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(54) **MEANS TO ELIMINATE BUBBLE ENTRAPMENT DURING ELECTROCHEMICAL PROCESSING OF WORKPIECE SURFACE**

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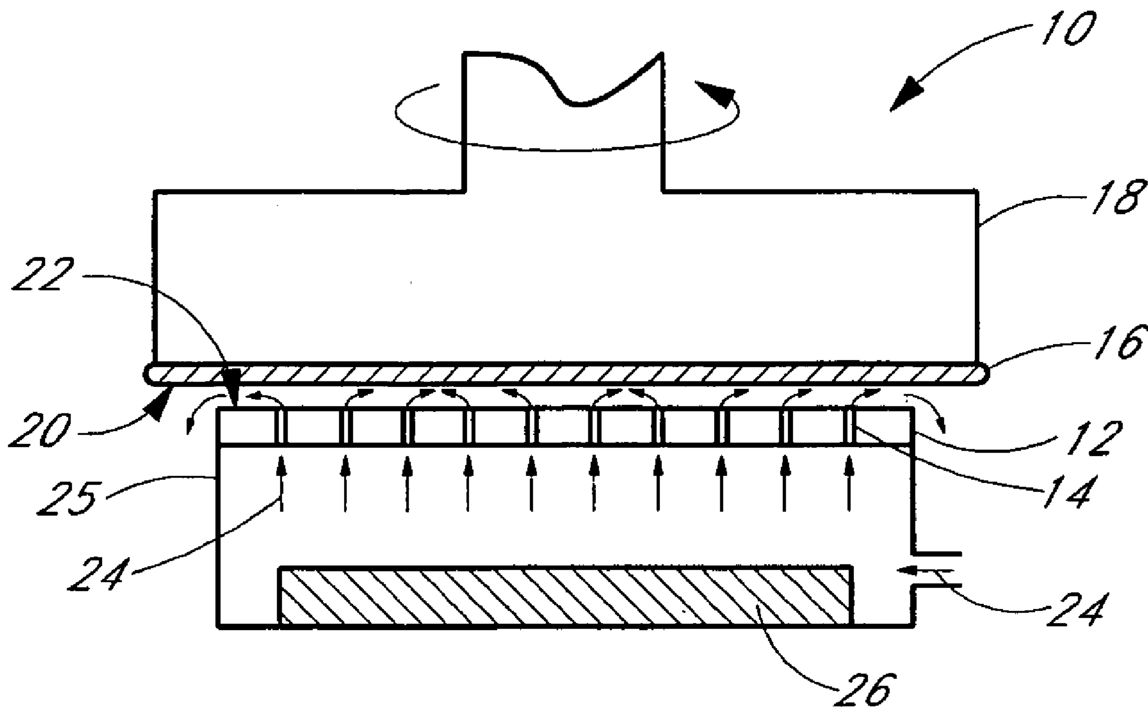
(52) **U.S. Cl.** **205/157**

(57) **ABSTRACT**

Methods and systems are provided to eliminate bubble entrapment during electrochemical processing of a substrate, wherein a rigid plate with fluid openings allow process solution to flow between the front surface of the substrate and an electrode. The plate includes a protruding region. In operation, the protruding region causes a raised solution surface to touch the front surface of the wafer prior to complete immersion of the substrate in the solution. In other embodiments, the raised surface of the solution can be provided by applying pressure to a flexible pad or other workpiece surface influencing device (WSID).



