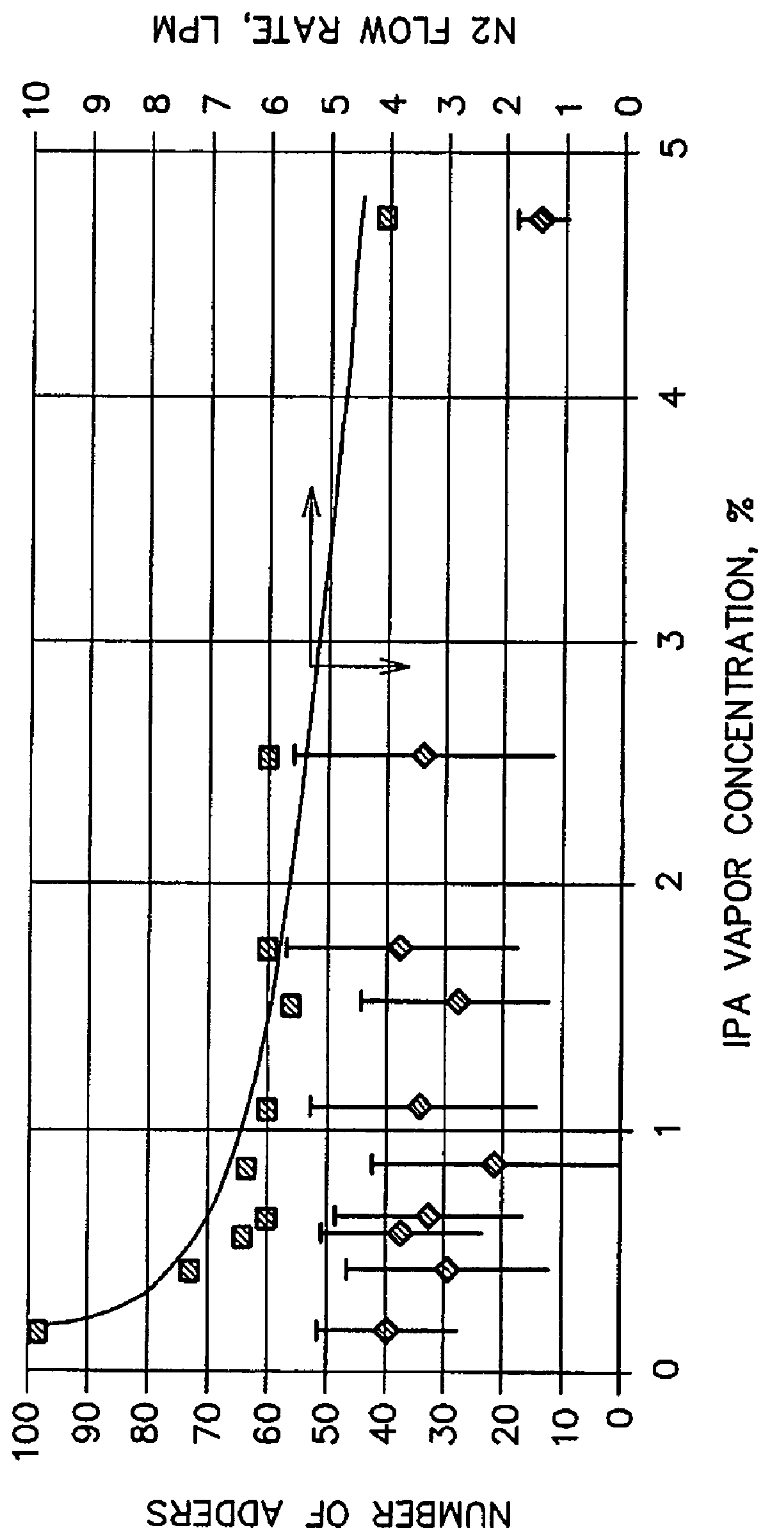


FIG. 7

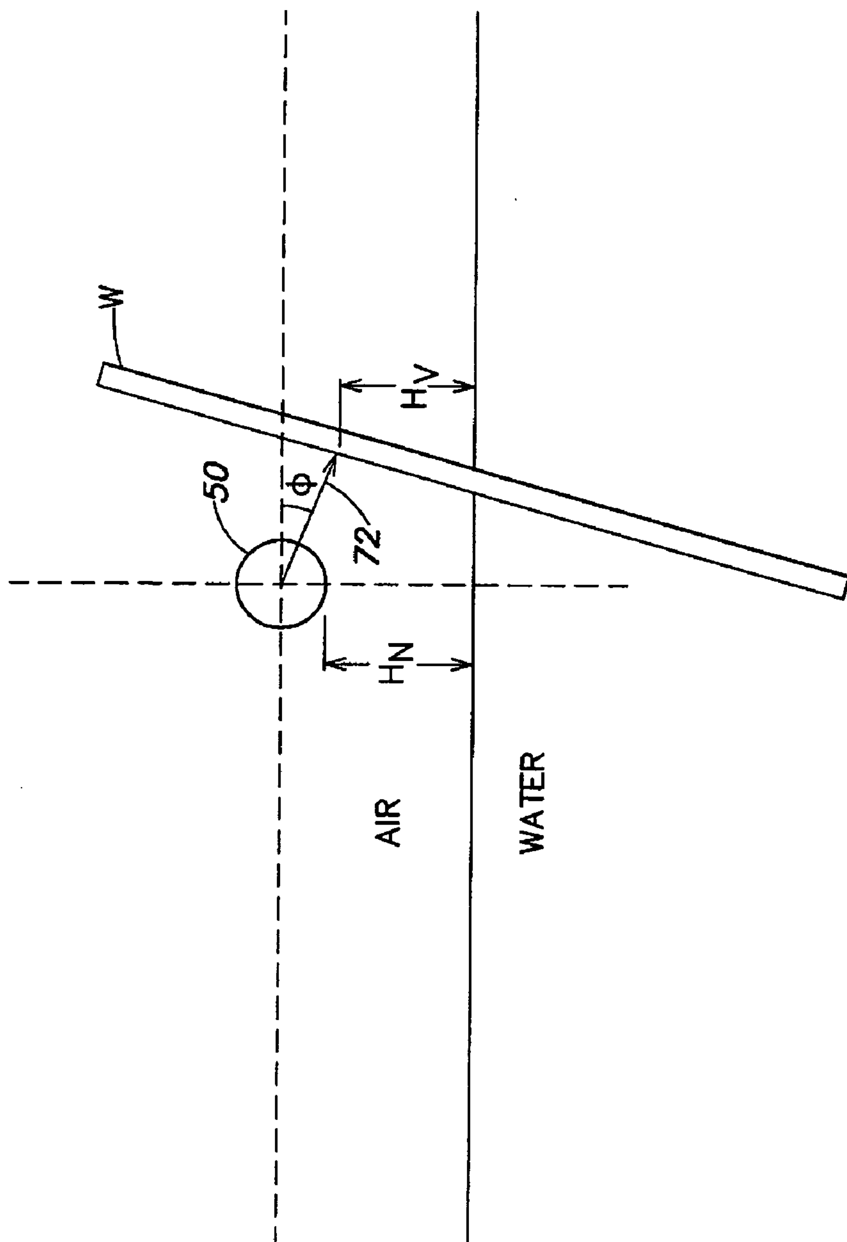


FIG. 8A

SURFACE MATERIAL	PREFERRED FLOW ANGLE
SILICON (DRY IN–DRY OUT)	12° – 38°
BLANKET COPPER (DRY IN–DRY OUT)	12° – 35°
COPPER OXIDE (DRY IN–DRY OUT)	12° – 30°
POLISHED BLACK DIAMOND (WET IN–DRY OUT)	22° – 38°
POLSIHED BLACK DIAMOND BACKSIDE (WET IN–DRY OUT)	22° – 30°

FIG. 8B

SINGLE WAFER DRYER AND DRYING METHODS

[0001] This application is a division of U.S. patent application Ser. No. 10/286,404 filed Nov. 1, 2002, which claims priority from U.S. Provisional Patent Application Ser. No. 60/335,335, filed Nov. 2, 2001. Both of the above-identified patent applications are hereby incorporated by reference herein in their entirety.

FIELD OF THE INVENTION

[0002] This invention is concerned with semiconductor manufacturing and is more particularly concerned with techniques for drying a substrate.

BACKGROUND OF THE INVENTION

[0003] As semiconductor device geometries continue to decrease, the importance of ultra clean processing increases. Aqueous cleaning within a tank of fluid (or a bath) followed by a rinsing bath (e.g., within a separate tank, or by replacing the cleaning tank fluid) achieves desirable cleaning levels. After removal from the rinsing bath, absent use of a drying apparatus, the bath fluid would evaporate from the substrate's surface causing streaking, spotting and/or leaving bath residue on the surface of the substrate. Such streaking, spotting and residue can cause subsequent device failure. Accordingly, much attention has been directed to improved methods for drying a substrate as it is removed from an aqueous bath.

[0004] A method known as Marangoni drying creates a surface tension gradient to induce bath fluid to flow from the substrate in a manner that leaves the substrate virtually free of bath fluid, and thus may avoid streaking, spotting and residue marks. Specifically, during Marangoni drying a solvent miscible with the bath fluid (e.g., IPA vapor) is introduced to a fluid meniscus which forms as the substrate is lifted from the bath or as the bath fluid is drained past the substrate. The solvent vapor is absorbed along the surface of the fluid, with the concentration of the absorbed vapor being higher at the tip of the meniscus. The higher concentration of absorbed vapor causes surface tension to be lower at the tip of the meniscus than in the bulk of the bath fluid, causing bath fluid to flow from the drying meniscus toward the bulk bath fluid. Such a flow is known as a "Marangoni" flow, and can be employed to achieve substrate drying without leaving streaks, spotting or bath residue on the substrate.

SUMMARY OF THE INVENTION

[0005] In a first aspect of the invention, a first module is provided that is adapted to process a wafer. The module includes a processing portion having a load port through which a wafer may be lowered into the processing portion, and an unload port, horizontally displaced from the load port, such that the wafer may be raised out of the processing portion at the unload port. The module also includes a rotatable wafer support for rotating an input wafer from a first orientation wherein the wafer is in line with the load port, to a second orientation wherein the wafer is in line with the unload port.

