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(71) Applicant: LAM RESEARCH CORPORATION

[US/US]; 4650 Cushing Parkway, Fremont, California 94538 (US).

(72) Inventors: YANG, Liu; 12366 SW Autumnview St, Portland, Oregon 97224 (US). MA, Quan; 19987 SW 64TH TER, Tualatin, Oregon 97062 (US). HE, Zhian; 5709 Charles Cir, Lake Oswego, Oregon 97035 (US). GHON-GADI, Shantinath; 15245 SW Turnagain Dr, Tigard, Oregon 97224 (US).

(74) Agent: WIGGINS, Michael D. et al.; Harness, Dickey & Pierce, P.L.C., 5445 Corporate Drive, Suite 200, Troy, Michigan 48098 (US).

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(54) Title: PLATING-DEPLATING WAVEFORM BASED CONTACT CLEANING FOR A SUBSTRATE ELECTROPLATING SYSTEM

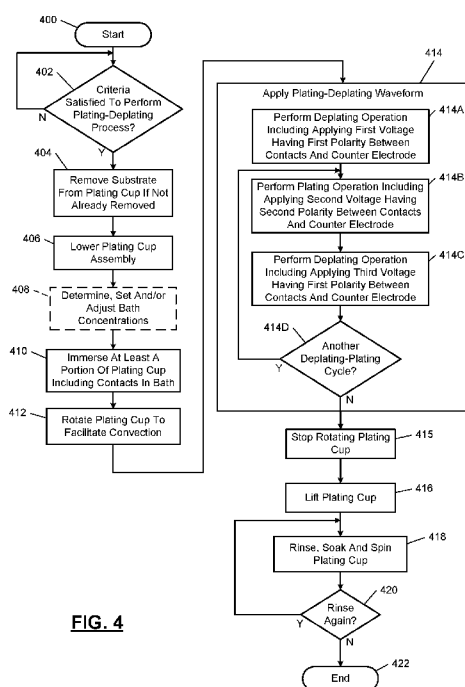


FIG. 4

(57) Abstract: An electrochemical deposition system configured for electrochemical plating of a substrate includes a chamber, an electrode, a plating cup and a controller. The chamber holds a plating bath. The electrode is disposed in the plating bath. The plating cup includes a contact ring. The contact ring includes contacts. The contacts are immersed in the plating bath. The controller is configured to apply a voltage signal across the contact ring and the electrode to remove residual from the contacts. The voltage signal includes a plating-de-plating waveform. The plating-de-plating waveform includes multiple cycles. Each of the cycles includes a pair of pulses with different polarity.

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PLATING-DEPLATING WAVEFORM BASED CONTACT CLEANING FOR A SUBSTRATE ELECTROPLATING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/065,634, filed on August 14, 2020. The entire disclosure of the application referenced above is incorporated herein by reference.

FIELD

[0002] The present disclosure relates to electroplating systems and more particularly to cleaning contacts of electroplating systems.

BACKGROUND

[0003] The background description provided here is for the purpose 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 prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0004] An electrochemical deposition (ECD) process, also known as electroplating or simply plating, is often used for metallization during fabrication of integrated circuits. The ECD process involves immersing a substrate in a plating bath and performing electrochemical deposition of metal to fill recessed patterns on a surface of the substrate. The recessed patterns include features (e.g., vias and trenches) of various sizes and are formed by plasma etching dielectric layers of the substrate. Prior to the ECD process, multiple thin film layers are deposited conformally or near-conformally on the substrate. The thin film layers typically include: a barrier layer to prevent metal diffusion into dielectric material of the substrate; a liner layer to improve adhesion to barrier layer; and a seed layer formed from a same metal as being deposited for current conduction across the whole substrate.

[0005] During the ECD process, metal is deposited on the seed layer. Various additives are added to the plating bath to enable super-conformal deposition, thus filling the features of the recessed patterns without any voids in the features. After filling the features, the deposition process continues until an overburden layer having a target overburden thickness is formed. After the ECD process, a chemical mechanical

polishing (CMP) process is employed to first remove the overburden layer and then an over-polishing operation is performed to remove a thin upper portion of dielectric material. The metal-filled features (or recesses) are as a result revealed as individual metal patterns. The ECD process may be iteratively performed multiple times to fabricate multiple layers of metal interconnect features. The metals deposited during the ECD process may include copper (Cu), cobalt (Co), zinc (Zn), etc.

SUMMARY

[0006] An electrochemical deposition system configured for electrochemical plating of a substrate is provided. The electrochemical deposition system includes a chamber, an electrode, a plating cup and a controller. The chamber holds a plating bath. The electrode is disposed in the plating bath. The plating cup includes a contact ring. The contact ring includes contacts. The contacts are immersed in the plating bath. The controller is configured to apply a voltage signal across the contact ring and the electrode to remove residual from the contacts. The voltage signal includes a plating-de-plating waveform. The plating-de-plating waveform includes multiple cycles. Each of the cycles includes a pair of pulses with different polarity.

[0007] In other features, the electrochemical deposition system further includes a membrane disposed in the chamber between the electrode and the contact ring. The membrane separates a first portion of the plating bath from a second portion of the plating bath.

[0008] In other features, a respective portion of the residual is removed during each of the cycles. In other features, the controller is configured to adjust a voltage of one of the pulses prior to or during a corresponding one of the plurality of cycles.

[0009] In other features, the controller is configured to adjust a duration of one of the pulses prior to or during a corresponding one of the cycles. In other features, the controller is configured to adjust a current level of one of the pulses prior to or during a corresponding one of the cycles.

[0010] In other features, the controller is configured to: determine whether a predetermined criterion is satisfied; and based on whether the predetermined criterion is satisfied, proceed with applying the voltage signal.

[0011] In other features, the plating-de-plating waveform includes an initial de-plating pulse prior to the cycles. In other features, a last de-plating pulse of the plating-de-

plating waveform has an extended duration such that a duration of the last de-plating pulse is longer than durations of other de-plating pulses of the plating-de-plating waveform. In other features, the controller is configured to perform one or more passive etching operations to further remove residual from the contacts.

5 **[0012]** In other features, a residual removal method for an electrochemical deposition system configured for electrochemical plating of a substrate is provided. The method includes: removing the substrate from a plating cup, wherein the plating cup includes contacts for contacting the substrate; immersing the contacts in a plating bath in a chamber of the electrochemical deposition system; applying a voltage signal across an
10 electrode and the contacts to remove residual from the contacts, where the electrode is disposed in the plating bath, where the voltage signal includes a plating-de-plating waveform, where the plating-de-plating waveform includes multiple cycles, and where each of the cycles includes a pair of pulses with different polarity; and subsequent to applying the voltage signal, rinsing the contacts with deionized water.

15 **[0013]** In other features, a respective portion of the residual is removed during each of the plurality of cycles. In other features, the residual removal method further includes adjusting a voltage of one of the pulses prior to or during a corresponding one of the cycles.

20 **[0014]** In other features, the residual removal method further includes adjusting a duration of one of the pulses prior to or during a corresponding one of the cycles. In other features, the residual removal method further includes adjusting a current level of one of the pulses prior to or during a corresponding one of the of cycles.

25 **[0015]** In other features, the residual removal method further includes: determining whether a predetermined criterion is satisfied; and based on whether the predetermined criterion is satisfied, proceeding with the residual removal method.

30 **[0016]** In other features, the predetermined criterion includes determining whether a predetermined number of substrates have been processed in the chamber. In other features, the plating-de-plating waveform includes an initial de-plating pulse prior to the plurality of cycles.

