

**ELECTROPOLISHING AND/OR ELECTROPLATING
APPARATUS AND METHODS**

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority of earlier filed provisional applications U.S. Application Nos. 60/372,542, entitled "MAINFRAMES FOR ELECTROPOLISHING AND/OR ELECTROPLATING AND/OR ELECTROPLATING ASSEMBLY," filed on April 14, 2002; No. 60/379,919, entitled "END EFFECTOR SEAL," filed on April 8, 2002; No. 60/370,955, entitled "METHOD AND APPARATUS FOR WAFER CLEANING," filed on April 8, 2002; No. 60/372,566, entitled "METHOD AND APPARATUS FOR ELECTROPOLISHING AND/OR ELECTROPLATING," filed on April 14, 2002; No. 60/370,956, entitled "METHOD AND APPARATUS FOR DELIVERING LIQUID," filed on April 8, 2002; No. 60/370,929, entitled "METHOD AND APPARATUS FOR LEVELING WAFER," filed on April 8, 2002; No. 60/372,567, entitled "METHOD AND APPARATUS FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE," filed on April 14, 2002; and No. 60/390,460, entitled "ELECTROPLATING APPARATUS," filed on June 21, 2002, all of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field:

[0002] This invention relates generally to semiconductor processing apparatus and methods, and more particularly to electropolishing and/or electroplating apparatus and methods for electropolishing and/or electroplating conductive layers on semiconductor devices.

2. Description of the Related Art:

[0003] Semiconductor devices are manufactured or fabricated on semiconductor wafers using a number of different processing steps to create transistor and interconnection elements. To electrically connect transistor terminals associated with the semiconductor wafer, conductive (e.g., metal) trenches, vias, and the like are formed in dielectric materials as part of the semiconductor device. The trenches and vias couple electrical signals and power between transistors, internal circuit of the semiconductor devices, and circuits external to the semiconductor device.

[0004] In forming the interconnection elements the semiconductor wafer may undergo, for example, masking, etching, and deposition processes to form the desired electronic circuitry of the semiconductor devices. In particular, multiple masking and etching steps can be performed to form a pattern of recessed areas in a dielectric layer on a semiconductor wafer that serve as trenches and vias for the interconnections. A deposition process may then be performed to deposit a metal layer

over the semiconductor wafer thereby depositing metal both in the trenches and vias and also on the non-recessed areas of the semiconductor wafer. To isolate the interconnections, such as patterned trenches and vias, the metal deposited on the non-recessed areas of the semiconductor wafer is removed.

[0005] Conventional methods of removing the metal film deposited on the non-recessed areas of the dielectric layer on the semiconductor wafer include, for example, chemical mechanical polishing (CMP). CMP methods are widely known and used in the semiconductor industry to polish and planarize the metal layer within the trenches and vias with the non-recessed areas of the dielectric layer to form interconnection lines.

[0006] CMP methods, however, may have deleterious effects on the underlying semiconductor structure because of the relatively strong mechanical forces involved. For example, as interconnection geometries move to 0.13 microns and below, there can exist a large difference between the mechanical properties of the conductive materials, for example copper and the low k films used in typical damascene processes. For instance, the Young Modulus of a low k dielectric film may be less than one tenth of the magnitude of copper. Consequently, the relatively strong mechanical force applied on the dielectric films and copper in a CMP process, among other things, can cause stress related defects on the semiconductor structure that include delamination, dishing, erosion, film lifting, scratching, or the like.

[0007] New processing apparatus and techniques are therefore desired to deposit and polish metal layer. For example, a metal layer may be removed or deposited from a wafer using an electropolishing or electroplating process. In general, in an electropolishing or electroplating process the portion of the wafer to be polished or plated is immersed within an electrolyte fluid solution and an electric charge is applied to the wafer. These conditions result in copper being deposited or removed from the wafer depending on the relative charge applied to the wafer.

BRIEF SUMMARY OF THE INVENTION

[0008] One aspect of the present invention relates to an exemplary apparatus and method for electropolishing and/or electroplating a conductive film on a wafer. The exemplary apparatus includes various processing modules such as cleaning modules, processing modules, alignment modules, as well as various apparatus for carrying out the processes of the difference modules such as robotics, end effectors, liquid delivery systems, and the like.

[0009] Another aspect of the present invention includes various apparatus and processing methods. One exemplary apparatus includes a cleaning module having a wafer edge clean assembly to remove metal residue on the bevel or outer portion of a major surface of a wafer. The edge cleaning apparatus includes a nozzle head configured to supply a liquid and a gas to a major surface of the wafer. The nozzle supplies the liquid in a region adjacent an outer edge of the major

surface of the wafer, and supplies the gas radially inward relative to the location the liquid is supplied. Directing the gas to the wafer surface at a location radially inward of the location the liquid is supplied may reduce the potential of the liquid flowing radially inward on the wafer to a metal layer formed thereon.

[0010] The present invention is better understood upon consideration of the detailed description below in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Fig. 1 illustrates an exemplary semiconductor processing assembly that may be used to electropolish and/or electroplate semiconductor wafers;

[0012] Fig. 2 illustrates a robot including an exemplary end effector for transferring semiconductor wafers;

[0013] Fig. 3 illustrates a plan view of an exemplary end effector;

[0014] Figs. 4A and 4B illustrate plan and cross-sectional views of an exemplary end effector;

[0015] Fig. 5 illustrates a plan view of an exemplary end effector;

[0016] Fig. 6 illustrates a plan view of an exemplary end effector;

[0017] Fig. 7 illustrates a plan view of an exemplary end effector;

[0018] Fig. 8 illustrates a side view of an exemplary vacuum cup;

[0019] Fig. 9A illustrates an exemplary cleaning chamber module with a dome cover;

[0020] Fig. 9B illustrates a partial interior view of a cleaning chamber module;

[0021] Fig. 9C illustrates an exploded view of cleaning chamber module with details of cleaning nozzles;

[0022] Figs. 10A and 10B illustrate a top view and side view of an exemplary edge clean assembly;

[0023] Figs. 11A – 11H illustrate various views of an exemplary nozzle head included as a part of a bevel clean assembly;

[0024] Fig. 12 illustrates an exploded view of an exemplary chuck motor assembly included as part of a cleaning chamber module;

[0025] Fig. 13 illustrates an exploded view of a cleaning chamber window included in a cleaning chamber module;

[0026] Fig. 14 illustrates an exploded view of an exemplary optical sensor included in a cleaning chamber module;

[0027] Fig. 15 illustrates an exemplary method for determining proper placement of a wafer in a chuck;

[0028] Figs. 16A-16C and 17A-17C illustrate exemplary wafer cleaning processes;

[0029] Fig. 18 illustrates an exploded view of an exemplary process chamber assembly;

- [0030] Fig. 19 illustrates an exploded view of an exemplary process drive system, which may be included in the process chamber assembly embodied in Fig. 18;
- [0031] Fig. 20 illustrates an exemplary nozzle with an energy enhancement element;
- [0032] Fig. 21 illustrates an exploded view of an exemplary electroplating apparatus;
- [0033] Fig. 22 illustrates an exploded view of the exemplary plating shower head assembly shown in Fig. 21;
- [0034] Fig. 23 illustrates an exploded view of an exemplary plating shower head for 300 mm wafers;
- [0035] Fig. 24 illustrates an exploded view of an exemplary plating shower head for 200 mm wafers;
- [0036] Figs. 25A-25E illustrate various views of the shower head shown in Figs. 22 – 24;
- [0037] Figs. 26A and 26B illustrate a top view and cross-sectional view of an exemplary leveling tool and wafer chuck;
- [0038] Fig. 26C illustrates a cross-sectional view of an exemplary sensor shown in Figs. 26A and 26B; and
- [0039] Fig. 27 illustrates an exemplary view of a software panel for a leveling tool.

DETAILED DESCRIPTION

[0040] In order to provide a more thorough understanding of the present invention, the following description sets forth numerous specific details, such as specific materials, parameters, and the like. It should be recognized, however, that the description is not intended as a limitation on the scope of the present invention, but is instead provided to enable a better description of the exemplary embodiments.

I. Exemplary Electropolishing and/or Electroplating Assembly:

[0041] A first aspect of the invention includes an exemplary electropolishing and/or electroplating assembly for processing semiconductor wafers. In one example, an apparatus for processing one or more semiconductor wafers may include a module for storing wafers, two or more vertically stacked processing modules for electropolishing the wafer or electroplating the wafer, a cleaning module, and a robot (with an end effector or the like) for transferring the wafer. The apparatus may be divided into two or more sections characterized by separate frames. In general the robot transfers the wafer between the module for storing the wafer, the processing module, and the cleaning module to perform a desired process on the wafer. Additionally, various other modules and features may be included for the processing of semiconductor wafers as will be described.

[0042] Fig. 1 illustrates an exploded view of an exemplary electropolishing and/or electroplating assembly 100. In this example, the assembly 100 includes a mainframe (backend, "BE") 108 and frontframe (factory interface, "FI") 132; however, the assembly 100 may be divided into fewer or more sections.