[0006] In a second aspect of the invention, a second module is provided that is adapted to process a wafer. The second module includes a processing portion having the load port and unload port described with regard to the first module. The second module also includes (1) an external overflow weir positioned along the exterior of the processing portion; and (2) a separation wall positioned between the load port and the unload port so as to divide an upper region of the processing portion into a first section and a second section, and so as to deter surface fluid from traveling between the first section and the second section.

[0007] In a third aspect of the invention, a third module is provided that is adapted to process a wafer. The third module includes a processing portion having the load port described with regard to the first module. The third module also includes a spray mechanism adapted to be submerged in fluid contained in the processing portion during processing, and positioned so as to spray fluid to the underwater surface of a wafer as the wafer is lowered through the load port.

[0008] In a fourth aspect of the invention, a fourth module is provided that is adapted to process a wafer. The fourth module includes a processing portion having the load port and unload port described with regard to the first module. The fourth module also includes an output portion having (1) a first wafer receiver adapted to receive a wafer raised through the unload port; and (2) a catcher coupled to the wafer receiver and adapted to contact a wafer being elevated from the unload port and to elevate passively therewith.

[0009] In a fifth aspect of the invention, a fifth module is provided that is adapted to process a wafer. The fifth module includes a processing portion having the load port and unload port described with regard to the first module. The fifth module also includes an output portion having a first wafer receiver adapted to receive a wafer raised through the unload port, and an enclosure surrounding the first wafer receiver. The enclosure includes (1) a first opening adapted such that a wafer may be raised from the processing portion, through the unload port, to the first wafer receiver; (2) a second opening adapted to allow a wafer handler to extract a wafer from the first wafer receiver; and (3) a plurality of additional openings adapted to allow a laminar flow of air to be established within the enclosure.

[0010] In a sixth aspect of the invention, a sixth module is provided that is adapted to process a wafer. The fifth module includes a processing portion having the load port and unload port described with regard to the first module. The fifth module also includes an output portion having (1) a first wafer receiver adapted to receive a wafer raised through the unload port; and (2) a second wafer receiver adapted to receive a wafer raised through the unload port. The first and second wafer receivers are adapted to translate between a first position wherein the first wafer receiver is positioned to receive a wafer raised through the unload port, and a second position wherein the second wafer receiver is positioned to receive a wafer raised through the unload port. Numerous other aspects are provided, as are methods, apparatus and systems in accordance with these and other aspects.