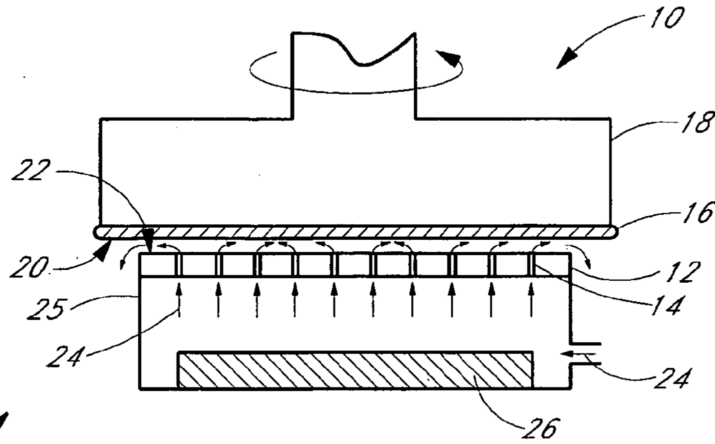


FIG. 1

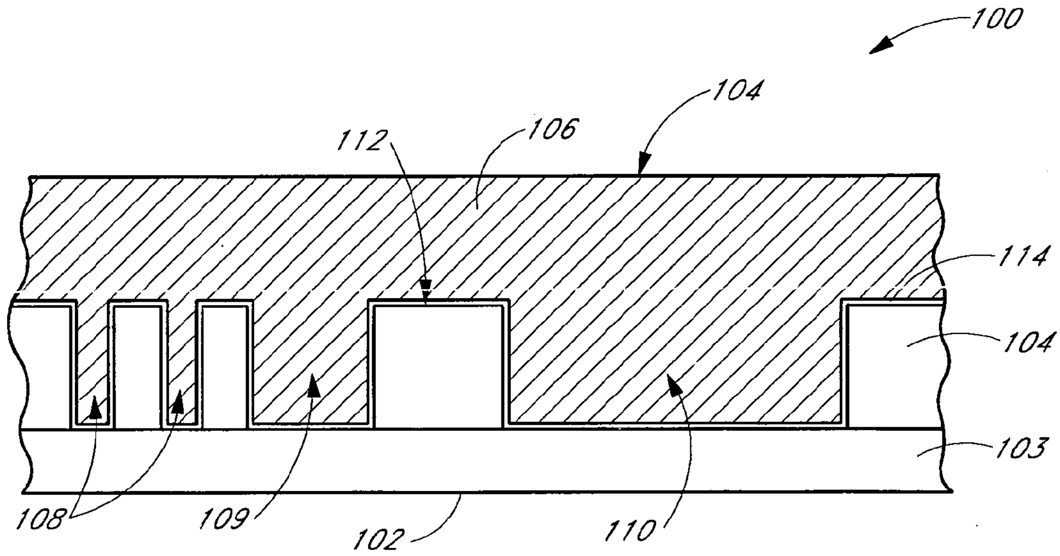


FIG. 2

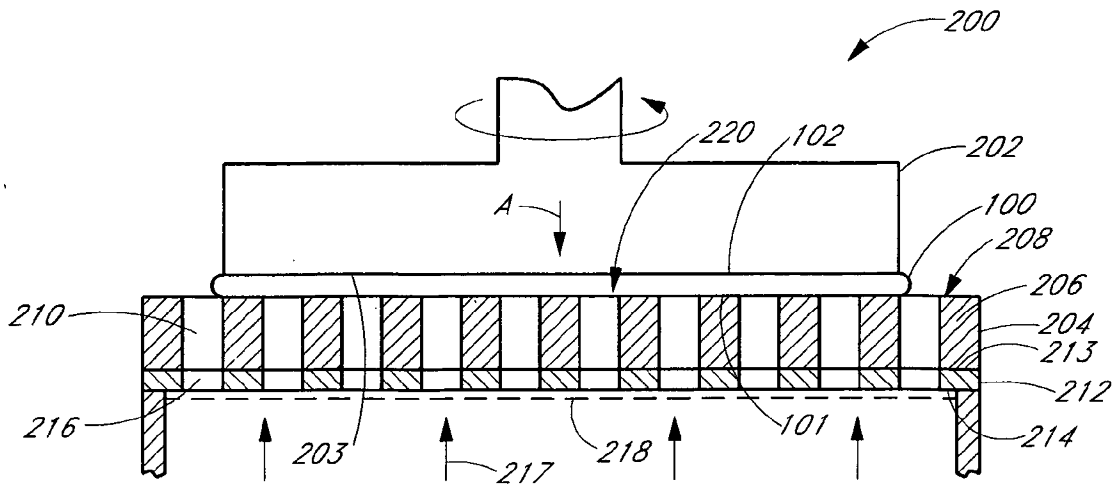


FIG. 3

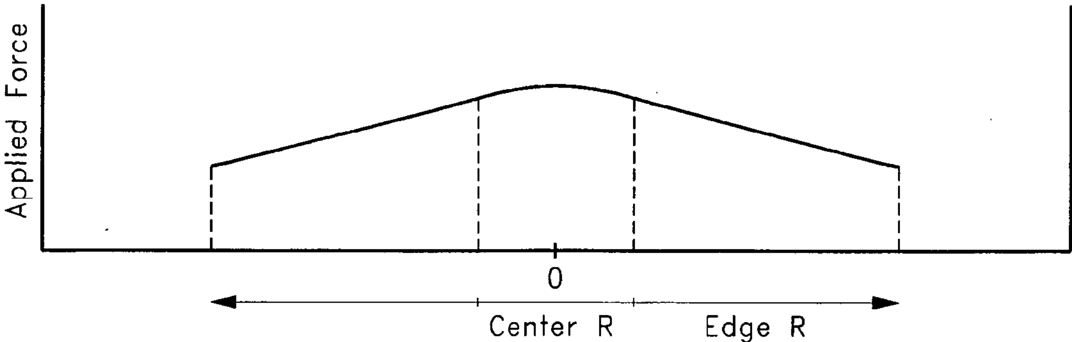


FIG. 4

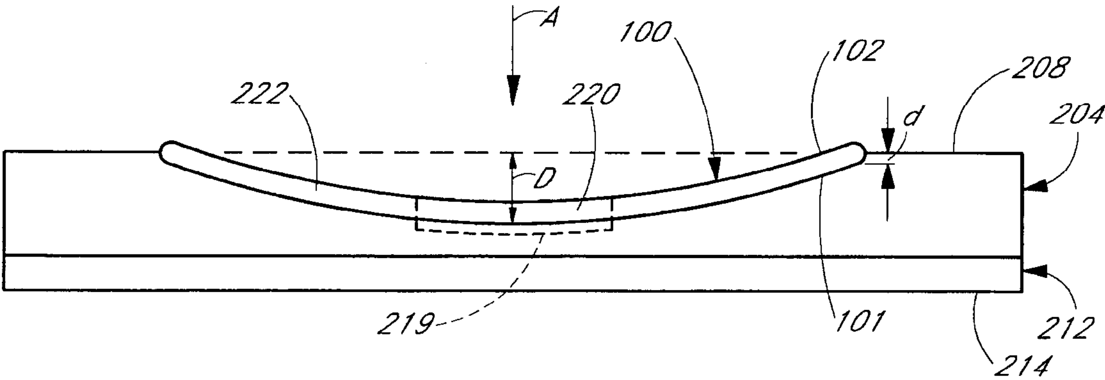