30 **[0017]** In other features, a last de-plating pulse of the plating-de-plating waveform has an extended duration such that a duration of the last de-plating pulse is longer than durations of other de-plating pulses of the plating-de-plating waveform. In other

features, the residual removal method further includes performing one or more passive etching operations to further remove residual from the contacts.

[0018] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0020] FIG. 1 is a functional block diagram and cross-sectional view of a portion of an electroplating system illustrating contacts of a plating cup relative to a plating bath in accordance with the present disclosure;

[0021] FIG. 2 is a cross-sectional diagram of a portion of an electroplating system illustrating components of a plating cup and contact with a substrate;

[0022] FIG. 3A is a top view of a contact ring including an annular-shaped body;

[0023] FIG. 3B is a top view of a portion of the contact ring of FIG. 3A illustrating contact fingers;

[0024] FIG. 3C is a top view of a portion of the contact fingers of FIG. 3B having non-metallic residual;

[0025] FIG. 3D is a top view of the portion of the contact fingers of FIG. 3C with the non-metallic residual removed as a result of implementing a residual removal process in accordance with the present disclosure;

[0026] FIG. 4 illustrates an example residual removal process in accordance with the present disclosure; and

[0027] FIG. 5 shows an example plating-de-plating waveform in accordance with the present disclosure.

[0028] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0029] During an ECD process, an electrical contact is made on an outer circumferential edge of a substrate by metal finger contacts (or pins) of a contact ring. The pins are typically formed from corrosion-resistant metal alloys or noble metals. The contact areas where the pins contact the surface of the substrate can range from a few millimeters to less than 1 millimeter in width. The number of contact pins per contact ring is typically large (e.g., many hundreds of pins) to enable uniform low-resistance electrical contact with the surface of the substrate.

[0030] During the ECD (or plating) process, the surface of the substrate is immersed in a plating bath. An anode is also immersed in the same plating bath. The anode is typically formed of a same type of metal material that is being deposited on the substrate. A power supply supplies an electric current that flows through the anode, the plating bath, the surface of the substrate, and the contact pins of the contact ring. Metal is deposited onto the surface of the substrate through electrochemical reduction of metal ions present in the plating bath. The anode is oxidized and supplies metal ions to the plating bath. In a sealed contact design, a region on the outer circumferential edge of the substrate, where the electrical contact with the contact pins occurs, is sealed with a lip seal to isolate the electrical contact and the circumferential edge from the plating bath.

[0031] The part of the plating cell holding the substrate is designed as an open “cup” with the lip seal (or a sealing rim) and may be referred to as a plating cup. The substrate is placed inside the cup with the lip seal sealing the circumferential edge. Only the surface of the substrate to be plated is exposed to the plating bath. No electrochemical reaction happens on the contact pins or the sealed circumferential edge of the substrate. A requirement of the ECD process is to provide thickness uniformity of deposited metal film. Uniform low-resistance electrical contact along the entire perimeter of the substrate is needed to control plating thickness uniformity. To maintain a consistent contact on the circumferential edge, the metal contact pins need to be kept clean and free of residual formations.

[0032] Although the contact pins and the edge of the substrate are sealed from the plating bath, liquid droplets can get to the contact pins during substrate handling. For example, a thin liquid film is present on a portion of the downward facing surface of the substrate being acted on adjacent to the lip seal. This is due to the height difference between the substrate and the lip seal. When the substrate is removed from the plating

cell, the liquid film may be dragged out by substrate movement and falls onto the contact pins as droplets. Such droplets are typically rinsed and diluted in the plating bath with deionized wafer (DIW).

[0033] During the plating process, current flows from the substrate to the contact pins.

5 An electric potential difference arises across the contact pin-substrate interface due to an I-R (or power) drop associated with a high contact resistance of the pin-substrate interface. In the presence of liquid, a mini-electrochemical cell forms due to existence of a contact-liquid-substrate interface, where the surface of the substrate functions as an anode while the contact pins function as a cathode. A seed layer on a circumferential
10 edge of the substrate is in contact with the liquid and is dissolved and re-deposited onto the contact pins. As the contact pins dry, the organic additives used in the plating bath also precipitate onto the contact pins. The material deposited on the contact pins is subsequently oxidized due to oxygen present in ambient air. This process gives rise to a non-conductive residual on the contact pins. The residual is a mixture of metal oxide
15 and components from the plating bath and has a brown to black appearance. Depending on the substrate and plating bath used, the residual on the contact pins may build up a significant amount and be a thick brown to black material easily visible to the naked eye. The residual may negatively affect electrical contact to the substrate and degrade plating uniformity. Excessive buildup leads to degradation of tool performance
20 and causes potential damage. The residual may peel off from the contact pins and fall onto a surface of the substrate, leading to an increased defect count. Metal dendrites may form around the contact pins and lead to arcing, which can damage the plating cup.

[0034] The plating cup is regularly rinsed with DIW and then dried by spinning. The
25 residual on contact pins is not soluble in water and thus is not removed during this rinsing process. A portion of the plating cup, which includes the contact ring and other components, may also be immersed into the plating bath for soaking and subsequent rinsing as a means of automated cleaning. However, it has been determined through experimentation that this soaking process, although at least partially dissolves the
30 residual, is very slow and not practical for production tools.

[0035] A de-plating process including applying an externally supplied anodic electric current or potential may be used to electrochemically dissolve metal deposited on the contacts. However, the de-plating process only removes metallic material deposited on the contacts. Direct application of such a de-plating process to contacts with non-

metallic residual as previously described does not fully dissolve the buildup. This is also true for extended exposures to the supplied anodic electric current or potential.

[0036] For at least the above-stated reasons, the residual is not easily removed by rinsing with DIW, soaking in a plating bath, and/or simply de-plating by applying an anodic potential. Removal of the residual typically requires performing a manual chemical etch process followed by lengthy rinsing and soaking. The chemical etch process may be used to remove the residual from the contact pins. An entire tool including a plating cup assembly is taken off production and put down in order to perform the chemical etch process. The plating cup assembly is then removed from the tool, such that at least some of the components of the plating cup assembly are able to be subjected to chemical etching. An etching solution made up of sulfuric acid (H_2SO_4) and peroxide (H_2O_2) at various concentration levels is prepared prior to etching. An example mass concentration includes 1-10% of each of H_2SO_4 and H_2O_2 . The plating cup assembly is then disassembled to remove the metal contacts. The metal contacts are immersed in the etching solution to chemically dissolve the residuals. Alternatively, the plating cup assembly is directly etched by placing the entire plating cup assembly into the etching solution with the contact pins fully immersed. The former approach is typically performed to minimize the amount of etching solution trapped inside the plating cup assembly. The etching process is about 30 minutes in length, depending on the concentration and temperature of the etching solution.

[0037] After etching, the contact pins and/or plating cup is thoroughly rinsed and then soaked in DIW for about 30 minutes to remove the etching solution as much as possible. This rinse-soak process may be repeated multiple times and is performed until the contact pins are pH neutral and dried using nitrogen (N_2). The components of the plating cup assembly are then assembled and the plating cup assembly is reinstalled back into the tool. Concentricity and eccentricity of the plating cup assembly are checked. Calibration is then performed. After calibration of the components and robot handoff operations are performed, the tool is put back up for a qualification test. The qualification test may include running a blanket wafer to check uniformity and check whether the number of defects meet predetermined requirements.