[0011] Other features and aspects of the present invention will become more fully apparent from the following detailed description, the appended claims and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is a schematic side view of an inventive drying apparatus comprising a processing portion, and an output portion, both configured according to a first aspect;

[0013] FIGS. 2A-I are schematic side views of the inventive drying apparatus of **FIG. 1** showing sequential stages of wafer transport through, and output from, the inventive drying apparatus;

[0014] FIGS. 3A-B are a schematic side view and a top plan view respectively showing the drying apparatus of FIG. 1 wherein the output portion is configured according to a second aspect;

[0015] FIGS. 4A-I are schematic side views of the inventive drying apparatus of FIGS. 3A-B showing sequential positions of the output portion during wafer output thereto;

[0016] **FIG. 5** is a schematic side view showing the inventive drying apparatus wherein the processing portion is configured according to a second aspect;

[0017] **FIG. 6** is a schematic side view of a vapor flow deflector that may be installed in association with a vapor nozzle in a drying apparatus;

[0018] **FIG. 7** is a graph which plots the number of particles observed on wafers dried via various IPA concentrations and various flow rates;

[0019] **FIG. 8A** is a schematic drawing useful in describing a vapor flow angle; and

[0020] **FIG. 8B** is a table showing preferred vapor flow angles for drying substrates comprising various materials.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] A drying apparatus provided in accordance with the present invention comprises a processing portion and an output portion. The processing portion includes a main chamber that may be configured according to two main aspects. A first aspect (submersion chamber **18***a*) submerges a wafer in a bath of fluid and is shown and described with reference to **FIGS. 1-2I**; a second aspect (spray chamber **18***b*) sprays an unsubmerged wafer with fluid and is shown and described with reference to **FIG. 5**.

[0022] Similarly, the output portion includes an output platform that may be configured according to two main aspects. A first aspect (rotation platform **58**) rotates a wafer from a generally vertical orientation to a generally horizontal orientation and is shown and described with reference to **FIGS. 1-2I**; a second aspect (translation platform **158**) translates horizontally so as to receive a generally vertically oriented wafer in one of a plurality of wafer receivers, and is shown and described with reference to **FIGS. 3A-4K**.

[0023] Each aspect of the processing portion and output portion is considered inventive on its own. Accordingly, each aspect of the processing portion may be used with either aspect of the output portion, and vice versa. Additionally each aspect of the processing portion and the output portion may be used with conventional output portions and processing portions, respectively. Finally, numerous individual features of the processing portions and output portions are inventive, as will be apparent with reference to the figures and the description that follows.

[0024] **FIG. 1** is a side schematic view of an inventive drying apparatus **11** in which the processing portion and the output portion are configured according to a first aspect of the present invention. The inventive drying apparatus **11** comprises a processing portion **10** and an output portion **12**.

[0025] Processing Portion—First Aspect

[0026] The processing portion **10** comprises a submersion chamber **18***a* which submerges a wafer in a bath of fluid, such as deionized water, and which may or may not include a surfactant, or other cleaning chemistry such as Applied Materials' ElectraClean™ solution.

[0027] An upper separation wall **24** (**FIG. 2A**) divides the submersion chamber **18***a* into two sections: a rinsing section **26** and a "drying" section **28**. By separating the drying section **28** from the rinsing section **26**, a cleaner exit zone is maintained and the risk of removed particles re-adhering to the wafer during drying is reduced, as particles tend to be removed in the rinsing section **26** and overflowed therefrom. The submersion chamber **18***a* may have an overflow weir **20** surrounding the chamber **18***a* such that fluid may be overflowed thereto. Fluid may be continuously supplied, for example, to the lower portion of the chamber **18***a* so that fluid continuously overflows to the weir **20**. An overflow weir **20***a* (FIGS. 2A-I) may be coupled to the upper separation wall **24** to aid in removing particles from the rinsing section **26** as well as from the drying section **28**. High and low fluid level sensors (not shown) may be coupled to both the chamber **18***a* and the weirs **20**, **20***a*. In an alternative aspect, not shown, the overflow weir **20** may comprise a chamber in which the processing portion **10** is mounted. An exhaust line (e.g., a facilities exhaust line) may be coupled to the chamber (e.g., near the bottom thereof) and a drain line may be positioned along the bottom of the chamber, which may be slanted to facilitate drainage.

[0028] The rinsing section **26** may be equipped with overhead spray nozzles **30** and/or submerged spray nozzles **32** each of which are adapted to direct fluid to the surface of the wafer as it enters the rinsing section **26**. The rinsing section **26** may, in one aspect, be used to rinse from the wafer any fluid film (e.g., surfactant) which may have been sprayed on the wafer prior to transfer into the inventive drying apparatus **11**. It has been found that such a surfactant spraying step prevents a hydrophobic wafer from drying during transfer to the inventive apparatus **11**. A surfactant spray (preferably a spray containing a low concentration of a surfactant such as an Alfonic surfactant) is therefore desirable prior to loading the wafer into a drying apparatus in order to prevent the formation of watermarks on the wafer. Such an inventive process may be performed in a scrubber or during wafer transfer (e.g., a wafer handler or scrubber may comprise a mechanism for wetting the substrate with surfactant either during scrubbing or as the substrate is removed from the scrubber or during transfer via the wafer handler).

[0029] The rinsing section **26** further includes a load port **34**, which may be merely a location through which the wafer passes as it enters the rinsing section **26**, or which may be an opening defined by a top wall or lid (if any) of the rinsing section **26**.

[0030] Located at or near the bottom of the submersion chamber **18***a* is a cradle **36**, adapted to receive and support a generally vertically oriented wafer (which may be slightly inclined from normal). The cradle **36** is further adapted to rotate from a first position in which the cradle **36** may

receive a wafer that enters the rinsing section **26** via the load port **34**, to a second position in which a wafer may be lifted from the cradle **36** through an exit port **37** of the drying section **28**. As the cradle **36** rotates the wafer from the rinsing section **26** to the drying section **28** the wafer remains submerged in the fluid.

[**0031**] A mechanism for rotating the cradle **36** is preferably mounted outside the processing portion **10** and is coupled to the cradle **36** either directly or magnetically through a wall of the processing portion **10**. In the exemplary embodiment of **FIG. 1**, a linkage system **38** is configured to rotate the cradle **36** from the first position (within the rinsing section **26**) to the second position (within the drying section **28**) when the linkage is downwardly actuated, and to retract the cradle **36** from the drying section **28** to the rinsing section **26** when the linkage system **38** is upwardly actuated. An actuator **40** is shown coupled to the linkage system **38**. The actuator **40** may be any conventional actuator such as an air cylinder or the like.

[**0032**] An alternative configuration for achieving cradle rotation may comprise mounting the cradle **36** on a rod that extends horizontally along the bottom of the submersion chamber **18***a* so that the cradle **36** may rotate about the rod. In such a configuration the cradle **36** may be, for example, nearly as wide as the submersion chamber **18***a*, such that a magnet may be mounted on both sides of the cradle **36**, and may couple through the side walls of the chamber **18***a* to external magnets. The external magnets may be driven forward and backward by an actuator (such as pneumatic actuator **40**). To facilitate rotation of both the cradle **36** and the external magnets, rollers may be mounted thereto so as to contact and roll along the side walls of the submersion chamber **18***a*.

[**0033**] A pair of sensors (not shown) may be coupled to the actuator **40**, the linkage system **38** and/or the cradle **36** so as to detect the first and second cradle positions. Further, a sensor, such as an optical sensor (not shown) may detect the presence of the wafer on the cradle **36**. Once wafer presence is detected a signal may be sent to the actuator **40** to cause the actuator **40** to rotate the cradle **36** from the first position to second position.