FIG. 5

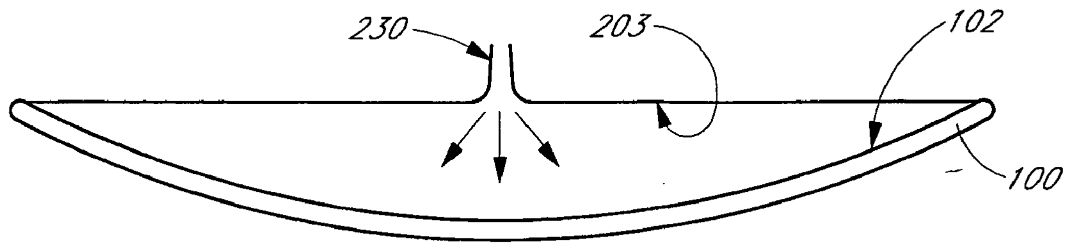


FIG. 6A

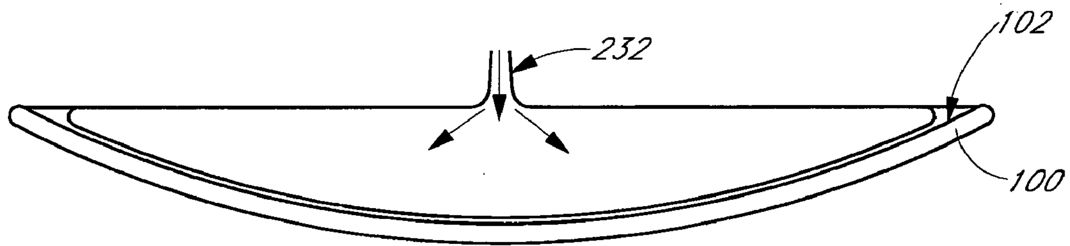


FIG. 6B

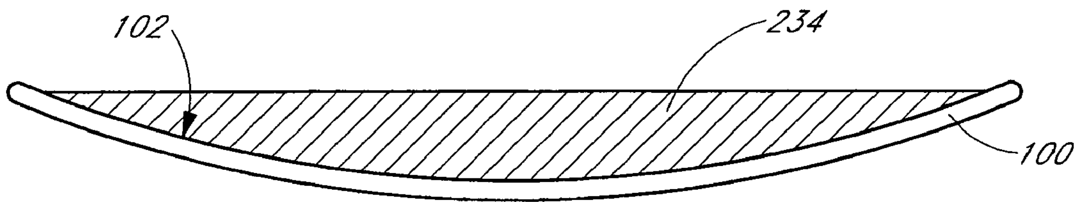


FIG. 6C

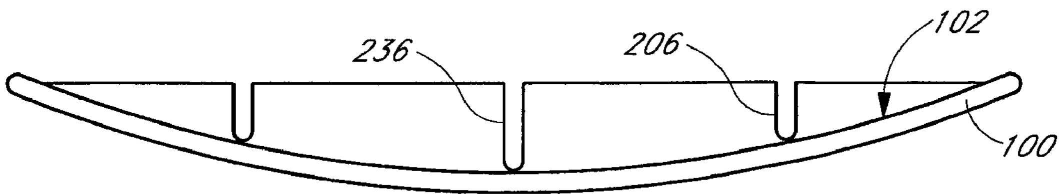


FIG. 6D