[0038] The described chemical etching approach has some significant drawbacks including calibration and qualification of delicate components, significant impact on tool availability, and handling of hazardous chemicals. In order to perform chemical etching on one plating cell, the entire tool needs to be put down. The contact etching and

rinsing process and the hardware calibration after installation of the plating cup assembly are time consuming. Also, after successful hardware calibration, the tool needs to pass process qualification before the tool can be put back into production. As the chemical etching process needs to be performed periodically to remove residual build up, the tool availability can be significantly impacted. In addition, the etching solution is prepared from a strong acid and oxidizer, which are both hazardous chemicals. Strict environmental, health and safety (EHS) protocols need to be followed when handling such chemicals. Moreover, every component exposed to the etching solution needs to be thoroughly cleaned. Any residual etching solution remaining inside the plating cup assembly may accelerate future residual buildup.

[0039] The examples set forth herein include removing residual build-up on contacts by performing a plating-de-plating process. The plating-de-plating process addresses the aforementioned issues of the chemical etching process and includes providing a plating-de-plating waveform to continuously remove non-metallic non-conductive residual from contacts. By repeating plating and de-plating cycles of the waveform multiple times, the residual is able to be fully removed. The plating-de-plating waveform is applied as a varying voltage potential between (i) contact pins of a plating cup and (ii) a counter electrode. The counter electrode is located in a plating bath. The contact pins are immersed in the plating bath. Full removal of thick residual from the contact pins using the described plating-de-plating process has been demonstrated. No manual chemical etching of contacts is involved. The corresponding tool, which may include multiple plating chambers having respective plating cups, is able to remain productive during the cleaning of an individual plating chamber. The total clean time is significantly reduced as compared to the chemical etch process and tool availability is improved.

[0040] FIG. 1 shows a portion 100 of an electrochemical deposition (ECD) (or electroplating) system configured to operate as a residual removal system to clean contacts (e.g., contact fingers) 102 of a contact ring 104 of a plating cup assembly 106. Examples of the contact ring 104 and contacts 102 are shown in FIGs. 3A-3D. The portion 100 includes the plating cup assembly 106, a controller 108, a switch circuit 110 and a power source 112. The plating cup assembly 106 includes an electroplating cell 118 having a cup 120 and a cone 122. While a specific assembly is shown for discussion purposes, the examples set forth herein are applicable to other types of assemblies, handling equipment or processing equipment.

[0041] The electroplating cell 118 includes a chamber 123 defined by chamber walls 125 and a chamber bottom 127. The cup 120 is supported by a top plate 124 and struts 126. The top plate 124 may be connected to the spindle 160. During electrochemical deposition (or plating) a substrate may be deposited on the contacts 102 of the cup 120.

5 An example substrate is shown in FIG. 2. FIG. 1 illustrates when a substrate is not present and the contacts 102 are being cleaned. During cleaning (residual removal), the controller 108 generates a voltage signal having a plating-de-plating waveform that is supplied via the switch circuit 110 and applied across the (i) contacts 102 and (ii) an electrode 130 (referred to as a “counter electrode”). Current may be supplied to the
10 electrode 130 when operating in a plating mode or to the contacts 102 when in a de-plating mode. The voltage signal may be supplied via the struts 126 and/or the plating cup 120, which may be conductive and/or formed to include conductive elements for supplying current to and/or receiving current from the contacts 102. Current passes through the electrode 130, a first electrolyte or first portion of the plating bath in a lower
15 chamber portion 140 of the chamber 123, a second electrolyte or second portion of the plating bath in an upper chamber portion 142, and the contacts 102. The second electrolyte in the upper chamber portion 142 may be referred to as a “plating bath” and/or a “plating-de-plating bath” when used to clean the contacts 102. The same bath may be used for substrate deposition as used for removal of residual.

20 **[0042]** As an example, the contacts 102 may be formed of a noble material. The contacts may be formed of silver, palladium, cobalt, aluminum, gold, zirconium, curium, platinum, and/or zinc. As another example and when the metal to be plated is cobalt, the residual may include a mixture of cobalt oxide and organic material including carbon. The residual may be formed of other plating metals and corresponding
25 materials. The residual coats the contacts 102 and does not change material makeup of the contacts 102. The plating bath may include a mixture of a salt, an acid and additives. The salt includes the metal to be plated. As an example, the plating bath may include, if plating copper, copper sulfate (CuSO_4), sulfuric acid (H_2SO_4) and additives. As another example, the plating bath may include, if plating cobalt, cobalt sulfate (CoSO_4),
30 boric acid (H_3BO_3) and additives.

[0043] The upper chamber portion 142 of the chamber 123 is separated by the lower chamber portion 140 by a membrane 144 held by a membrane frame 146. In some examples, the membrane 144 includes an ion permeable membrane. The membrane 144 may be an ion permeable membrane that allows ions to pass but otherwise

separates the first electrolyte from the second electrolyte. An electrode 130 is arranged in a bottom of the chamber 123 and may be formed at partially of a material being deposited, such as cobalt or copper. As an example, a dashed line 131 is shown and represents a sample fill height of the second electrolyte also referred to as an immersion depth of the cup 120 and the contacts 102.

[0044] Each of the first electrolyte and the second electrolyte may include an anolyte or a catholyte depending on the operating mode. The second electrolyte may be supplied through inlets 150, into the upper chamber portion 142 of the chamber 123, through vertical holes (not shown) in a plate 152 (e.g., a high-resistance virtual anode (HRVA) plate) and into an area 154 (or corresponding manifold). The second electrolyte may also be supplied through a channel 156 to the area 154.

[0045] During use, the cup 120 is lowered to expose the contacts 102 (to be plated) to the second electrolyte in the upper chamber portion 142 of the chamber 123. Spindle 160, which is connected to the cone 122, is rotated in one or both directions. The spindle 160 may be raised, lowered and/or rotated via one or more motors 161 of an actuator assembly 163, which may be controlled by the controller 108. The spindle 160 may rotate the cup 120.

[0046] The cup 120 includes a lip seal 162 and holds the contact ring 104. The spindle 160 causes the cone 122 to press against a cone seal 164 to hold a substrate (not shown in FIG. 1) in place and to seal the substrate against the lip seal 162. The contact ring 104 is located between an upwardly facing surface of the lip seal 162 and a downwardly facing surface of the substrate. The contact ring 104 provides an electrical connection to the substrate during plating of the substrate. A top side insert 165, which may include a flow ring (not shown), is disposed between the plate 152 and the cup 120. The top side insert 165 may be annular-shaped.

[0047] The ECD system may further include sensors 170, such as temperature sensors and a robot 172. The sensors 170 may be located on or in the chamber 123 and/or elsewhere. Signals from the sensors are received at the controller 108. The controller 108 may perform operations describe herein based on signals from the sensors 170. As an example, the plating bath may be maintained at a predetermined temperature (e.g., 18-20°C) during contact cleaning. The robot 172 may be controlled to place a substrate on and remove the substrate from the plating cup 120. Upon

initiating substrate plating, the cone 122 is raised above the cup 120 and a substrate is placed onto the lip seal 162 by an arm of the robot 172.

[0048] FIG. 2 shows a portion 200 of an ECD (or electroplating) system configured to operate as a residual removal system. The portion 200 includes a plating cup assembly 202 that may replace and/or be configured similarly as the plating cup assembly 202 of FIG. 1. During a substrate deposition process, a substrate 210 may be set on contacts 212 of a cup 214. The cup 214 includes an opening through which an electrolyte from a plating cell 220 contacts a downward facing surface (or front/working side) 222 of the substrate 210, where plating occurs. An outer periphery of the substrate 210 rests on a lip seal 224 of the cup 214. A spindle 226 causes a cone 230 to press against a cone seal 232 to hold the substrate 210 in place and to seal the substrate 210 against the lip seal 224. A contact ring 240 including the contacts 212 (or contact fingers) is located between an upwardly facing surface of the lip seal 224 and the downwardly facing surface 222 of the substrate 210. The contact ring 240 provides an electrical connection to the substrate 210 during plating.