[**0034**] The drying section **28** may include a pusher **44** which is preferably adapted to contact the lower edge of the wafer with minimal contact area. Such pushers are conventionally referred to as knife-edged pushers. The knife-edged pusher **44** may be coupled to a vertical guide (not shown) positioned along the rear wall of the drying section **28**, and may be further coupled (e.g., magnetically) to an actuator (for example a lead screw **48** of **FIG. 1**, driven by a motor) which is adapted to lift and lower the pusher **44** along the guide so that the pusher **44** may elevate a wafer from the drying section **28** and may then return to the pusher's original position below the cradle **36**.

[**0035**] The rear wall of the drying section **28** is preferably inclined (e.g., nine degrees) such that the pusher maintains the wafer in an inclined position as it is elevated from the drying section **28**, so as to ensure more repeatable wafer position than can be achieved with a non-inclined, vertical orientation.

[**0036**] A pair of inclined guides **46** may also be coupled to the rear wall of the drying section **28** and positioned so as to contact the opposing edges of the wafer as the wafer is lifted from the cradle **36** through the drying section **28**. Each guide **46** may be include a slot such as V or U shaped slot in which the wafer's edge is held. Alternatively each guide **46** may include a beveled surface against which the wafer's edge may rest, or the guides **46** may be angled away from the wafer so as to minimize contact therewith.

[**0037**] The exit port **37** of the drying section **28** is preferably defined by a top wall or lid of the drying section **28**, such that drying vapors may be exhausted therefrom (e.g., via a pump) rather than escaping into the surrounding atmosphere. Positioned above the fluid level but below the exit port **37** are a pair of spray mechanisms **50** adapted to provide a continuous spray of vapor across both the front and back surfaces of the wafer as the wafer is elevated from the fluid. Spray mechanisms **50** are positioned so as to spray vapor to a meniscus that forms as the wafer is lifted from the fluid. Although the spray mechanisms **50** may comprise a single linear nozzle, or a plurality of nozzles, they preferably comprise a tube having a line of holes formed therein (e.g., 114 holes having 0.005-0.007 inch diameters and being uniformly spaced along the 8.5 inches that are adjacent to the wafer). Such spray tubes **50** are preferably made of quartz or stainless steel.

[**0038**] Each spray tube **50** may be manually oriented so as to direct a vapor flow (e.g., IPA vapor) at a desired angle (e.g., relative to a horizontal line drawn through the center of the tubes **50** and parallel to the fluid surface as shown in **FIG. 8A**). The IPA vapor flow may be directed with or without the aid of a flow deflector as described further with reference to **FIG. 6**. A specific angle of the flow may vary depending upon the material of the wafer to be dried. The table listing preferred flow angles for exemplary materials is shown in **FIG. 8B**.

[**0039**] The IPA vapor flow supplied to the fluid meniscus creates a Marangoni force that results in a downward liquid flow opposite to the wafer lift direction. Thus, the wafer surface above the meniscus is dried.

[**0040**] In order to contain and exhaust the IPA vapor inside the drying section **28**, an exhaust manifold **51** and a nitrogen blanket manifold **54** are provided. These manifolds may be built into a top cover **56** of the drying section **28**, above the spray mechanisms **50**. A gas flow module (not shown) coupled to spray mechanisms **50**, the exhaust manifold **51** and the nitrogen blanket manifold **54** controls the IPA vapor flow rate, the exhaust rate and the nitrogen blanket flow rate. In addition, an exhaust line (not shown) may be located beneath the output portion **12** and may maintain a vertical laminar flow through the output portion **12**, as well as diluting any IPA vapor that may escape from the drying section **28**. The spray mechanisms **50** are preferably positioned close to the meniscus, and the nitrogen blanket manifold **54** is preferably positioned close to the unload port **37**.

[**0041**] Wafer Processing—First Aspect

[**0042**] FIGS. **2**A-I are schematic side elevational views which show a wafer at various stages as the wafer travels through the inventive apparatus **11**. Referring to **FIG. 2A**, as a robot (such as a walking beam robot, not shown herein although disclosed in U.S. patent application Ser. No. 09/558,815, filed Apr. 26, 2000, the entire disclosure of

which is incorporated herein by reference) loads the wafer W into the rinsing section **26** via the load port **34**, the nozzles **30**, **32** spray DI water onto both sides of the wafer W. The robot releases the wafer onto the cradle **36**, and then retracts from the rinsing section **26** to its home position, above the loadport **34**. An optical sensor (not shown) detects the presence of the wafer on the cradle **36** (**FIG. 2B**), and signals the actuator **40** to actuate the linkage system **38** thereby causing the cradle **36** to rotate from the rinsing section **26** to the drying section **28**.

[**0043**] The cradle **36**, located at or near the bottom of the submersion tank **18***a*, transfers the wafer from the rinsing section **26** to the drying section **28**. During this transfer the wafer remains submerged in the fluid. Thus the cradle **36** rotates from a vertical position, for receipt of the wafer, to an inclined position (e.g., 9° incline), for wafer elevation through the drying section **28** (**FIG. 2C**).

[**0044**] The wafer W is then lifted, via the pusher **44**, toward the unload port **37** with a lifting velocity profile that lifts at a process speed (e.g., 10 mm/sec) from a time when the top of the wafer emerges from the tank fluid (and the drying vapor spray is initiated) until a time when the wafer's lower edge (e.g., the lower 30-40 mm of the wafer) emerges from the tank fluid. While the lower edge of the wafer emerges from the tank fluid and passes through the drying vapor, the wafer is lifted at a slower speed (e.g., less than 5 mm/sec.) because the lower portion of the wafer is more difficult to dry (due to the wafer's curvature). After the entire wafer has been dried, the wafer may be lifted at a faster speed (e.g., greater than 10 mm/sec.) to a transfer position. As the wafer is lifted, the wafer edges lean by the force of gravity, on the two parallel inclined guides **46**, which are submerged in the fluid.

[**0045**] As the wafer W is lifted out of the fluid, the pair of spray mechanisms **50** (**FIG. 2D**) spray an IPA vapor and nitrogen mixture at the meniscus that forms on both sides of the wafer W. The IPA vapor flow may be directed with or without the help of a flow deflector as described further with reference to **FIG. 6**. The specific angle of the flow may vary depending upon the type of material on the wafer to be dried.