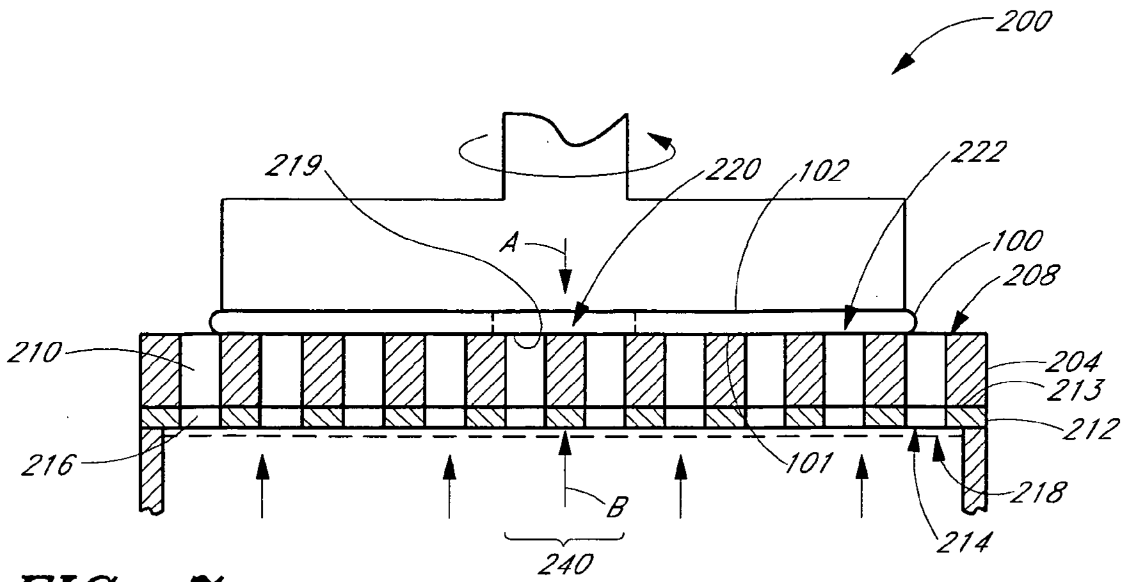


FIG. 7

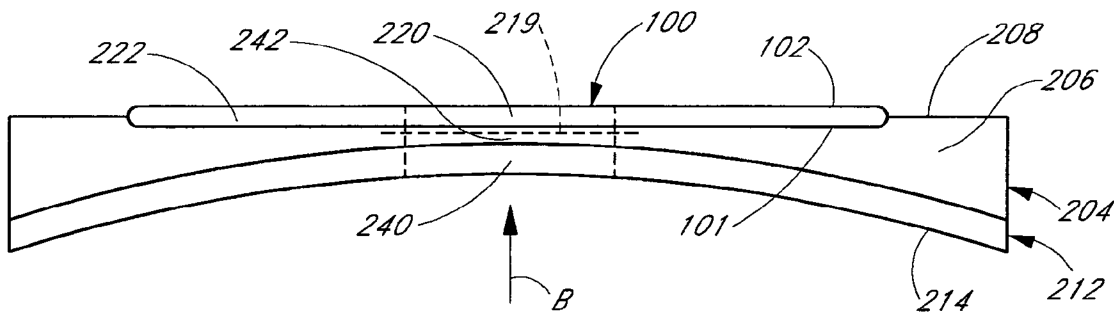


FIG. 8

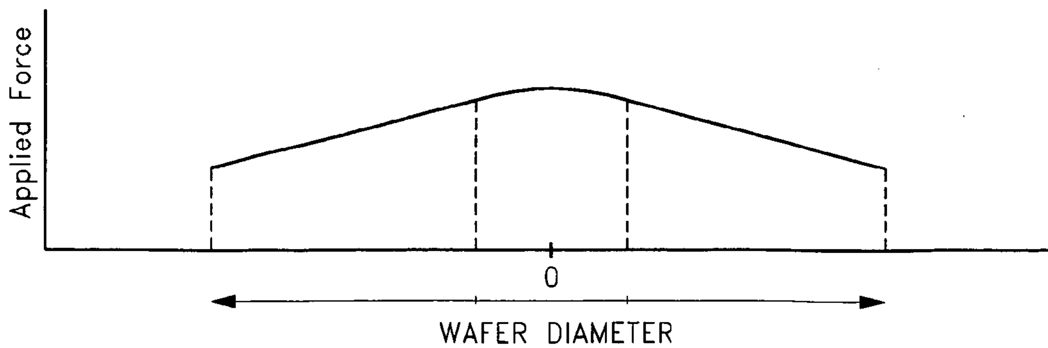


FIG. 9

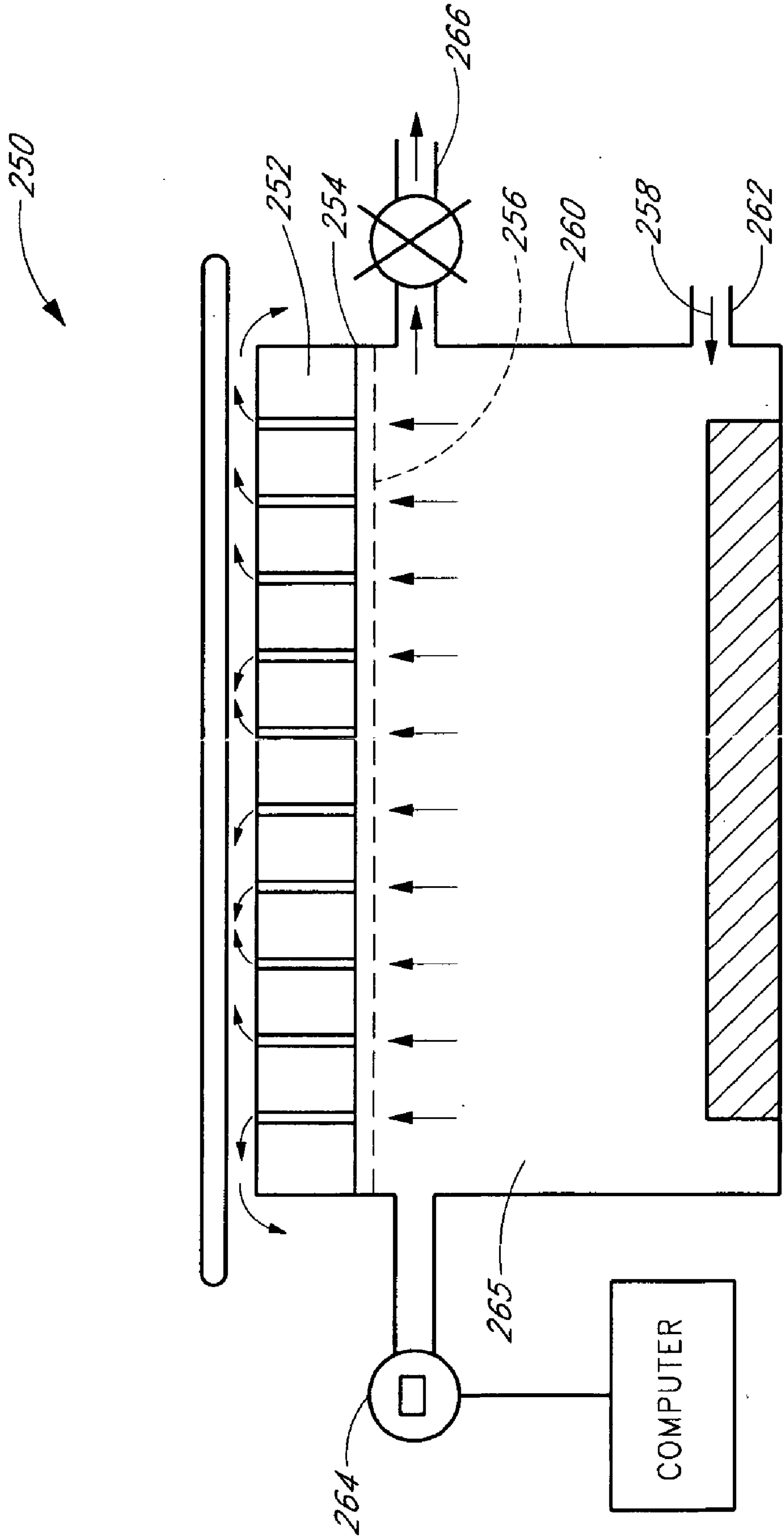


FIG. 10

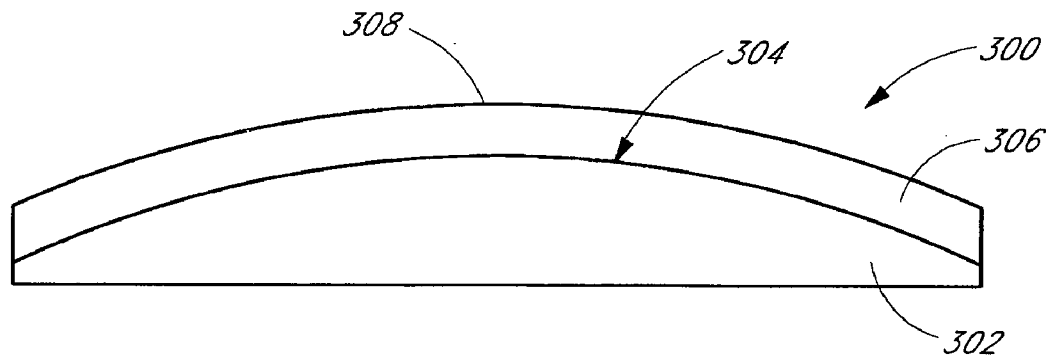


FIG. 11A

