

ELECTROPLATING CELL NEUTRALIZATION

INCORPORATION BY REFERENCE

[0001] A PCT Request Form is filed concurrently with this specification as part of the present application. Each application that the present application claims benefit of or priority to as
5 identified in the concurrently filed PCT Request Form is incorporated by reference herein in its entirety and for all purposes.

FIELD

[0002] The present disclosure relates to methods, apparatuses, and tools for electroplating material onto substrates. Specifically, the present disclosure pertains to neutralization of
10 electroplating cells, filters, and other components of an electroplating apparatus or tool.

BACKGROUND

[0003] Electrochemical deposition is now poised to fill a commercial need for sophisticated packaging and multichip interconnection technologies known generally and colloquially as wafer level packaging (WLP) and through silicon via (TSV) electrical connection technology. These
15 technologies present their own very significant challenges due in part to the generally larger feature sizes (compared to Front End of Line (FEOL) interconnects) and high aspect ratios.

[0004] Electroplating tools and apparatuses utilize plating circuit flow loops to deliver electrolyte for electrochemical deposition of metals. Such plating circuit flow loops may consist of various components such as reservoirs, pumps, filters, flow meters, degassers, isolation valves,
20 and electroplating cells. The electroplating cells may include a stack up of components that form a separated anode chamber housing an anode, a plating chamber, a cross flow area, and a drain area. Often, service engineers or technicians need to perform maintenance on one or more components of the electroplating tool or apparatus, which puts the service engineers or technicians at risk of exposure to hazardous chemicals.

[0005] The background description provided herein is for the purposes of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as
25 prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

SUMMARY

[0006] Provided herein is an electroplating apparatus. The electroplating apparatus includes a reservoir configured to hold electroplating solution, a pump, and one or more electroplating cells.
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Each of the one or more electroplating cells includes a cathode chamber, an anode chamber configured to contain an anode, and a membrane between the cathode chamber and the anode chamber. The electroplating apparatus further includes a feed line fluidly coupled to an outlet of the pump and to the one or more electroplating cells, and a return line fluidly coupled to the one or more electroplating cells and also fluidly coupled to one or more of the following: (1) a reservoir return line, where the reservoir return line is fluidly coupled to the reservoir, (2) a bypass return line, where the bypass return line bypasses the reservoir and is fluidly coupled to the pump, and (3) a drain line, where the drain line is directed to waste. The electroplating apparatus further includes a neutralization fill line fluidly coupled to the one or more electroplating cells and configured to supply neutralization solution to the one or more electroplating cells.

[0007] In some implementations, the neutralization solution includes deionized water. In some implementations, an inlet of the pump is fluidly coupled to the bypass return line and a reservoir output line. In some implementations, the return line is fluidly coupled to the drain line, where the neutralization fill line is configured to circulate the neutralization solution through the one or more electroplating cells to the drain line via the return line. In some implementations, the return line is fluidly coupled to the bypass return line, where the neutralization fill line is configured to circulate the neutralization solution through the one or more electroplating cells and the bypass return line via the pump and the feed line. In some implementations, the return line is fluidly coupled to the reservoir, where the neutralization fill line circulates the neutralization solution to the bypass return line or the drain line, and bypasses the reservoir. In some implementations, the electroplating apparatus further includes a drain line, where the drain line is fluidly coupled to either the return line or to the feed line. In some implementations, the electroplating apparatus further includes an aspiration line fluidly coupled to the one or more electroplating cells, where the aspiration line includes a bulk aspiration valve configured to aspirate the one or more electroplating cells. In some implementations, each of the one or more electroplating cells further includes an ionically resistive element above the membrane. In some implementations, each of the one or more electroplating cells further includes a membrane frame configured to support the membrane. In some implementations, the electroplating apparatus further includes an HRVA chamber aspiration line fluidly coupled to a region below the ionically resistive element in the one or more electroplating cells, where the HRVA chamber aspiration line includes an HRVA chamber aspiration valve configured to aspirate the region below the ionically resistive element. In some implementations, the electroplating apparatus further includes a system controller configured with instructions to perform the following operations: (a) open a drain isolation valve between the return line and the reservoir to return electrolyte in the one or more electroplating cells to the reservoir,

(b) close the drain isolation valve to isolate selected one or more electroplating cells to be isolated from the reservoir, (c) open one or both of the bulk aspiration valve and the HRVA chamber aspiration valve to aspirate the selected one or more electroplating cells, and (d) open a neutralization fill valve connected to the neutralization fill line to fill the selected one or more electroplating cells with the neutralization solution. In some implementations, the system controller is further configured with instructions to perform the following operations: repeat steps (c) and (d) until a pH of a solution from the selected one or more electroplating cells reaches a threshold safety value. In some implementations, the system controller is further configured with instructions to perform the following operations: close, after step (c) is complete and prior to step (d), the bulk aspiration valve and the HRVA chamber aspiration valve after aspiration of the selected one or more electroplating cells, and close, after step (d) is complete, the neutralization fill valve. In some implementations, the system controller is further configured with instructions to perform the following operations: open, after step (d), a recirculation valve connected to the return line and the bypass return line to recirculate the neutralization solution through the selected one or more electroplating cells. In some implementations, the electroplating apparatus further includes a second neutralization fill line fluidly coupled to the one or more electroplating cells, where the second neutralization fill line includes a secondary neutralization fill valve configured to supply a second neutralization solution to a tower that is fluidly coupled to the one or more electroplating cells, and an anode chamber aspiration line fluidly coupled to the tower, where the anode chamber aspiration line includes an anode chamber aspiration valve configured to aspirate the tower, where the system controller is further configured with instructions to perform the following operations: open, after step (d), the secondary neutralization fill valve to fill the tower with the second neutralization solution, and close the second neutralization fill valve upon filling the tower with the second neutralization solution. In some implementations, the neutralization fill line further includes a precursor dose valve to dose the one or more electroplating cells with a precursor, where the system controller is further configured with instructions to perform the following operations: open, prior to step (d), the precursor dose valve to dose the selected one or more electroplating cells with the precursor. In some implementations, the precursor includes methane sulfonic acid (MSA) and prevents precipitation upon mixing the neutralization solution with the electroplating solution. In some implementations, the electroplating apparatus further includes a system controller configured with instructions to perform the following operations: (a) select at least one of the one or more electroplating cells to isolate and neutralize with the neutralization solution, (b) aspirate the selected at least one of the one or more electroplating cells, (c) neutralize the selected at least one of the one or more electroplating cells with the neutralization

solution, and (d) electroplate metal onto one or more wafers in the one or more electroplating cells that are not selected for isolation and neutralization, where metal is electroplated onto the one or more wafers simultaneous with steps (b)-(c). In some implementations, the feed line includes a filter downstream of the pump, where the neutralization fill line is configured to supply the neutralization solution to the pump and flow the neutralization solution through the feed line and the filter. In some implementations, the electroplating apparatus further includes a system controller configured with instructions to perform the following operations: (a) close a cell isolation valve connected to the feed line to isolate the pump from the one or more electroplating cells, and (b) open a neutralization fill valve connected to the neutralization fill line to flush the filter with the neutralization solution.

[0008] Also provided herein is a method of neutralizing one or more electroplating cells in an electroplating apparatus. The method includes isolating selected one or more electroplating cells to be isolated from a reservoir configured to hold electroplating solution in the electroplating apparatus, aspirating the selected one or more electroplating cells, filling the selected one or more electroplating cells with neutralization solution, and repeating operations of aspirating and filling with neutralization solution until a pH of a solution from the one or more electroplating cells reaches a threshold safety value.

[0009] In some implementations, the neutralization solution includes deionized water. In some implementations, the neutralization solution includes a base. In some implementations, aspirating the selected one or more electroplating cells includes opening a first aspiration valve that is fluidly coupled to the selected one or more electroplating cells, where each of the electroplating cells comprises a cathode chamber, an anode chamber, and an ionically resistive element between the cathode chamber and the anode chamber, and opening a second aspiration valve that is fluidly coupled to an area below the ionically resistive element in the selected one or more electroplating cells. In some implementations, the method further includes recirculating, after filling the selected one or more electroplating cells with the neutralization solution, the neutralization solution through the selected one or more electroplating cells. In some implementations, the method further includes reclaiming, prior to isolating the selected one or more electroplating cells, electrolyte in the one or more electroplating cells to the reservoir. In some implementations, the method further includes electroplating metal onto one or more wafers in the one or more electroplating cells that are not selected for isolation and neutralization, where metal is electroplated onto the one or more wafers simultaneous with aspirating and filling the selected one or more electroplating cells with the neutralization solution.

[0010] Also provided herein is a method of performing filter flush. The method includes isolating a pump from one or more electroplating cells in an electroplating apparatus, where the pump is configured to draw electroplating solution from a reservoir, aspirating a filter positioned downstream of the pump, where the filter is fluidly coupled to the one or more electroplating cells, flushing the filter with neutralization solution using a neutralization fill valve fluidly coupled to a feed line, and repeating operations of aspirating and flushing with neutralization solution until a pH of a solution from the filter reaches a threshold safety value.

[0011] In some implementations, the neutralization solution includes deionized water. In some implementations, the neutralization solution includes a base.

BRIEF DESCRIPTION OF DRAWINGS

[0012] Figure 1 shows a diagram of a flow loop of an electroplating apparatus having multiple electroplating cells in fluid communication with an electrolyte reservoir.

[0013] Figure 2 shows a diagram of an example flow loop of the electroplating apparatus with a neutralization flush line that bypasses the electrolyte reservoir according to some implementations.

[0014] Figure 3A shows a diagram of an example flow loop of an electroplating apparatus with a drain line that bypasses the electrolyte reservoir according to some implementations.

[0015] Figure 3B shows a diagram of an alternative flow loop of an electroplating apparatus with a drain line that bypasses the electrolyte reservoir according to some implementations.

[0016] Figure 3C shows a diagram of an alternative flow loop of an electroplating apparatus according to some implementations.

[0017] Figure 4A shows a schematic illustration of an example electroplating cell that utilizes a combination of cross flow and impinging flow on the substrate surface during electroplating.

[0018] Figure 4B shows a cross-sectional view of various hardware components in the electroplating cell.

[0019] Figure 4C shows an isometric cross-sectional view of the electroplating cell including a high resistance virtual anode (HRVA) chamber.

[0020] Figure 5 shows a schematic illustration of fluid flow through a channeled ionically resistive element beneath the channeled ionically resistive element.

[0021] Figure 6A shows a diagram of a flow loop of an electroplating apparatus configured to perform neutralization of electroplating cells, where each electroplating cell is arranged in a recirculating separated anode chamber (R-SAC) configuration according to some implementations.

[0022] Figure 6B shows a diagram of a flow loop of an electroplating apparatus configured to perform neutralization of electroplating cells, where each electroplating cell is arranged in a cascade separated anode chamber (C-SAC) configuration according to some implementations.

5 [0023] Figure 6C shows a diagram of a flow loop of an electroplating apparatus configured to perform neutralization of a filter according to some implementations.

[0024] Figure 7 shows a flow diagram of an example method for performing electroplating cell neutralization of electroplating cells in an R-SAC configuration according to some implementations.

10 [0025] Figure 8 shows a flow diagram of an example method for performing electroplating cell neutralization of electroplating cells in a C-SAC configuration according to some implementations.