[**0046**] **FIG. 8A** is a schematic diagram useful in describing vapor flow angle. With reference to **FIG. 8A**, flow angle θ of a stream **72** of vapor/carrier gas is measured relative to the water/air interface (and/or a horizontal center line through a nozzle tube **50**) as shown. (In one embodiment, a nozzle tube **50** is positioned about 0.5 inches laterally from the wafer W, the flow angle is selected to be about 25° and the nozzle height H_N is selected so that the stream **72** strikes the wafer W at a height H_V of about 3.7 mm above the water/air interface. Other lateral spacings, flow angles, nozzle heights H_N and vapor strike heights H_v may be employed.) A table listing preferred flow angles (measured relative to the water/air interface) for exemplary materials is shown in **FIG. 8B**. Surface material refers to the material on a wafer that is to be dried. Dry-in or wet-in refer to whether a wafer is dry or wet prior to processing within the drying apparatus **11**. Dry-out means that a wafer is dry when removed from the drying apparatus **11**. Black Diamond® is a low k dielectric available from Applied Materials, Inc. (e.g., carbon-doped oxide). IPA vapor flow creates a "Marangoni" force resulting in a downward liquid flow opposite to the wafer lift direction. Thus, the wafer surface above the meniscus is dried.

[**0047**] During the drying process, the IPA vapors are exhausted from the processing portion **10** via the exhaust manifold **51**, and a flow of nitrogen is directed across the output port **37** (via the nitrogen blanket manifold **54**) to deter IPA vapor from exiting the processing portion **10**. The gas delivery module (not shown) controls the IPA vapor flow, the exhaust rate and the nitrogen blanket flow rate.

[**0048**] Output Portion—First Aspect

[**0049**] In the embodiment shown in **FIGS. 1-2I** the output portion **12** includes a platform **58**, adapted to rotate between two positions: a processing position (**FIG. 2E**) for receiving a wafer from the drying section **28** and a FAB interface position (**FIG. 2G**) for outputting a wafer to a transfer robot. The processing position matches the incline at which the wafer is elevated form the drying section **28**, and the processing position is generally horizontal. A motor or other driving mechanism coupled to the output portion **12** drives rotation of the platform **58**.

[**0050**] The output portion **12** may include a catcher **60** adapted to move passively with the wafer W. The catcher **60** may be, for example, mounted on a linear ball slide (not shown) that has a stopper at each end. When the platform **58** is in the processing position (e.g., vertically inclined toward the processing portion **10** with the same 9° incline as the inclined guides **46**), the catcher **60** moves to the bottom of the linear ball slide due to gravity. This low position may be detected with an optical sensor (not shown). The catcher **60** may contact the wafer at two points that are separated by a distance and that may be closely toleranced to follow the wafers circumference. Accordingly, the catcher **60** may aid in precise wafer positioning.

[**0051**] The output portion **12** may also include a finger **62** adapted to move between a wafer securing position and a wafer passage position. When in the wafer securing position the finger **62** may lock and secure the wafer after the wafer is elevated above the finger **62**, thereby allowing the pusher **44** to retract, leaving the wafer held in place on the output portion **12** by the finger **62** and the catcher **60**. The finger **62** may be, for example, actuated by an air cylinder (not shown) and equipped with a pair of switches (not shown) to detect the wafer securing and wafer passage positions of the finger **62**. An optical sensor (not shown) may also be provided to sense when the wafer is at a sufficient elevation above the finger **62** so that the finger **62** may safely assume the wafer securing position.

[**0052**] Wafer Output—First Aspect

[**0053**] Prior to lifting the wafer W through the drying section **28**, the platform **58** is generally vertically inclined (e.g., with a 9° incline) (**FIG. 2C**). The catcher **60** is at its low position and the finger **62** is in the wafer passage position. As the wafer W exits the drying section **28** (**FIG. 2D**), it pushes the catcher **60** (e.g., at two points of contact) and causes the catcher **60** to move upward therewith against gravity. The wafer W is thus secured between three points (via the pusher **44** and the catcher **60**). When the pusher **44** reaches its high position, the finger **62** is actuated to the wafer securing position so as to secure the wafer W on the platform **58**, and the pusher **44** may then retract. (The finger **62** is shown in the wafer securing position in **FIG. 2E**.) Because the catcher **60** moves passively with the elevating wafer W, wafer rubbing and particle generation during transfer into the output portion **12** may be reduced.

[0054] After the wafer W is secured on the platform **58**, the platform **58** rotates to its horizontal position (**FIG. 2F**). An air cylinder **64** (**FIG. 1**) which may include an adjustable stop and shock absorber (not shown) may be used to lower the platform **58** to a defined output position, for example, at an elevation where a wafer handler **66** (**FIG. 2H**) may extract the wafer W. The finger **62** is then retracted as shown in **FIG. 2H**, and the wafer handler **66** picks up the wafer W to transfer it to another location (e.g., to a cassette). The platform **58** then returns to its generally vertically inclined process position (**FIG. 2I**) ready to receive the next processed wafer W' as the next processing wafer W' when it is elevated from the drying section **28**.

[0055] In one or more embodiments of the invention, a dedicated gas delivery and exhaust module (not shown) may be employed to deliver isopropyl alcohol (IPA) vapor, nitrogen and exhaust to the drying apparatus **11** (e.g., near the spray mechanism **50**). For example, clean, dry air combined with one or more venturis (not shown) may provide the exhaust (e.g., a gas line (not shown) may supply clean, dry air to a pressure port of a venturi mounted near the unload port **42** to provide exhaust).

[0056] To provide an IPA/nitrogen flow to the spray mechanism **50**, a mass flow controller (not shown) may provide a flow of nitrogen at a predetermined rate to an IPA bubbler (not shown). In at least one embodiment, a 1.4 liter bubbler is employed to deliver an IPA/nitrogen mixture having a concentration of about 5% IPA. Other bubbler sizes and/or IPA concentrations may be employed.

[0057] In one particular embodiment of the invention, the bubbler may be equipped with three level sensors: Low, High and Hi-Hi level sensors. The first two level sensors may be used, for example, during an automatic refill of the IPA bubbler. The latter Hi-Hi sensor may be used, for example, as a hardware interlock to prevent overfilling the bubbler. A pressurized supply vessel (not shown), such as a 1-Liter or otherwise appropriately sized vessel, may be employed to automatically refill the bubbler with liquid IPA. The supply vessel may include a low-level sensor and may be automatically or manually refilled when its low-level sensor is triggered.

[0058] A nitrogen blanket flow rate (e.g., for preventing IPA vapor from escaping from the processing portion **10**) may be controlled with a needle valve or other suitable mechanism. Clean dry air and nitrogen blanket supply lines may each be provided with a flow switch for safety purposes (e.g., hardware interlock flow switches that may be used to shut-off the IPA vapor supply when the exhaust or nitrogen blanket flow are lost). Pressure regulators may be used to control pressure in each supply line.

