SINGLE SIDE WORKPIECE PROCESSING

This application is a continuation-in-part of U.S. patent application Ser. No. 11/075,099, filed Mar. 8, 2005 and now pending, and claiming priority to U.S. Provisional Patent Application No. 60/552,642, filed Mar. 12, 2004. These applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Remarkable progress made in microelectronic devices over the past several years has led to more useful yet less expensive electronic products of all types. It has also led to entirely new types of products. A major factor in the development of microelectronic devices has been the machines and methods used to manufacture them. Manufacturing of microelectronic devices requires extreme precision, extremely pure materials, and an extremely clean manufacturing environment. Even microscopic particles can cause defects and failures in devices.

Microelectronic devices are typically manufactured on a front or device side of a semiconductor wafer. In general, no microelectronic devices are on the back side of the wafer. However, contaminants on the back side of the wafer, such as metal particles, residues, films, etc., if not removed, can result in damage to devices on the front side of the wafer. For example, certain metals used in the manufacturing process, such as copper, can migrate through the wafer, from the back side to the front side, where they can cause defects in the microelectronic devices. Processing the backside of the wafer is therefore important.

The back side of the wafer may be processed using existing techniques, to remove contaminants. These techniques involve applying process fluids onto the back side, usually while spinning the wafer. However, the process fluids may damage microelectronic devices if the process fluids contact the front side of the wafer. Therefore, during back side processing, or single side processing in general, the process fluids should ideally make minimal or no contact with the front side or opposite side of the wafer. As the process fluids include liquids, gases or vapors, and as the wafer is usually spinning when they are applied, this objective has largely not yet been reached with current wafer processing technology.

Wafer processing machines have used various designs to try to solve the problem of how to exclude process fluids from the front side while processing the back side. Some of these machines have used flows of inert gas to try to confine the process fluids only to the back side. Others have used gaskets, membranes, or other types of mechanical seals or barriers to keep the process fluids off of the top side of the wafer. However, in the machines using gas flow, some amounts of process fluids tend to still reach the top side of the wafer. In the machines using mechanical seals, the seal must physically touch the top side of the wafer. This physical touching may damage microelectronic devices. Consequently, use of seals or physical barriers can have serious disadvantages.

Physical contact with the wafer by seals, fingers, clamps or other sealing, holding or positioning elements, as often used in current processing machines, creates risk of contamination via particle generation or particle release. These types of elements can also disrupt the uniform flow of process fluids on the wafer, resulting in varying degrees of processing at different areas of the wafer. Accordingly, regardless of whether one side or both sides are processed, minimizing physical contact with wafer generally provides better results. On the other hand, the wafer must be properly positioned and secured in place during processing. Accordingly, better

machines and methods are needed to provide single side wafer processing, and for processing generally with less physical contact with the wafer.

SUMMARY OF THE INVENTION

New processing machines and methods for solving these difficult wafer back side processing and physical wafer contact problems have now been invented. These machines and methods provide dramatic improvements in manufacturing microelectronic and similar devices. In one aspect of the invention, a circulating gas is provided on one side of the wafer. The circulating gas creates gas pressure and flow conditions that keep process fluids away from the front side, during processing of the back side of the wafer. Accordingly, the back side may be processed using a wide range of process chemicals, without risk of damage to microelectronic devices the front side.

The circulating flow of gas may also hold the wafer in place during processing, via gas pressure forces. The gas flow and pressure conditions created by the circulating gas can exert holding forces at the edges of the wafer, while applying relatively little or no forces towards the unsupported central area of the wafer. The wafer is accordingly held securely in place during processing, with minimal stress applied to the wafer. Physical contact with the wafer during processing of the front side or the back side, or both, is minimized. This reduces potential for contamination and increases wafer yield. As a result, more useable device chips may be produced from each wafer.

A wafer processing machine using circulating gas may have a bowl having one or more process fluid inlets for applying a process fluid onto a first side of a wafer. The machine has a head which can be positioned in engagement with the bowl during workpiece processing. Rotational gas flow is created in a rotor supported on the head. One way of creating the rotational gas flow is by releasing pressurized gas in the rotor in directions at or near tangent to direction of rotation. The rotational gas flow holds the wafer in place on or in the rotor, with minimal physical contact with the wafer. The fluid inlets apply one or more process fluids onto the first side of the wafer, while the wafer rotates with the rotor. In addition to holding the wafer in place, for single side processing, the rotational gas flow in the rotor can also be used to exclude process fluids from the second side of the wafer. The wafer is positioned on the rotor with a gap around the edge of the wafer. Some or all of the circulating gas provided into the rotor escapes out through the gap and around the edge of the wafer. This outflow of gas prevents any of the process fluids applied to the first side from reaching the second side. The invention resides as well in sub-combinations of the machines and methods described.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, the same reference number indicates the same element, throughout the several views. Electrical wiring and gas and liquid plumbing lines are generally omitted from the drawings for clarity of illustration.