[0043] The BE 108 may include an electrical chassis assembly 102, cleaning drain/process exhaust 104, cleaning module assembly 106, AC control assembly 110, liquid delivery system (LDS) 112, gas control system (GCS) 114, process drain 116, pumps and surge suppressors 118, cabinet exhaust 120, process tank 122, liquid filters 124, liquid containment tray 126, and double containment area 128, process module assembly 130.

[0044] The FI 132 may include a wafer pre-aligner 134, front panels 136, light tower 138, robot frame assembly 140, robot controller 142, emergency machine off (EMO) button 144, front opening unified pod (FOUP) 146, and fan filter unit 152.

[0045] Assembly 100 may be detached into two sections, i.e., the FI 132 and the BE 108, allowing the two sections to be transported separately and be reassembled on site into a single unit. Furthermore, the robot frame assembly 140, which can include robot assembly 147, dry end effector 148, wet end effector 149, and robot controller 142, may detach from and roll out of the FI 132 during transit or for maintenance, for example. Assembly 100 may therefore be modularized or divided into various sections to assist in transporting, cleaning, maintenance, and the like.

[0046] As shown in Fig. 1, FOUP 146 may include one or more pods for storing wafers. The dry end effector 148 transfers a wafer 150 from any one of the pods to the wafer pre-aligner 134. The wafer pre-aligner 134 aligns wafer 150 before the wet end effector 149 retrieves the wafer and transfers it to the process module assembly 130. It should be recognized that wafer 150 may be transported between modules by other methods and devices.

[0047] The process module assembly 130 may include one or more racks of electropolishing assemblies for polishing wafers, or electroplating assemblies for plating wafers 131. The electropolishing assemblies or electroplating assemblies 131 may be stacked vertically to reduce the footprint of the process module assembly 130. The cleaning module assembly 106 can include racks of cleaning chamber modules 107 for cleaning wafers. Similarly, cleaning chamber modules 107 may be stacked vertically. After wafer 150 has been processed for electropolishing or electroplating, the wet end effector 149 transfers wafer 150 to the cleaning chamber module 107. Dry end effector 148 retrieves wafer 150 from cleaning chamber 107 and returns wafer 150 to its pod in FOUP 146. Generally, the "dry" end effector 148 is used when retrieving wafer 150 from and returning to a pod in FOUP 146, or from the cleaning chamber module 107. The "wet" end effector 149 is generally used to retrieve wafer 150 after processing because wafer 150 may have residue from the processing. Limiting the retrieval of processed wafers with the wet end effector

149 will reduce the potential for cross contamination between dry end effector 148 and wet end effector 149 and the wafers they handle and transfer within assembly 100.

[0048] An exemplary electropolishing assembly that may be used in conjunction with assembly 100 is described in PCT Patent Application No. PCT/US02/36567, entitled ELECTROPOLISHING ASSEMBLY AND METHODS FOR ELECTROPOLISHING CONDUCTIVE LAYERS, filed on November 13, 2002, which is incorporated in its entirety by reference herein.

[0049] As shown in Fig. 1, a majority of the electrical equipment is housed in the BE 108, particularly, in electrical chassis assembly 102 and AC control assembly 110. The LDS 112 and the GCS 114 are also located in the BE 108.

[0050] The LDS 112 can include supply lines for DI water, and various chemical and/or electrolyte fluids, which may vary in composition depending on the particular application and processing modules included in assembly 100. The GCS 114 may also include various control valves, sensors, and supply lines to control and monitor delivery of various chemicals and fluids.

[0051] Pumps and surge suppressors 118 pump the process liquid from the process tank 122 to process module assembly 130. Liquid filters 124 may be included in the supply lines to filter the process liquid before it goes to the process module assembly 130. After wafer 150 is processed, the process liquid may be drained into the process tank 122 through process drain 116. Any gases, e.g., potentially harmful gases, from process module assembly 130 and cleaning module assembly 106 may be exhausted through process exhaust 104. The cleaning drain/process exhaust 104 can also be used to release DI water or gas from the cleaning module assembly 106. The cabinet exhaust 120 can be used to release gas generally present inside of the BE 108. FI 132 may include a fan filter unit 152 to provide filtered clean air in FI 132.

[0052] The BE 108 may also include liquid containment tray 126 and double containment area 128. The liquid containment tray 126 can be useful in case of an overflow from the process tank 122, or leaks in the supply lines. The liquid containment tray 126 may further include leak sensors to detect leaks. The double containment area 128 can contain leaks from supply lines that are already insulated by external tubing.

[0053] The supply lines, pumps and surge suppressors 118, liquid filters 124, liquid containment tray 126, and double containment area 128 may generally include materials resistant to acid and corrosion.

[0054] BE 108, FI 132, and robot frame assembly 140 can be made of stainless steel, preferably grade 316 stainless steel. The robot assembly 147 can be made of aluminum, stainless steel, or the like. If robot assembly 147 includes aluminum or other materials susceptible to corrosion, the surface of the aluminum portions may be anodized and coated with Teflon or the like to protect them from corrosion. Cleaning module assembly 106 can be made of stainless steel, plastic, PVC, PVDF, polyurethane, Teflon, and the like, preferably grade 316 stainless steel. GCS 114 and liquid

containment tray 126 can be made of plastic materials, preferably non-flammable plastics. Process tank 122 can be made of plastics such as PVC, PVDF, Teflon, and the like, preferably PVDF. It should be recognized, however, that other suitable materials or coatings for use in BE 108 and/or FI 132 are contemplated.

[0055] An exemplary process for electropolishing or electroplating a semiconductor wafer begins with a pod containing wafers placed in FOUP 146. The pod, or door to the pod, is opened to allow robot assembly 147 access therein to pick a wafer with end effector 148. Robot assembly 147 and dry end effector 148 transfer wafer 150 to wafer pre-aligner 134 to align wafer 150 for processing. After wafer pre-aligner 134 aligns wafer 150, robot assembly 147 picks up wafer 150 from wafer pre-aligner 134 using the wet end effector 149, and transfers wafer 150 to electropolishing or electroplating assembly 131 for processing.

[0056] After the electropolishing or electroplating process is completed, robot assembly 147 picks up wafer 150 by using the wet end effector 149, and moves the wafer into cleaning chamber module 107. After the cleaning process is completed, dry end effector 148 picks up wafer 150 and transfers wafer 150 back to the pod in FOUP 146 for retrieval.

[0057] In another exemplary process including multiple wafers and multiple electropolishing or electroplating assemblies, the exemplary process described above may be applied to a first wafer as simultaneously similar steps are applied to a second wafer, a third wafer, etc.

[0058] Various components of assembly 100 will be described in greater detail below. Although the exemplary electropolishing and/or electroplating apparatus has been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

II. End Effector Seal

[0059] In one aspect of a semiconductor assembly, an exemplary end effector apparatus and method are described. End effectors are commonly used in wafer fabrication processes for transferring wafers, for example, from one processing module to another for further processing, cleaning, storage, and the like. An exemplary end effector according to one embodiment includes a vacuum cup seal to securely hold and transfer a semiconductor wafer. The exemplary end effector may be included within a semiconductor processing assembly, and more specifically, a robot assembly of a semiconductor assembly. The exemplary end effector may enable a more secure hold of a semiconductor wafer surface and in turn may transfer the wafer more accurately and reliably to its destination.

[0060] Fig. 2 illustrates an exemplary robot assembly for transferring semiconductor wafers in a processing assembly. Robot assembly includes exemplary end effector 206 associated with the robot for picking up and transferring wafer 216. End effector 206 creates a vacuum on the

underside of end effector 206 to secure wafer 216 thereto for transfers from one module to another. End effector 206 may place or release wafer 216 by eliminating the vacuum or increasing the pressure such that the force of gravity overcomes the seal and wafer 216 is released from end effector 206. Additionally, end effector 206 may hold the underside of wafer 216 with a relatively smaller pressure than the environment to hold the wafer 216 thereto against vibration, acceleration during transfer, and the like.

[0061] Fig. 3 illustrates one side of an exemplary end effector 306 in greater detail. As shown in Fig. 3, end effector 306 is coupled to a vacuum source controlled by vacuum valve 322 and with a pressured nitrogen source controlled by nitrogen valve 320. When vacuum valve 322 is turned ON, the vacuum source is coupled to end effector 306 and will reduce the pressure in vacuum cup 302 to hold wafer 216 to end effector 306. When vacuum valve 322 is turned OFF and nitrogen valve 320 is turned ON, end effector 306 will release wafer 216 from vacuum cup 302 as the pressure is increased within cup 302.

[0062] It should be understood that an absolute or near absolute vacuum is not required; rather, a reduced pressure relative to the processing environment sufficient to hold and secure wafer 216 against gravity, vibrations, acceleration during transfer, and the like is sufficient. Further, gas other than nitrogen, for example, air or the like may be used to introduce gas and increase the pressure when releasing a wafer.

[0063] Nitrogen valve 320 may be left ON when a wafer is not being held or transferred to purge particles and/or prevent acid and the like from entering vacuum cup 302 or the vacuum passage within end effector 306 by maintaining the pressure near or greater than the surrounding environment pressure within vacuum cup 302.