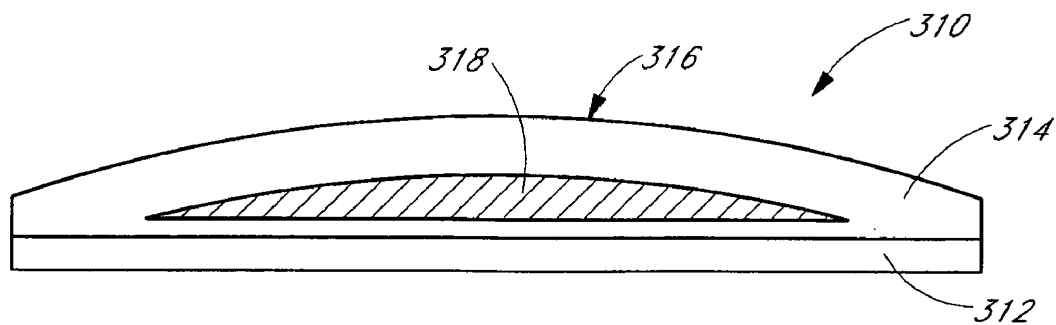


FIG. 11B

FIG. 12A

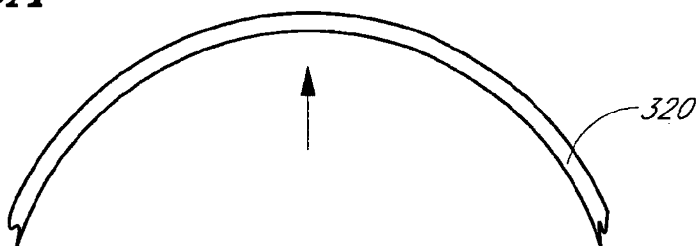


FIG. 12B

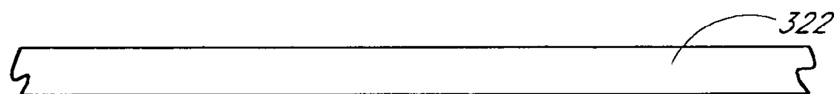


FIG. 13A

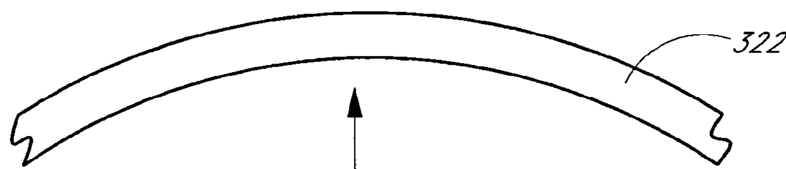


FIG. 13B