FIG. **1** is a section view showing principles of operation of the invention.

FIG. **1A** is a section view taken along line **1A-1A** of FIG. **1**.

FIG. **1B** is a section view of an alternative design.

FIG. **2** is a top perspective view of a workpiece processor.

FIG. **3** is a side view of the processor shown in FIG. **2**, in an open or load/unload position.

FIG. **4** is a section view taken along line **4-4** of FIG. **2**.

FIG. **5** is a section view of the processor as shown in FIG. **3**.

FIG. **6** is a top perspective view of the head shown in FIGS. **2-5**, with the cover removed for illustration.

FIG. **7** is a top perspective view of the rotor shown in FIGS. **4** and **5**.

FIG. **8** is a bottom perspective view of the rotor shown in FIG. **7**.

FIG. **9** is a section view taken along line **9-9** of FIG. **7**.

FIG. **10** is a bottom perspective view of an alternative rotor design.

FIG. **11** is a section view taken along line **11-11** of FIG. **10**

FIG. **12** is a perspective view of a workpiece processing system including several of the processors as shown in FIGS. **2-9**.

FIG. **13** is a plan view of the system shown in FIG. **12**.

FIG. **14** is a perspective view of components or subsystems shown in FIG. **12**.

FIG. **15** is a perspective view of selected components and subsystems of an alternative processing system.

FIG. **16** is a perspective view of one of the processing assemblies shown in FIG. **15**.

FIG. **17** is a section view taken along line **17-17** of FIG. **16**.

FIG. **18** is a perspective view of the bowl shown in FIGS. **16** and **17**.

FIG. **19** is a schematic diagram of an alternative processing system.

DETAILED DESCRIPTION OF THE DRAWINGS

The invention is directed to apparatus and methods for processing a workpiece, such as a semiconductor wafer. The term workpiece, wafer, or semiconductor wafer means any flat media or article, including semiconductor wafers and other substrates or wafers, glass, mask, and optical or memory media, MEMS substrates, or any other workpiece having micro-electronic, micro-mechanical, or microelectro-mechanical devices.

Turning to FIG. **1**, a processor **20** may perform single side processing. Single side processing means applying one or more process fluids to only one side (referred to here as the back side) of the wafer, and with the process fluid substantially excluded from contacting the second (front) side of the wafer. The process fluid may optionally also contact the bevel edge of the wafer. The process fluid may be a liquid, a gas or a vapor. In FIG. **1**, the processor **20** includes a rotor **24** linked to a spin motor in a head **22**. Guide pins **25** may be provided around a perimeter of the rotor **24**, to help guide a wafer **100** into position. Gas nozzles or inlets **26** spray or jet out gas in a direction which creates a gas vortex flow in the rotor **24**. The arrows **23** in FIGS. **1** and **1A** indicate the direction of gas flow. This gas flow creates a negative or lower pressure zone in the space above the wafer **100**. As a result, pressure forces may be used hold the wafer **100** onto the rotor **24**.

Referring to FIG. **1**, the rotor **24** may be designed so that the only escape path for the gas is the annular opening between the edge of the wafer and the rotor. In this design, as the gas escapes or flows out of the rotor **24**, the gas substantially prevents the wafer **100** from touching the rotor **24**. The wafer is essentially be supported on, or held up by, a cushion of moving gas. The guide pins **25** may be provided to minimize or limit any side-to-side movement of the wafer in the rotor **24**.

Referring still to FIG. **1**, the head **22** may be placed in or moved into alignment or engagement with a base or bowl **28**. Process fluids are applied onto the back side of the wafer from

one or more nozzles or inlets **29** in the bowl **28**. During processing, the motor **84** spins the rotor **24**. The wafer **100** spins with the rotor **24**. Process fluids are applied to the back side of the wafer. In FIG. **1**, the back side is the down facing side. The gas flow escaping from the rotor **24** acts as an isolation barrier for the front side of the wafer. As the gas is constantly flowing outwardly, no process fluid can move into the rotor **24** or contact the top side of the wafer. Consequently, highly effective single side wafer processing may be achieved.