[0064] Figs. 4A and 4B illustrate a plan view and cross-sectional view of one exemplary end effector 406, which includes vacuum cup 402, mushroom cap 404, groove 405, cut out portions 408 (to reduce weight of end effector), vacuum passage 412, and screws 416 (for attachment to a robot or the like). End effector 406 may include any suitable material in its construction, such as stainless steel, aluminum, various alloys or metals, ceramics, plastics, and the like.

[0065] As shown in Figs. 3 and 4A, a vacuum source removes gas through vacuum passage 412 and aperture 414 located on a major side and near the distal end of end effector 406. Vacuum passage 412 may be formed integral or within end effector 406 (as shown) or through a separate passage located adjacent to end effector 406, e.g., on the opposite surface of end effector 406.

[0066] With the vacuum or reduced pressure created in vacuum passage 412 a wafer positioned adjacent end effector 406 is pulled or forced compliant against the vacuum cup 402 to create a temporary seal between the opposing major surface of the wafer and the vacuum cup 402 of end effector 406. Vacuum cup 402 may have any suitable shape such as elliptical, elongated circle, square, and the like. Vacuum cup 402 fits over the rim of a mushroom cap 404 and extends above

the surface of end effector 406. Vacuum cup 402 may include an elastomer, silicon rubber, or other suitable material that is generally flexible or compliant to create a temporary seal with a wafer without causing damage to the wafer such as scratching or cracking.

[0067] As shown in Figs. 4A – 4B, a shallow groove 405 is formed across the mushroom cap 404 for increasing the hold of the vacuum, e.g., to prevent the wafer 416 from plugging aperture 414. The groove 405 separates the top plane of mushroom cap 404 into two half circles. The shallow groove 405 may also be formed as a cross-hair shape, square, circle, or other suitable shape to improve suction and vacuum of end effector 406 and reduce the potential for aperture 414 from becoming blocked. Mushroom cap 404 may be made out of a similar material as end effector 406 such as metal or plastic. In one example, mushroom cap 404 is at a similar height as the distal end of end effector 406 (see Fig. 4B), such that as the wafer is pulled by vacuum cup 402 the wafer is pulled against the to distal ends and the mushroom cap 404.

[0068] Fig. 8 illustrates a cross-section view of a vacuum cup that may be included in an exemplary end effector. As shown in Fig. 8, the vacuum cup is generally a cavity formed on one surface of an end effector that may include a bottom portion 818 and sidewall 820 slanted generally at angle α . Angle α may vary between 0-180 degrees depending on the particular application, preferably between 5 and 50 degrees, and more preferably approximately 30 degrees. Sidewall 820 may extend to a height H above the surface of the end effector to be compliant and form a seal with a wafer. With additional reference to Figs. 4A, 4B, and 8, end effector 406 will be positioned such that wafer 416 comes in contact with the edge of sidewall 820 as gas is drawn out from aperture 414 through the vacuum passage 410. The vacuum cup 402 will pull and hold wafer 416 by the vacuum created in the cavity of vacuum cup 402. The pressure difference will create a sufficient force to maintain a holding force on wafer 416 greater than the force of gravity on the wafer. To release wafer 1016 from the hold of end effector 406, gas (e.g. nitrogen or the like) may be introduced through vacuum passage 410 and through aperture 414 to increase the pressure within the aperture 414 such that the holding force is overcome by gravity.

[0069] Fig. 5 illustrates a plan view of another exemplary end effector 506. End effector 506 illustrated in Fig. 5 is similar to that of Figs. 3, 4A, and 4B except that end effector 506 includes three apertures 514 and three vacuum cups 502. The apertures 514 and vacuum cups 502 may be located in various positions on the end effector 506, depending on the design and particular application of the end effector 506. Further, the shape of an end effector may include any suitable shape, such as horseshoe, rectangular, circular, pronged including one or more prongs, and the like.

[0070] Fig. 6 illustrates a plan view of another exemplary end effector 606. End effector 606 is similar to that of Figs. 4A and 4B except that end effector 606 has a plurality of vacuum cups 602, in this instance five vacuum cups 602, each including an elongated (i.e., not circular) mushroom caps 604. Further, end effector 606 includes a common vacuum passage positioned adjacent the

apertures 614 as opposed to Fig. 5, which includes vacuum passages branched apart for each separate aperture 514.

[0071] Fig. 7 illustrates a plan view of another exemplary end effector 706. The end effector 706 of Fig. 7 is similar to that of Figs. 3A and 3B except that one vacuum cup 702 includes a plurality of apertures 714 therein. Vacuum cup 702 of this example, is shaped like a horseshoe, but with similar functionality as vacuum cup 402 and includes several elongated mushroom caps 704, which are similar to the mushroom caps 604.

[0072] Although the exemplary end effector seals have been described with respect to certain examples and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention. For example, various methods of creating a vacuum within the vacuum cup are contemplated as well as various other shapes and configurations of vacuum cups and mushroom caps to create seal when picking and transferring a wafer.

III. Method and Apparatus for Wafer Cleaning

[0073] In one exemplary aspect of a semiconductor assembly, an exemplary wafer cleaning method and apparatus are described. The exemplary wafer cleaning method and apparatus, may clean a wafer of debris or particles before an electropolishing or electroplating process as well as clean the wafer of processing liquid after an electropolishing or electroplating processing step. For example, after an electropolishing process the edge or outer region of the major surface of the wafer (often referred to as the "bevel region") may include copper residue. It is desirable to etch away this copper residue from the outer region and clean the wafer without damaging the thin metal layer in the inner region of the wafer. Therefore, in one aspect a cleaning module includes an edge clean assembly to remove metal residue on the outer or edge portion of a wafer. The edge cleaning apparatus includes a nozzle head configured to supply a liquid and a gas to a major surface of the wafer. The nozzle supplies the liquid in the edge region and supplies the gas at the inner edge of the edge to reduce the potential of the liquid flowing radially inward on the wafer to the metal film.

[0074] Figs. 9A – 9C illustrate various views of an exemplary cleaning chamber module for cleaning a wafer. As shown in Figs. 9A – 9C, the exemplary cleaning chamber module may include a dome cover 902, cleaning chamber window 904, cylinder cover 906, leak sensor 908, drip pan drain line 910, base block 912, drip pan clamp 914, drip pan 916, bottom chamber 918, cutout for chuck motor assembly wiring 920, two DI water nozzles 922 (backside) and 926 (top), two nitrogen nozzles 924 (backside) and 928 (top), edge clean assembly 930, optical sensor 932, nozzle for wafer front side chemical 934, chuck 936, drain plate 938, top chamber 940, exhaust and drain tube 942, nitrogen line 944, edge clean cover 946, nozzle for wafer backside chemical 948, and

chuck motor assembly 950. In addition to the one nozzle for chemical 934, a cleaning chamber module can include one or more nozzles for chemicals.

[0075] Wafer 901 may be positioned in the cleaning chamber by an end effector 903 or the like. When wafer 901 is determined to be in an acceptable position on chuck 936 for a cleaning process, the chuck motor assembly 950 can rotate chuck 936 and wafer 901 around the axis perpendicular to the major surfaces of the wafer. As chuck 936 and wafer 901 are rotating at a rotation speed of about 30 rpm, the DI water nozzles 922 and 926 can supply streams of DI water to the top and backside surfaces of wafer 901. The DI water can flow past the edge of wafer 901 toward the wall of the cleaning chamber and drain through the drain plate 938 and into the exhaust and drain tube 942. To remove the DI water from and to dry wafer 901, the chuck motor assembly 950 may increase the rotation speed to 2,000 rpm, $\pm$ 1,000 rpm. The nitrogen nozzles 924 and 928 can then supply streams of nitrogen (or other suitable gas) to the top and backside of wafer 901 to further remove DI water from the top and backside of wafer 901.

[0076] After wafer 901 is washed and dried and the chuck motor assembly 950 is stopped, the edge clean assembly 930 glides into position for edge cleaning. Figs. 10A – 10B illustrate an exemplary wafer edge clean assembly 930, which may include DI water tube 1006, rod 1010, adapter rod 1008, bracket 1012, screws 1014, air table cylinder 1016, adjustable screw 1018, flow regulator 1020, compressed air tube 1022, rod clamp 1024, acid tube 1026, nitrogen tube 1028, nozzle head 1030, rod wiper 1032, nitrogen nozzle 1034, and liquid nozzle 1036. The length of the edge clean assembly 930 may be adjusted for use with 200mm wafer, 300 mm wafer, or other size by adding or removing adapter rod 1008. The gap between the top of wafer 901 and the nitrogen nozzle 1034 can be in the range from 0.1 to 10 mm, and the liquid nozzle 1036 can be positioned above the edge area 1004.