[0026] Figure 9 shows a flow diagram of an example method for performing electroplating cell neutralization according to some implementations.

15 [0027] Figure 10 shows a flow diagram of an example method for performing filter flush according to some implementations.

[0028] Figure 11 shows a multi-chamber electroplating apparatus according to some implementations.

DETAILED DESCRIPTION

20 [0029] The implementations disclosed below may describe processing of a material on a substrate such as a wafer, substrate, or other work piece. The work piece may be of various shapes, sizes, and materials. In this application, the terms “semiconductor wafer,” “wafer,” “substrate,” “wafer substrate,” and “partially fabricated integrated circuit” are used interchangeably. One of ordinary skill in the art would understand that the term “partially fabricated integrated circuit” can
25 refer to a silicon wafer during any of many stages of integrated circuit fabrication thereon. A wafer or substrate used in the semiconductor device industry typically has a diameter of 200 mm, or 300 mm, or 450 mm. Unless otherwise stated, the processing details recited herein (e.g., flow rates, power levels, etc.) are relevant for processing 300 mm diameter substrates, or for treating chambers that are configured to process 300 mm diameter substrates and can be scaled as
30 appropriate for substrates or chambers of other sizes. In addition to semiconductor wafers, other work pieces that may be used implementations disclosed herein include various articles such as printed circuit boards and the like. The processes and apparatuses can be used in the fabrication of semiconductor devices, displays, LEDs, photovoltaic panels and the like.

Introduction

[0030] Integrated circuit fabrication typically involves the deposition of one or more layers of conductive metal on a semiconductor wafer. Electroplating processes are a common methodology which is used to accomplish such metal layer deposition. Typical electroplating applications include but are not limited to damascene electrofill, electrofill in WLP applications, and electrofill of TSVs. A variety of metals and metal alloys can be electroplated. Such metals or metal alloys can include but are not limited to copper, tin, silver, tin-silver alloy, nickel, gold, indium, and cobalt.

[0031] During electroplating, electrical contacts are made to a conductive seed layer (e.g., a copper seed layer) at the periphery of a semiconductor wafer. In a typical electroplating process the semiconductor wafer containing an exposed conductive seed layer is cathodically biased and is brought in contact with an electroplating solution containing ions of a metal that is being plated. Ions are electrochemically reduced at the surface of the seed layer to form a metal layer. The electroplating solution contains an acid that provides sufficient conductivity to the electroplating solution. The electroplating solution may also contain additives such as accelerators, suppressors, and levelers that modulate electrodeposition rates on different surfaces of the semiconductor wafer.

[0032] The electroplating solution is an electrolyte containing an acid, metal salt, and other chemicals. The electroplating solution can be highly acidic and hazardous to the human health upon exposure. In an electroplating system or apparatus, the electroplating solution is contained not only in a vessel or reservoir, but also is circulated in a plating loop through filters, degassers, electroplating cells, and other hardware components. These hardware components of the plating loop may contain the highly acidic electroplating solution.

[0033] Various hardware components in the plating loop may require maintenance from time to time. Such maintenance tasks may include preventative measures such as a process kit change or part replacement or may include unscheduled machine or part failures such as a pump or valve failure. In some instances, an anode in an anode chamber of an electroplating cell may need to be replaced periodically. In some instances, a filter in the plating loop may need to be replaced periodically. In some instances, a pump or valve failure may necessitate maintenance. Service engineers or technicians risk exposure to hazardous chemicals when performing maintenance on an electroplating system or apparatus. The only way to minimize the risk is for the service engineer or technician to wear heavy personal protective equipment (PPE). However, heavy PPE can only be worn for a short period of time and then requires a lengthy recovery period. Thus, the process of servicing the electroplating system or apparatus, whether it's a filter or anode replacement or

other maintenance task, can require multiple personnel and/or significant downtime to complete the maintenance.

[0034] The present disclosure provides a process for neutralizing one or more electroplating cells and other parts of a plating loop for maintenance. As used herein, “neutralization” refers to a process that brings a fluid closer to a neutral pH (i.e., pH closer to 7). The process involves mixing or rinsing a neutralization solution with the highly acidic electroplating solution until the electroplating solution reaches a pH level that satisfies a desirable safety threshold.

[0035] By neutralizing the electroplating cells or other parts, the service engineer or technician will only need to wear heavy PPE for a short period of time to perform maintenance. The short period of time may only be to confirm that neutralization was successful. After confirmation that neutralization was successful, the service engineer or technician may only need to wear standard PPE (if necessary) to perform various maintenance tasks. Such tasks may include but is not limited to: (1) reading/adjusting sensors, (2) removing top hats to visually inspect an HRVA, (3) removing process kits (anode maintenance), and (4) plating cell filter replacement. Neutralization of acidic chemistry prior to maintenance reduces human risk and the amount of labor required by the service engineer or technician, which ultimately increases throughput and reduces the cost of ownership. In some cases, neutralization may be performed on selected electroplating duets/cells so that maintenance can occur while production can continue on other electroplating duets/cells.

Electroplating Cell Neutralization

[0036] Figure 1 shows a diagram of a flow loop of an electroplating apparatus having multiple electroplating cells in fluid communication with an electrolyte reservoir. The electroplating apparatus 100 may include a reservoir 110, electroplating cells 130, feed line 120 that fluidly connects the reservoir 110 to the electroplating cells 130, and return line 160 that fluidly connects the electroplating cells 130 back to the reservoir 110. Electroplating solution may be held in a reservoir 110. Electroplating solution may also be referred to as electrolyte, plating solution, or processing fluid. Reservoir 110 may also be referred to as an electrolyte reservoir, plating bath, plating vessel, or tank. From the reservoir 110, the electroplating solution is transferred through a pump 104 that is fluidly coupled to the reservoir 110. A bath isolation valve 102 is positioned between the pump 104 and the reservoir 110, where the bath isolation valve 102 is configured to isolate the reservoir 110 from the pump 104. The bath isolation valve 102 controls the flow of the electroplating solution to the pump 104. The pump 104 drives the electroplating solution through a feed line 120 that is fluidly coupled to the pump 104 and to electroplating cells 130.

[0037] The feed line 120 may include a filter 122, where the filter 122 may serve to filter out any particulates from the electroplating solution. The feed line 120 may further include a fluid contactor 124, where the fluid contactor 124 may serve to remove dissolved oxygen or other gas(es) from the circulating electroplating solution. The fluid contactor 124 may include a membrane through which the electroplating solution is driven through, where a vacuum port on one side of the filter 122 may draw out dissolved oxygen or other gas(es). In some implementations, the feed line 120 may further include a flow meter 126, where the flow meter 126 may be configured to control a flow of liquid passing through it. The feed line 120 may further include a cell isolation valve 128, where the cell isolation valve 128 is configured to isolate the electroplating cells 130 from the pump 104. The cell isolation valve 128 controls the flow of the electroplating solution to the electroplating cells 130. Along the feed line 120, the filter 122 may be located downstream of the pump 104, the fluid contactor 124 may be located downstream of the filter 122, the flow meter 126 may be located downstream of the fluid contactor 124, and the cell isolation valve 128 may be located downstream of the flow meter 126.

[0038] The electroplating solution flows through the feed line 120 before it is split at a tee 140. Each outlet of the tee 140 feeds into an individual electroplating cell 130. In some embodiments, the electroplating cells 130 are fountain-type plating cells. Details regarding each of the electroplating cells 130 are described below with reference to Figures 3A–3C. Each of the electroplating cells 130 may include a cathode chamber 132, an ionically resistive element 134, a membrane 136, and an anode chamber 138. The electroplating solution flowing through the cathode chamber 132 and the ionically resistive element 134 may be referred to as catholyte. The ionically resistive element 134 approximates a nearly constant and uniform current source in the proximity of a substrate (cathode) and, as such, may be referred to as a high resistance virtual anode (HRVA) or channeled ionically resistive element (CIRP). The membrane 136 is below the ionically resistive element 134, where the membrane 136 separates the anode chamber 138 from the cathode chamber 132. The membrane 136 may be an ionically permeable membrane and may block bulk electrolyte flow while permitting transport of ions such as cations. The anode chamber 138 contains or otherwise houses an anode (e.g., a copper anode or a non-metal inert anode). Electroplating solution in the anode chamber 138 may be referred to as anolyte. Frequently, catholyte and anolyte have different compositions, with the anolyte containing little or no plating additives and the catholyte containing significant concentrations of such plating additives. The anode chamber 138 may also be referred to as a separated anode chamber (SAC).

[0039] As electroplating solution passes through the electroplating cells 130, the electroplating solution may flow into a collection trough 150. The collection trough 150 may be used to

accumulate electroplating solution prior to passing the electroplating solution to the reservoir 110. The collection trough 150 may also be referred to as a drain manifold. The collection trough 150 may be used to accumulate electroplating solution from multiple electroplating cells 130. In some cases, as the electroplating solution is delivered to the electroplating cells 130, the electroplating solution may flow over a weir wall and ultimately provided to the collection trough 150 for collection and recirculation.

[0040] A return line 160 may be fluidly coupled to the electroplating cells 130 and the reservoir 110. The return line 160 includes a drain isolation valve 162 configured to isolate the electroplating cells 130 from the reservoir 110. The return line 160 may be fluidly coupled to the electroplating cells 130 at the collection trough 150. A level sensor (not shown) may be used to determine a level of fluid in the electroplating cells 130. The level sensor may maintain a target level of fluid in the electroplating cells 130. Signal from the level sensor may be used to regulate the drain isolation valve 162 so that fluid returning to the reservoir 110 does not undesirably introduce bubbles/foam back to the reservoir 110. More specifically, by monitoring when the fluid reaches a certain height in the electroplating cells 130, the fluid may be drained back to the reservoir 110 so that it falls a short distance rather than a long distance. Electroplating solution that returns to the reservoir 110 may be used for recirculation through the feed line 120 and the electroplating cells 130.

[0041] In some implementations, the electroplating cells 130 are fluidly connected with an anode chamber tower 152 (also referred to as the “SAC tower”). The anode chamber tower 152 may operate to provide a static pressure head, thereby establishing a relatively constant pressure in the anode chamber 138 during certain desired times, for example during electroplating and/or during idling. In some implementations, the anode chamber tower 152 may be omitted. When draining fluid from the anode chamber 138 of the electroplating cells 130, the anode chamber tower 152 may provide an air break.

[0042] In the present disclosure, an electroplating system or apparatus is configured to neutralize electroplating cells and/or other components in a plating cell loop so that maintenance can be performed with minimal exposure to acidic and hazardous chemicals. The electroplating system or apparatus may include a neutralization flush line (or neutralization fill line) with a neutralization fill valve configured to deliver a neutralization solution such as deionized water to the plating cell loop. Selected one or more electroplating cells may be isolated for neutralization, where an electrolyte reservoir is isolated from the selected one or more electroplating cells during neutralization. The selected one or more electroplating cells may be aspirated to remove residual chemistry, and the selected one or more electroplating cells are filled with neutralization solution.

This process may be repeated until a pH of a solution from the selected one or more electroplating cells reaches a threshold safety value. In some cases, the electroplating system or apparatus may isolate a filter for neutralization and flow the neutralization solution to the filter.