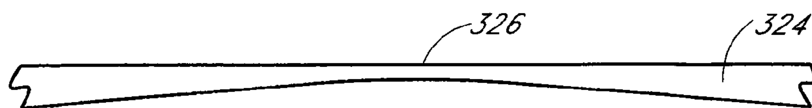


FIG. 14A

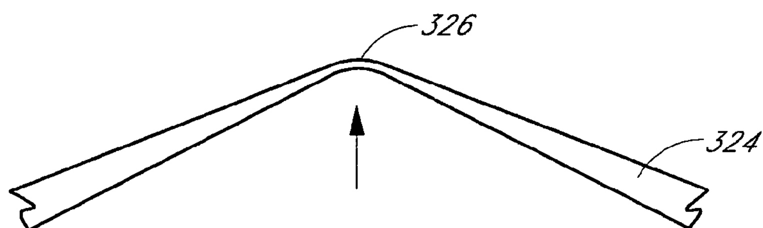


FIG. 14B

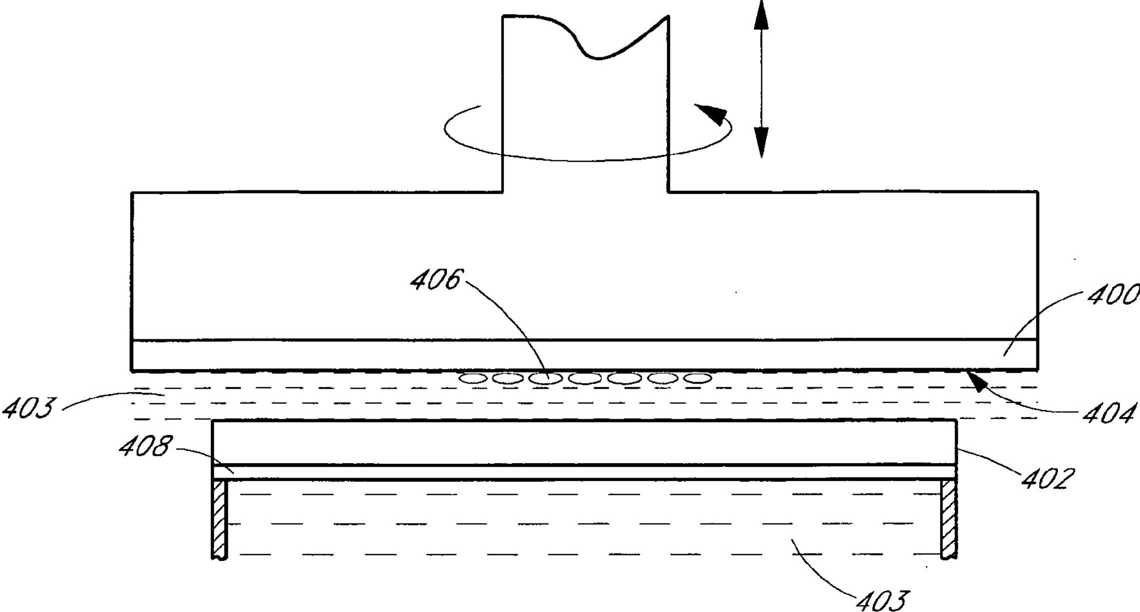


FIG. 15A

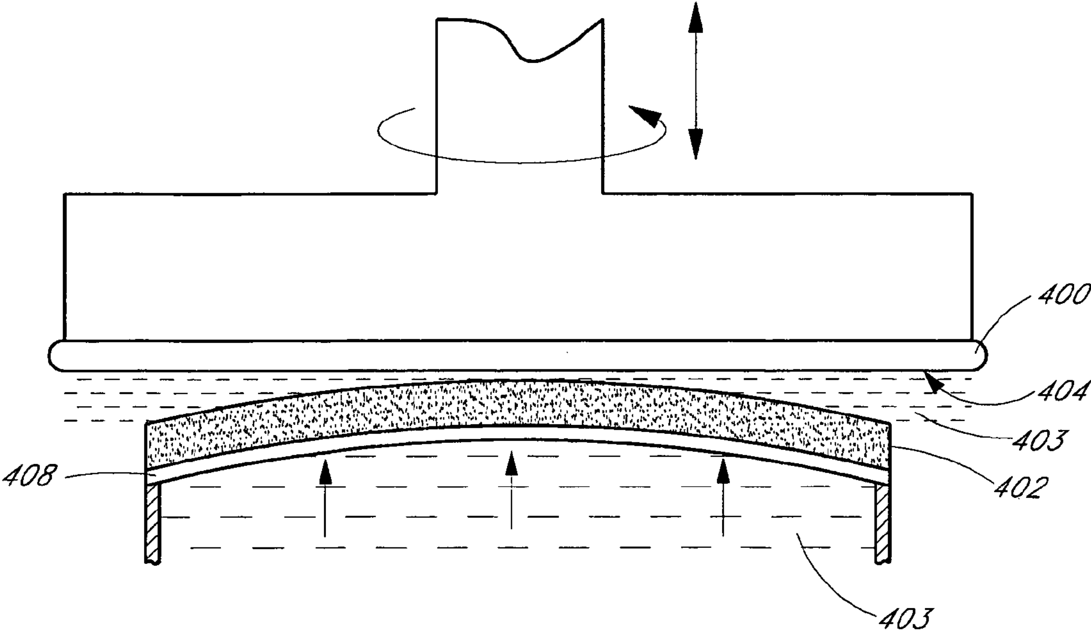


FIG. 15B

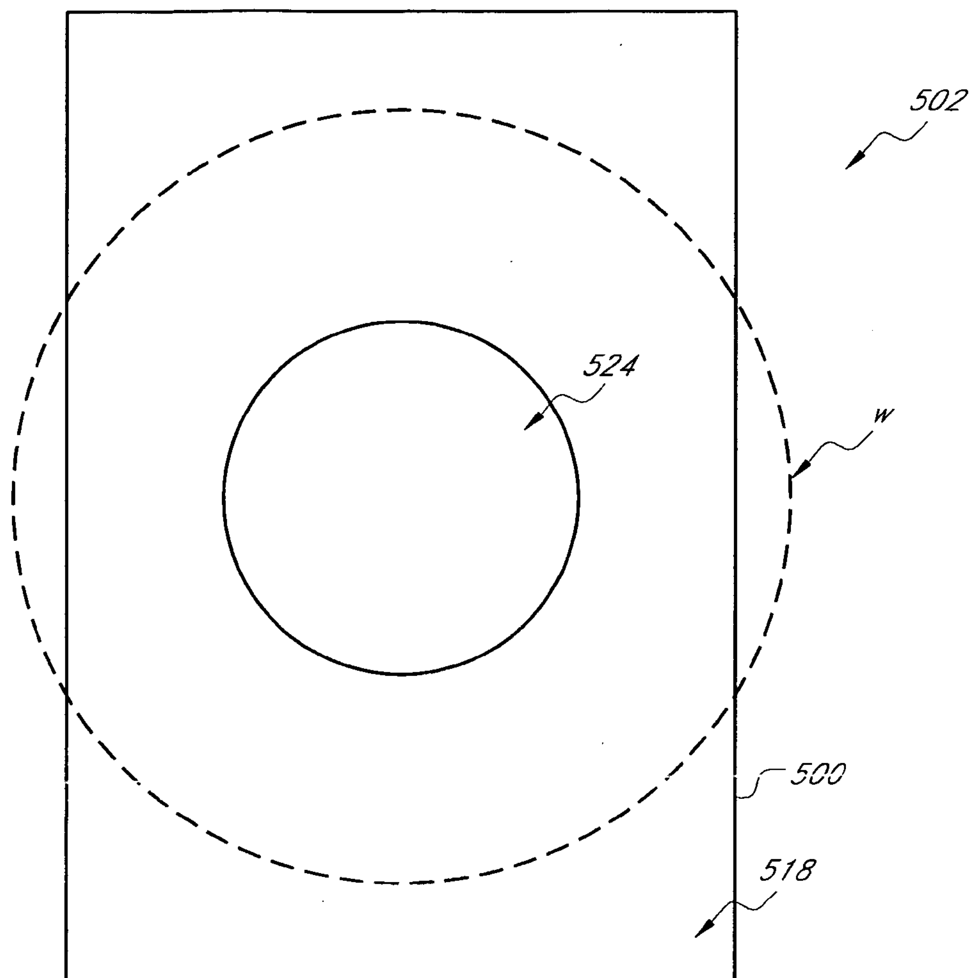


FIG. 16A