[0077] Figs. 11A – 11C illustrate plan, side, and front views respectively of exemplary nozzle head 1030 included with an edge clean assembly. As shown in Figs. 11A – 11C, nitrogen nozzle 1034 produces a nitrogen curtain 1102 of nitrogen gas near the edge of wafer 901. In an exemplary edge cleaning process, wafer 901 may rotate at a rotation speed of approximately 50 ~ 500 rpm, preferably at 200 rpm. Liquid nozzle 1036 supplies a stream of chemical to form a thin layer of about 10 mm in width on the outer major surface of wafer 901 or edge area 1004. The chemical removes the metal layer or metal residue, but the chemical may accidentally spread toward the center of wafer 901, which may have deleterious effects on the metal layer. A variety of chemicals can be used to etch the metal residue in edge area 1004. For instance, H_2SO_4 at 10% concentration and H_2O_2 at 20% concentration can be used to etch copper metal from edge area 1004. Also, for increasing etch rates, the chemical solution can be heated to the range of 25°C to 80°C.

[0078] To reduce the potential for the chemical spreading inward from the edge, nitrogen nozzle 1034 supplies or directs a stream of gas, e.g., nitrogen, to create nitrogen curtain 1102 at the inside

edge of the edge area 1004 to prevent or at least reduce the potential of the chemical from spreading toward the center of wafer 901. After edge area 1004 is cleaned, liquid nozzle 1036 can supply liquid jet 1104 of DI water to dilute and/or rinse off the chemical from wafer 901 at the edge area 1004. Additionally, in one example, after the edge cleaning process an additional DI water wash may be performed by using DI water nozzles 922 and 926 to clean the top and backside of wafer 901.

[0079] When the edge cleaning process is finished, chuck motor assembly 950 can stop rotating chuck 936 and wafer 901, and edge clean assembly 930 can glide back from the edge cleaning position to a rest position.

[0080] Figs. 11D – 11E illustrate various views of another exemplary nozzle head 1030. The example in Figs. 11D – 11E are similar to that of Figs. 11A – 11C except that the nitrogen nozzle 1034 has a horizontal span 1034h extended from the nozzle. The horizontal span 1034h may create a nitrogen curtain 3002 that more effectively prevents chemicals from edge nozzle 1036 from spreading towards the center of wafer 901. The distance between the horizontal span 1034h and wafer 901 surface is preferably in the range of approximately 0.1mm to 3.0mm, and more preferably approximately 1.5 mm.

[0081] Figs. 11F – 11G illustrate various views of another exemplary nozzle head 1030. The example in Figs. 11F – 11G is similar to that of Figs. 11D – 11E except that the horizontal span 1034h is extended from both sides of the lower portion of the nozzle.

[0082] Fig. 11H illustrates another exemplary nozzle head 1030. The example in Fig. 11H is similar to that of Figs. 11A – 11C except that it has two liquid nozzles 1036, one for chemical and another for DI water. Separate nozzles may provide improved performance during a DI water rinse, for example.

[0083] Fig. 12 illustrates an exemplary chuck motor assembly 950 that may be included in the wafer cleaning apparatus. In this example, chuck motor assembly 950 includes chuck 936, top motor plate 1202, optical sensor 1204, shaft sleeve 1206, motor 1208, flag 1210, spacer 1212, centrifugal block shaft 1214, centrifugal block 1216, and plug 1218.

[0084] With reference again to Figs. 9A, 9B and 10A, to place a wafer 901 on chuck 936 an end effector 903 takes wafer 901 from a process chamber or the pre-aligner (see Fig. 1) and moves it to the cleaning chamber module through the cleaning chamber window 904 for cleaning. Fig. 13 illustrates an exemplary cleaning chamber window 904 that includes inner plate 1302, outer plate 1304, bracket 1306, flow controller 1308, cylinder 1310, cylinder cover 906, and limit sensor 1312. The end effector 903 loads wafer 901 in chuck 936. The cylinder 1310 can raise the outer plate 1304 and close the cleaning chamber window 904 to begin a wafer cleaning process.

[0085] As shown in Fig. 12, exemplary chuck 936 includes base 1220 and three positioners 1222. Chuck 936 may be modified for 200mm wafer, 300 mm wafer, or any other wafer size.

When the end effector 903 loads wafer 901 in chuck 936, wafer 901 is positioned in the chuck 936 by the three positioners 1222. With reference again to Figs. 9A – 9C, optical sensor 932 can detect the position of wafer 901 in chuck 936. To check the error in wafer positioning, optical sensor 932 directs a beam to the top surface of wafer 901 as shown in Fig. 15. If end effector 903 positions wafer 901 on the top surface of a positioner 1222, the beam will not fully reflect back to reflective sensor 932. As chuck 936 rotates, the reflectivity may change accordingly. Furthermore, since the distance between wafer 901 and reflective sensor 932 changes, the difference or variance in the reflectivity may be used to verify if wafer 901 is placed accurately on chuck 936 and the three positioners 1222 or not. In one example, when wafer 901 is accurately positioned on chuck 936, by the three positioners 1222, the reflectivity is read between approximately 70 ~ 75 % while the chuck is rotating. However, when wafer 901 is not positioned accurately, the reflectivity is read between approximately 30 ~ 60%. A misplaced wafer might move out of chuck 936 when chuck 936 is rotating at high speeds, which may cause wafer 901 to break inside of the cleaning chamber module.

[0086] An exemplary optical sensor 932 is shown in Fig. 14 and may include a fitting tube 1402, fitting o-ring 1404, reflective sensor 1406, holder 1408, viton o-ring 1410, and holder flange 1412. It should be recognized that other suitable optical sensors may be used to determine proper positioning of a wafer in relation to chuck 936. In other examples, optical sensor 932 may be replaced by a non-optical sensor to measure the surface of a wafer such as a proximity sensor, eddy current sensor, acoustic sensor, and the like.

[0087] To prevent wafer 901 from spinning out of chuck 936 by the motion of relatively high centrifugal forces during various cleaning processes such as a drying cycle and the like, chuck positioner 1222 may include a centrifugal block 1216. The centrifugal block 1216 can include a lower element (i.e., a weight) that is heavier than the top portion, which is approximate to the centrifugal block shaft 1214. When chuck 936 is rotating at a rotation speed of about 1,000 rpm or higher, the centrifugal force will cause the weights in centrifugal blocks 1216 to rotate outward. Consequently, the upper portion of centrifugal block 1216 moves inward to hold and secure wafer 901 to chuck 936. The weight, length, and the like of positioner 1222 and centrifugal block 1216 may be varied to change the speed at which the positioner 1222 moves to secure the wafer. When the chuck motor assembly 950 decelerates or stops, centrifugal block 1216 will return to its upright position due to reduced or zero centrifugal force. In order to secure the wafer, the chuck rotation speed is set in the range of approximately 200 ~ 3,000 rpm, preferably at 2,000 rpm.

[0088] Figs. 16A-16C illustrate an exemplary backside wafer cleaning process and the wafer in relation to positioners 1222 and wafer backside chemical 948. In an exemplary wafer backside cleaning process, motor 1208 oscillates chuck 936 to face the nozzle for wafer backside chemical 948 such that the chemicals can be delivered to the backside of wafer 901 without splashing the

three wafer positioners 1222. Chemicals that contact wafer positioner 1222 may splash onto and chemically etch the top surface of wafer 901, which may cause defects in the structures and devices formed on wafer 901. The backside chemical 948 may be positioned between two positioners 1222 and oscillated between angles β and $-\beta$. The backside chemicals may cover an area of wafer 901 beyond angles β and $-\beta$ by directing backside chemical 948 off center by moving backside chemical 948 between angles $-\gamma$ and γ as illustrated in Figs. 16A-16C.

[0089] The chemical delivered by chemical 948 will reach the backside of wafer 901, and the cleaning time can be in the range of 5 ~ 100 seconds, preferably in 10 seconds. The cleaning process is then repeated for each one-third of the backside of wafer 901.

[0090] Figs. 17A-17C illustrate another exemplary backside wafer cleaning process. The process is similar to that described with reference to Figs. 16A-16C except that chuck 936 is continuously rotated and backside chemical 948 is pulsed or timed to be "on" between positioners 1222 and "off" when directed at positioners 1222. Similar to Figs. 16A-16C, nozzle backside chemical 948 may oscillate $\pm\gamma$ during the process. As shown in Figs. 17B and 17C, as chuck 936 rotates counter-clockwise backside chemical 948 directs liquid to the wafer until angle a_1 where it is turned off. Liquid is again directed to the backside of the wafer at angle a_2 .

[0091] In another example, to clean the portion of the backside of wafer 901 in contact with positioner 1222, motor 1208 will generate a rotational movement with a sufficient level of rotational acceleration such that wafer 901 will displace from its original position. Therefore, chemicals delivered by nozzle for wafer backside chemical 948 can reach the portion of the backside of wafer 901 that had been in contact with positioner 1222 before the rotational movement. After cleaning the entire surface of the backside of wafer 901, DI water nozzle 922 will supply streams of DI water to rinse the chemicals on the backside of wafer 901.