[0043] Figure 2 shows a diagram of an example flow loop of the electroplating apparatus with a neutralization flush line that bypasses the electrolyte reservoir according to some implementations. Some aspects of the electroplating apparatus of Figure 1, such as the return line 160, the electroplating cells 130, the feed line 120, the reservoir 110, the pump 104, the filter 122, and the fluid contactor 124, are included in the electroplating apparatus of Figure 2 and not repeated for the sake of brevity.

[0044] A neutralization flush line 210 is fluidly coupled to the electroplating cells 130 and the pump 104. The neutralization flush line 210 includes a neutralization fill valve 212 configured to supply a neutralization solution to the pump 104 and circulate the neutralization solution through the feed line 120 and the electroplating cells 130. In some implementations, the neutralization solution is water or deionized water. In some other implementations, the neutralization solution contains a base or other non-acidic chemistry.

[0045] The neutralization flush line 210 may be fluidly connected to the electroplating cells 130 at the collection trough 150. Alternatively, the neutralization flush line 210 may be fluidly connected to the electroplating cells at the return line 160 prior to (e.g., upstream) of the drain isolation valve 162. The neutralization flush line 210 bypasses a reservoir return line 164 and the reservoir 110. In some implementations, the neutralization flush line 210 may recycle and recirculate the electroplating solution back to the electroplating cells 130 via the pump 104 and the feed line 120. In some alternative implementations, the neutralization flush line 210 may recycle and recirculate the neutralization solution back to the electroplating cells 130 via the pump 104 and the feed line 120. The neutralization flush line 210 may further include a recirculation valve 214 configured to recirculate electroplating solution, neutralization solution, or mixtures thereof directly from the electroplating cells 130 to the pump 104. That way, the recirculation valve 214 and the neutralization flush line 210 provide a source of fluid to the pump 104 instead of the reservoir 110. The recirculation valve 214 may supply fluid (e.g., electroplating solution, neutralization solution) to the electroplating cells 130, via the pump 104, at a desired flow rate, such as between about 20 liters per minute and 150 liters per minute, between about 30 liters per minute and 100 liters per minute, or between about 40 liters per minute and 80 liters per minute.

[0046] The neutralization flush line 210 may be divided into two parts: (a) a bypass return line 210a that is fluidly coupled to the electroplating cells 130, and (b) a neutralization fill line 210b that is fluidly coupled to the pump 104. Rather than flowing fluid back to the reservoir 110 via

the return line 160, the fluid may be circulated from the electroplating cells 130 to the bypass return line 210a. The fluid may flow from the bypass return line 210a to the neutralization fill line 210b by control of the recirculation valve 214. Neutralization solution may be flowed from a neutralization fill valve 212 to the neutralization fill line 210b to supply neutralization solution to the electroplating cells 130.

[0047] In some implementations, the neutralization flush line 210 further includes a bleed valve 216. During a normal plating process, the recirculation valve 214 remains closed to allow electroplating solution to circulate normally via the reservoir 110 and the pump 104. This can cause fluid above the recirculation valve 214 to become stagnant, which can adversely affect the concentration of the electroplating solution. Rather than periodically opening the recirculation valve 214, the bleed valve 216 may allow some of the fluid “trapped” above the recirculation valve 214 to bleed into the electroplating solution during the normal plating process. This allows the “trapped” fluid to remain in concentration so that it does not become stagnant. In some embodiments, the bleed valve 216 may flow fluid trapped above the recirculation valve 214 to the pump 104 at a desired flow rate, such as between about 0.1 liters per minute and about 5 liters per minute, between about 0.5 liters per minute and about 3 liters per minute, or between about 1 liters per minute and about 2 liters per minute.

[0048] Prior to delivery of the neutralization solution to the electroplating cells 130, the electroplating cells 130 may undergo aspiration to empty the electroplating cells 130 and the feed line 120 from any residual chemistry. Instead of returning fluid to the reservoir 110 or recirculating the fluid to the electroplating cells 130, fluid may be removed from the plating cell loop by aspiration. In some embodiments, the neutralization flush line 210 further includes a bulk aspiration valve 218 that is connected to an aspiration line (not shown) and bulk aspirator pump (not shown) for removing fluid out of the plating cell loop. In certain embodiments, filling the plating cell loop can be accomplished using the neutralization fill valve 212 and aspirating the plating cell loop can be accomplished using the bulk aspiration valve 218. Neutralization solution may be supplied by the neutralization fill valve 212 at a desired flow rate, such as between about 3 liters per minute and about 40 liters per minute, between about 5 liters per minute and about 30 liters per minute, or between about 10 liters per minute and about 20 liters per minute. The bulk aspiration valve 218 may aspirate at a similar rate.

[0049] Figure 3A shows a diagram of an example flow loop of the electroplating apparatus with a drain line that bypasses the electrolyte reservoir according to some implementations. Some aspects of the electroplating apparatus of Figure 1, such as the return line 160, the electroplating cells 130, the feed line 120, the reservoir 110, the pump 104, the filter 122, and the fluid contactor

124, are included in the electroplating apparatus of Figure 3A and not repeated for the sake of brevity.

[0050] In the electroplating apparatus of Figure 3A, a drain line 310 may be fluidly connected to the electroplating cells 130 at the collection trough 150. Alternatively, the drain line 310 may be fluidly connected to the return line 160 prior to (e.g., upstream) of the drain isolation valve 162. The drain line 310 bypasses the reservoir return line 164 and the reservoir 110. The drain line 310 may include a drain valve 312, where the drain valve 312 is configured to control a flow of electroplating solution, neutralization solution, or mixtures thereof from the drain line 310 to waste 314. Thus, fluid may pass through the electroplating cells 130 and flow directly to waste 314 through the drain line 310. This bypasses the reservoir return line 164 for returning fluid to the reservoir 110. This also bypasses a bypass return line 210a for recirculating fluid back through the feed line 120 and the electroplating cells 130. In such instances, gravity may assist drainage of fluid through the drain line 310 to waste 314, as residual chemistry may be heavier than the fluid and may be more easily pushed down to waste 314. The flow loop of the electroplating apparatus of Figure 3A may or may not include the bypass return line 210a for recirculation of fluid.

[0051] The neutralization fill valve 212 is configured to supply neutralization solution to the electroplating cells 130. In Figure 2, the neutralization fill valve 212 may be located downstream of the electroplating cells 130 and supplies neutralization solution to the electroplating cells 130 via the pump 104 and the feed line 120. However, in Figure 3A, the neutralization fill valve 212 and the neutralization fill line 210b may be located upstream of the electroplating cells 130 and supplies neutralization solution directly to the electroplating cells 130. In fact, the neutralization fill valve 212 may be located anywhere in the flow loop for supplying neutralization solution to the electroplating cells 130, and may be positioned along lines such as the feed line 120 or the bypass return line 210a.

[0052] Figure 3B shows a diagram of an alternative flow loop of an electroplating apparatus with a drain line that bypasses the electrolyte reservoir according to some implementations. Some aspects of the electroplating apparatus of Figure 1, such as the return line 160, the electroplating cells 130, the feed line 120, the reservoir 110, the pump 104, the filter 122, and the fluid contactor 124, are included in the electroplating apparatus of Figure 3B and not repeated for the sake of brevity.

[0053] In the electroplating apparatus of Figure 3B, a drain line 310 may be fluidly connected to the feed line 120. In fact, the drain line 310 may be located anywhere in the flow loop for draining electroplating solution, neutralization solution, or mixtures thereof. For example, the

drain line 310 may be fluidly connected to the feed line 120 at the filter 122. In such instances, flow may be reversed so that fluid travels from the electroplating cells 130 to the feed line 120 and through the fluid contactor 124 and the filter 122. The drain line 310 may include the drain valve 312, where the drain valve 312 is configured to control a flow of electroplating solution, neutralization solution, or mixtures thereof from the drain line 310 to waste 314.

[0054] Figure 3C shows a diagram of an alternative flow loop of an electroplating apparatus according to some implementations. Some aspects of the electroplating apparatus of Figure 1, such as the return line 160, the electroplating cells 130, the feed line 120, the reservoir 110, the pump 104, the filter 122, and the fluid contactor 124, are included in the electroplating apparatus of Figure 3C and not repeated for the sake of brevity.

[0055] The electroplating apparatus includes a return line 160 that is fluidly coupled to the electroplating cells 130. In some implementations, the return line 160 is also fluidly coupled to one or more of the following: (1) a reservoir return line 164 that is fluidly coupled to the reservoir 110, (2) a bypass return line 210a that bypasses the reservoir 110 and is fluidly coupled to the pump 104, and (3) a drain line 310 that is directed to waste 314. In some implementations, the electroplating apparatus only includes the drain line 310 fluidly coupled to the return line 160. In some implementations, the electroplating apparatus only includes the bypass return line 210a fluidly coupled to the return line 160. In some implementation, the electroplating apparatus includes both the bypass return line 210a fluidly coupled to the return line 160 and the reservoir return line 164 fluidly coupled to the return line 160. In some implementations, the electroplating apparatus includes both the bypass return line 210a fluidly coupled to the return line 160 and the drain line 310 fluidly coupled to the return line 160. In some implementations, the electroplating apparatus includes the bypass return line 210a, the drain line 310, and the reservoir return line 164 fluidly coupled to the return line 160.

[0056] Electroplating apparatus configurations in Figures 2 and 3A–3C are illustrative and not considered to be restrictive to the scope of the present disclosure. Other configurations of an electroplating apparatus may be designed for electroplating cell neutralization. The electroplating apparatus, such as shown in Figures 2 and 3A–3C, may include a reservoir (e.g., reservoir 110) configured to hold electroplating solution. The electroplating apparatus may further include a pump (e.g., pump 104) having an outlet and an inlet. The electroplating apparatus further includes one or more electroplating cells (e.g., electroplating cells 130), where each of the one or more electroplating cells includes a cathode chamber (e.g., cathode chamber 132), an anode chamber (e.g., anode chamber 138) configured to contain an anode, and a membrane (e.g., membrane 136) between the cathode chamber and the anode chamber. In some cases, each of the one or more

electroplating cells may further include an ionically resistive element (e.g., ionically resistive element 134) above the membrane. The electroplating apparatus further includes a feed line (e.g., feed line 120) fluidly coupled to the outlet of the pump and to the one or more electroplating cells. The electroplating apparatus further includes a return line (e.g., return line 160) that is fluidly coupled to the one or more electroplating cells. The return line may also be fluidly coupled to one or more of the following: (1) a reservoir return line (e.g., reservoir return line 164) that is fluidly coupled to the reservoir, (2) a bypass return line (e.g., bypass return line 210a) that bypasses the reservoir and is fluidly coupled to the pump, and (3) a drain line (e.g., drain line 310) that is directed to waste (e.g., waste 314). The electroplating apparatus further includes a neutralization fill line (e.g., neutralization fill line 210b) that is fluidly coupled to the one or more electroplating cells and configured to supply neutralization solution to the one or more electroplating cells. In some implementations, the neutralization solution includes deionized water. In some implementations, the neutralization solution includes a base. In some implementations, the inlet of the pump is fluidly coupled to the bypass return line and to a reservoir output line. In some implementations, the return line is fluidly coupled to the drain line, where the neutralization fill line is configured to circulate the neutralization solution through the one or more electroplating cells to the drain line via the return line. In some implementations, the return line is fluidly coupled to the bypass return line, where the neutralization fill line is configured to circulate the neutralization solution through the one or more electroplating cells and the bypass return line via the pump and the feed line. Processes may be performed by the electroplating apparatus using the neutralization fill line to aspirate and/or flush selected one or more electroplating cells using the neutralization solution until a pH of the selected one or more electroplating cells reaches a threshold safety value. Alternatively, processes may be performed by the electroplating apparatus using the neutralization fill line to aspirate and/or flush a filter using the neutralization solution until a pH of the filter reaches a threshold safety value.