[0049] FIGs. 3A-3D show a contact ring 300 having an annular-shaped body 302 with contact fingers (or pins) 304. The contact ring 300 may replace and/or be configured as either of the contact rings 120, 240 of FIGs. 1-2. In FIG. 3A, the contact ring 300 includes an outer portion 310 and an inner portion 314 extending radially inwardly from the outer portion 310. The inner portion 314 includes the contact fingers 304 projecting radially inward. The contact fingers 304 are not shown in FIG. 3A, but are shown in FIG. 3B. While the contact ring 300 is shown including a particular arrangement of contact fingers, the contact ring 300 may include a different arrangement of contact fingers.

[0050] FIG. 3C shows a portion 330 of the contact fingers 304 of FIG. 3B having non-metallic non-conductive residual (hereinafter referred to as "residual"). Residual may build up on contacts as a dark brown or black in color material. As an example, the composition of the residual may include cobalt oxide (an organic mixture). As shown, the contact fingers 304 have tips with residual 334. The tips are radially inward of the remainder of the contact fingers 304. FIG. 3D shows the portion 330 of the contact fingers 304 of FIG. 3C with the residual removed as a result of implementing a residual removal process disclosed herein. An example of the process is shown in FIG. 4.

[0051] FIG. 4 shows a residual removal process. Although the following operations are primarily described with respect to the implementations of FIG. 1, the operations may be easily modified to apply to other implementations of the present disclosure. The operations may be iteratively performed. The method may begin at 400. At 402, the controller 108 may determine whether predetermined criteria has been satisfied to perform a plating-de-plating process. For example, the controller 108 may determine whether the number of substrates processed for a corresponding ECD system is equal to or exceeded a predetermined number of substrates. When the predetermined number has been reached, operation 404 is performed. At 404, the controller 108 removes a last processed substrate from the cup 120 if not already removed.

[0052] Operations 406, 408 and 410 may be performed in a different order and/or combined into a single operation. In one embodiment, one or more of operations 406, 408 and 410 are not performed. At 406, the controller 108 may lower the plating cup assembly 106 onto the chamber 123. At 408, the controller 108 may determine plating bath concentrations for the residual removal process and/or obtain the plating bath concentrations from memory. The controller 108 may adjust levels of the plating bath and/or concentrations thereof based on predetermined settings. In one embodiment, the plating bath used for cleaning is the same plating bath used for plating the last removed substrate. At 410, the controller 108 immerses at least a portion of the plating cup 120 in a plating bath. This may be done by lowering the plating cup 120 into the plating bath and/or adjusting levels of the plating bath. This operation may be based on the concentrations determined at 408. At least radially inner portions of the plating cup 120 are immersed into the plating bath without a substrate, as shown in FIG. 1. The contacts 102 are put in direct contact with the plating bath. The plating cup 120 is rotated at a specified speed to facilitate convection.

[0053] At 412, the controller 108 rotates the plating cup 120 to facilitate convection for mass transfer of material to be plated on the contacts. The rotating agitates the electrolyte solution(s) in the chamber 123 and allows the process to continue at a same speed with uniform process continuity performance.

[0054] At 414, the controller 108 applies a plating-de-plating (or voltage) waveform across the (i) contacts 102 and (ii) electrode 130. The voltage waveform is applied between the plating cup 120 and the counter electrode 130. The plating cup 120 and the counter electrode 130 may each operate as an anode or a cathode, depending on whether plating or de-plating is occurring. An example plating-de-plating waveform 500

is shown in FIG. 5, where U is voltage potential, t is time, PU is plating voltage potential, and DU is de-plating voltage potential. The plating-de-plating waveform 500 may include an upper portion 502, where a first voltage (or set of voltages) having a first polarity is applied, a lower portion 504, where a second voltage (or set of voltages) having a second polarity is applied. The first polarity may be, for example, positive and the second voltage polarity may be negative. A positive voltage means anodic, i.e. current flowing from the contacts 102 to the electrode via the plating bath. A negative voltage means cathodic, i.e. current flowing from the electrode 130 to the contacts 102 via the plating bath.

[0055] The upper portion 502 is associated with plating and the lower portion 504 is associated with de-plating. In the example shown, the upper portion 502 includes a set of pulses having pulse widths PD1, PD2, PD3, PD4. The lower portion 504 includes a set of pulses having pulse widths DD1, DD2, DD3, DD4, and DD5.

[0056] In the example shown, an initial de-plating pulse 510 is included followed by four plating-de-plating cycles, which begin with a first plating pulse 512 and end with a last de-plating pulse 514. In one embodiment, the initial de-plating pulse 510 is not provided and the process begins with plating. Any number of plating-de-plating cycles may be included. In an embodiment, 4-10 cycles are included. In one embodiment, a predetermined number of plating-de-plating cycles are performed to assure that there is not any residual remaining on the contacts 102 at the end of the process. The durations and amplitudes of each of the pulses of the upper portion 502 may be the same or different. The durations and amplitudes of each of the pulses of the lower portion 504 may be the same or different. The stated durations and amplitudes may be adjusted based on systems parameters, materials, compositions, etc. Durations, voltage setpoints and/or current setpoints may be adjusted during one or more of the cycles. For example, the durations and amplitudes may be based on system temperatures, types of materials of the contacts 102 and the residual and the compositions of the plating bath. The durations and amplitudes of each of the pulses of the upper portion 502 may be different than the durations and pulses of the lower portion 504.

[0057] In one embodiment, the plating-de-plating process lasts a few minutes, however the process may last a different amount of time. In an embodiment, the widths of the plating pulses (or durations of the plating events) are set to deposit a layer on the contacts having a predetermined thickness (e.g., 10 nano-meters). In another embodiment, the widths of the de-plating pulses (or durations of the de-plating events)

are predetermined and set to assure that the material deposited during a last plating event is removed during a next subsequent de-plating event.

[0058] The electrode 130, which is the original metal electrode used for substrate plating, is also used as a counter electrode for cleaning. The applied voltage between the contacts 102 and the counter electrode 130 is selected such that the voltage is sufficiently high to facilitate the electrochemical dissolution of any components in the residual, but not too high that it converts the residual to a substance more difficult to remove. The voltage depends on the tool setup and plating bath composition, conductivity and resistivity.

[0059] The following operations may be represented by a plating-de-plating waveform, such as that shown in FIG. 5.

[0060] At 414A, an initial de-plating operation may be performed as described above. In one embodiment, operation 414A is not performed.

[0061] At 414B, one of the plating operations associated with the voltage waveform is performed. During plating, the contacts 102 operate as a cathode and the counter electrode 130 operates as an anode. Metal is deposited on to the contacts.

[0062] At 414C, one of the de-plating operations associated with the voltage waveform is performed. The contacts 102 operate as an anode and the counter electrode 130 operates as a cathode. The metal deposited during the last plating operation is dissolved. The de-plating duration is selected to allow full dissolution of the metal deposited in the last plating operation. In one implementation for cobalt metal deposition (or cobalt plating) of the contacts 102, the de-plating voltage amplitude is set between 0.5-3V.

[0063] During each cycle, some of the residual on contacts 102 is either dissolved and/or delaminated from the contacts 102 and subsequently dissolved in the plating bath. As an example, for cobalt metal deposition, an average cobalt plating thickness of 3-10 nanometers is deposited and is sufficient to induce such a cleaning effect. In one implementation the plating-de-plating cycle is repeated 4 times.

[0064] A last plating-deplating cycle includes a final de-plating operation to fully remove any deposited metal that may have been left in places difficult to dissolve, e.g. narrow crevices. The last de-plating operation may be longer than previous de-plating operations.