[0092] Wafer 901 can go through one final cleaning cycle. As chuck 936 and wafer 901 are rotating at a rotation speed of about 30 rpm, the DI water nozzles 922 and 926 can supply streams of DI water to the top and backside of wafer 901 simultaneously. To remove the DI water from and to dry wafer 901, the chuck rotation speed can be increased to 2,000 rpm, $\pm 1,000$ rpm. The nitrogen nozzles 924 and 928 can then supply streams of nitrogen to the top and backside of wafer 901 to remove DI water film from the top and backside of wafer 901.

[0093] In light of the above description of exemplary apparatus and methods, exemplary cleaning recipes or sequences may proceed as follows.

[0094] Initiate Cleaning:

- a. Home chuck.
- b. Open outer plate 1302.
- c. Place wafer 901 on chuck 936.
- d. Close outer plate 1302.

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[0095] Front side Cleaning:

- e. Rotate chuck 936 at speed of 10 to 100 rpm, preferably at 50 rpm.
- f. Deliver DI water from DI water nozzle (top) 926 to the front side of wafer 901.
- g. Stop DI water from DI water nozzle (top) 926, then increase chuck rotation speed to 1,000 ~ 2,000 rpm, preferably 2,000 rpm.
- h. Deliver nitrogen from nitrogen nozzle (top) 928 to dry the top surface of wafer 901.
- i. Stop nitrogen stream and stop chuck rotation.

[0096] Edge Cleaning:

- j. Move the edge cleaning assembly 930 from its rest position to edge cleaning position by powering the air tube cylinder 1016.
- k. Rotate wafer 901 at the rotation speed of 100 ~ 500 rpm, preferably at 350 rpm, deliver nitrogen from nitrogen nozzle 1034 through nitrogen tube 1028.
- l. Deliver edge cleaning chemical from liquid nozzle 1036 through acid tube 1026.
- m. After the metal on the edge area 1004 is etched away, stop delivering edge cleaning chemicals.
- n. Deliver DI water from the liquid nozzle 1036 through DI water tube 2006.
- o. After chemicals on edge area 1004 are rinsed away, stop DI water stream.
- p. Deliver nitrogen from nitrogen nozzle 1034 through nitrogen tube 1028.
- q. Stop chuck rotation and move edge cleaning assembly 930 back to the rest position.

[0097] Backside Cleaning:

- r. Move chuck 936 to backside cleaning position, i.e., the position where the distance between the nozzle for wafer backside chemical 948 and the two adjacent positioners 1222 is equal. Motor 1208 starts to oscillate chuck 936 around the nozzle for wafer backside chemical 948. The oscillation angle should be less than $45^\circ \pm 5^\circ$. The nozzle for wafer backside chemical 948 then delivers chemicals to the backside of wafer 901.
- s. Repeat step r for the second and third sections of wafer 901. Alternatively, wafer 901 may be rotated continuously in one direction and backside chemical 948 is pulsed avoid positioners 1222.

[0098] Shift Turn Cleaning:

- t. To shift wafer 901 from its position by using high acceleration speed during a swift turn.
- u. Repeat step s.
- v. Repeat steps s through u for the second one-third of wafer 901.
- w. Repeat steps s through u for the last one-third of wafer 901.
- x. Deliver DI water through DI water nozzle (backside) 922 to the backside of wafer 901 and to the front side of wafer 901 through DI water nozzle (top) 926, with wafer rotating at a rotation speed of about 50 rpm.

y. Stop delivering stream of DI water. Rotate chuck 936 at a rotation speed of about 1,000 ~ 3,000 rpm, preferably at 2,000 rpm, then deliver nitrogen to both front side and backside of wafer 901.

z. Stop delivering stream of nitrogen and stop chuck 936. Open the cleaning chamber window 904 by lowering the outer plate 1304 with cylinder 1310. End effector 903 will then pick up wafer 901 and move said wafer to the storing pod (not shown).

[0099] The above sequence describes one exemplary recipe for wafer cleaning and is not intended to be limiting. There are various alternative methods to clean wafer 901 in accordance with other various aspects of the present invention. For example, a second exemplary recipe includes following steps *a* through *d* as described above to initiate the cleaning process, followed by steps *j* through *q* for edge cleaning, and finishing with steps *e* through *i* to clean and dry the front side with DI water and nitrogen gas.

[00100] Another exemplary recipe includes: following steps *a* through *d* as described above to initiate the cleaning process; followed by steps *j* through *q* for edge cleaning; continuing with steps *r* and *s* to clean the backside with chemical; steps *e* through *i* to clean and dry the front side using DI water and nitrogen gas; and steps *t* through *z* to clean and dry the backside with DI water and nitrogen gas. Additionally, during a backside cleaning process, DI water may be supplied to the top of the wafer to protect the top surface from any of the chemical used during the backside etch. Accordingly, it should be apparent to those skilled in the art that various processes are contemplated for cleaning semiconductor wafers with the exemplary apparatus and methods.

[00101] Although the apparatus and methods for cleaning wafers have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

IV. Process Chamber

[00102] In another aspect of a semiconductor assembly, a processing chamber is included for electropolishing and/or electroplating semiconductor wafers. The exemplary processing chamber is interchangeable with electropolishing apparatus and electroplating apparatus.

[00103] In one exemplary process, a wafer is rotated while a stream of process fluid is directed to a relatively small portion of a major surface of the wafer. A nozzle or the like directing the stream of fluid is translated along a linear direction parallel to the major surface of the wafer, e.g., from the inner to outer radius of the wafer. To increase the uniformity of plating or polishing a metal layer on the wafer, the rotation of the wafer may be varied to create a constant linear velocity of the wafer surface with respect to the incident stream of fluid. Additionally, various exemplary methods for determining a thin film profile and electropolishing or electroplating process are described.

[00104] Fig. 18 includes an exploded view of an exemplary process chamber assembly according to one embodiment. Exemplary process chamber assembly can include dynamic shroud 1802,

magnetic coupler 1804, shaft 1806, bracket for mounting shaft 1808, splashguard 1810, tube 1812, chamber tray 1814, bottom chamber 1816, feed through for optical sensor 1818, plugs 1820, process chamber 1822, manifold 1824, nozzle plate 1826, end point detector 1828, nozzle block 1830, side plate 1832, chamber window 1834, half moon chamber 1836, gate chuck 1838, and window cylinder 1840.

[00105] The exemplary chambers may be used equally well for electropolishing and/or electroplating, but are described generally with regard to electropolishing processes. When using the present invention for electroplating, nozzle block 1830, nozzle plate 1826, manifold 1824 and dynamic shroud 1802 may also be used in an electropolishing process. Alternatively, they may be replaced with a concentric circle electroplating apparatus. An exemplary concentric circle electroplating apparatus is described in U.S. Patent No. 6,395,152, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on July 2, 1999, and U.S. Patent No. 6,440,295, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on February 4, 2000, both of which are incorporated in their entireties by reference herein. Further, exemplary electropolishing and electroplating processes are described in PCT Patent Application No. PCT/US02/36567, entitled ELECTROPOLISHING ASSEMBLY AND METHODS FOR ELECTROPOLISHING CONDUCTIVE LAYERS, filed on November 13, 2002, U.S. Patent No. 6,391,166, entitled PLATING APPARATUS AND METHOD, filed on January 15, 1999, and PCT Patent Application No. PCT/US99/15506, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on August 7, 1999, all of which are hereby incorporated by reference in their entirety.

[00106] Further, an exemplary end-point detector and methods are described in U.S. Patent No. 6,447,668 entitled METHODS AND APPARATUS FOR END-POINT DETECTION, filed on September 10, 2002, and is hereby incorporated by reference in its entirety.

[00107] As shown in Fig. 19, the power drive system, which can be included in the process chamber assembly, can include x-axis flag 1902, x-axis drive assembly 1904, coupling 1906, motor 1908, bracket for z-axis mount 1910, theta drive belt and pulley 1912, ~~theta y-axis~~ reflective sensor 1914, x-axis sensor 1916, theta mount 1918, z-axis universal ball joints 1920, z-drive table assembly 1922, bracket for z-motion mount 1924, theta motor 1926, theta drive pulley 1928, chuck assembly 1930, lid back cover assembly 1932, x-axis linear bearing 1934, y-axis adjustment thumb screw 1936, z-axis plate 1938, top lid 1940, z-axis linear bearings 1942, shafts 1944, x-axis magnet 1946, magnetic disconnect plate 1948, y-axis stage 1950, magnets 1952, and bracket for magnet mount 1954.

[00108] An exemplary chuck assembly is described, e.g., in U.S. Patent No. 6,248,222 B1, entitled METHOD AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on September 7, 1999, U.S. Patent Serial No. 09/800,990, entitled METHODS AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on March 7, 2001, and U.S. Patent Serial No. 09/856,855, entitled METHODS AND APPARTUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on May 21, 2001, all three of which are incorporated in their entireties by reference herein.

[00109] As shown in Fig. 18, the process chamber 1822 can include a dynamic shroud 1802 that translates with chuck assembly 1930 and a splashguard 1810 to contain process liquid or electrolyte fluid within the chamber area. An optical sensor cable can be installed through the feed-through 1818 for an optical sensor and end point detector 1828, or other components such as sensors to detect leaks in the bottom chamber 1816 or the chamber tray 1814. Additional plugs 1820 may be used for further feed-throughs.