Referring now to FIGS. **1** and **1A**, the gas flow is shown by the arrows **23**. The rotor is designed to create a rotational gas flow. Near the inlets **26** (adjacent to the perimeter of the rotor), gas flow velocity is relatively high, and gas pressure is correspondingly relatively low. Towards or at the center of the rotor, gas flow velocity is relatively lower, and gas pressure is correspondingly higher. Consequently, pressure forces holding the wafer in place on the rotor are highest near the wafer edges (where the negative gas pressure is highest) and are lowest towards the center. Towards or at the center of the rotor, gas flow velocity may be at or close to zero. Thus gas pressure in the inner area of the rotor will typically be only slightly negative, neutral, or even slightly positive. As a result, the edge areas of the wafer can be securely held against the rotor, with minimum forces acting on the center of the wafer. Bending stresses on the wafer may therefore be reduced.

FIG. **1B** shows a design where the rotor **24B** has a diameter larger than the wafer **100**. In this design, the wafer is entirely within the rotor **24B**. The rotor **24B** operates in the same way as the rotor in FIGS. **1** and **1A**. However, the wafer is held away from the face of the rotor **24B** by standoffs or pins **27**. In this design, guide pins **25** are not needed, as the cylindrical side walls of the rotor prevent the wafer **100** from shifting excessively off center.

In each of the designs described here, the way that the gas escapes from the rotor may vary. In FIG. **1**, gas escapes out through the annular opening between the edge of the wafer and the rotor. In the design shown in FIG. **1B**, the gas escapes out through the annular gap between the edge of the wafer and the cylindrical side walls of the rotor. However, other gas escape openings may be used, alone or in combination with the opening and gap shown in FIGS. **1** and **1B**. For example, gas outlets **147** shown in dotted lines in FIG. **1** may be provided in the rotor. The gas outlets **147** may be holes, slots, or other openings. The gas outlets **147** may be located anywhere on the rotor, and take any form which will facilitate the rotational gas flow described above.

With some processes and wafers, seals making physical contact with the wafer may be used. In these applications, a contact sealing element, such as a seal ring **149** shown in FIG. **1**, may also be used to provide a physical seal between the rotor and wafer during processing. The negative pressure or vacuum conditions described above hold the edges of wafer securely against the seal ring **149**. Gas outlets **147** in the rotor provide an escape path for the gas flow. The positioning pins **25** can be omitted since the wafer is held in physical contact with the seal ring, largely preventing any shifting of the wafer during processing.

FIGS. **2-5** show an example of a processor **50** which may use the principles of operation described above relative to FIG. **1**. However, FIGS. **2-5** show various additional elements which are not essential to the invention. As shown in FIGS. **2-5**, the processor **50** includes a head **80** and a bowl **78**. The bowl **78** may be supported on a mounting plate **70** which in turn may be attached to the deck **52**. As shown in FIGS. **6** and **7**, a spin motor **84** may be supported on a base plate **88** of the head **80**, and covered by a head cover **82**. A rotor **92** is

typically driven by the spin motor **84** and spins within the head **80**. However, the motor **84** can be omitted in favor of other techniques used to spin the rotor.

The head **80** is engageable with the bowl **78**. Specifically, for processing, the head **80** may be moved to a position adjacent to (but not contacting) the bowl **78**, or the head **80** may be physically contacting with the bowl **78**, or even sealed against the bowl **78**, as shown in FIG. **4**.

As shown in FIGS. **4** and **5**, the bowl **78** has liquid spray nozzles or inlets **112**, for applying a process liquid onto the back or down facing surface of a workpiece **100** held in the head **80**. The nozzles or inlets **112** may be fixed in position on the sides or bottom surfaces of the bowl **78**. Alternatively, some or all of the nozzles **112** may be moving, e.g., on a swing arm. Combinations of fixed and moving nozzles **112** may also be used. Fixed or moving spray manifolds having multiple nozzles or inlets, may also be used in the bowl **78**. Gases or vapors may also be applied to the workpiece **100** via the nozzles **112**. A drain **114** collects spent process fluid for removal from the bowl **78**. One or more valves **116** may be associated with the drain **114**. Bowl stand-offs **110**, if used, are attached to the bowl and project upwardly from the bowl **78** towards the workpiece **100** on the head **80**. As shown in FIG. **5**, the head **80** may be lifted vertically away from the bowl **78** by a head lifter (not shown) connected to the head by a head lifting arm **90**, shown in FIG. **4**.