[0065] At 414D, the controller 108 determines whether to perform another plating-de-plating cycle. If yes, operation 414B may be performed. In one embodiment, operation 414D is not performed. The plating-de-plating operations are over after a predetermined number of plating-de-plating cycles have been applied.

5 **[0066]** At 415, the controller 108 stops rotation of the plating cup.

[0067] At 416, the plating cup 120 is lifted. This may include separating the plating cup 120 from the chamber walls 125 and thereby removing the contacts 102 from the plating bath.

10 **[0068]** At 418, at least portions of the plating cup 120 are rinsed and/or soaked with deionized water (DIW). The plating cup 120 may also be spun. This includes rinsing the contacts 102 with DIW. The plating cup 120 is rinsed with DIW to remove any plating bath dragged out from the previous operations. At 420, the controller 108 may determine whether to rinse the plating cup 120 again. If yes, operation 418 is repeated, otherwise the method may end at 422. The plating cup 120 is repeatedly rinsed with
15 DIW, soaked to allow any trapped bath to diffuse out, and spun to remove the liquid. The plating cup 120 is fully dry in a final spin dry operation.

[0069] The above-described operations are meant to be illustrative examples. The operations may be performed sequentially, synchronously, simultaneously, continuously, during overlapping time periods or in a different order depending upon the
20 application. Also, any of the operations may not be performed or skipped depending on the implementation and/or sequence of events.

[0070] The plating or de-plating operations described above may be voltage-controlled or current-controlled. In the case of voltage control, the voltage being applied may correspond to (i) a potential difference between the contacts 102 and the counter
25 electrode 130, or (ii) a potential difference between the contacts 102 and a reference electrode. The reference electrode may be located in the chamber 123 and have a reference voltage potential. No current passes through the reference electrode. When voltage-controlled, a requested voltage may be provided and applied. When current-controlled, a requested current level may be requested and a voltage may be
30 determined by the controller 108 to provide the requested current level.

[0071] The counter electrode 130 may be the anode used for plating, any auxiliary electrode used in the plating bath, or a dedicated electrode. The counter electrode 130

may be formed of a same metallic material being deposited or may be formed of different corrosion-resistant metals and/or alloys.

[0072] Durations of the plating and de-plating operations may be either time-based or endpoint-based. In the time-based implementation, the durations are set to predetermined fixed lengths of time. In the endpoint-based implementation, the endpoints of the operations are detected when (i) an applied current amplitude drops below a certain predetermined threshold while in the voltage-controlled mode, or (ii) an applied voltage amplitude increases above a certain predetermined threshold while in the current-controlled mode.

[0073] The above-described method may be repeated one or more times and may include one or more additional passive etching operations, which do not include applying an electric current or voltage. For example, a soak operation may be performed before or after operation 415. The controller 108 may return to operation 414 after the soaking operation or proceed to operation 416. These operations include soaking the contacts 102 in the plating bath for predetermined periods of time. The passive etching operations may be referred to as slow etching operations.

[0074] The above-described cleaning process may be implemented as automated periodic preventative maintenance method and/or be executed manually as needed. The controller 108 may schedule performance of the method after a predetermined number of substrates (e.g., 100-200 substrates) have been processed.

[0075] Traditionally, chemical etching with a strong acid and oxidizer is generally required to remove insoluble residual buildup. Traditional techniques include using a de-plating process to remove metallic deposition on contacts, not to remove non-conductive residuals. By performing both plating and de-plating operations in each cycle, the described method achieves a synergy to remove residual from contacts in an efficient manner.

[0076] A single plating-de-plating operation typically does not sufficiently clean non-conductive residual from contacts. The described method uses multiple plating-de-plating cycles to iteratively remove portions of non-conductive residual until contacts are fully cleaned. This repetition enables effective cleaning of contacts. Extending the plating operation duration alone or the de-plating operation alone does not accelerate the contact cleaning process.

[0077] The described method may also use the same plating bath for contact cleaning as for substrate deposition processing and does not require any additional etching chemistry, which can significantly reduce any potential impacts on environment, health and safety. The cleaning process is performed with at least portions of a plating cup
5 immersed in a same plating bath used for processing. Thus, no extra chemicals are required. No hazardous chemicals are used. As no strong acids or oxidizers are used, the risk of accelerated buildup after cleaning due to residual chemicals being trapped is mitigated.

[0078] In one embodiment, the described method may include the controller 108
10 executing an automated software program. The method may be implemented as an automated program that executes on schedule or on demand. No manual hardware operation and/or manual manipulation of the tool is involved. No disassembling, assembling or calibration is required during or after performing the described cleaning method. The described method thus provides a simplified and efficient technique for
15 cleaning contacts and removing residual. The method significantly reduces the amount of time and resources needed to clean contacts. As a result, the impact of the contact clean operations on tool availability is reduced, such that tool down time is minimized. The program may be executed on an individual plating cell without interfering with other modules of the tool. There is no need to pull the tool out from production, and no need
20 to open the tool to perform the described method. There is also no need to perform hardware calibration after the cleaning process is performed. The entire cleaning process may be completed in up to or less than tens of minutes, a significant reduction in time from the tens of hours required by traditional cleaning approaches.

[0079] The foregoing description is merely illustrative in nature and is in no way
25 intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps
30 within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that

combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

[0080] Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including “connected,” “engaged,” “coupled,” “adjacent,” “next to,” “on top of,” “above,” “below,” and “disposed.” Unless explicitly described as being “direct,” when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

[0081] In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, 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 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 processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0082] 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 a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0083] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with the system, 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 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.

- 5 **[0084]** Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.
- 10 **[0085]** As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from
- 15 tool locations and/or load ports in a semiconductor manufacturing factory.

CLAIMS

What is claimed is:

1. An electrochemical deposition system configured for electrochemical plating of a substrate, the electrochemical deposition system comprising:
 - 5 a chamber holding a plating bath;
 - an electrode disposed in the plating bath;
 - a plating cup comprising a contact ring, wherein the contact ring comprises contacts, and wherein the contacts are immersed in the plating bath; and
 - a controller configured to apply a voltage signal across the contact ring and the
 - 10 electrode to remove residual from the contacts, wherein the voltage signal comprises a plating-de-plating waveform, wherein the plating-de-plating waveform comprises a plurality of cycles, and wherein each of the plurality of cycles includes a pair of pulses with different polarity.
2. The electrochemical deposition system of claim 1, further comprising a
- 15 membrane disposed in the chamber between the electrode and the contact ring and separating a first portion of the plating bath from a second portion of the plating bath.
3. The electrochemical deposition system of claim 1, wherein a respective portion of the residual is removed during each of the plurality of cycles.
4. The electrochemical deposition system of claim 1, wherein the controller is
- 20 configured to adjust a voltage of one of the pulses prior to or during a corresponding one of the plurality of cycles.
5. The electrochemical deposition system of claim 1, wherein the controller is configured to adjust a duration of one of the pulses prior to or during a corresponding one of the plurality of cycles.
- 25 6. The electrochemical deposition system of claim 5, wherein the controller is configured to adjust a current level of one of the pulses prior to or during a corresponding one of the plurality of cycles.

7. The electrochemical deposition system of claim 1, wherein the controller is configured to:

determine whether a predetermined criterion is satisfied; and

based on whether the predetermined criterion is satisfied, proceed with applying

5 the voltage signal.

8. The electrochemical deposition system of claim 1, wherein the plating-de-plating waveform includes an initial de-plating pulse prior to the plurality of cycles.