[00110] The exemplary apparatus of Figs. 18 and 19 includes magnets 1952 to connect to the x-axis drive magnet mount plate 1946. The chuck assembly 1930 can move along the x-direction by gliding on shafts 1944 through the x-axis linear bearing 1934. When the exemplary apparatus is not in operation, e.g., to change processing apparatus or during maintenance, the process drive system can undock from the process chamber assembly. Motor 1908 will rotate an internal screw in the x-axis drive assembly 1904 counterclockwise to move forward along the x-direction. The same or new process drive assembly may dock with the process chamber assembly in the same fashion. One example includes a safety measure such that if there is an object between the process drive system and the chamber, or something preventing the x-axis drive assembly 1904 from moving forward or backward, the magnets 1952 or 1946 will disengage from the x-axis disconnect plate 1948. The x-axis drive 1904 and motor 1908 will not be able to move the chuck assembly and top lid further; at which point, the x-axis sensor 1916 will recognize the disengagement of x-axis from the rest of the process drive system and motor 1908 will power down.

[00111] During the installation or periodic maintenance of the exemplary apparatus, y-axis adjustment thumb-screw 1936 can adjust the position of chuck assembly 1930 over the dynamic shroud 1802 and nozzle plate 1826 along the y-direction.

[00112] With reference to both Figs. 18 and 19, when the exemplary process chamber is used in a process application, the process drive system will be docked in the process chamber assembly by connecting magnets 1952 on the process drive system to magnetic coupler 1804 on the process

chamber assembly. Window cylinder 1840 raises gate chuck 1838 from half moon chamber 1836 to create an opening in the chamber window 1834. A robot (see Fig. 1) may transfer wafer 1801 from a pre-aligner (see Fig. 1) through the chamber window 1834. Wafer 1801 is loaded into chuck assembly 1930 for an electropolishing and/or electroplating process.

[00113] To move chuck assembly 1930 from the load or home position to a position for electropolishing or electroplating, the motor in z-drive table assembly 1922 turns its internal shaft assembly to lower the z-axis plate 1938 from the top of the z-axis linear bearings 1942 until the gap between chuck assembly 1930 and the top of nozzle block 1830 is in the range of approximately 0.5 to 10 mm, and preferably 5 mm. Alternatively, if the exemplary process chamber is used for electroplating, the motor in z-drive table assembly 1922 can lower the z-axis plate 1938 from the top of the z-axis linear bearings 1942 until the gap between wafer 1801 on chuck assembly 1930 and the top of concentric circle apparatus is in the range of approximately 0.5 to 20 mm, and preferably 5 mm. After a first metal layer is plated on wafer 1801, z-axis plate 1938 may move up incrementally in accordance with a process recipe for the wafer 1801 for additional plating.

[00114] To polish wafer 1801, the exemplary process chamber removes copper from the plated copper wafer 1801 uniformly and incrementally by applying electrical current at a different current density for different locations on the wafer 1801. The recipe for electrical current and flow of process liquid will be based on the profile of said wafer and other user-defined requirements depending on the particular application. User-defined requirements might include the number of runs for large removals, the use of larger or smaller nozzles, or thickness of the copper layers to remain on the wafers. Typically, a wafer measurement metrology tool measures the thickness profile of the copper plating on a sampling of wafers. The measurements will help generate a current ratio table that can include the current ratio to be used in the polishing process at a given set-point on the wafers. The data and the resulting ratio table create a metal film thickness profile, which can be further modified by user-defined requirements to formulate the profiled thickness of the wafers, and the recipe for electrical current density and flow rate during a polishing process.

[00115] The electrical current density applied to wafer 1801 may vary depending on the type of removals. For example, to remove a thick metal film on wafer 1801, a higher current will generally be used. To remove a thin metal film a smaller current will generally be used to enable a more controlled and precise removal process.

[00116] An exemplary process, or recipe, for electropolishing a wafer including a relatively thick layer of metal will now be described. The exemplary recipe generally entails four or more steps of processing. First, a removal of a large portion of the thick layer of the metal, e.g., copper, is performed. Second, the end point detector 1828 measures the reflectivity of the remaining copper layer to determine set-points for further polishing at a given location on wafer 1801. This process recalculates the film thickness profile based on the reflectivity readings. Third, the process removes

relatively thin layers of the copper in accordance with the new metal film thickness profile. Fourth, the end point detector 1828 measures the reflectivity of the copper layers to determine if wafer 1801 has been polished to the desired thickness and/or profile. The third and fourth processes may be repeated until wafer 1801 is polished to the desired thickness and/or profile.

[00117] It should be recognized, however, that if the end point detector 1828 determines that too much copper plating was removed from wafer 1801, e.g., in the initial removal process, the present invention may include a electroplating process wherein certain areas on the surface of the wafer are re-plated with copper. The electroplating process can include a method of reversing the voltage for the nozzle in the nozzle block 1830 with a suitable electrolyte fluid such as $\text{CuSO}_4 + \text{H}_2\text{SO}_4 + \text{H}_2\text{O}$ or the like. An exemplary electroplating apparatus and method is described in U.S. Patent No. 6,391,166 cited previously and incorporated herein.

[00118] Exemplary Process Recipe:

- Step 1. In order to remove layers of copper on wafer 1801, theta motor 1926 rotates chuck assembly 1930 in a constant linear velocity as the chuck assembly 1930 moves along the x-direction. The nozzle in nozzle block 1830 may direct process liquid to wafer 1801 at a constant flow rate. The rotation speed of theta motor 1926 can be in relation to the current density and the linear travel distance of rotating chuck assembly 1930. The electrical current ratio that is being applied to wafer 1801 can also be based on the metal film thickness profile and user-defined requirements. The exemplary recipe can continuously extrapolate new current density between, and new linear velocity at, each data point on the linear travel of rotating chuck assembly 1930. The recipe can be further recalculated using the new current ratio and linear velocity. Process drive system moves the chuck assembly 1930 back to the start position along the x-direction.
- Step 2: End point detector 1828 measures the reflectivity of copper plated surface of wafer 1801, as theta motor 1926 rotates chuck assembly 1930 again in a constant linear velocity as the chuck assembly moves back and forth along the x-direction. The present example records the reflectivity of wafer 1801 and the corresponding linear distance of the chuck assembly, at a user defined intervals. The present example extrapolates the new data into part of the metal film thickness profile.
- Step 3. Repeat Step 1 except the current flow will be adjusted based upon the reflectivity of end point detector 1828 to wafer 1801 at a given wafer location of linear distance. A smaller nozzle in nozzle block 1830 can be used to achieve a more controlled polishing of the copper plated surface.
- Step 4. Repeat Step 2. If the new reflectivity measurements from the end point detector 1828 are larger than a pre-set value, repeat Step 3.

[00119] During exemplary polishing processes, chuck assembly 1930 may be rotated in the following three modes:

[00120] 1) Constant linear velocity mode:

$$\dot{\theta} = \frac{C_1}{2\pi R} \quad (1)$$

Where, R is the horizontal distance between nozzle and wafer center,

C_1 is a constant, and

$\dot{\theta}$ is the rotation speed.

[00121] In practical control, $R=0$ gives infinite rotational speed; therefore, equation (1) can be expressed as follows:

$$\dot{\theta} = \frac{C_1}{2\pi(R + C_2)} \quad (2)$$

Where C_2 is a constant set according to the particular apparatus and application.

[00122] 2) Constant rotation speed mode:

$$\dot{\theta} = C_3 \quad (3)$$

Where C_3 is a constant set by process recipe.

[00123] 3) Constant centrifugal force mode:

$$\frac{V^2}{R} = C_4 = \text{Centrifugal force} \quad (4)$$

Where, V is the linear velocity, R is the horizontal distance between nozzle and wafer center, and C_4 is a constant set according to the particular apparatus and application.

[00124] Equation (4) can be rewritten by using $V = \dot{\theta} \cdot 2\pi R$

$$\dot{\theta} = \frac{\sqrt{C_4}}{2\pi\sqrt{R}} \quad (5)$$

Again, $R=0$ gives infinite rotational speed, $\dot{\theta}$, in practical, formula (5) can be written as:

$$\dot{\theta} = \frac{\sqrt{C_4}}{2\pi\sqrt{R + C_5}} \quad (6)$$

Where C_5 is a constant set according to the particular apparatus and application.

[00125] Horizontal direction or x-direction movement of chuck can be written as:

$$\dot{R} = \frac{C_6}{2\pi R} \quad (7)$$

Where $\dot{R}$ is the speed of chuck assembly 1930 in x-direction and $R=0$ gives infinite $\dot{R}$, in practical, formula (7) can be written as:

$$\dot{R} = \frac{C_6}{2\pi(R + C_7)} \quad (8)$$

Where C_7 is a constant set according to the particular apparatus and application.

[00126] Although Figs. 18 and 19 show a process drive system in which the chuck assembly 1930 moves along the x-direction, it should be recognized that during a process the nozzle plate 1826 or both the chuck assembly 1930 and nozzle plate 1826 can move along the x-direction depending on the particular application.