[0057] Challenges may exist to fill and aspirate certain regions in an electroplating cell. For example, it may be difficult to fill and aspirate a region formed by the ionically resistive element 134, the membrane 136, and a membrane frame (not shown) that supports the membrane 136. Filling such a region (referred to as an “HRVA chamber”) may be assisted by the recirculation valve 214 that is able to flow neutralization solution at a sufficiently high flow rate to the electroplating cells 130. Aspirating such a region may be assisted by an HRVA chamber aspiration valve 220. The HRVA chamber aspiration valve 220 may be fluidly connected to the HRVA chamber via an aspiration line 222. In some embodiments, the aspiration line 222 may include a straw that is attached to a side wall of the membrane frame. The HRVA chamber aspiration valve

220 may be connected to the aspiration line 222 and an HRVA chamber aspirator pump (not shown) for evacuating fluid from the HRVA chamber. Additional methods, techniques, and components are discussed in further detail below regarding strategies for effectively filling and aspirating the HRVA chamber of the electroplating cells 130.

- 5 **[0058]** Figure 4A shows a schematic illustration of an example electroplating cell that utilizes a combination of cross flow and impinging flow on the substrate surface during electroplating. In the electroplating cell 401, a substrate 402 is positioned in a substrate support 403. Substrate support 403 is often referred to as a cup, and it may support the substrate 402 at its periphery. An anode 404 is positioned near the bottom of the electroplating cell 401. The anode 404 is separated
- 10 from the substrate 402 by a membrane 405, which is positioned below and supported by a membrane frame 406. Membrane frame 406 is sometimes referred to as an anode chamber membrane frame. Further, the anode 404 is separated from the substrate 402 by an ionically resistive element 407. The ionically resistive element 407 includes openings that allow electrolyte to travel through the ionically resistive element 407 to impinge upon the substrate 402. A front
- 15 side insert 408 is positioned above the ionically resistive element 407, proximate to the periphery of the substrate 402. The front side insert 408 may be arc-shaped or ring-shaped, and may be azimuthally non-uniform, as shown. The front side insert 408 is sometimes also referred to as a cross flow confinement ring. A ring-shaped or arc-shaped sealing member 416 is provided between the front side insert 408 and the substrate support 403.
- 20 **[0059]** An anode chamber 412 is below the membrane 405, and is where the anode 404 is located. An ionically resistive element manifold 411 is above the membrane 405 and below the ionically resistive element 407. A cross flow manifold 410 is above the ionically resistive element 407 and below the substrate 402. The height of the cross flow manifold 410 is considered to be the distance between the substrate 402 and the plane of the ionically resistive element 407
- 25 (excluding the ribs on the upper surface of the ionically resistive element 407, if present). In some cases, the cross flow manifold 410 may have a height between about 1 mm and about 4 mm, or between about 0.5 mm and about 15 mm. The cross flow manifold 410 is defined on its sides by the front side insert 408, which acts to contain the cross flowing electrolyte within the cross flow manifold 410. A side inlet 413 to the cross flow manifold 410 is provided azimuthally opposite a
- 30 side outlet 414 to the cross flow manifold 410. The side inlet 413 and side outlet 414 may be formed, at least partially, by the front side insert 408. The sealing member 416 provides a seal between the front side insert 408 and the substrate support 403, thereby ensuring that electrolyte only exits the cross flow manifold 410 at the side outlet 414 when the sealing member 416 is

engaged. In various cases the sealing member 416 may be integral with the cross flow confinement ring, or with the substrate support 403, or it may be provided as a separate unit.

[0060] As shown by the arrows in Figure 4A, electrolyte travels through the side inlet 413, into the cross flow manifold 410, and out the side outlet 414. In addition, electrolyte may travel through one or more inlets (not shown) to the ionically resistive element manifold 411, into the ionically resistive element manifold 411, through the openings in the ionically resistive element 407, into the cross flow manifold 410, and out the side outlet 414. After passing through the side outlet 414, the electrolyte spills over weir wall 409. The electrolyte may be recovered and recycled. The electrolyte flowing through the ionically resistive element manifold 411, the ionically resistive element 407, the side inlet 413, the cross flow manifold 410, and the side outlet 414 may be referred to as catholyte. In addition to the catholyte flow, a separate anolyte flow is typically provided. The electrolyte that circulates in contact with the anode may be referred to as anolyte. The membrane 405 operates to separate the catholyte and anolyte from one another, ensuring that their respective compositions are maintained, while allowing ionic transport through the mechanism during electroplating. The anode chamber 412 includes an inlet (not shown) for receiving anolyte and an outlet (not shown) for removing the anolyte from the anode chamber 412. The inlet and outlet to the anode chamber 412 may be connected with an anolyte recirculation system.

[0061] As mentioned above, the ionically resistive element 407 approximates a nearly constant and uniform current source in the proximity of the substrate and, as such, may be referred to as an HRVA or CIRP in some contexts. The ionically resistive element 407 is normally placed in close proximity with respect to the substrate. The ionically resistive element 407 contains micro size (typically less than 0.04 inches) through-holes that are spatially and ionically isolated from each other and do not form interconnecting channels within the body of ionically resistive element 407, in many but not all implementations. Such through-holes are often referred to as non-communicating through-holes. They typically extend in one dimension, often, but not necessarily, normal to the plated surface of the wafer (in some embodiments the non-communicating holes are at an angle with respect to the wafer which is generally parallel to the ionically resistive element front surface). Often the through-holes are parallel to one another. Often the holes are arranged in a square array. Other times the layout is in an offset spiral pattern. These through-holes are distinct from 3-D porous networks, where the channels extend in three dimensions and form interconnecting pore structures, because the through-holes restructure both ionic current flow and (in certain cases) fluid flow parallel to the surface therein, and straighten the path of both current and fluid flow towards the substrate surface. However, in certain embodiments, such a porous

plate, having an interconnected network of pores, may be used as the ionically resistive element. When the distance from the plate's top surface to the substrate is small (e.g., a gap of about 1/10 the size of the substrate radius, for example less than about 5 mm), divergence of both current flow and fluid flow is locally restricted, imparted and aligned with the ionically resistive element channels.

[0062] The ionically resistive element 407 may optionally include a series of linear ribs 415 that extend into/out of the page. The ribs 415 are sometimes referred to as protuberances. The ribs 415 are positioned on the top surface of the ionically resistive element 407, and they are oriented such that their length (e.g., their longest dimension) is perpendicular to the direction of cross flowing electrolyte. The ribs 415 affect the fluid flow and current distribution within the cross flow manifold 410. For instance, the cross flow of electrolyte is largely confined to the area above the top surface of the ribs 415, creating a high rate of electrolyte cross flow. In the regions between adjacent ribs 415, current delivered upward through the ionically resistive element 407 is redistributed, becoming more uniform, before it is delivered to the substrate surface.

[0063] In Figures 4A and 4B, the direction of cross flowing electrolyte is left-to-right (e.g., from the side inlet 413 to the side outlet 414), and the ribs 415 are oriented such that their lengths extend into/out of the page. The ribs 415 may be provided over an area that is about coextensive with the substrate, as shown in Figure 4A. The channels/openings in the ionically resistive element 407 may be positioned between adjacent ribs 415, or they may extend through the ribs 415 (in other words, the ribs 415 may or may not be channeled). In some other embodiments, the ionically resistive element 407 may have an upper surface that is flat (e.g., does not include the ribs 415). In some other embodiments, the ribs 415 may be replaced with a raised plateau region.

[0064] Figure 4B shows a cross-sectional view of various hardware components in the electroplating cell. The electroplating cell 401 includes a cathode chamber 432, which includes a membrane frame 406 and a membrane 405 that separate the anode chamber 412 from the cathode chamber 432. The membrane 405 is typically an ion exchange membrane that separates the anode chamber 412 from the cathode chamber 432. The membrane frame 406 is a structural element configured to support the membrane 405. Fluid in the cathode chamber 432 is largely located either in a cross flow manifold 410 or in the ionically resistive element manifold 411 or in channels for delivering the fluid to these two separate manifolds.

[0065] Fluid may enter the cross flow manifold 410 through two separate entry points: (1) the channels in the ionically resistive element 407 and (2) a cross flow initiating structure 450. The fluid (e.g., catholyte) arriving in the cross flow manifold 410 via the channels in the ionically

resistive element 407 may be directed toward the face of the work piece, typically in a substantially perpendicular direction. Such channel-delivered fluid may form small jets that impinge on the face of the work piece. The fluid arriving in the cross flow manifold 410 via the cross flow initiating structure 450 is, in contrast, directed substantially parallel to the face of the work piece.

- 5 A cross flow injection manifold 422 directs fluid vertically upwards to the cross flow initiating structure 450, where the cross flow initiating structure 450 redirects the fluid to be oriented parallel or substantially parallel to the substrate in the cross flow manifold 410. Fluid exiting the cross flow manifold 410 may exit at a cross flow outlet 434.

[0066] Figure 4C shows an isometric cross-sectional view of the electroplating cell including a
10 high resistance virtual anode (HRVA) chamber. As discussed above, fluid may be delivered into the cross-flow manifold 410 of the cathode chamber 432 by at least two different flow paths. Some of the fluid may be delivered via channels in the ionically resistive element 407. Some of the fluid may be delivered to the cross flow injection manifold 422, which then passes the fluid to the cross flow initiating structure 450. The cross flow initiating structure 450 has a geometry that redirects
15 the fluid in a direction parallel or substantially to the substrate. The direction of the flow through the ionically resistive element 407 is initially directed at the substrate and is then turned parallel to the substrate due to the presence of the substrate, whereas the cross flow portion coming from the cross flow injection manifold 422 and out through the cross flow initiating structure 450 starts substantially parallel to the substrate.

- 20 [0067] A region under the ionically resistive element 407 is defined by the ionically resistive element 407, the membrane 405, and the membrane frame 406. This region is referred to as the HRVA chamber 460. It is difficult to fill and aspirate this region known as the HRVA chamber 460. When fluid is introduced via the cross flow injection manifold 422 and the cross flow initiating structure 450 into the cross flow manifold 410, the fluid is flowed in a horizontal
25 orientation across the top of the ionically resistive element 407. When a substrate is in the electroplating cell 401, there exists a pressure build up in the electroplating cell 401 that forces an amount of fluid down the ionically resistive element 407 and into the HRVA chamber 460. Filling of the HRVA chamber 460 may require a sufficiently high flow rate of fluid across the ionically resistive element 407, such as a flow rate between about 20 liters per minute and 150 liters per
30 minute, between about 30 liters per minute and 100 liters per minute, or between about 40 liters per minute and 80 liters per minute.