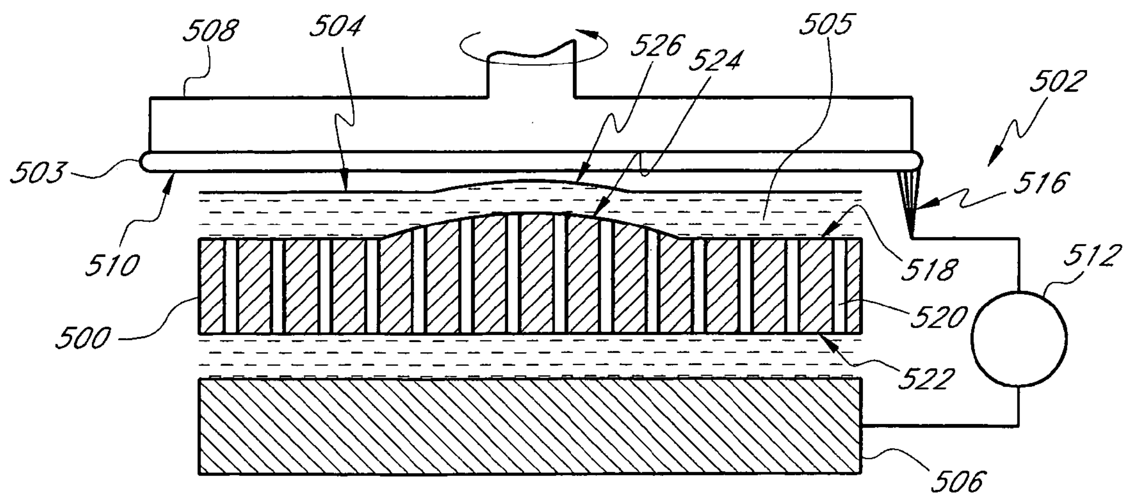


FIG. 16B

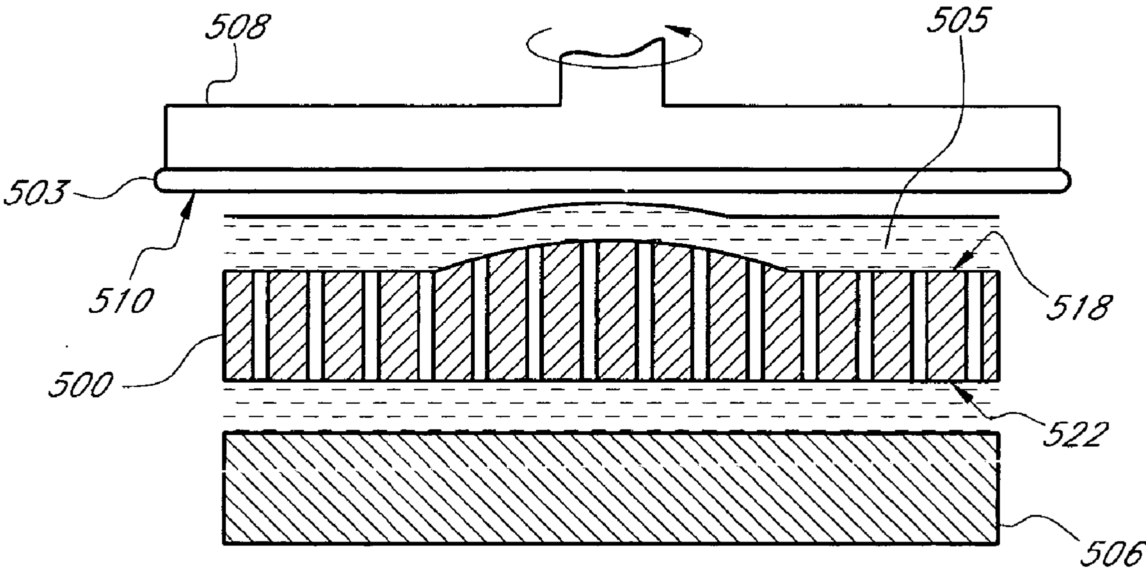


FIG. 16C

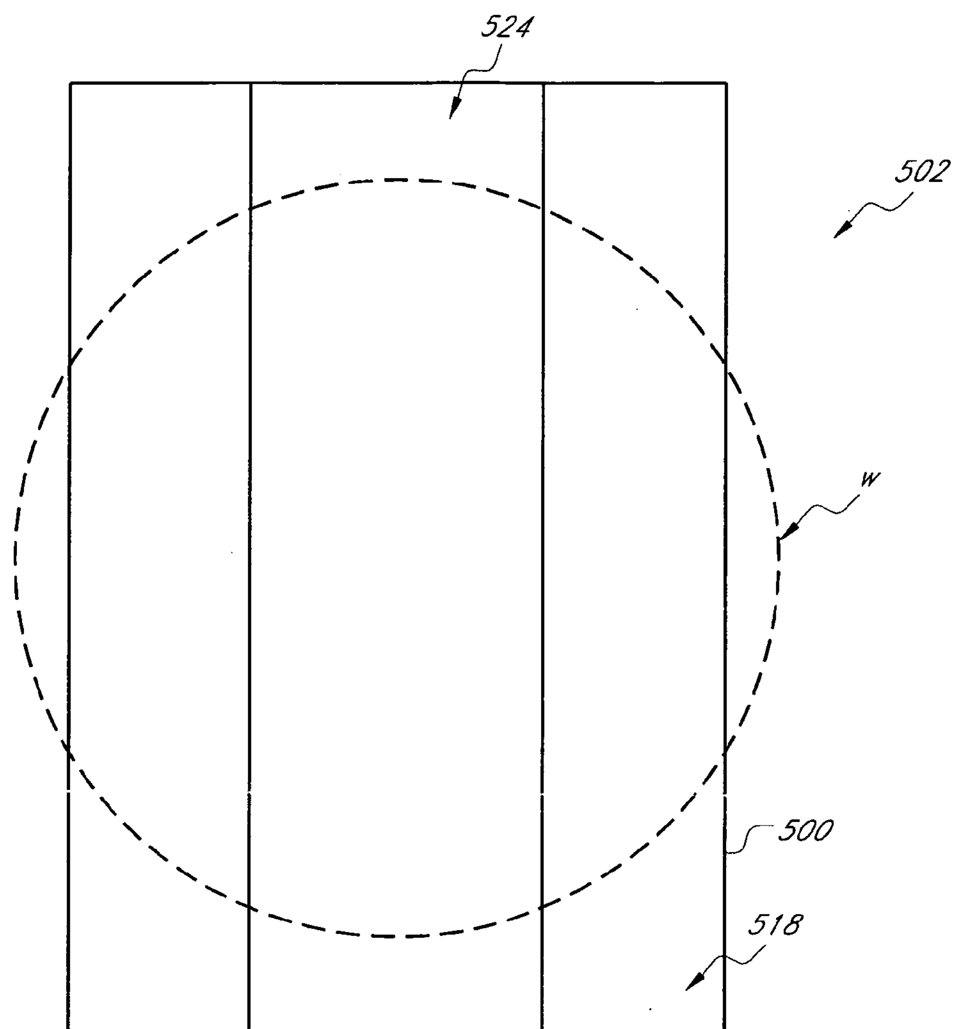


FIG. 17A

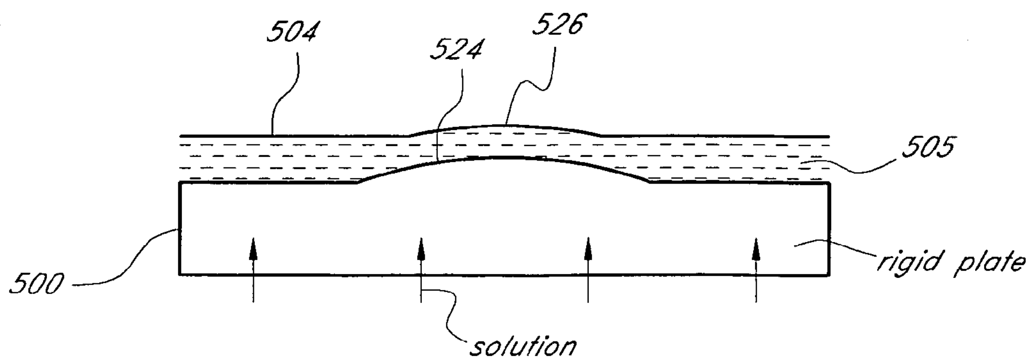


FIG. 17B

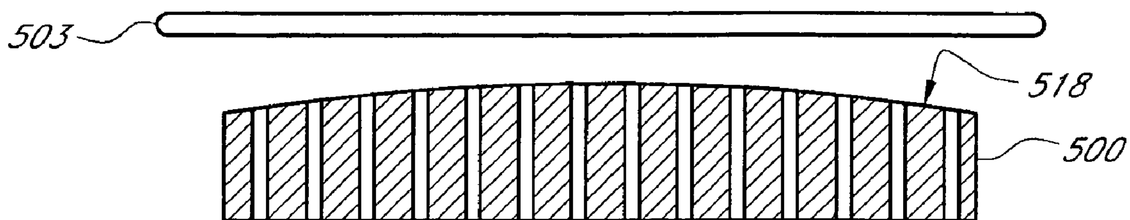