[00127] Fig. 20 shows an exemplary nozzle 2054 that may be included in the exemplary process chamber assembly. The exemplary nozzle 2054 includes an enhancement energy unit 2080 that may be attached or mechanically coupled to the nozzle 2054. The enhancement energy unit 2080 may enhance the agitation of electrolyte fluid 2081 at the metal film 2004 surface to provide a higher polishing rate, better surface finishing, and quality.

[00128] In one exemplary nozzle 2054 the energy enhancement energy unit 2080 includes an ultrasonic or magnasonic transducer. Electrolyte fluid 2081 may be input from side inlet 5200 of nozzle 2054. The frequency of an ultrasonic transducer may be in the range of 15 kHz to 100 Mega Hz to agitate the fluid. Ultrasonic transducer can be made of ferroelectric ceramics such as barium titanate (LiTaO_3), lead titanate, lead zirconate, and the like. The power of an ultrasonic transducer may be in the range of 0.01 to 1 W/cm².

[00129] In another example, the energy enhancement energy unit 2080 may include a laser. For the similar purpose as described above, a laser can be irradiated on the metal surface during an electropolishing process. The laser may be, e.g., a solid state laser such as ruby laser, Nd-glass laser, or Nd:YAG (yttrium aluminum garnet, $\text{Y}_3\text{Al}_5\text{O}_{12}$) laser, gas laser such as He-Ne laser, CO₂ laser, HF laser, or the like. The average power of the laser may be in the range of 1 watt to 100 watt/cm² for continuous mode. In another example, the laser can be operated in pulse mode. The pulse mode laser power can be much higher than the average mode power as will be recognized by those skilled in the art.

[00130] The laser may also detect film thickness of the metal film on wafer 1004. In this example, a laser directed to the metal film stimulates ultrasonic waves on metal film. The metal film 2004 thickness may be measured through the detected ultrasonic wave during an electropolishing process. The thickness of metal film 2004 may be used to control the polishing rate by changing the current, the nozzle speed in the radius direction, and the like.

[00131] In another example, the energy enhancement energy unit 2080 may include an infrared light source to anneal the metal film 2004 during a polishing process. The infrared light source can provide additional options to control surface temperature of the metal film during polishing. The power of the infrared source may be in the range of 1w to 100 w/cm². An infrared source may also

be used to anneal the metal film during a polishing process. The grain size and structure are very important for determining the copper interconnect electro-migration performance and resistivity. Because the temperature is a factor in determining the grain size and structure of the metal layer, an infrared sensor can also be used to detect a surface temperature of the metal film during a polishing process.

[00132] An infrared sensor may also be used to determine the temperature of metal film 2004. Monitoring the temperatures allows adjustments of the temperature during a polishing process with varying infrared source power, changing the current density, and the like.

[00133] In another example, the energy enhancement energy unit 2080 may include a magnetic field to focus the polishing current on the metal film 2004 during a polishing process. Focusing the polishing current allows for increased control of the polishing rate profile of the nozzle, which is increasingly important for relatively large diameter nozzles. The magnetic field may be generated in the direction of electrolyte flow, i.e., vertical direction to the metal film surface. A magnet and electric magnet, superconductor coil driving magnet or the like may be used to create and focus the magnetic field.

[00134] It should be recognized that other energy sources such as ultraviolet, X-ray, microwave sources, and the like may also be used to enhance the performance of an electropolishing process as generally described above.

[00135] Although the exemplary chamber modules and processes have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

V. Electroplating Apparatus and Process

[00136] In another aspect of a semiconductor assembly, an electroplating apparatus and method is included for electroplating semiconductor wafers. In a plating apparatus and process it is generally desired for process fluid to be distributed evenly over the surface of the wafer to plate a metal film of uniform thickness. In one exemplary process a shower head for plating apparatus is described that includes a filter block that impedes an immediate stream of electrolyte fluid and distributes the process fluid more uniformly through a channel of the shower head prior to emerging from the shower head. Distributing the fluid through the channel more uniformly leads to equal or nearly equal flow rates of electrolyte fluid from each orifice of the shower head assembly to increase the uniformity of the plating process.

[00137] Fig. 21 illustrates an exploded view of an exemplary electroplating apparatus for plating semiconductor wafers 2102. The electroplating apparatus can include half-moon chamber 2104, stationary shroud 2106, plating shower head assembly 2108, exhaust 2110, liquid inlets 2112, electrolyte fit through 2114, liquid fit through 2116, chamber tray 2118, bottom chamber window 2120, bottom chamber 2122, process chamber 2124, chamber window 2126, top lid assembly 2130,

liquid inlet tubing **2132**, electrode cable **2134**, and shafts **2136**. Top lid assembly **2130** may be functionally similar to the exemplary top lid assembly previously discussed under the heading "Process Chamber." The stationary shroud **2106** covers the wafer chuck (not shown) to prevent electrolyte from splashing out of the chamber during the electroplating and spin dry process, for example.

[00138] As shown in **Fig. 21**, wafer **2102** is loaded into the electroplating apparatus through half moon chamber **2104** to the wafer chuck of top lid assembly **2130**. To plate copper on wafer **2102**, top lid assembly **2130** will lower wafer **2102** and position the wafer above the top of plating shower head assembly **2108**. In one exemplary process of plating, a first metal layer partial deposition is performed while the gap between wafer **2102** and plating shower head assembly **2108** is in a range of about 0.1 mm to about 10 mm, and preferably about 2 mm. Top lid assembly **2130** may raise wafer **2102** an additional 2 mm to 5 mm and a second layer deposition may be performed where a thicker layer of copper is deposited on the wafer.

[00139] Exemplary electroplating processes and sequences are described in U.S. Patent No. 6,391,166, entitled PLATING APPARATUS AND METHOD, filed on January 15, 1999, U.S. Patent Application Serial No. 09/837,902, entitled PLATING APPARATUS AND METHOD, filed on April 18, 2001, and U.S. Patent Application Serial No. 09/837,911, entitled PLATING APPARATUS AND METHOD, filed on April 18, 2001, the entire contents of which are incorporated herein by reference.

[00140] **Fig. 22** illustrates an exploded view of an exemplary shower head assembly **2108** for a plating process. Shower head assembly **2108** may include outer channel ring **2202**, shower head top **2204**, and shower head **2206**. **Figs. 23 and 24** illustrate exploded views of exemplary shower heads configured for electroplating 300 mm wafer and 200 mm wafer respectively. For use with 200 mm wafers, simply replace the 300 mm outer channel ring **2302** with the 200 mm outer channel ring **2402**, and the 300 mm shower head top **2304** with the 200 mm shower head top **2404**. Thus, shower head **2206** can be used for both 300 mm and 200 mm wafers. With reference to **Fig. 24**, as the size of wafer decreases from 300 mm to 200 mm, the shower head top **2404** may include fewer rings and the outer channel ring **2402** may be smaller in diameter. It should be recognized, however, that the exemplary shower head may be configured for any size wafer.

[00141] **Fig. 25A** illustrates an exploded view of an exemplary shower head. As shown in **Fig. 25A**, shower head **2206** may include electrode rings **2502**, nuts **2504**, electrode connectors **2506**, electrode outer connectors **2508**, small inlet flare fittings **2510**, inlet flare fittings **2512**, plate filter blocks **2514**, shower head base **2516**, filter spacers **2518**, and plate filter rings **2520**. Each electrode ring **2502** is fitted on top of a matching plate filter ring **2520** and locked into place on the shower head base **2516** by fastening the electrode of electrode ring **2502** with nuts **2504**, electrode connector **2506** and electrode outer connector **2508**. Each electrode is attached with an electrode

cable 2134 to electrode outer connector 2508 as shown in Fig. 21. Electrode ring 2502 can be made of anticorrosive metals or alloys, such as platinum, titanium coated with platinum, and the like. Shower head base 2516 will have channels for electrolyte flow from inlet flare fittings 2512 and from small inlet flare fittings 2510.

[00142] As further seen in Fig. 25A, an inlet flare fitting 2512 can be larger than the width of a channel in shower head base 2516 and the inlet flare fittings cannot be fastened on the same position for all 7- or 10-rings. In order to fasten the inlet flare fittings to shower head base 2516 and to evenly distribute the tension and weight to the rings, every other small inlet flare fitting 2510 or inlet flare fitting 2512 and opposing filter block 2514 are positioned on an opposite half of the circle (not shown for filter blocks 2514). Similar to inlet flare fitting 2512, electrode ring 2502 fits over plate filter ring 2520 such that the electrode is positioned on the other half of the circle with every other electrode ring.