[0059] Output Portion—Second Aspect

[0060] FIGS. **3**A-B are a schematic side view and a top plan view, respectively, of a second embodiment of the output portion **12** of the inventive drying apparatus. The inventive apparatus **11***a* of FIGS. **3**A-B includes an enclosure **111** that surrounds the output portion **12**. A translatable platform **158** of the output portion **12** may include two or more wafer receivers **113***a*, **113***b*, each comprising the catcher **60** and the finger **62** described with reference to **FIGS. 1-2I**. In this embodiment the translatable platform **158** is adapted to move horizontally (e.g., via a lead screw, pneumatic cylinder, motor or the like), so that the wafer being elevated from the drying portion **28** may be received by either the first or second wafer receiver **113***a*, **113***b*. In this manner wafer throughput may be maximized, as a first wafer may be held at the first wafer receiver **113***a* for pick up by a wafer handler (not shown) while a second wafer is being output to the second wafer receiver **113***b*, or vice versa.

[0061] The enclosure **111** has a first side wall **115***a* which may be positioned adjacent a transfer robot (not shown). The first side wall **115***a* has an opening **117** through which the transfer robot may extract wafers. The enclosure **111** may also have an internal partition wall **115***b* positioned opposite the first side wall **115***a*, for dividing the enclosure **111** into two chambers **111***a*, **111***b*. The first chamber **111***a* may enclose the translatable platform **158** with sufficient space to allow the translatable platform to translate back and forth so as to receive a wafer at either the first or second wafer receivers **113***a-b*. The second chamber **111***b* may enclose the mechanisms employed to translate the translatable platform **158**, as well as any other moving parts (represented generally by reference numeral **159** in **FIG. 3B**). Such an internal partition wall **115***b*, that separates the two chambers may have a plurality of small openings **119** (**FIG. 3A**) that preferably cover the entire internal partition wall **115***b*. When the region adjacent the transfer robot is maintained at a higher pressure than the region adjacent the inventive drying apparatus **11***a*, air may flow laminarly in the opening **117**, across the first and second wafer receivers **113***a*, **113***b* (parallel to the wafers' major surface as indicated by arrow F) and through the small openings **119** into the second chamber **111***b*. The second chamber **111***b* may be exhausted via an exhaust system not shown.

[0062] In addition, an exhaust line (not shown) located beneath the output portion **12** maintains an acceptable vertical laminar flow through the output portion **12**, and also dilutes any IPA vapors that escape from the drying section **28**. The enclosure **111** of the output portion **12** acts as an additional containment mechanism for preventing IPA vapor from entering the atmosphere surrounding the drying apparatus **11***a*.

[0063] In order to allow a wafer to be output to the first wafer receiver **113***a* without blocking the processing portion **26** of the main tank **118**, a front wall **121** of the main tank **118** (i.e., the front wall of the processing portion **26**) may be angled (e.g., 9°), as shown in **FIG. 3A**. By angling the front wall of the processing portion **26**, the load port **34** is able to be located far enough from the output port **37** so as to avoid blockage by the output enclosure **111**, yet the fluid volume of the processing portion **10** is not increased as much as it would be if a straight front wall were employed. In embodiments that employ such an angled front wall the cradle **36** may be adapted to elevate to a position near the load port **34**, such that a wafer handler may place a wafer on the elevated cradle **36**. Such an elevating cradle **36** allows for use of a wafer handler that does not have the ability to rotate so as to match the angle between the load port **34** and the bottom of the processing portion **10**. The elevatable cradle **36** may be coupled to a guide located along an inside surface of the angled front wall, and may magnetically coupled through the front wall to an external actuator, and thus may operate similarly to the elevatable pusher **44**.

[0064] Wafer Output—Second Aspect

[0065] FIGS. 4A-I are schematic side views that show a wafer at various stages of processing within the alternative apparatus **11***a* of FIGS. 3A-B. As shown in **FIG. 4A** wafer **W1** is positioned on wafer receiver **113***a* of output platform **158** and output platform **158** is in its right-most position with the second wafer receiver **113***b* positioned to receive the next wafer output from the drying section **28**. A wafer **W2** is positioned on the submerged cradle **36** and the pusher **44** is in positioned below the cradle **36**. In **FIG. 4B** the pusher **44** has elevated (e.g., through a slot or opening in the cradle **36**) so as to lift the wafer **W2** from the cradle **36**, and the cradle **36** has rotated back to a vertical position.

[0066] In **FIG. 4C** the pusher **44** has reached the elevation where the wafer **W2** passes through the unload port **37** and the top edge of the wafer **W2** contacts the catcher **60**. As the wafer moves into the unload port **37** the IPA vapor spray, the nitrogen blanket and the exhaust are initiated. Also in **FIG. 4C** the cradle **36** has elevated and is positioned inside the load port **34** ready to receive the next incoming wafer.

[0067] As shown in **FIG. 4D** the first wafer **W1** has been extracted from the first wafer receiver **113***a* of the enclosure **111** and the catcher **60** has returned to the lowered position. The second wafer **W2** has been elevated onto the second wafer receiver **113***b* to an elevation above the finger **62**, the finger **62** has moved into positioned below the second wafer **W2** and the pusher **44** has lowered and is no longer supporting the second wafer **W2** which is now held between the finger **62** and the catcher **60**. A third wafer **W3** has been loaded onto the cradle **36** and the cradle **36** has lowered to the bottom of the processing portion **10**. Note that as the third wafer **W3** lowers through the load port **34** in may be sprayed by submerged nozzles **32** and/or by unsubmerged nozzles **30** (not shown).

[0068] As shown in **FIG. 4E** the platform **158** has moved to its left-most position such that the first wafer receiver **113***a* is in position to receive the next wafer output from the drying section **28**. The pusher **44** has lowered to a position below the elevation of the cradle **36** and the cradle **36** is beginning to rotate the third wafer W from the rinsing portion **26** to the drying portion **28**.

[0069] As shown in **FIG. 4F** the cradle **36** has rotated to position the third wafer **W3** in the drying portion **28** and the upper portion of the third wafer **W3** is resting on the wafer guides **46**.

[0070] As shown in **FIG. 4G** the pusher **44** has elevated, lifting the third wafer **W3** off of the cradle **36** and the cradle **36** has rotated back to a vertical position.

[0071] As shown in **FIG. 4H** the pusher **44** begins to lift the third wafer **W3** through the IPA vapor spray and through the nitrogen blanket, to a position where the top of the third wafer **W3** contacts the catcher **60** of the first wafer receiver **113***a*. The cradle **36** has elevated to position itself within the load port **34**, ready to receive the next incoming wafer.

[0072] As shown in **FIG. 4I** the second wafer **W2** has been extracted from the second wafer receiver **113***b* of the output enclosure **111** and the catcher **60** has returned to its lowered position. The third wafer **W3** has been elevated onto the first wafer receiver **113***a* to an elevation above the finger **62**, the finger **62** has moved into positioned below the third wafer **W3** and the pusher **44** has lowered and is no longer supporting the third wafer **W3**, which is now held between the finger **62** and the catcher **60**. A fourth wafer **W4** has been loaded onto the cradle **36** and the cradle **36** has been lowered to the bottom of the rinsing portion **10**. Note that as the fourth wafer **W4** lowers through the load port **34** it may be sprayed by submerged nozzles **32** and/or by unsubmerged nozzles (not shown).