FIG. **6** shows the head **80** with the cover **82** and other components removed for illustration. Head gas supply lines **102** advantageously deliver gas or clean dry air to gas ports **96** passing through the base plate **88**, to provide a flow of gas between the base plate **88** and the rotor **92**. This flow of head gas or clean dry air helps to prevent migration of process liquids, vapors, or gases into the head **80**, thereby reducing corrosion of head components. A head ring **94** may be attached around the outside of the base plate **88**. An inflatable seal **98** may be provided in a groove in the head ring, to seal the head **80** against the bowl **78** during processing. The components shown in FIG. **6** which are part of the head **80**, are supported by the head lifting arm **90**, and do not rotate.

Turning now to FIGS. **7**, **8** and **9**, in the example shown, the rotor **92** has a drive plate **130** attached to a shaft **124** at a hub **122**. The shaft **124** is keyed to the spin motor **84** in the head **80**. A chuck **132** is attached to the drive plate **130** by screws **128** or other fasteners. As shown in FIGS. **8** and **9**, guide pins **134** extend out (or downwardly) from an outer rim **142** of the chuck **132**. The guide pins **134** may have a conical or tapered section **135**. As shown in FIG. **9**, contact pins **154** project slightly from the chuck outer rim **142**. The contact pins **154** are shorter than the guide pins **134** and are positioned radially inside of the guide pins **134**.

Referring still to FIG. **9**, the chuck **132** has a cylindrical side wall **138** joined, typically substantially perpendicularly, to a top or web plate **148**. An O-ring or other seal **144**, if used, seals the outer surface or perimeter of the chuck **132** against the drive plate **130**. The web or top plate section **148** of the chuck **132** is generally spaced apart from the drive plate **130** by a gap G (except at the fastener **128** attachment points).

A gas flow path generally designated **145** and indicated by the arrows in FIGS. **7-9** extends through the rotor **92**. A supply of gas, such as nitrogen, or clean dry air, under pressure, connects from a supply line in the head **80**, through a labyrinth cap **126** (shown in FIGS. **4**, **5** and **7**) attached to the motor housing and into an inlet line **86** extending through a sleeve **125** within the shaft **124**. The sleeve **125** is attached to the drive plate **130** and rotates within the cap **126**

Gas provided to the head **80** flows (downwardly in the design shown) through the inlet line **86**, as shown in FIG. **9**,

radially outwardly in the gap G, as shown in FIGS. **7** and **9**, to gas inlets **136**. The gas inlets **136**, located in the side wall **138** of the chuck **132** are positioned to jet or spray gas in a direction fully or at least partially tangent to the cylindrical side wall **138**. The inlets are oriented so that the gas direction is tangent to the sidewalls, or within 40, 30, 20 or 10 degrees of tangent. Multiple gas inlets **136**, for example, 3, 4, 5, 6, 7 or 8 gas inlets **136** are advantageously radially spaced apart and positioned in the side wall **138**, close to the top or web **148** of the chuck **132**. The number, shape, configuration, and location of the gas inlets **136** may of course be changed, as various designs may be used to create gas flow conditions which will cause the workpiece **100** to be held in place on the rotor **92**. The O-ring or seal **144** may be used to prevent gas from escaping from the gas flow path **145**, except through the gas inlets **136**.

The side walls **138** of outer rim **142** on the chuck plate **132** form a space generally designated **155** in the chuck **132** having a diameter D, and a depth or height H, as shown in FIG. **9**. The dimension H is substantially uniform, except at the central area around the hub **122**.

A central opening may be provided in the chuck plate **132** for alignment purposes. If used, the opening is closed via a plug **146** before the rotor **92** is put into use. Referring now to FIGS. **8** and **9**, the guide pins **134** are positioned on a diameter DD slightly larger than the diameter of the workpiece **100** (which in turn is slightly larger than the diameter D of the cylindrical or disk-shaped space **155**). Accordingly, with a workpiece placed into the rotor **92**, as shown in FIG. **4**, there is only nominal radial or lateral clearance between the guide pins **134** and the edge of the workpiece.

Referring to FIG. **3**, the processor **50** is in the up or open position for loading and unloading. In the design shown, the head lifting arm **90** lifts the head **82** up from the bowl **78**. A workpiece **100** is moved into a position between the head **82** and the bowl **78**, with the workpiece **100** generally aligned with the rotor **92**. The workpiece is then moved vertically upwardly, with the guide pins **134** around the outside edge of the workpiece. The workpiece at this point is at or above the plane P of the guide pins **134**, as shown in FIG. **11**. These workpiece loading movements may be performed manually, or by a robot, as further described below.