9. The electrochemical deposition system of claim 1, wherein a last de-plating pulse of the plating-de-plating waveform has an extended duration such that a duration
10 of the last de-plating pulse is longer than durations of other de-plating pulses of the plating-de-plating waveform.

10. The electrochemical deposition system of claim 1, wherein the controller is configured to perform one or more passive etching operations to further remove residual from the contacts.

15 11. A residual removal method for an electrochemical deposition system configured for electrochemical plating of a substrate, the method comprising:

removing the substrate from a plating cup, wherein the plating cup includes contacts for contacting the substrate;

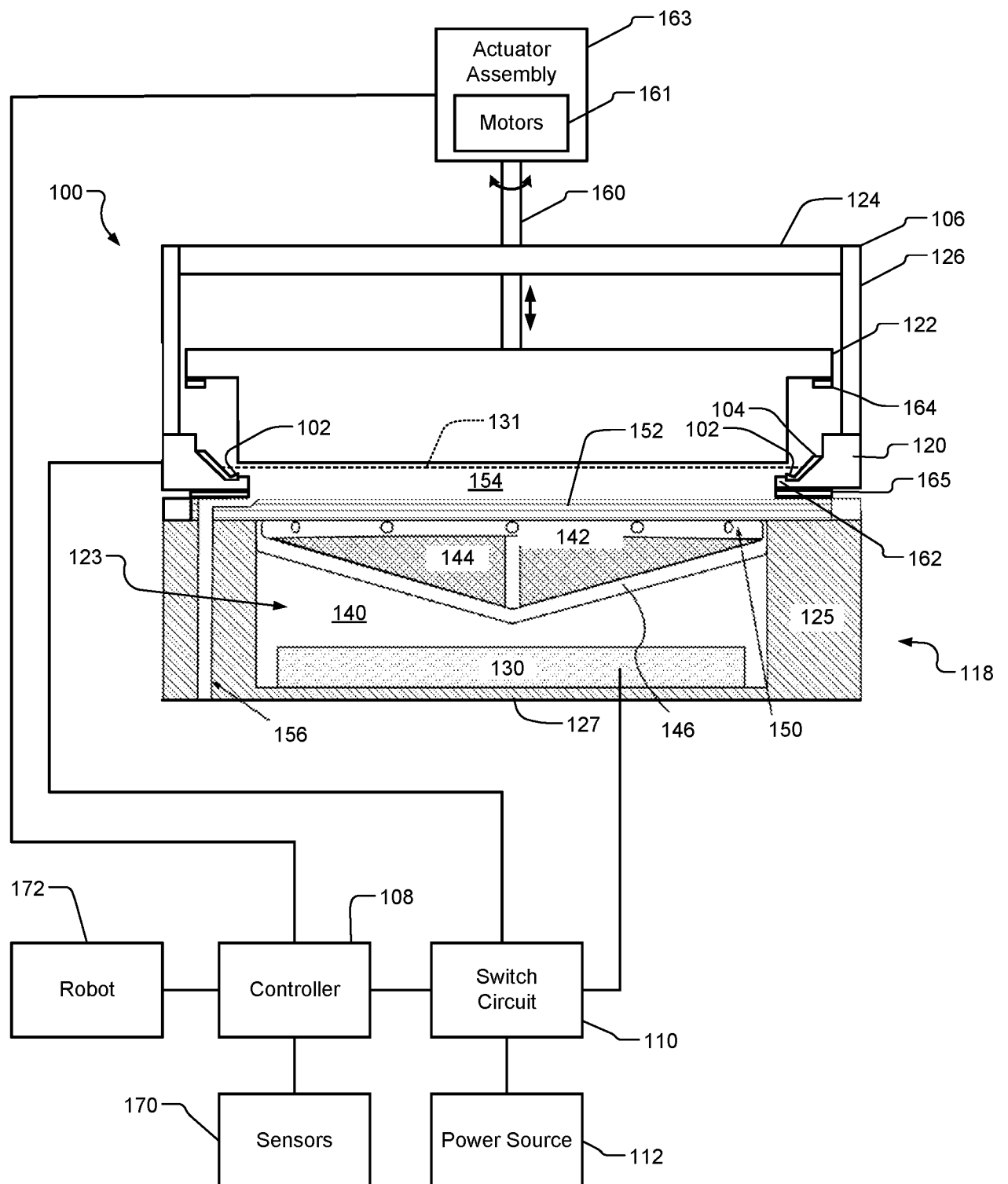
immersing the contacts in a plating bath in a chamber of the electrochemical
20 deposition system;

applying a voltage signal across an electrode and the contacts to remove residual from the contacts, wherein the electrode is disposed in the plating bath, wherein the voltage signal includes a plating-de-plating waveform, wherein the plating-de-plating waveform comprises a plurality of cycles, and wherein each of the plurality of
25 cycles includes a pair of pulses with different polarity; and

subsequent to applying the voltage signal, rinsing the contacts with deionized water.

12. The residual removal method of claim 11, wherein a respective portion of the residual is removed during each of the plurality of cycles.

13. The residual removal method of claim 11, further comprising adjusting a voltage of one of the pulses prior to or during a corresponding one of the plurality of cycles.
14. The residual removal method of claim 11, further comprising adjusting a duration of one of the pulses prior to or during a corresponding one of the plurality of cycles.
- 5 15. The residual removal method of claim 11, further comprising adjusting a current level of one of the pulses prior to or during a corresponding one of the plurality of cycles.
16. The residual removal method of claim 11, further comprising:
determining whether a predetermined criterion is satisfied; and
10 based on whether the predetermined criterion is satisfied, proceeding with the residual removal method.
17. The residual removal method of claim 16, wherein the predetermined criterion includes determining whether a predetermined number of substrates have been processed in the chamber.
- 15 18. The residual removal method of claim 11, wherein the plating-de-plating waveform includes an initial de-plating pulse prior to the plurality of cycles.
19. The residual removal method of claim 11, wherein a last de-plating pulse of the plating-de-plating waveform has an extended duration such that a duration of the last de-plating pulse is longer than durations of other de-plating pulses of the plating-de-
20 plating waveform.
20. The residual removal method of claim 11, further comprising performing one or more passive etching operations to further remove residual from the contacts.