[0068] As shown in Figure 5, as fluid is flowed across the ionically resistive element 407 while a substrate is in place, pressure is created that forces the fluid down the channels 417 and into the HRVA chamber 460. As the fluid is forced downwards through the channels 417, eddy currents

are created in the HRVA chamber 460 that cause fluid flow to come back up. The eddy currents associated with the fluid flow may generate effective rinsing actions for rinsing the membrane 405, the membrane frame 406, and the ionically resistive element 407. During electroplating cell neutralization, placing a substrate in the electroplating cell 401 may drive sufficient pressure
5 buildup to create eddy currents for rinsing the region underneath the ionically resistive element 407 (i.e., the HRVA chamber 460).

[0069] Electroplating cell neutralization of the present disclosure may be configured for different types of separated anode chamber configurations. One type of separated anode chamber configuration is the recirculating separated anode chamber (R-SAC) configuration. Another type
10 of separated anode chamber configuration is the cascade separated anode chamber (C-SAC). However, it will be understood that electroplating cell neutralization is not only limited to such configurations. The R-SAC configuration is commonly used in tin, tin-silver, and nickel plating applications. The C-SAC configuration is commonly used in copper plating applications. The R-SAC configuration typically uses a polymer-based membrane that is tough and strongly resistant
15 to pressure differentials across the polymer-based membrane. The C-SAC configuration typically uses a cationic membrane that is soft and less resistant to pressure differentials across the cationic membrane. Accordingly, the behaviors and properties of the different SAC configurations may necessitate different approaches for filling and aspirating the SAC. The SAC may need its own loop for flushing, rinsing, and aspirating that is independent of a plating cell loop. Thus, strategies
20 and sequences for neutralizing the R-SAC configuration may be different than the C-SAC configuration.

[0070] Figure 6A shows a diagram of a flow loop of an electroplating apparatus configured to perform neutralization of electroplating cells, where each electroplating cell is arranged in a
25 recirculating separated anode chamber (R-SAC) configuration according to some implementations. In the R-SAC configuration, the anode chamber contains the same fluid as the electroplating cell. Neutralization of the anode chamber is integrated with the main plating loop in the R-SAC configuration. In other words, the neutralization solution that circulates through the electroplating cell is also used to flush the anode chamber.

[0071] In the R-SAC configuration as shown in Figure 6A, the anode chamber 138 receives
30 neutralization solution (or electroplating solution) from a pressurized line 642 off of the plating cell loop. The line 642 is pressurized when the pump 104 is on. The line 642 is fluidly connected to the feed line 120. The flow of the neutralization solution (or electroplating solution) into the anode chamber 138 is proportional to the plating cell flow rate. In order to obtain a higher flow rate into the anode chamber 138, a first R-SAC valve 644 is used in conjunction with a second R-

SAC valve 646. The first R-SAC valve 644 is in parallel with the second R-SAC valve 646 as a fluid source off of the feed line 120. The first R-SAC valve 644 and the second R-SAC valve 646 supplies fluid from the feed line 120 to the anode chamber 138. After the fluid travels through the anode chamber 138 and into the anode chamber tower 152, the fluid may be gravity drained using an R-SAC drain line 648. A divert valve 654 may be fluidly connected to the R-SAC drain line 648. The divert valve 654 may allow the fluid to return to the reservoir 110 during normal plating operation and may divert the fluid to drain away from the reservoir 110 during neutralization. In some implementations, the divert valve 654 may be a 3-way valve. Aspiration of the anode chamber 138 may be assisted by an anode chamber aspiration valve 656. The anode chamber aspiration valve 656 is fluidly connected to the anode chamber 138 via an anode chamber aspiration line 658. In some embodiments, the anode chamber aspiration valve 656 may be connected to the anode chamber aspiration line 658 and an HRVA/SAC aspiration pump 662. The HRVA/SAC aspiration pump 662 may be configured to evacuate fluid from the HRVA chamber and the anode chamber 138.

[0072] In Figure 6A, the neutralization flush line 210 may optionally include a precursor dose valve 664. The precursor dose valve 664 may be fluidly coupled to the pump 104 and the feed line 120. The precursor dose valve 664 may be configured to dose the electroplating cells 130 with a precursor. For example, the precursor may comprise a chemistry such as methane sulfonic acid (MSA) that prevents precipitation upon mixing the neutralization solution with the electroplating solution. Such precipitation may occur with tin, tin-silver, and nickel plating solutions. The precursor may be delivered to the plating cell loop after circulating electroplating solution in the electroplating cells 130 and prior to delivering neutralization solution to the electroplating cells 130.

[0073] Figure 6B shows a diagram of a flow loop of an electroplating apparatus configured to perform neutralization of electroplating cells, where each electroplating cell is arranged in a cascade separated anode chamber (C-SAC) configuration according to some implementations. In the C-SAC configuration, the anode chamber is filled and aspirated in its own loop independent of the plating cell loop. The anode chamber does not necessarily contain the same fluid as the bulk electroplating cell in the C-SAC configuration. Neutralization of the anode chamber is performed by recirculating neutralization solution in a distinct SAC loop from the plating cell loop.

[0074] In the C-SAC configuration as shown in Figure 6B, a separate source of neutralization solution is provided to the anode chamber 138. In the C-SAC configuration, a C-SAC pump 672 draws fluid out of the anode chamber tower 152 and drives it through a flow meter 674 and into the anode chamber 138. The anode chamber 138 is fluidly coupled to the anode chamber tower

152, thereby providing recirculation of fluid through a SAC loop distinct from the plating cell loop. In order to fill the anode chamber 138, a split valve 676 is added just downstream of the C-SAC pump 672 to break the SAC loop and allow it to be filled with the neutralization solution. A secondary neutralization fill valve 678 is provided at the split valve 676. The secondary
5 neutralization fill valve 678 is distinct from the neutralization fill valve 212, thereby providing the separate source of neutralization solution for the anode chamber 138. The secondary neutralization fill valve 678 is configured to supply neutralization solution such as deionized water through the flow meter 674 and to the anode chamber 138 and the anode chamber tower 152. From the anode chamber tower 152, the C-SAC pump 672 may recirculate the neutralization solution back into
10 the input side of the C-SAC pump 672. When the anode chamber tower 152 reaches a certain level, the neutralization fill valve 678 may shut off, and the split valve 676 will open. At that point, the C-SAC pump 672 may turn on to recirculate the neutralization solution. This sequence can cause air bubbles to become trapped in the SAC loop. In some implementations, a bleed valve 682 may be configured to bleed fluid at the input side of C-SAC pump 672 to remove air bubbles
15 that may be trapped in the SAC loop. Repeated opening of the neutralization fill valve 678 and the bleed valve 682 may perform bleed and feed of the SAC loop. In some embodiments, an aspiration valve (not shown) may be connected to the input side of the C-SAC pump 672 and the HRVA/SAC aspiration pump 662. The HRVA/SAC aspiration pump 662 may be configured to evacuate fluid from the anode chamber tower 152, the C-SAC pump 672, and the flow meter 674.

20 **[0075]** In Figure 6B as in Figure 6A, aspiration of the anode chamber 138 may be assisted by the anode chamber aspiration valve 656. The anode chamber aspiration valve 656 is fluidly connected to the anode chamber 138 via the anode chamber aspiration line 558. In some embodiments, the anode chamber aspiration valve 656 may be connected to the anode chamber aspiration line 658 and the HRVA/SAC aspiration pump 662. The HRVA/SAC aspiration pump 662 may be configured to evacuate fluid from the HRVA chamber and the anode chamber 138.

25 **[0076]** In the C-SAC configuration, aspiration of the anode chamber 138 may follow a specific sequence. For instance, the HRVA chamber may be aspirated before the anode chamber 138. This avoids exerting too much pressure on the membrane 136, as the membrane 136 in the C-SAC configuration is generally soft. Furthermore, in the C-SAC configuration, filling of the anode chamber 138 may proceed according to a specific sequence. For example, the anode chamber 138
30 may be filled before the HRVA chamber.

[0077] Adherence to a specific sequence of steps in neutralization of one or more selected electroplating cells may be critical to the success of neutralization. Steps in the plating cell loop may be different than steps in the SAC loop. This is due in part to the fact that flushing, filling,

and aspirating in the HRVA/anode chamber behave differently than in the bulk electroplating cell. Hardware controls for flushing, filling, and aspirating the HRVA/anode chamber during neutralization may also be different than hardware controls for flushing, filling, and aspirating the bulk electroplating cell. Moreover, the sequence of steps for neutralization in the plating cell loop may be contingent upon activity in the SAC loop, and vice versa. The sequence of steps in a plating cell loop and SAC loop for an R-SAC configuration are illustrated in Figure 7. The sequence of steps in a plating cell loop and SAC loop for a C-SAC configuration are illustrated in Figure 8.

[0078] Figure 7 shows a flow diagram of an example method for performing electroplating cell neutralization of electroplating cells in an R-SAC configuration according to some implementations. A system controller as described below may be configured with instructions to perform the various operations of Figure 7. The operations of Figure 7 may be performed using hardware components described in Figures 1, 2, 3A–3C, 4A–4C, and 6A–6C.

[0079] Electroplating cell neutralization may be initiated by isolating one or more electroplating cells. The one or more electroplating cells are selected for neutralization. The selected electroplating cells may be duets in an electroplating system or apparatus. Electroplating cells may be neutralized asynchronously. The selected electroplating cells may be neutralized simultaneous with electroplating metal on wafers in non-selected electroplating cells. This means that metal can be electroplated in one or more electroplating cells that are not selected for neutralization while selected electroplating cells are neutralized for maintenance.

[0080] With reference to Figure 6A, the selected electroplating cells 130 may be isolated by closing the drain isolation valve 162, thereby isolating the selected electroplating cells 130 from the reservoir 110. In some implementations, the selected electroplating cells 130 may be isolated or further isolated by closing the bath isolation valve 102, thereby isolating the reservoir 110 from the pump 104. In some implementations, the selected electroplating cells 130 may be isolated or further isolated by closing the divert valve 654, thereby isolating the anode chamber 138 from the reservoir 110. The plating cell loop is now completely isolated from the reservoir 110.

[0081] In some embodiments, a chemical reclaim may be performed prior to isolation or after isolation of the selected one or more electroplating cells. The chemical reclaim may recover as much chemistry as possible from the plating cell loop. A gravity chemical reclaim may be performed prior to an active chemical reclaim, whereby residual chemistry in the plating cell loop is brought back to the reservoir.

[0082] With reference to Figure 6A, a gravity chemical reclaim may be performed by opening the drain isolation valve 162 so that residual chemistry (e.g., electrolyte) in the return line 160 and

the electroplating cells 130 is reclaimed into the reservoir 110. In addition, the cell isolation valve 128 may be opened so that residual chemistry in the feed line 120 is reclaimed into the reservoir 110 while the drain isolation valve 162 remains open.

5 **[0083]** In some embodiments, a chemical reclaim may be performed after isolation of the selected one or more electroplating cells. An active chemical reclaim may be performed that supplies one or more gases through a feed line, filter, fluid contactor, or other hardware components so that residual chemistry is brought back to the reservoir. For example, the one or more gases include nitrogen.