Gas is then supplied to the gas flow path **145**. Referring momentarily to FIG. **8**, due to the generally tangential orientation of the gas inlets **136** and the relatively high velocity of the gas flowing out of the inlets **136**, a rotational gas flow or vortex is created within the space **155**, between the workpiece and the top plate **148** of the chuck **132**. The gas flows in a circular pattern in the space **155**. The gas may then move out of the space by flowing around the edge of the workpiece **100** and into the bowl **78**. This creates a negative pressure or vacuum at the outer areas of the space **155**, causing the workpiece to lift up and off of the robot **44**. The negative pressure in the outer areas space **155** above the workpiece **100** holds the top surface of the workpiece against the contact pins **154**. This prevents the workpiece from rotating or shifting relative to the rotor **92**. The contact pin **154** may have a spherical end which essentially makes point contact with the wafer. Alternatively, the contact pin may have an end that makes contact over a very small area, e.g., over a diameter of 0.2-3 mm.

The normal force acting to hold the workpiece **100** against the contact pins **154** depends on the pressure difference created by the vortex gas flow, and the surface area of the workpiece on which the pressure acts. The normal force may be adjusted by controlling the gas flow. In general, the normal force will significantly exceed the weight of the workpiece, so that the workpiece remains held against the contact pins **154**,

regardless of its orientation relative to gravity. The contact pins **154** which are the only surfaces supporting the workpiece, are generally positioned within 2-10, 4-8, or 5-7 mm of the edge of the workpiece.

The head lifter then lowers the head lifting arm **90** and the head **80**, with the head moving from the open position shown in FIG. **5**, to the closed or processing position shown in FIG. **4**. The seal **98**, if used, is inflated, creating a partial or full seal between the head **80** and the bowl **78**.

The only escape path for the gas in the space **155** is the small annular opening between the workpiece and the rim **142** of the chuck **132**. As gas escapes from the space **155**, it tends to prevent the workpiece **100** from touching the chuck **132**, or any part of the rotor **92** or processor **50**, except for the contact pins **154**. The workpiece **100** is otherwise essentially suspended within a flow of gas. The guide pins **134** act, if needed, to prevent the workpiece **100** from moving too far off center of the spin axis of the rotor **92**. Ordinarily though, the gas flow around the edges of the workpiece, and the normal force holding the workpiece against the contact pins **154**, will tend to keep the workpiece centered.

The spin motor **84** is turned on, spinning the rotor **92** and the workpiece **100**. In general, the gas flow vortex spins within the rotor in the same direction as the rotor spins. Process liquid is sprayed or jetted from the nozzles or inlets **112** onto the bottom or down facing surface of the spinning workpiece **100**. Process gases or vapors may also be used. Centrifugal force helps to distribute the process liquids over the entire bottom surface of the workpiece **100**. The gas flow via the flow path **145** in the rotor **92** helps to prevent any process liquids or gases from contacting the top surface of the workpiece **100**, as there is a constant flow of gas from the space above the workpiece to the space below the workpiece.

Following the application of process liquids and/or gases, the wafer may optionally be rinsed and/or dried, also while in the position shown in FIG. **4**. When all processing within the processor **50** is completed, the workpiece **100** is unloaded following the reverse sequence of steps described above.

Interruption of the flow of gas to the rotor **92**, while the rotor is holding a workpiece **100**, could result in the workpiece **100** moving or falling out of the rotor **92**. To reduce the potential for damage in this event, bowl stand off posts **110** are positioned in the bowl **78** and extend up to a position about 10-15 millimeters below the workpiece **100** (when in the processing position) as shown in FIG. **4**. In the event of a gas flow interruption, the workpiece will drop only a short distance and come to rest on the stand-off posts **110**.

After the gas moves out of the rotor **92**, it is drawn into a gas exhaust plenum **120** and then removed from the processor **50**. Depending on the specific processes to be run in the processor **50**, the chuck **132** and drive plate **130** may optionally be made of corrosion resistant materials, such as PVDF plastic materials or equivalents. The rotor **92** as described above, and the entire head **80**, may be used in virtually any centrifugal process where a process chemical, typically a liquid, is applied to one side only of a workpiece. While the processor **50** is shown in a vertical and upright position, it may also be used in other positions or orientations. Accordingly, the description here of top or bottom surfaces and up and down directions are provided to describe the examples shown in the drawings, and are not requirements or essential operating parameters.

In each of the embodiments described, the front or device side of the wafer may be facing towards or away from the rotor. For back side cleaning or processing, the wafer is placed into the rotor with device side facing the rotor. For front side cleaning or processing, the wafer is place into the rotor with the front side facing away from the rotor. The

desired face up/face down orientation of the rotor may be achieved via robotic or manual handling. A separate inverting or wafer flipping station may also be used.