**FIG. 1**

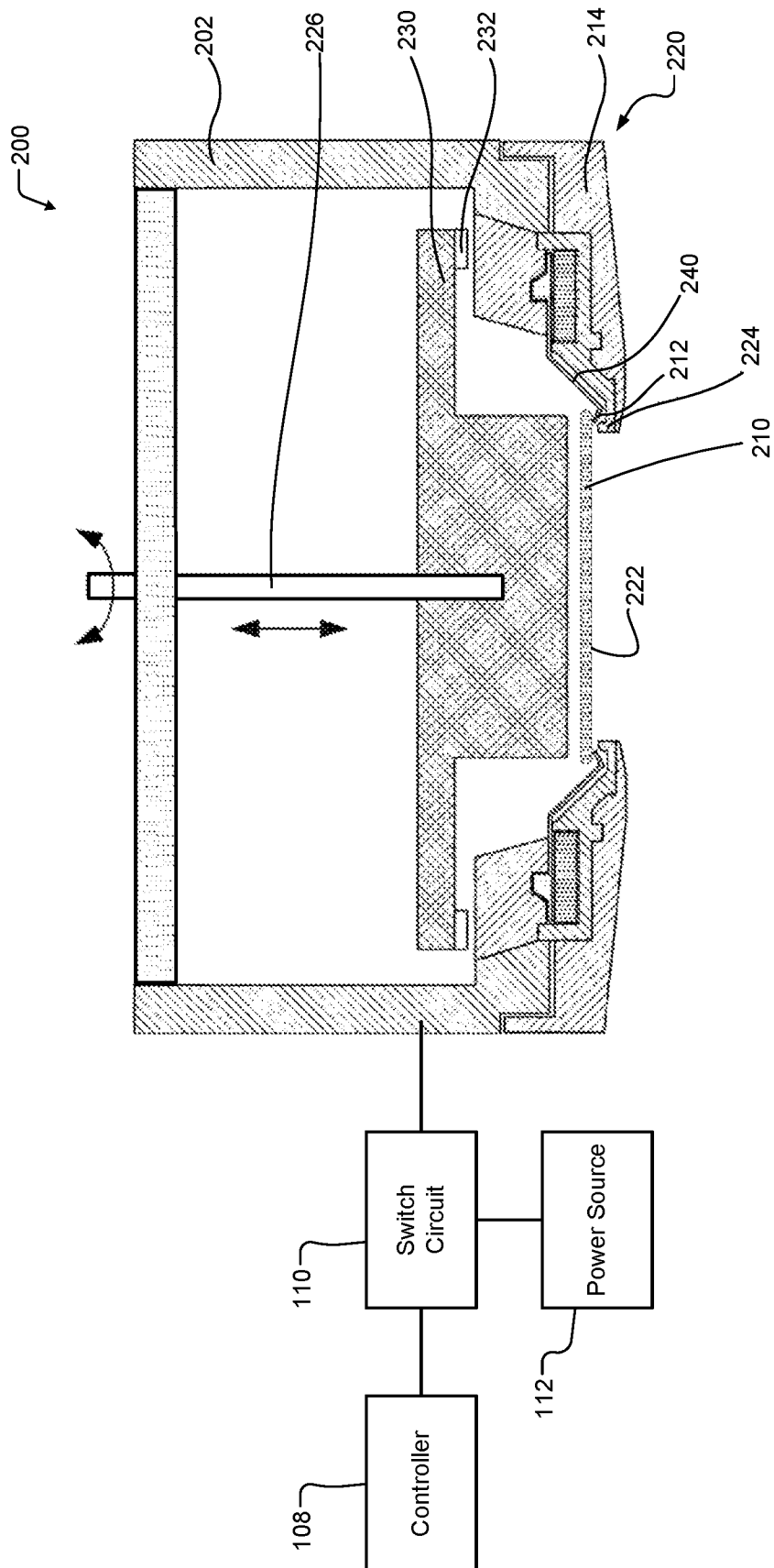


FIG. 2

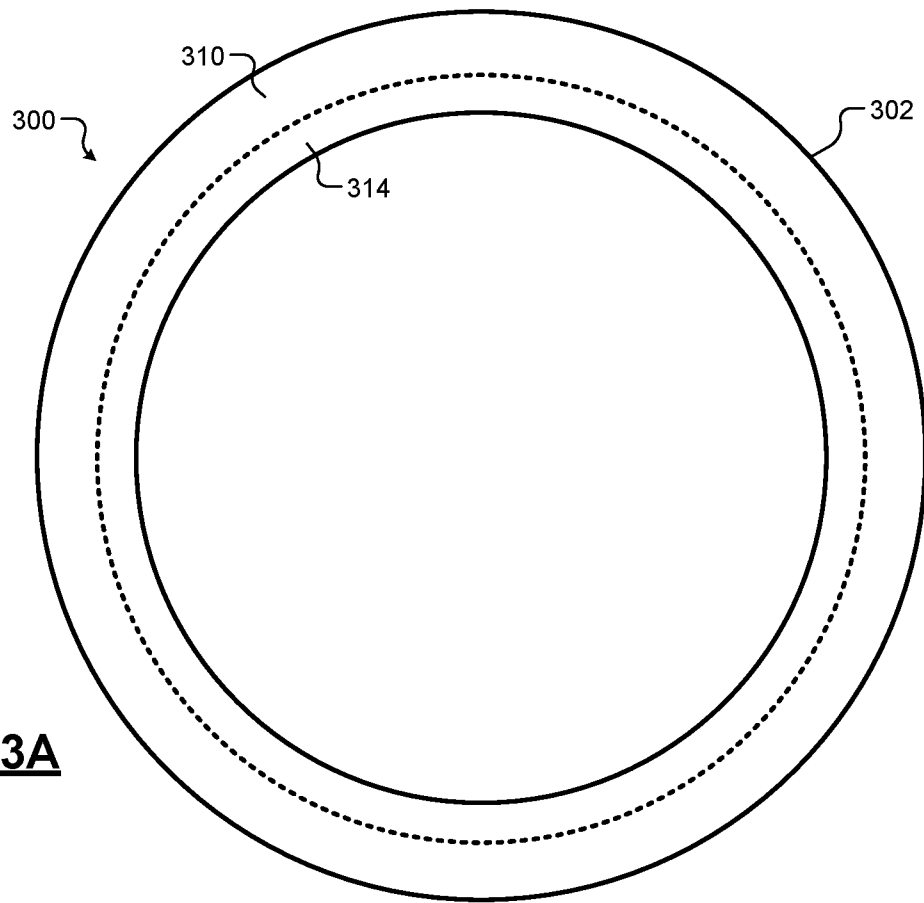


FIG. 3A

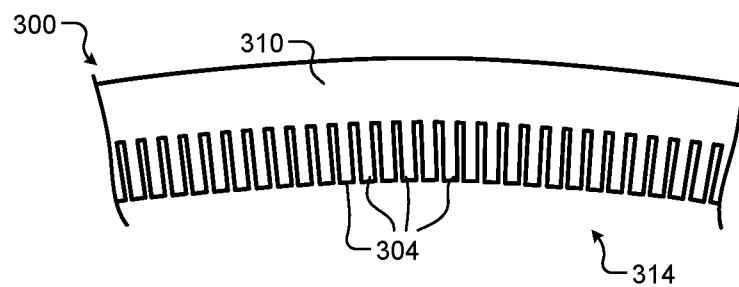


FIG. 3B

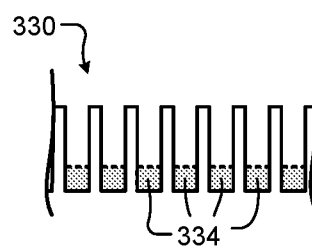


FIG. 3C

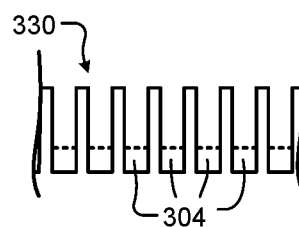
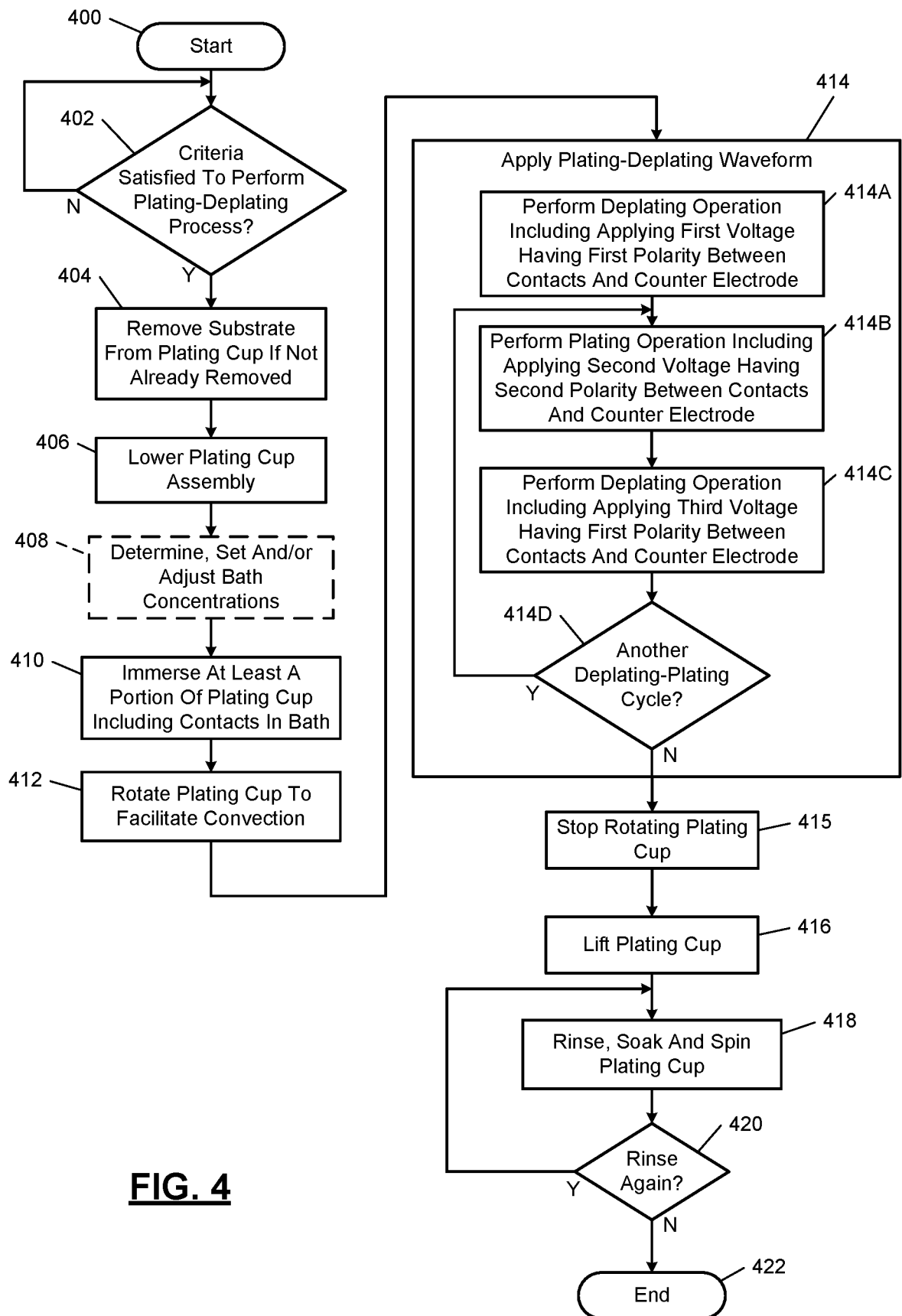


FIG. 3D



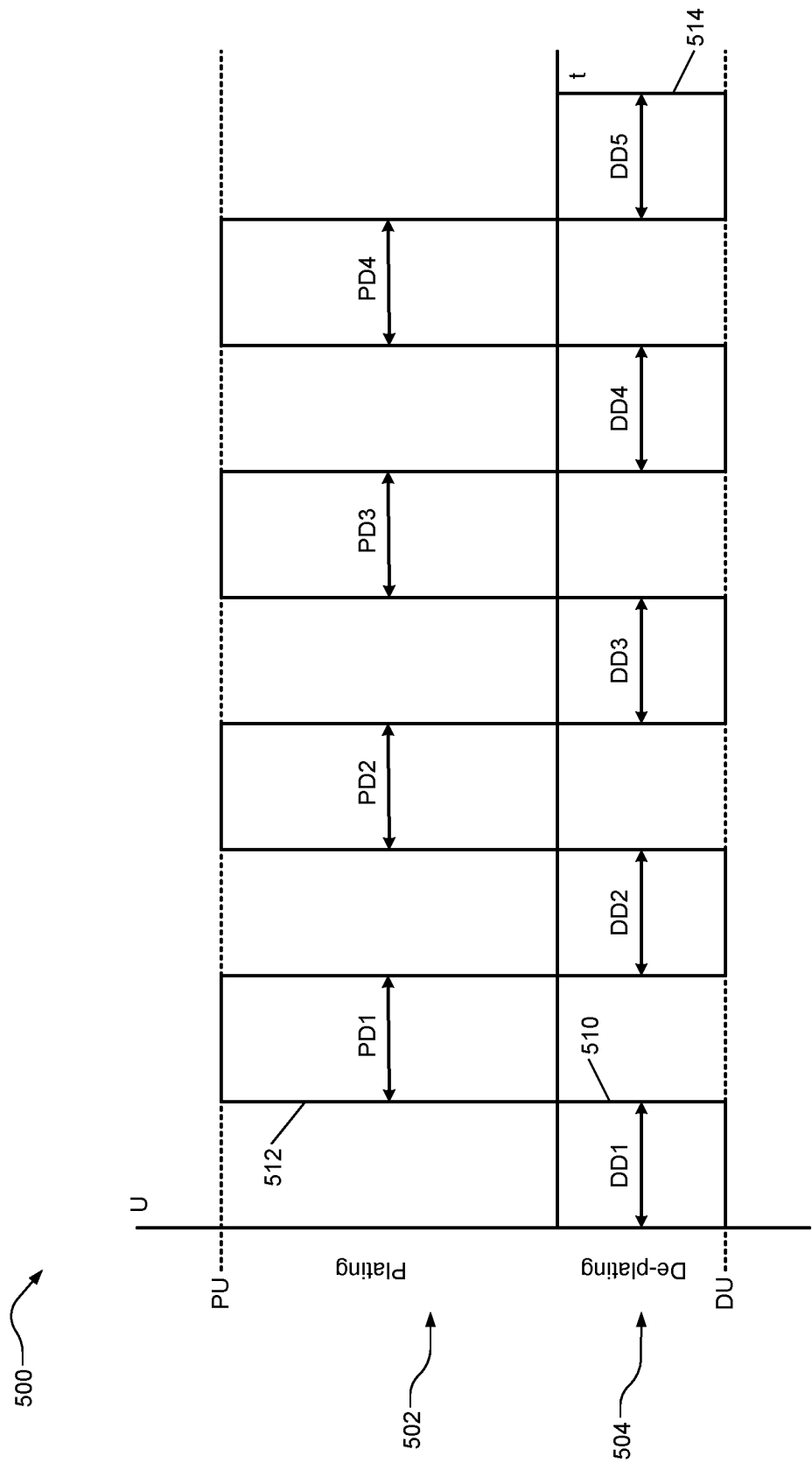


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2021/045967

A. CLASSIFICATION OF SUBJECT MATTER**C25D 5/18(2006.01)i; C25D 17/00(2006.01)i; C25D 21/00(2006.01)i; C25D 17/14(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C25D 5/18(2006.01); C25D 5/48(2006.01); C25D 7/04(2006.01); C25F 1/00(2006.01); H01L 21/288(2006.01); H01L 21/302(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: cleaning, residual, electroplating, plating cup, contact ring, waveform, lip seal, voltage signal, waveform, cycle, pulse

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013-0256146 A1 (CHUA et al.) 03 October 2013 (2013-10-03) paragraphs [0064]-[0065], [0067], [0081], [0093], [0101], claims 10, 27, 30, and figures 4, 7	1-20
Y	US 2002-0046952 A1 (GRAHAM et al.) 25 April 2002 (2002-04-25) claim 32	1-20
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Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“O” document referring to an oral disclosure, use, exhibition or other means

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“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

06 December 2021

Date of mailing of the international search report

08 December 2021

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon
35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

LEE, Eon Su

Telephone No. +82-42-481-8539

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2021/045967

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

International application No.

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