[00143] Fig. 25B illustrates an exploded view of a plate filter ring 2520 and plate filter block 2514 joined together by filter spacers 2518 to form a liquid flow block assembly, with an electrode ring 2502 fitting over the liquid flow block assembly. The exemplary liquid flow block assembly will be positioned above shower head base 2516 with an inlet flare fitting 2512 beneath and center of each plate filter block 2514 with an o-ring 2530 (not shown). Each plate filter ring 2520 has orifices 2522 with a narrow aperture in the center of each orifice. With reference now to both Figs. 25A and 25B, as the liquid flow block assembly and an electrode ring 2502 are fastened to shower head base 2516, a channel is formed between plate filter ring 2520 and the bottom of the shower head base. Electrolyte fluid will flow in from inlet flare fitting 2512. The electrolyte stream will first hit the center of the plate filter block 2514 above the inlet and be distributed throughout the channel. As the electrolyte fluid rises in the channels, the electrolyte will flow out of orifice 2522 uniformly and reach the electrode rings 2502. The electrolyte fluid passes the electrode ring 2502, and flows uniformly to the surface of wafer 2102 through apertures 2524 in nozzle head 2004.

[00144] Fig. 25C illustrates the relationship between orifices 2522 and the nozzle head's apertures 2524 on the bottom of shower head 2006. As shown in Fig. 25C and Fig. 22, the shower head top 2004 is stacked over shower head 2006 such that the apertures 2524 are positioned in between two orifices 2522. This staggered positioning allows the flow of electrolyte discussed in above to flow more uniformly through each recess on the liquid block flow assembly. As illustrated in the top view of the shower head in Fig. 25D, the apertures 2524 are disposed around the outer ring on shower head top 2204 (or 2304 or 2404). These apertures 2524, also inside of the enclosing rings on the shower head top 2204, may be formed in any shape, such as circle, elongated, and the like depending on the particular application. With reference to Fig. 24, apertures 2524 may be formed in an elongated circular shape created by forming three round holes.

[00145] Without plate filter block 2514, inlet flare fitting 2512 may deliver electrolyte directly through one or more apertures above the proximity of the inlet flare fitting, causing disproportionate distribution of electrolyte throughout the channel. Since electrolyte is flowing from one outlet, the liquid pressure of electrolyte can be difficult to control. Using the liquid flow block assembly, the exemplary apparatus may provide for better control of electrolyte for metal deposition, e.g., copper, because plate filter block 2514 will impede the immediate stream of electrolyte and distribute the electrolyte throughout the channel. Distributing the electrolyte throughout the channel allows equal or nearly equal volumes of electrolyte to flow out of each orifice 2522 on plate filter ring 2520. As shown in Fig. 25E, electrolyte comes out of electrode outer connectors 2508, through the shower head base 2516 and plate filter ring 2520, then around the sides of electrode ring 2502 and flows out of the apertures 2524 on shower head top 2004.

[00146] Although the exemplary shower head apparatus has been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

VI. Method and Apparatus for Leveling Wafer

[00147] According to another aspect, a method and apparatus for leveling a semiconductor wafer relative to a processing module such as an electropolishing or electroplating apparatus. Generally, while processing a wafer it is desired that the wafer be leveled such that the major surface of the wafer is generally parallel to a level surface of a processing chamber or tool. For example, aligning the wafer in the processing apparatus increases the uniformity of the polishing or plating processes.

[00148] Figs. 26A and 26B show an exemplary leveling tool 2604 that may be used to measure the parallelism of wafer 2602 within ± 0.001 inch relative to the processing apparatus, e.g., a processing chamber. As shown in Figs. 26A and 26B, the leveling apparatus generally includes leveling tool 2604, ground line 2610, signal lines 1612, control system 2614, and chuck 2616.

[00149] An exemplary chuck is described in U.S. Patent No. 6,248,222 B1, entitled METHOD AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on September 7, 1999, and U.S. Patent No. 6,495,007, entitled METHODS AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on March 7, 2001, both of which are incorporated in their entireties by reference herein.

[00150] With reference to Figs. 26A and 26B, chuck 2616 holds wafer 2602 during a semiconductor electropolishing and/or electroplating process. In order to provide for a more uniform process of the electropolishing and/or electroplating process, wafer 2602 is positioned parallel or nearly parallel to processing chamber 2630, and in particular with the plating head or

polishing nozzles (not shown) of the processing apparatus. Leveling tool 2604 may be positioned within the process chamber 2630 to provide increased alignment of the wafer 2602.

[00151] Leveling tool 2604 may include three sensors 2606 and corresponding signal lines 2612. When leveling tool 2604 is placed under chuck 2616 and the wafer 2602 is brought down to leveling tool 2604, signal lines 2612 (through sensors 2606) provide connection to the control system 2614 through a thin metal layer formed on the surface of the wafer 2602. A ground line 2610 from control system 2614 is connected to the wafer 2602 metal layer. As sensors 2606 contact the thin metal layer a circuit is completed between the sensors 2606 and the ground line 2610 that may be measured by controller system 2614.

[00152] Additionally, as shown in Fig. 26B, leveling tool 2604 may include supports 2608 for use in measuring the parallelism of wafer 2602 in chuck 2616 and the polishing nozzles as well as position the leveling tool 2604 near the surface of wafer 2602.

[00153] Fig. 26C illustrates a cross-sectional view of an exemplary sensor 2606. Sensor 2606 can include holder 2626, set screws 2618, pin adjustment 2620, contact screw 2622, and pin 2624. Signal line 2602 is connected to sensor 2606 through contact screw 2622. Holder 2626, pin adjustment 2620, and pin 2624 can be made of metals or alloys, such as stainless steel, titanium, tantalum, or gold.

[00154] In one exemplary process for measuring the alignment or parallelism of wafer 2602 in relation to the process tool, chuck 2616 descends toward leveling tool 2604 until the pin 2624 of one of sensors 2606 contacts the conductive surface of wafer 2602. The contact completes an electrical circuit that includes signal line 2612, ground line 2610, and control system 2614, and provides a signal to control system 2614. The control system 2614 determines the distance from the original (home) position of chuck 2616 to the pin's position at the moment of the contact.

[00155] Chuck 2616 continues its descent until the second sensor 2606, and the third sensor 2606 contact the surface of wafer 2602. Corresponding distances for both sensor contacts are taken and the measurement process ends.

[00156] As shown in Fig. 27, the exemplary process may include a software interface, which displays the measured distance in the moment of contact for each sensor 2606. The interface can also display the location of sensors 2606. The smaller in the difference between a maximum and minimum distance of the measured distances the closer the wafer 2602 is to being aligned or in a parallel relationship. The data can be used to make adjustment to chuck 2616 and consequently, position of wafer 2602. After the adjustment is made, the measurement cycle can be repeated until the difference between the maximum and minimum of the measured distances is within design specification such as ± 0.001 inch or the like depending on the particular application.

[00157] Although the exemplary wafer alignment methods and systems have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

[00158] The above detailed description of various devices, methods, and systems is provided to illustrate exemplary embodiments and is not intended to be limiting. It will be apparent to those skilled in the art that numerous modifications and variations within the scope of the present inventions are possible. For example, the different exemplary electropolishing and electroplating devices, such as the cleaning chamber, the optical sensors, the liquid delivery system, end-point detectors, and the like may be used together in a single process assembly or may be used separately to enhance electropolishing and/or electroplating systems and methods. Accordingly, the present invention is defined by the appended claims and should not be limited by the description herein.

CLAIMS

1. An apparatus for processing one or more semiconductor wafers, comprising:
a module for storing a wafer;
a plurality of vertically stacked processing modules for at least one of electropolishing the wafer
and electroplating the wafer;
a cleaning module; and
a robot for transferring the wafer between the module for storing, the processing module, and the
cleaning module,
wherein the apparatus is divided into at least two sections characterized by separate frames.
2. The apparatus of claim 1, further including a pre-alignment module to align the wafer prior to
processing.
3. The apparatus of claim 1, wherein the robot includes one or more end effectors for picking and
transferring the wafer.
4. The apparatus of claim 1, wherein the robot is removable by rolling or sliding out from one of
the at least two sections.
5. The apparatus of claim 1, wherein the robot includes,
a first end effector for transferring the wafer to the processing modules, and
a second end effector for transferring the wafer from the processing modules.
6. The apparatus of claim 1, further including a liquid delivery system for delivering process
liquid to the processing modules.
7. The apparatus of claim 6, wherein the liquid delivery system includes a surge suppressor.
8. The apparatus of claim 6, wherein the liquid delivery system includes a controller to modulate a
flow rate of the process liquid.
9. The apparatus of claim 6, wherein the liquid delivery system is housed in a containment tray.
10. The apparatus of claim 1, wherein the apparatus includes an exhaust to remove gases from the
processing modules.

11. A method for at least one of electropolishing and electroplating a semiconductor wafer in a process assembly, comprising:
transferring a wafer to one of a plurality of stacked processing modules with a first end effector;
electropolishing or electroplating the wafer in the processing module;
transferring the wafer from the processing module to a cleaning module with a second end effector; and
cleaning the wafer in the cleaning module, wherein the process assembly is divided into at least two sections characterized by separate frames.
12. The method of claim 11, further wherein transferring the wafer includes using a robot and wherein the robot is configured to slide or roll out of the process assembly.
13. The method of claim 11, further including delivering liquid to the processing module through a supply line, wherein a surge suppressor is associated with the supply line.
14. The method of claim 11, further including removing gases from the processing module through an exhaust system.