Generally, the gas provided to the rotor is inert, i.e., it does not significantly chemically react with the wafer. However, process chemical gases may be used in place of inert gases. Providing a process chemical gas to the rotor allows for chemically processing the side of the wafer facing the rotor, optionally while simultaneously processing the other side of the wafer with the same process chemical gas, or with a different process chemical gas or liquid.

As may be appreciated from the description above, the head **50** requires no moving parts for holding or securing the workpiece **100**. Since gas flow is used to hold the workpiece in place, the head **80** may have a relatively simple design. In addition, generally, chemically compatible plastic materials may be used for most components. This reduces the need for metal components, which can lead to contamination. There are also no obstructions or components over or shadowing the workpiece **100**. This allows distribution of process liquids onto the workpiece to be highly uniform, resulting in more consistent and uniform processing. The guide pins **134** only touch the edge of the workpiece. The contact pins **154** contact only very small areas of the front or top side of the workpiece **100**. Consequently, touching the workpiece **100** is minimized.

FIGS. **10** and **11** show an alternative rotor **160**. The rotor **160** is similar to the rotor **92**, except for the differences described below. As shown in FIG. **10**, on one side, the rotor **160** has short guide pins **162**. The remaining guide pins **134** are full length guide pins, with the tip of the guide pin **134** extending by a dimension K beyond the rim **142** to the plane P. The full height guide pins **134** and workpiece holders **166** are spaced apart by dimensions greater than the diameter of the workpiece **100**. L-shape workpiece holders **166** are attached to the drive plate **130** and have a horizontal leg extending radially inwardly. The short guide pins **162** create a entrance pathway **164**, allowing a workpiece **100** to move laterally into the rotor **160** (in contrast to the vertical workpiece movement described above relative to the rotor shown in FIGS. **7-9**. With lateral movement, the robot **44** can generally align the wafer **100** with the rotor **160**, and then move down to place the workpiece **100** on the holders **166**. The upfacing ends of each holder **166** preferably have a flat land area **168** for supporting the workpiece **100**. The robot **44** can then withdraw to perform other functions within the system **30** even if the processor having the rotor **160** is not active. Accordingly, a workpiece **100** may be placed into the rotor **160** even when no gas is flowing through the rotor **160**.

The rotor **160** shown in FIG. **11**, in comparison to the rotor **92** shown in FIG. **9**, is designed for handling smaller diameter workpieces. For example, the rotor **92** shown in FIG. **9** is designed for 300 mm diameter workpieces, while the rotor **160** shown in FIG. **11** is designed for 200 mm diameter workpieces. Of course, the rotor can be made in various other sizes as well for processing workpieces having other sizes.

The processors described above may be used in automated processing systems. An example of one processing system **30** is shown in FIG. **12**. The processing system **30** generally has an enclosure **32**, a control/display **34**, and an input/output or docking station **36**. Wafers or workpieces within pods or boxes **38** (e.g., FOUPs) are removed from the boxes **38** at the input/output station **36** and processed within the system **30**.

Turning to FIG. **13**, the processing system **30** preferably includes a frame **48** that supports an array of workpiece processors **50** on a deck **52** within the enclosure **32**. Facility or fab air inlets **42** are typically provided along with air filters, at

the top of the system **30**. Each workpiece processor **50** may be configured to process workpieces, such as 200 or 300 mm diameter semiconductor wafers or similar workpieces, which may be provided within sealed boxes **38**, open cassettes, or other carriers or containers.

The frame **48** in FIG. **13** is shown supporting ten workpiece processors **50**, but any desired number of processors **50** may be included. The frame **42** preferably includes one or more centrally located rails **46** between the processors **50**. One or more robots **44** can move on the rails **46** to load and unload workpieces into and out of the processors **50**.

Referring to FIGS. **12-14**, in use, workpieces or wafers **100** are typically moved to the processing system **30** within containers **38** such as front opening unified pods (FOUPs) or similar closeable or sealable containers. Alternatively, open containers such as cassettes or other carriers may also be used. At the docking or input/output station **36**, the door or cover of the container **38**, if any, is removed, generally via a robotic or automated subsystem. The load port door or window in the enclosure **32**, if any, is opened. The robot **44** removes a workpiece **100** from a container **38** and carries it to one of the processors **20** or **50**. The workpiece **100** is then ready for loading into a processor. This sequence of steps, as well as the components or apparatus used in moving the workpiece **100** to the processor may of course vary, and are not essential to the invention. Rather, the sequence described above and as shown in FIGS. **12-14** represents an example, for purposes of explanation.