10 **[0084]** With reference to Figures 6A and 6C, an active chemical reclaim may be performed after isolating the one or more electroplating cells 130. The nitrogen gas supply valve 680 may be opened so that nitrogen gas is pushed through the feed line 120 to the reservoir 110. In doing so, the filter flush valve 690 that is fluidly coupled to the reservoir 110 is open. The nitrogen gas may be pushed through the fluid contactor 124 and the filter 122 to reclaim residual chemistry in the fluid contactor 124 and/or the filter 122 back to the reservoir 110.

15 **[0085]** After isolation of the selected one or more electroplating cells, the selected one or more electroplating cells are aspirated. Aspiration removes any residual chemistry in the bulk electroplating cell. This may be accomplished by a bulk aspiration valve and bulk aspiration pump that are fluidly coupled to the selected one or more electroplating cells. Aspiration also removes any residual chemistry in the HRVA chamber and anode chamber. Aspiration of the HRVA
20 chamber may be accomplished by an HRVA chamber aspiration valve and a HRVA/SAC aspiration pump that are fluidly coupled to the HRVA chamber. Aspiration of the anode chamber may be accomplished by an anode chamber aspiration valve and the HRVA/SAC aspiration pump that are fluidly coupled to the anode chamber.

25 **[0086]** With reference to Figure 6A, aspiration may proceed by opening the bulk aspiration valve 218. Furthermore, the cell isolation valve 128 and the recirculation valve 214 are opened to facilitate aspiration of the selected one or more electroplating cells 130. This achieves aspiration of the recirculation loop. At the same time that aspiration of the recirculation loop is initiated by opening the bulk aspiration valve 218, aspiration of the HRVA chamber may be initiated by opening the HRVA chamber aspiration valve 220. When aspiration of the HRVA chamber is
30 complete, the HRVA chamber aspiration valve 220 is closed and aspiration of the anode chamber 138 may be initiated by opening the anode chamber aspiration valve 656. When aspiration of the anode chamber 138 is complete, the anode chamber aspiration valve 656 is closed.

[0087] After aspiration of the selected one or more electroplating cells, the selected one or more electroplating cells are filled with neutralization solution (e.g., deionized water). During

neutralization solution fill, the neutralization fill valve is opened to supply neutralization solution to the selected one or more electroplating cells. The bulk electroplating cell may be filled at a different rate (e.g., faster rate) than the anode chamber. When the plating cell loop is filled with neutralization solution, the anode chamber may only be partially filled. A drain level monitoring
5 system may determine that the plating cell loop is filled. Upon determining that the plating cell loop is filled, recirculation may be initiated so that the neutralization solution is recirculated through the plating cell loop. In the meantime, the anode chamber may eventually be filled. The anode chamber may undergo bleed and feed to prevent stagnant solution buildup and to continually flush the anode chamber with neutralization solution.

10 **[0088]** With reference to Figure 6A, filling may proceed by opening the neutralization fill valve 212. This supplies neutralization solution such as deionized water to the feed line 120 via the pump 104, where the neutralization solution is flowed to the selected one or more electroplating cells 130. At the same time, the first R-SAC valve 644 and the second R-SAC valve 646 are opened to provide the neutralization solution from the line 642 to the anode chamber 138. Once
15 the selected one or more electroplating cells 130 are filled, the recirculation valve 214 may be opened so that neutralization solution is recirculated through the plating cell loop. The anode chamber 138 may be filled at a slower rate. Once the anode chamber 138 is filled the neutralization solution will continually flow out of the anode chamber tower 152 and down the drain via the drain divert valve 654 while additional neutralization solution is fed into the anode chamber 138.

20 **[0089]** In some implementations, a precursor dose is supplied to the plating cell loop prior to filling the plating cell loop with neutralization solution. In some cases, the neutralization solution may cause unwanted precipitation to occur with the chemistry of the electroplating solution in the plating cell loop. Thus, a precursor dose may be delivered to the selected one or more electroplating cells prior to filling by opening a precursor dose valve. In some implementations,
25 the precursor is MSA.

[0090] With reference to Figure 6A, the precursor dose may be delivered to the selected one or more electroplating cells 130 by opening the precursor dose valve 664. The precursor dose valve 664 may be opened after aspiration of the selected one or more electroplating cells 130 and before filling the selected one or more electroplating cells 130 with neutralization solution.

30 **[0091]** After aspiration and fill, a pH check may be performed to determine a pH of the solution in the selected one or more electroplating cells. If the pH of the solution meets a threshold safety value, then neutralization is complete and maintenance may be performed. If the pH of the solution does not meet the threshold safety value, then the process of aspiration and fill is repeated for at least another cycle. In some implementations, a number of cycles may be between about 3 cycles

and about 50 cycles, between about 5 cycles and about 30 cycles, or between about 10 cycles and about 20 cycles. In some implementations, the threshold safety value may be a pH between about 3 and about 10, between about 4 and about 9, or between about 5 and about 8. In some cases, the pH may be measured manually by opening a door and/or removing a top hat of the selected one or more electroplating cells.

[0092] Figure 8 shows a flow diagram of an example method for performing electroplating cell neutralization of electroplating cells in a C-SAC configuration according to some implementations. A system controller as described below may be configured with instructions to perform the various operations of Figure 8. The operations of Figure 8 may be performed using hardware components described in Figures 1, 2, 3A–3C, 4A–4C, and 6A–6C.

[0093] Electroplating cell neutralization may be initiated by isolating one or more electroplating cells. The one or more electroplating cells are selected for neutralization. The selected electroplating cells may be duets in an electroplating system or apparatus. Electroplating cells may be neutralized asynchronously. The selected electroplating cells may be neutralized simultaneous with electroplating metal on wafers in non-selected electroplating cells.

[0094] With reference to Figure 6B, the selected electroplating cells 130 may be isolated by closing the drain isolation valve 162, thereby isolating the selected electroplating cells 130 from the reservoir 110. In some implementations, the selected electroplating cells 130 may be isolated or further isolated by closing the bath isolation valve 102, thereby isolating the reservoir 110 from the pump 104. In some implementations, the selected electroplating cells 130 may be isolated or further isolated by closing the divert valve 654, thereby isolating the anode chamber 138 from the reservoir 110. The plating cell loop is now completely isolated from the reservoir 110.

[0095] In some embodiments, a chemical reclaim may be performed prior to isolation or after isolation of the selected one or more electroplating cells. The chemical reclaim may recover as much chemistry as possible from the plating cell loop. A gravity chemical reclaim may be performed prior to an active chemical reclaim, whereby residual chemistry in the plating cell loop is brought back to the reservoir.

[0096] With reference to Figure 6B, a gravity chemical reclaim may be performed by opening the drain isolation valve 162 so that residual chemistry (e.g., electrolyte) in the return line 160 and the electroplating cells 130 is reclaimed into the reservoir 110. In addition, the cell isolation valve 128 may be opened so that residual chemistry in the feed line 120 is reclaimed into the reservoir 110 while the drain isolation valve 162 remains open.

[0097] In some embodiments, an active chemical purge may be performed after isolation of the selected one or more electroplating cells. An active chemical purge may be performed that supplies one or more gases through a feed line, filter, fluid contactor, or other hardware components so that residual chemistry is removed from the plating cell loop.

5 [0098] With reference to Figures 6B and 6C, an active chemical reclaim may be performed after isolating the one or more electroplating cells 130. The nitrogen gas supply valve 680 may be opened so that nitrogen gas is pushed through the feed line 120 and flushed out to drain.

[0099] After isolation of the selected one or more electroplating cells, the selected one or more electroplating cells are aspirated. Aspiration removes any residual chemistry in the bulk electroplating cell. This may be accomplished by a bulk aspiration valve and bulk aspiration pump that are fluidly coupled to the selected one or more electroplating cells. Aspiration also removes any residual chemistry in the HRVA chamber and anode chamber. Aspiration of the HRVA chamber may be accomplished by a an HRVA chamber aspiration valve and an HRVA/SAC aspiration pump that are fluidly coupled to the HRVA chamber. Aspiration of the anode chamber may be accomplished by an anode chamber aspiration valve and the HRVA/SAC aspiration pump that are fluidly coupled to the anode chamber. In C-SAC configurations, aspiration of the HRVA chamber occurs before aspiration of the anode chamber.

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[0100] With reference to Figure 6B, aspiration may proceed by opening the bulk aspiration valve 218. Furthermore, the cell isolation valve 128 and the recirculation valve 214 are opened to facilitate aspiration of the selected one or more electroplating cells 130. This achieves aspiration of the recirculation loop. At the same time that aspiration of the recirculation loop is initiated by opening the bulk aspiration valve 218, aspiration of the HRVA chamber may be initiated by opening the HRVA chamber aspiration valve 220. Aspiration of the HRVA chamber may continue even when aspiration of the recirculation loop is complete. In other words, the bulk aspiration valve 218 may be closed while aspiration of the HRVA chamber continues. When aspiration of the HRVA chamber is complete, the HRVA chamber aspiration valve 220 is closed and aspiration of the anode chamber 138 may be initiated by opening the anode chamber aspiration valve 656. When aspiration of the anode chamber 138 is complete, the anode chamber aspiration valve 656 is closed.

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30 [0101] The selected one or more electroplating cells are filled with neutralization solution (e.g., deionized water). During neutralization solution fill, the neutralization fill valve is opened to supply neutralization solution to the selected one or more electroplating cells. A drain level monitoring system may determine that the plating cell loop is filled. Once the plating cell loop is

filled, the plating cell loop is aspirated. Aspiration of the plating cell loop may proceed using the bulk aspiration valve and bulk aspiration pump that are fluidly coupled to the selected one or more electroplating cells. In some implementations, aspiration of the anode chamber may be completed at a certain point during fill and aspiration of the selected one or more electroplating cells in the plating cell loop.

[0102] With reference to Figure 6B, filling in the plating cell loop may proceed by opening the neutralization fill valve 212. This supplies neutralization solution such as deionized water to the feed line 120 via the pump 104, where the neutralization solution is flowed to the selected one or more electroplating cells 130. When the selected one or more electroplating cells 130 are filled with the neutralization solution, the selected one or more electroplating cells 130 are aspirated. Aspiration proceeds by opening the bulk aspiration valve 218. Additionally, the recirculation valve 214 and the cell isolation valve 128 may be opened to facilitate aspiration of the selected one or more electroplating cells 130. Once aspiration of the selected one or more electroplating cells 130 is complete, the bulk aspiration valve 218, the recirculation valve 214, and the cell isolation valve 128 are closed. As the plating cell loop undergoes fill and aspiration, the anode chamber 138 may be aspirated concurrently by opening the anode chamber aspiration valve 656. Once aspiration of the anode chamber 138 is complete, the anode chamber aspiration valve 656 is closed. The fill and aspiration of the anode chamber 138 occurs in sync with the one or more electroplating cells 130.

[0103] After aspiration of the selected one or more electroplating cells in the plating cell loop, and the after aspiration of the anode chamber, the plating cell loop and the SAC loop may be filled with neutralization solution (e.g., deionized water). The bulk electroplating cell may be filled at a different rate (e.g., faster rate) than the anode chamber. To fill the bulk electroplating cell in the plating cell loop, the neutralization fill valve is opened. To fill the anode chamber in the SAC loop, a separate neutralization fill valve for the SAC loop is opened. The split valve is closed and the secondary neutralization fill valve is opened. When the bulk electroplating cell is filled in the plating cell loop, recirculation may be initiated so that the neutralization solution is recirculated through the plating cell loop. When the anode chamber is filled in the SAC loop, the anode chamber may undergo bleed and feed to prevent stagnant solution buildup and further neutralization.