[0073] Processing Portion—Second Aspect

[0074] **FIG. 5** is a side schematic view of an inventive drying apparatus **211** showing only the processing portion **10** thereof. The processing portion **10** is configured according to a second aspect of the present invention. Specifically, rather than a main chamber that submerges a wafer (such as submersion chamber **18***a* of **FIGS. 1-2I**), in the second aspect of the invention the main chamber sprays an unsubmerged wafer with fluid both to rinse and/or maintain the wetness of the wafer in the rinsing chamber **226**, and sprays the unsubmerged wafer with fluid to create the fluid meniscus (for Marangoni drying) in the drying chamber **228**. Only minor hardware differences exist between a processing portion configured for submersion and a processing portion configured for spray processing.

[0075] As can be seen with reference to **FIG. 5**, the overflow weirs **20** and **20***a* of **FIGS. 1-2I** may be omitted. Preferably, a pair of spray nozzles **30** are positioned to spray fluid to both the front and back surfaces of a wafer as the wafer enters through the load port **34**. In the embodiment of **FIG. 5** the separation wall **24** deters fluid spray from splashing from the rinsing portion **226** into the region above the fluid nozzles provided in the drying portion **228** (and thus deters inadvertent rewetting of a dried wafer). Within the drying portion **228**, an additional fluid supplying spray mechanism **50***a* is provided below the IPA supplying spray mechanisms **50**.

[0076] In operation an incoming wafer is sprayed with a fluid such as deionized water which may or may not include a surfactant or other cleaning chemistry such as Applied Materials' ElectraClean™ solution so as to rinse and/or maintain the wetness of the wafer. As the wafer exits the drying portion **228** the wafer is sprayed with a fluid such as deionized water with or without a surfactant or another cleaning agent. This exit fluid spray forms a uniform fluid meniscus across the wafer. The IPA spray mechanism **50** sprays IPA vapor to the meniscus thereby creating a Marangoni flow that dries the wafer. Note that wafer transfer within the processing portion **10**, and wafer output to the output portion **12** may be as described with reference to **FIGS. 1-4I**.

[0077] Flow Deflector

[0078] The efficiency of the delivery of IPA vapor to the wafer/air/water interface (i.e., the meniscus) may be improved by installing a vapor flow deflector in association with each IPA vapor delivery nozzle/tube **50**. One such arrangement is schematically illustrated in **FIG. 6**. To simplify the drawing, a nozzle tube **50** (which may comprise the tube **50** described above) and flow deflector **68** are shown only on one side of the wafer W, although in practice a nozzle tube **50** and flow detector **68** may be provided on each side of the wafer W. Also the wafer W is shown as exiting normal to the surface of the water **76**, although the

wafer W may exit the surface of the water **76** at an incline (e.g., approximately 9° from normal, although other angles may be employed).

[**0079**] In one embodiment of the invention, the flow deflector **68** may take the form of a two part sleeve adapted to fit around the nozzle tube **50**. A first part **69** of the flow deflector **68** defines a wedge-shaped space **70** into which a stream **72** of IPA vapor (e.g., mixed with a carrier gas such as nitrogen) is sprayed and is designed to direct the stream **72** at a specific angle relative to, for example, a horizontal line L drawn through the center of the nozzle tube **50** and parallel to the water surface. The second part (e.g., a lower wing **74**) of the flow deflector **68** may dip below the surface of the water **76** to limit the volume of water exposed to the IPA vapor. The stream **72** of IPA vapor is preferably angled downwardly, as illustrated in **FIG. 6** so as to impinge on the inner surface **78** of the first part **69** of the flow deflector **68**. The stream **72** of IPA vapor may then be reflected (not shown) by inner surface **78** to the meniscus **80** formed at the wafer/air/water interface. In one or more embodiments, the angle between the IPA stream **72** and the inner surface **78** does not exceed 45°, although the angle of the IPA stream **72** preferably is selected so that IPA vapor strikes the meniscus **80** within a desired angular range (as described below with reference to FIGS. **8**A-B) and/or with a desired flow velocity to optimize IPA vapor delivery to the meniscus **80**.

[**0080**] In one exemplary embodiment, the flow deflector **68** has a slit opening **82** that may have a width of 0.05 inches and may be spaced, for example, 0.10 inches above the surface of the water **76**, and 0.10 inches away from wafer W so as to efficiently deliver IPA to the meniscus **80**. Other slit opening widths, distances above the surface of the water **76** and/or distances from the wafer W may be employed. The flow deflector **68** may be aimed at an angle of 45° relative to the surface of the water **76**, however other angles may be employed. Preferably the slit opening **82** is aimed so as to point just below the meniscus **80**.

[**0081**] The flow deflector **68** serves to limit the volume of water exposed to IPA vapor, thereby reducing waste and consumption of IPA, improving dryer efficiency and performance, and reducing safety risks. In one embodiment, the range of water volume exposed to IPA is about 0-12 milliliters for a 300 mm wafer and about 0-8 milliliters for a 200 mm wafer although other ranges may be employed.

[**0082**] If no flow deflector **68** is employed, the stream **72** of IPA vapor may impinge the surface of the water **76** at an angle in the range of 22°-30° which has been found to be suitable for drying several different types of films formed on a wafer. Other impingement angles may also be employed. The flow deflector **68** may be constructed from a single piece of material, or may comprise more than two parts. The flow deflector **68** may be formed from stainless steel or another suitable material.

[**0083**] Reduced Concentration IPA Mixture

[**0084**] The safety and efficiency of the cleaning/drying module can be further improved by reducing the concentration of IPA vapor in the IPA/carrier gas mixture (e.g., to 0.2% or less) while increasing the flow rate of the mixture (e.g., to at least 2-3 liters per minute and preferably about 5 liters per minute). The increased flow rate compensates for the low concentration of IPA and allows for highly efficient and low defect drying with a high drying rate (e.g., 10 mm/sec, resulting in a drying time of 20 seconds for a 200 mm wafer assuming a constant wafer lifting speed). **FIG. 7** is a graph which plots the number of particles larger than 0.12 microns (so called "adders" in **FIG. 3**) observed on wafers dried by gas (nitrogen) having various IPA concentrations and various flow rates. Results may also vary depending on nozzle diameter, nozzle spacing from wafer surface, use of and angle of flow deflectors, etc. Experimental data shows that for a carrier gas flow rate of 5 liters per minute, the number of defects on silicon and on low k dielectric containing wafers does not increase when the concentration of IPA vapor is reduced from 1 percent to 0.2 percent.