Referring momentarily to FIG. **5** flow sensors in the head **80** may be used to verify the flow of gas, indicating to the controller **34** that the robot **44** may be safely withdrawn. The robot **44** moves down and away from the rotor **92**. Sensors on the robot **44** verify that the workpiece **100** is no longer on the robot **44**. The robot then retracts away from the processor **50**. The processor then operates as described above

FIGS. **15-18** show an additional alternative system **180**. The components and operation discussed above with reference to FIG. **12** apply as well to the system **180** shown in FIG. **15**. The system **180** shown in FIG. **15** is similar to the system **30** shown in FIGS. **12-14**. However, processor assemblies **182** are installed on the deck **52** within the enclosure **32**, instead of the processors **50**. As shown in FIGS. **16** and **17**, one or more of the processor assemblies **182** includes a processor **184** which may be attached to a mounting plate **188**, and a lift/rotate unit **186**. The lift rotate unit **186** is attached to the head **80** through the head lifting arm **90**, in place of the head lifter used in the system **30** shown in FIGS. **12-14**. In addition to lifting the head **80** vertically up and away from the bowl **78**, the lift/rotate unit **186** can also flip or rotate the head **80** into an upside down position.

As shown in FIG. **16**, an air shield **190** is positioned on top of a rim **192** supported above the processor **184** on rim posts **194**. Electrical wiring runs through cable guides **198** which generally extend from near the top of the enclosure **32** to the mounting plate **188**. Referring to FIGS. **16** and **17**, a drying process swing arm **196** is supported on and driven by a swing arm actuator **200** on the mounting plate **188**, and to one side of the processor **184**.

The head **80** shown in FIG. **17** is similar or the same as the head **80** shown in FIGS. **2-9** and described above. The head **80** shown in FIG. **17** is engageable with a bowl **204**. The bowl **204** advantageously has a top section **210** having a cylindrical upper end **212**, a center section **208**, and a bottom plate **206**. The bowl **204** also has a reciprocating spray swing arm **220** driven by a actuator **222**. One or more spray or jet nozzles or inlets **218** are provided on the swing arm **220**. The bowl **204** is otherwise similar to the bowl **78** described above. The

process chemicals applied by the nozzles or inlets in the bowl **78** or **204** may be liquid acid solutions, such as HF, HCL, nitric acid, or sulphuric acid. Alternatively, the process chemicals may include liquid solvents.

The head **80** of the processor **184** operates in the same way as the head **80** described above relative to FIGS. **2-9**. The nozzles or inlets **218** on the swing arm **220** apply process liquids onto the bottom surface of a workpiece **100**. Fixed nozzles or inlets may also be used, with or without the swing arm nozzles. When this processing is complete, the lift/rotate unit **186** lifts the head **80** up and rotates the head into an upfacing position, i.e., the down facing surface of the wafer in the processing position shown in FIG. **17**, is moved into an upfacing position. While the rotor **92** is rotating, the drying process swing arm **196** applies drying fluids onto the workpiece **100**. The drying process swing arm **196** begins at or near the center of the workpiece and moves radially outwardly towards the edge of the workpiece, to dry the workpiece as described in U.S. patent application Ser. No. 11/075,099, incorporated herein by reference. The openings in the shield **190** help to diffuse and/or control downward air flow through the processor assembly **182**.

The drying process swing arm **196** typically applies deionized water (DI) along with nitrogen and a solvent, such as isopropyl alcohol vapor, as the arm sweeps across the upfacing surface of the workpiece. A similar process could alternatively be performed by the swing arm **220** in the bowl **204**. Other process liquids or gases including ozone gas, or ozone dissolved and/or entrained in a liquid, such as DI, may also be applied via fixed or moving nozzles or inlets in the bowl **78** or **204**.

While the head is inverted or upfacing, gas flow through the rotor **92** continues, thereby holding the workpiece **100** against the contact pins **154**. Similarly, the workpiece **100** is held onto the rotor **92** while the head **80** pivots from the downfacing position shown in FIG. **17** to the upfacing position by the normal force holding the workpiece against the contact pins **154**.

FIG. **19** shows an alternative system design **230** having processors or processor assemblies **50** or **182** arranged in an arc **234**, or other array or pattern, rather than the linear columns shown in FIGS. **12** and **15**. Workpieces **100** may be moved into and out of the processors **50** or **182** by a single robot **232**. While automated or robotic systems **30** and **180** have been shown and described, the head **80** and rotors **92** and **160** may be used in various other systems including manually operated and/or single processor machines.