[0104] With reference to Figure 6B, filling in the selected one or more electroplating cells 130 may proceed by opening the neutralization fill valve 212. This supplies neutralization solution such as deionized water to the feed line 120 via the pump 104, where the neutralization solution is

flowed to the selected one or more electroplating cells 130. Filling in the anode chamber 138 may proceed by closing the split valve 676 and opening the secondary neutralization fill valve 678 to provide neutralization solution to the anode chamber 138. Once the selected one or more electroplating cells 130 in the plating cell loop are filled, the recirculation valve 214 may be opened
5 to that neutralization solution is recirculated through the plating cell loop. The anode chamber 138 may be filled at a slower rate. Once the anode chamber 138 is filled, the anode chamber tower 152 reaches a certain level and the secondary neutralization fill valve 678 is closed. The bleed valve 682 may be opened to bleed fluid at the input side of the C-SAC pump 672 to remove air bubbles that may be trapped in the SAC loop. The secondary neutralization fill valve 678 may be
10 opened and closed periodically and the bleed valve 682 may be opened and closed periodically to perform bleed and feed of the SAC loop.

[0105] In some implementations, a precursor dose is supplied to the plating cell loop prior to filling the plating cell loop with neutralization solution. In some cases, the neutralization solution may cause unwanted precipitation to occur with the chemistry of the electroplating solution in the
15 plating cell loop. Thus, a precursor dose may be delivered to the selected one or more electroplating cells prior to filling by opening a precursor dose valve. In some implementations, the precursor is MSA.

[0106] After aspiration and fill, a pH check may be performed to determine a pH of the solution in the selected one or more electroplating cells. If the pH of the solution meets a threshold safety
20 value, then neutralization is complete and maintenance may be performed. If the pH of the solution does not meet the threshold safety value, then the process of aspiration and fill is repeated for at least another cycle. In some implementations, a number of cycles may be between about 3 cycles and about 50 cycles, between about 5 cycles and about 30 cycles, or between about 10 cycles and about 20 cycles. In some implementations, the threshold safety value may be a pH between about
25 3 and about 10, between about 4 and about 9, or between about 5 and about 8. In some cases, the pH may be measured manually by opening a door and/or removing a top hat of the selected one or more electroplating cells.

[0107] Figure 9 shows a flow diagram of an example method for performing electroplating cell neutralization according to some implementations.

30 **[0108]** At block 910 of the process 900, selected one or more electroplating cells are isolated to be isolated from a reservoir configured to hold electroplating solution in an electroplating apparatus. The electroplating solution may contain acidic and hazardous chemicals. The electroplating apparatus may include the reservoir, a pump fluidly connected to the reservoir, a

feed line that fluidly connects one or more electroplating cells with the pump, a return line that fluidly connects the one or more electroplating cells with the reservoir, and a neutralization flush line that fluidly connects the one or more electroplating cells with the pump while bypassing the return line and the reservoir. Isolating the selected one or more electroplating cells may include

5 closing a bath isolation valve between the reservoir and the pump, closing a cell isolation valve between the pump and the selected one or more electroplating cells, and closing a drain isolation valve between the selected one or more electroplating cells and the reservoir.

[0109] In some implementations, the process 900 includes reclaiming electrolyte in the selected one or more electroplating cells to the reservoir. This can be done prior to isolating the selected

10 one or more electroplating cells. Electrolyte may be reclaimed to the reservoir by a gravity reclamation process. By way of an example, a drain isolation valve and a cell isolation valve may be opened to recover residual chemistry to the reservoir. Additionally or alternatively, electrolyte may be reclaimed by an active chemical reclamation process. By way of an example, a gas such as nitrogen gas may be actively pushed through a feed line back to the reservoir to recover residual

15 chemistry in hardware components (e.g., filter) in the feed line.

[0110] At block 920 of the process 900, the selected one or more electroplating cells are aspirated. Aspiration removes residual chemistry from the selected one or more electroplating cells in a plating cell loop. Aspiration also removes residual chemistry from HRVA chambers and anode chambers of the selected one or more electroplating cells in a SAC loop. Aspiration of the

20 HRVA chambers and anode chambers of the selected one or more electroplating cells may be performed independently of aspiration of the selected one or more electroplating cells in the plating cell loop. In some implementations, aspirating the selected one or more electroplating cells in the plating cell loop may include opening a first aspiration valve that is fluidly coupled to the selected one or more electroplating cells. In some implementations, aspirating the HRVA chamber(s) and

25 anode chamber(s) of the selected one or more electroplating cells may include opening a second aspiration valve that is fluidly coupled to one or more both of the HRVA chamber(s) and the anode chamber(s). Each of the electroplating cells includes a cathode chamber, an anode chamber, a membrane between the cathode chamber and the anode chamber, a membrane frame configured to support the membrane, and an ionically resistive element above the membrane, where the

30 HRVA chamber is formed by the ionically resistive element, the membrane, and the membrane frame. In some implementations, aspiration of the HRVA chamber(s) occur before aspiration of the anode chamber(s).

[0111] At block 930 of the process 900, the selected one or more electroplating cells are filled with neutralization solution. In some implementations, the neutralization solution comprises water

or deionized water. In some implementations, the neutralization solution comprises a base or non-acidic chemistry. In some embodiments, filling the selected one or more electroplating cells may include opening a neutralization fill valve in the neutralization flush line that bypasses the return line and reservoir. In some embodiments, filling the selected one or more electroplating cells may include opening a neutralization fill valve configured to flow neutralization through the selected one or more electroplating cells and subsequently to a drain line to waste. Filling the selected one or more electroplating cells occurs after aspiration of the selected one or more electroplating cells. Filling the selected one or more electroplating cells in the plating cell loop may occur at a faster rate than filling the anode chamber(s) of the selected one or more electroplating cells in the SAC loop. In some implementations, a secondary neutralization fill valve is opened to fill the anode chamber(s) of the selected one or more electroplating cells in the SAC loop.

[0112] In some implementations, the process 900 further includes recirculating the neutralization solution through the selected one or more electroplating cells. Recirculation may be initiated after filling the selected one or more electroplating cells in the plating cell loop. A recirculation valve in the neutralization flush line may be opened to recirculate the neutralization solution.

[0113] In some implementations, the process 900 further includes circulating the neutralization solution through the selected one or more electroplating cells to a drain line to waste. In some cases, the drain line is fluidly coupled to the return line. In some cases, the drain line is fluidly coupled to the feed line.

[0114] In some implementations, the process 900 further includes bleeding and feeding the neutralization solution in the anode chamber(s) of the selected one or more electroplating cells. Bleed and feed may be initiated after filling the anode chamber(s) of the selected one or more electroplating cells in the SAC loop. A bleed valve may be periodically opened and closed to drain solution from the anode chamber(s), and the neutralization fill valve or the secondary neutralization fill valve may be periodically opened and closed to feed neutralization solution back to the anode chamber(s).

[0115] At block 940 of the process 900, operations of aspirating and filling with neutralization solution are repeated until a pH of a solution from the selected one or more electroplating cells reaches a threshold safety value. When the pH of the solution reaches the threshold safety value, neutralization is complete and maintenance may be performed on the electroplating apparatus.

[0116] When electroplating cells are selected for isolation and neutralization, other electroplating cells may continue to be used in production. Accordingly, the process 900 may include electroplating metal onto one or more wafers in the one or more electroplating cells that

are not selected for isolation and neutralization, where metal is electroplated onto the one or more wafers simultaneous with aspirating and filling the selected one or more electroplating cells with the neutralization solution. Furthermore, electroplating cells may be neutralized asynchronously. In other words, neutralization does not have to occur all at once for the entire electroplating apparatus. Rather, one or more electroplating cells can be undergoing neutralization while another one or more electroplating cells can be initiating neutralization.

[0117] Figure 10 shows a flow diagram of an example method for performing filter flush according to some implementations. Filter flush may be performed with reference to components illustrated in Figure 6C.

10 [0118] At block 1010 of the process 1000, one or more electroplating cells are isolated from a pump in an electroplating apparatus. The pump is configured to draw electroplating solution from a reservoir fluidly connected to the pump. The electroplating solution may contain acidic and hazardous chemicals. The electroplating apparatus may include the reservoir, the pump, a feed line that fluidly connects one or more electroplating cells with the pump, a return line that fluidly connects the one or more electroplating cells with the reservoir, and a neutralization flush line that fluidly connects the one or more electroplating cells with the pump while bypassing the return line and the reservoir. Isolating the selected one or more electroplating cells from pump may include closing the cell isolation valve and turning off the pump.

20 [0119] At block 1020 of the process 1000, a filter positioned downstream of the pump is aspirated. The filter is fluidly coupled to the one or more electroplating cells via a feed line and a cell isolation valve. Aspirating the filter may proceed by turning on an aspiration valve fluidly connected to the filter.

25 [0120] At block 1030 of the process 1000, the filter is flushed with neutralization solution using a neutralization fill valve fluidly coupled to the feed line. In some cases, the neutralization fill valve supplies neutralization solution through the pump to the feed line and ultimately to the filter. In some cases, the neutralization fill valve supplies neutralization solution in a reverse flow through the feed line to the fluid contactor and ultimately to the filter. In some implementations, neutralization solution passes through the filter and is drained to waste.

30 [0121] At block 1040 of the process 1000, operations of aspirating and flushing with neutralization solution are repeated until a pH of a solution from the filter reaches a threshold safety value. When the pH of the solution reaches the threshold safety value, neutralization is complete and maintenance may be performed on the filter for filter maintenance or replacement.

Multi-station Apparatus

[0122] The methods described herein may be performed by any suitable apparatus. A suitable apparatus includes hardware for accomplishing the process operations and a system controller having instructions for controlling process operations in accordance with the present embodiments.

5 For example, in some embodiments, the hardware may include one or more process stations included in a process tool.

[0123] Figure 11 shows a multi-chamber electroplating apparatus according to some implementations. The multi-chamber electroplating apparatus 1100 can include three separate electroplating modules 1102, 1104, and 1106. The multi-chamber electroplating apparatus 1100
10 can also include three separate modules 1112, 1114, and 1116 configured for various process operations. For example, in some embodiments, one or more of modules 1112, 1114, and 1116 may be a spin rinse drying (SRD) module. In other embodiments, one or more of the modules 1112, 1114, and 1116 may be post-electrofill modules (PEMs), each configured to perform a function, such as edge bevel removal, backside etching, and acid cleaning of substrates after they
15 have been processed by one of the electroplating modules 1102, 1104, and 1106.

[0124] The multi-chamber electroplating apparatus 1100 includes a central electrodeposition chamber 1124. The central electrodeposition chamber 1124 is a chamber that holds the chemical solution used as the electroplating solution in the electroplating modules 1102, 1104, and 1106. The multi-chamber electroplating apparatus 1100 also includes a dosing system 1126 that may
20 store and deliver additives for the electroplating solution. A chemical dilution module 1122 may store and mix chemicals to be used as an etchant. A filtration and pumping unit 1128 may filter the electroplating solution for the central electrodeposition chamber 1124 and pump it to the electroplating modules.