[**0085**] As previously noted, the wafer lifting speed may be reduced when the lower portion of the wafer W is being dried. Similarly, the IPA concentration in the IPA/carrier gas mixture may be increased and/or the flow rate of the IPA/carrier gas mixture may be increased when the lower portion of the wafer W is being dried. It will be understood that other inert gases can be employed instead of nitrogen. Also, it will be understood that IPA can be replaced with other organic vapors conventionally used for Marangoni drying, etc.

[**0086**] While the present invention has been disclosed in connection with the preferred embodiments thereof, it should be understood that other embodiments may fall within the spirit and scope of the invention. Particularly, it will be apparent that the inventive lifting profile, and the inventive IPA deflector can be used within any drying system, and are not limited to use within the system disclosed. Similarly, the use of spray nozzles (underwater and/or above the water/fluid bath) to rinse a substrate as it enters a rinsing tank may be employed in systems other than those disclosed herein. A module having an angled wall with angled wafer guides for outputting a wafer in a known orientation is considered inventive, as is a passive output catcher. Further inventive features include a method and apparatus for transferring a wafer (particularly a submerged wafer) from a first angle, to a second angle, and a module adapted to transfer the wafer from one angle to the next so as to move the wafer from alignment with an input port, to alignment with an output port. Accordingly, it will be understood that the embodiments described herein are merely exemplary, and an inventive apparatus may employ one or more of the inventive features.

[**0087**] Some of the inventive features which may be employed individually are as follows:

[**0088**] a module that combines a rinsing section and a drying section without having the rinsed wafer surface exposed to air;

[**0089**] a rinsing section equipped with submerged and/or overhead spray nozzles for better removal of surfactant and process tank particles (the overhead sprays providing the most aggressive rinsing);

[**0090**] a main tank with two sections to separate the loading and unloading ports;

[**0091**] tubes, nozzles and/or flow deflectors that precisely deliver IPA vapor (e.g., to the tip of the meniscus) to minimize IPA consumption;

[0092] IPA spray tubes that can be precisely oriented at the best angle for supplying IPA to the meniscus; (see U.S. Patent Application Ser. No. 60/273,786 filed Mar. 5, 2001, titled Spray Bar, the entire disclosure of which is incorporated herein by this reference);

[0093] a friction-free guide mechanism that employs a "catcher" mounted on the output station;

[0094] a cradle that simplifies the underwater wafer transfer from the rinsing section to the drying section;

[0095] a variable speed pusher having a lift velocity profile;

[0096] slanted back wall and/or slanted front wall;

[0097] internal overflow weir for tanks having separate input and output ports;

[0098] the enclosed output with laminar air flow;

[0099] a deflector that limits the surface area of fluid exposed to the drying (e.g., IPA) vapor;

[0100] exhaust employing venturi for diluting organic solvent concentration;

[0101] the use of a drying gas mixture having reduced concentration of organic solvent and increased flow rate;

[0102] a plurality of output wafer supports for at least partially simultaneous output from dryer and pick up by a robot; and

[0103] a module having a rinsing section and a section adapted for Marangoni drying, both of which employ spray mechanisms rather than wafer submersion.

[0104] Compared to a conventional SRD, the inventive apparatus **11** may provide superior performance and a wider process window for drying both hydrophobic and hydrophilic wafer surfaces. The novel drying technique based on the "Marangoni" principle may, in one example, leave only a 3 nm thick layer for evaporation as compared to a 200 nm layer which may be left by conventional SRDs. By combining the process module with the output station, the inventive apparatus may achieve a fast drying speed that may lead to a high throughput for a wide variety of different films. The rinsing section spray nozzles also may be capable of removing surfactant that may be applied to hydrophobic wafers during scrubbing and transfer to the drying module.

[0105] It should be noted that the nitrogen blanket is merely exemplary, and a blanket of any inert gas or air or plurality of gases (including air) can be employed to form a blanket across the output port and then to deter drying vapors from escaping from the apparatus. Also, it should be noted that IPA vapor is merely exemplary, and other vapors or gases that are miscible with the fluid (that is applied to the drying section) so as to create a Marangoni flow that dries the wafer surface may be similarly employed. Accordingly, such vapors or gases will be referred to herein as drying gases. The terms "catcher,""finger" and "cradle" as used herein are not intended to be limited to any specific shape or structure, but rather refer generally to any structure that functions as do the catcher, finger and cradle described herein.

[0106] Accordingly, while the present invention has been disclosed in connection with the preferred embodiments thereof, it should be understood that other embodiments may fall within the spirit and scope of the invention, as defined by the following claims.

The invention claimed is:

1. A module adapted to process a wafer, comprising:

a processing portion having:

a load port through which a wafer is lowered into the processing portion; and

a spray mechanism adapted to be submerged in a fluid contained in the processing portion during processing, and positioned so as to spray fluid to the underwater surface of a wafer as the wafer is lowered through the load port.

2. The module of claim 1 further comprising a spray mechanism adapted to be above a fluid level contained in the processing portion during processing, and positioned so as to spray fluid to the above water surface of a wafer as the wafer is lowered through the load port.

3. The module of claim 1 further comprising:

an unload port, horizontally displaced from the load port, such that the wafer may be raised out of the processing portion at the unload port; and

a separation wall positioned between the load port and the unload port so as to divide the upper region of the processing portion into a first section adjacent the load port and a second section adjacent the unload port, and so as to deter surface fluid from traveling from the first section to the second section.

4. The module of claim 3 wherein the second section comprises a spray mechanism adapted to spray a drying gas on the wafer as the wafer is raised out of the processing portion at the unload port.

5. The apparatus of claim 4 further comprising a flow deflector coupled to the drying gas spray mechanism and adapted to limit a volume of the fluid contained in the processing portion that is exposed to the drying gas.

6. A module adapted to process a wafer, comprising a processing portion having:

a load port through which a wafer may be lowered into the processing portion;

an unload port, horizontally displaced from the load port, such that the wafer may be raised out of the processing portion at the unload port;

a rotatable wafer support for rotating an input wafer from a first orientation wherein the wafer is in line with the load port to a second orientation wherein the wafer is in line with the unload port;

a first pair of spray mechanisms positioned adjacent the load port and adapted to supply fluid to both a front surface and a back surface of the wafer so as to cause the fluid to run downward along the front and the back surfaces thereby maintaining the front and the back surfaces in a wet condition;

a second pair of spray mechanisms positioned adjacent the unload port and adapted to supply fluid to both the front and the back surfaces of the wafer so as to form a fluid meniscus on both the front and the back surfaces of the wafer; and

a third pair of spray mechanisms positioned above the second pair of spray mechanisms and adapted to supply a drying vapor to the fluid meniscus formed on the front and the back surfaces of the wafer.

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