The terms cylindrical, round, or circular also include multi-segmented shapes. The term engaged or engagement includes actual physical contact, as well as adjacent positioning allowing cooperation between the elements without physical contact between them. The term vortex or gas flow vortex means a flow of gas having a generally circular characteristic, and includes helical, spiral, and similar flows. The plural, as used here, includes the singular as well, and vice-versa. The terms attached to or supported on include both direct and indirect connections or interactions. Novel systems and methods have been shown and described. Various changes, substitutions and uses of equivalents may of course be made, without departing from the spirit and scope of the invention. The invention, therefore, should not be limited, except by the following claims and their equivalents.

The invention claimed is:

1. A workpiece processor, comprising:

a bowl having one or more process fluid inlets;

a head configured to engage with the bowl during workpiece processing;

a rotor configured to hold a workpiece and having an annular sidewall around a perimeter of the rotor, with the rotor supported on the head and rotatable relative to the head;

a pressurized gas inlet line on the rotor; and

a plurality of gas inlets in the annular sidewall of the rotor, above the workpiece, with the inlets connected to the gas inlet line on the rotor and oriented to spray pressurized gas above an outer area of the workpiece in a direction at least partially tangent to the annular sidewall of the rotor, and with the spray of gas above the workpiece acting to hold the outer area of the workpiece onto the rotor.

2. The processor of claim **1** further comprising a plurality of gas nozzles in the annular sidewall oriented at least partially tangent to the annular sidewall.

3. The processor of claim **1** further comprising guide pins adjacent to a perimeter of the rotor.

4. The processor of claim **1** with the rotor including a drive plate and a chuck plate attached to the drive plate, and a gas flow path between the drive plate and the chuck plate.

5. The processor of claim **4** further comprising a seal between the drive plate and the chuck plate.

6. The processor of claim **4** further comprising a central opening in the chuck plate.

7. The processor of claim **1** further comprising process fluid inlets in the bowl positioned to spray a process liquid in a substantially straight line onto substantially all surfaces of a down facing side of a workpiece held in the rotor.

8. The processor of claim **1** further including guide pins on an outer perimeter of the rotor, with a workpiece holding position formed on the rotor inside of the guide pins, and with the guide pins extending from the rotor in a direction towards the bowl when the processor is in a processing position.

9. The processor of claim **1** with gas inlets oriented to spray pressurized gas in a direction within 30 degrees of a tangent of the sidewall of the rotor.

10. A centrifugal workpiece processor, comprising:

a base having one or more process liquid inlets;

a head movable onto the base;

a rotor on the head having a plate and side walls joined to the plate;

means for rotating the rotor;

partial vacuum creating means associated with the rotor for creating a partial vacuum adjacent to the sidewalls of the rotor, for holding an annular edge area of the workpiece into the rotor with no moving parts, via rotational gas flow.

11. The processor of claim **10** further comprising guide means associated with the rotor for maintaining a workpiece substantially aligned with the rotor.

12. The processor of claim **10** further comprising pins on a down-facing surface of the rotor, and with the holding means holding the workpiece into the rotor, and with the workpiece contacting only the pins and no other element of the rotor.

13. A workpiece processor, comprising:

a bowl having one or more process fluid inlets;

a head configured to engage with the bowl during workpiece processing;

a single rotor in the processor, with the rotor supported on the head and rotatable relative to the head;

a pressurized gas supply line in the rotor;

a plurality of gas inlets in the rotor at a perimeter of the rotor, with the inlets connected to the gas supply line and oriented to spray pressurized gas in a direction at least partially tangent to the sidewall of the rotor;

a plurality of circumferentially spaced apart pins adjacent to a perimeter of the lower surface of the rotor, and with the rotor configured to support a workpiece at a vertical position between the gas outlets and the bowl during processing with only the pins of the rotor contacting the back side of the workpiece when the workpiece is in a processing position in the rotor;

and with the rotor configured to hold the workpiece regardless of the orientation of the rotor relative to gravity, by providing reduced gas pressure above the workpiece.

14. The processor of claim **13** with gas inlets oriented to spray pressurized gas in a direction within 30 degrees of a tangent of the sidewall of the rotor.

15. A workpiece processor, comprising:

a bowl having one or more process fluid inlets;

a head;

a head lifter attached to the head;

a rotor in the head having an outer perimeter and an annular outer sidewall around the outer perimeter;

a plurality of gas inlet nozzles in the annular sidewall of the rotor with the nozzles oriented to spray pressurized gas in a direction at least partially tangent to the annular sidewall of the rotor, and with the spray of gas having a higher velocity and lower pressure adjacent to the annular sidewall of the rotor and a lower velocity and a higher pressure adjacent to the center of the rotor, to hold the outer area of the workpiece onto the rotor.