[0125] A system controller 1130 provides electronic and interface controls required to operate
25 the electroplating apparatus 1100. The system controller 1130 (which may include one or more physical or logical controllers) controls some or all of the properties of the electroplating apparatus 1100.

[0126] Signals for monitoring the process may be provided by analog and/or digital input connections of the system controller 1130 from various process tool sensors. The signals for
30 controlling the process may be output on the analog and digital output connections of the process tool. Non-limiting examples of process tool sensors that may be monitored include mass flow controllers, pressure sensors (such as manometers), thermocouples, optical position sensors, etc.

Appropriately programmed feedback and control algorithms may be used with data from these sensors to maintain process conditions.

[0127] A hand-off tool 1140 may select a substrate from a substrate cassette such as the cassette 1142 or the cassette 1144. The cassettes 1142 or 1144 may be front opening unified pods (FOUPs).

5 A FOUP is an enclosure designed to hold substrates securely and safely in a controlled environment and to allow the substrates to be removed for processing or measurement by tools equipped with appropriate load ports and robotic handling systems. The hand-off tool 1140 may hold the substrate using a vacuum attachment or some other attaching mechanism.

[0128] The hand-off tool 1140 may interface with a wafer handling station 1132, the cassettes 10 1142 or 1144, a transfer station 1150, or an aligner 1148. From the transfer station 1150, a hand-off tool 1146 may gain access to the substrate. The transfer station 1150 may be a slot or a position from and to which hand-off tools 1140 and 1146 may pass substrates without going through the aligner 1148. In some embodiments, however, to ensure that a substrate is properly aligned on the hand-off tool 1146 for precision delivery to an electroplating module, the hand-off tool 1146 may 15 align the substrate with an aligner 1148. The hand-off tool 1146 may also deliver a substrate to one of the electroplating modules 1102, 1104, or 1106 or to one of the three separate modules 1112, 1114, and 1116 configured for various process operations.

[0129] In some implementations, the controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, 20 including a processing tool or tools, chamber or chambers, a platform or platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. The 25 controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of fluids, selection of electroplating cells for neutralization, isolation of electroplating cells, opening/closing of valves, initiating sequences of filling and/or aspirating, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools 30 and/or load locks connected to or interfaced with a specific system.

[0130] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated

circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for neutralization of one or more electroplating cells.

[0131] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication or neutralization operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

Conclusion

[0132] It is understood that the examples and implementations described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art. Although various details have been omitted for clarity’s sake, various design alternatives may be implemented. Therefore, the present examples are to be

considered as illustrative and not restrictive, and the disclosure is not to be limited to the details given herein, but may be modified within the scope of the disclosure.

CLAIMS

What is claimed is:

1. An electroplating apparatus, comprising:
 - 5 a reservoir configured to hold electroplating solution;
 - a pump;
 - one or more electroplating cells, wherein each of the one or more electroplating cells comprises:
 - a cathode chamber;
 - 10 an anode chamber configured to contain an anode; and
 - a membrane between the cathode chamber and the anode chamber;
 - a feed line fluidly coupled to an outlet of the pump and to the one or more electroplating cells;
 - a return line fluidly coupled to the one or more electroplating cells and also fluidly
 - 15 coupled to one or more of the following: (1) a reservoir return line, wherein the reservoir return line is fluidly coupled to the reservoir, (2) a bypass return line, wherein the bypass return line bypasses the reservoir and is fluidly coupled to the pump, and (3) a drain line, wherein the drain line is directed to waste; and
 - a neutralization fill line fluidly coupled to the one or more electroplating cells and
 - 20 configured to supply neutralization solution to the one or more electroplating cells.
2. The electroplating apparatus of claim 1, wherein the neutralization solution comprises deionized water.
3. The electroplating apparatus of claim 1, wherein an inlet of the pump is fluidly coupled to the bypass return line and a reservoir output line.
- 25 4. The electroplating apparatus of claim 1, wherein the return line is fluidly coupled to the drain line, wherein the neutralization fill line is configured to circulate the neutralization solution through the one or more electroplating cells to the drain line via the return line.
5. The electroplating apparatus of claim 1, wherein the return line is fluidly coupled to the bypass return line, wherein the neutralization fill line is configured to circulate the neutralization
- 30 solution through the one or more electroplating cells and the bypass return line via the pump and the feed line.

6. The electroplating apparatus of claim 1, wherein the return line is fluidly coupled to the reservoir, wherein the neutralization fill line circulates the neutralization solution to the bypass return line or the drain line, and bypasses the reservoir.
7. The electroplating apparatus of claim 1, further comprising:
- 5 a drain line, wherein the drain line is fluidly coupled to either the return line or to the feed line.
8. The electroplating apparatus of claim 1, further comprising:
- an aspiration line fluidly coupled to the one or more electroplating cells, wherein the aspiration line comprises a bulk aspiration valve configured to aspirate the one or more
- 10 electroplating cells.
9. The electroplating apparatus of claim 8, wherein each of the one or more electroplating cells further comprises an ionically resistive element above the membrane.
10. The electroplating apparatus of claim 9, wherein each of the one or more electroplating cells further comprises a membrane frame configured to support the membrane.
- 15 11. The electroplating apparatus of claim 10, further comprising:
- an HRVA chamber aspiration line fluidly coupled to a region below the ionically resistive element in the one or more electroplating cells, wherein the HRVA chamber aspiration line comprises an HRVA chamber aspiration valve configured to aspirate the region below the ionically resistive element.
- 20 12. The electroplating apparatus of claim 11, further comprising:
- a system controller configured with instructions to perform the following operations:
- (a) open a drain isolation valve between the return line and the reservoir to return electrolyte in the one or more electroplating cells to the reservoir.
- (b) close the drain isolation valve to isolate selected one or more
- 25 electroplating cells to be isolated from the reservoir;
- (c) open one or both of the bulk aspiration valve and the HRVA chamber aspiration valve to aspirate the selected one or more electroplating cells; and
- (d) open a neutralization fill valve connected to the neutralization fill line to fill the selected one or more electroplating cells with the neutralization solution.
- 30 13. The electroplating apparatus of claim 12, wherein the system controller is further configured with instructions to perform the following operations:
- repeat steps (c) and (d) until a pH of a solution from the selected one or more electroplating cells reaches a threshold safety value.

14. The electroplating apparatus of claim 12, wherein the system controller is further configured with instructions to perform the following operations:

close, after step (c) is complete and prior to step (d), the bulk aspiration valve and the HRVA chamber aspiration valve after aspiration of the selected one or more electroplating

5 cells; and

close, after step (d) is complete, the neutralization fill valve.

15. The electroplating apparatus of claim 12, wherein the system controller is further configured with instructions to perform the following operations:

open, after step (d), a recirculation valve connected to the return line and the
10 bypass return line to recirculate the neutralization solution through the selected one or more electroplating cells.

16. The electroplating apparatus of claim 12, further comprising:

a second neutralization fill line fluidly coupled to the one or more electroplating cells, wherein the second neutralization fill line comprises a secondary neutralization fill valve
15 configured to supply a second neutralization solution to a tower that is fluidly coupled to the one or more electroplating cells; and

an anode chamber aspiration line fluidly coupled to the tower, wherein the anode chamber aspiration line comprises an anode chamber aspiration valve configured to aspirate the tower, wherein the system controller is further configured with instructions to perform the
20 following operations:

open, after step (d), the secondary neutralization fill valve to fill the tower with the second neutralization solution; and

close the second neutralization fill valve upon filling the tower with the second neutralization solution.

25 17. The electroplating apparatus of claim 12, wherein the neutralization fill line further comprises a precursor dose valve to dose the one or more electroplating cells with a precursor, wherein the system controller is further configured with instructions to perform the following operations:

open, prior to step (d), the precursor dose valve to dose the selected one or more
30 electroplating cells with the precursor.

18. The electroplating apparatus of claim 17, wherein the precursor comprises methane sulfonic acid (MSA) and prevents precipitation upon mixing the neutralization solution with the electroplating solution.

19. The electroplating apparatus of claim 1, further comprising:

a system controller configured with instructions to perform the following operations:

- (a) select at least one of the one or more electroplating cells to isolate and neutralize with the neutralization solution;
- (b) aspirate the selected at least one of the one or more electroplating cells;
- 5 (c) neutralize the selected at least one of the one or more electroplating cells with the neutralization solution; and
- (d) electroplate metal onto one or more wafers in the one or more electroplating cells that are not selected for isolation and neutralization, wherein metal is electroplated onto the one or more wafers simultaneous with steps (b)-(c).

10 20. The electroplating apparatus of claim 1, wherein the feed line comprises a filter downstream of the pump, wherein the neutralization fill line is configured to supply the neutralization solution to the pump and flow the neutralization solution through the feed line and the filter.

21. The electroplating apparatus of claim 20, further comprising:

15 a system controller configured with instructions to perform the following operations:

- (a) close a cell isolation valve connected to the feed line to isolate the pump from the one or more electroplating cells; and
- (b) open a neutralization fill valve connected to the neutralization fill line to flush the filter with the neutralization solution.

20 22. A method of neutralizing one or more electroplating cells in an electroplating apparatus, the method comprising:

isolating selected one or more electroplating cells to be isolated from a reservoir configured to hold electroplating solution in the electroplating apparatus;

aspirating the selected one or more electroplating cells;

25 filling the selected one or more electroplating cells with neutralization solution; and

repeating operations of aspirating and filling with neutralization solution until a pH of a solution from the one or more electroplating cells reaches a threshold safety value.

23. The method of claim 22, wherein the neutralization solution comprises deionized water.

24. The method of claim 22, wherein the neutralization solution comprises a base.

30 25. The method of claim 22, wherein aspirating the selected one or more electroplating cells comprises:

opening a first aspiration valve that is fluidly coupled to the selected one or more electroplating cells, wherein each of the electroplating cells comprises a cathode chamber, an

anode chamber, and an ionically resistive element between the cathode chamber and the anode chamber; and

opening a second aspiration valve that is fluidly coupled to an area below the ionically resistive element in the selected one or more electroplating cells.

5 26. The method of claim 22, further comprising:

recirculating, after filling the selected one or more electroplating cells with the neutralization solution, the neutralization solution through the selected one or more electroplating cells.

27. The method of claim 22, further comprising:

10 reclaiming, prior to isolating the selected one or more electroplating cells, electrolyte in the one or more electroplating cells to the reservoir.

28. The method of claim 22, further comprising:

electroplating metal onto one or more wafers in the one or more electroplating cells that are not selected for isolation and neutralization, wherein metal is electroplated onto the one or
15 more wafers simultaneous with aspirating and filling the selected one or more electroplating cells with the neutralization solution.

29. A method of performing filter flush, the method comprising:

isolating a pump from one or more electroplating cells in an electroplating apparatus, wherein the pump is configured to draw electroplating solution from a reservoir;

20 aspirating a filter positioned downstream of the pump, wherein the filter is fluidly coupled to the one or more electroplating cells;

flushing the filter with neutralization solution using a neutralization fill valve fluidly coupled to a feed line; and

25 repeating operations of aspirating and flushing with neutralization solution until a pH of a solution from the filter reaches a threshold safety value.

30. The method of claim 29, wherein the neutralization solution comprises deionized water.