FIG. 18A

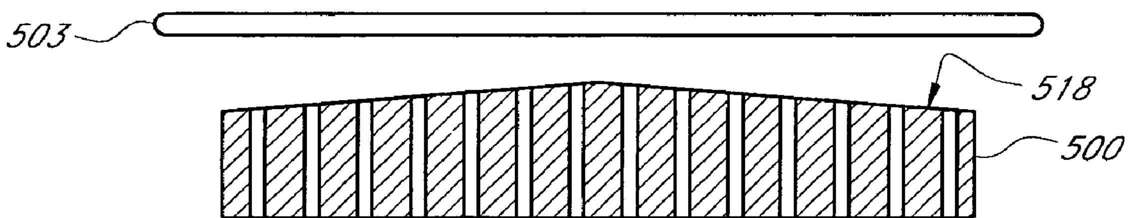


FIG. 18B

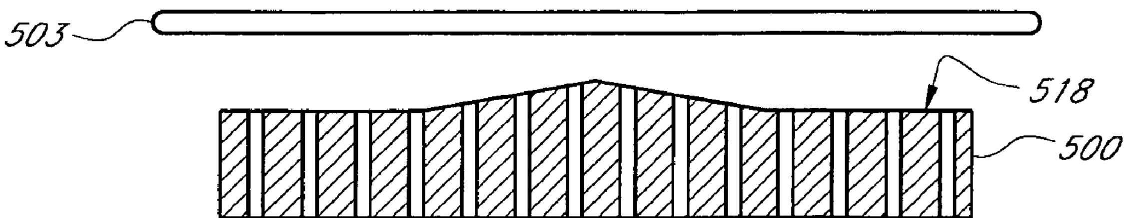


FIG. 18C

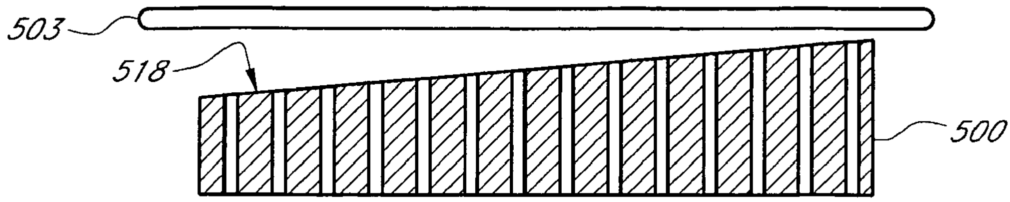


FIG. 18D

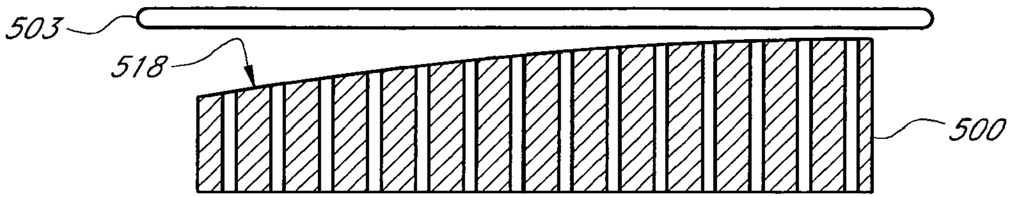


FIG. 18E

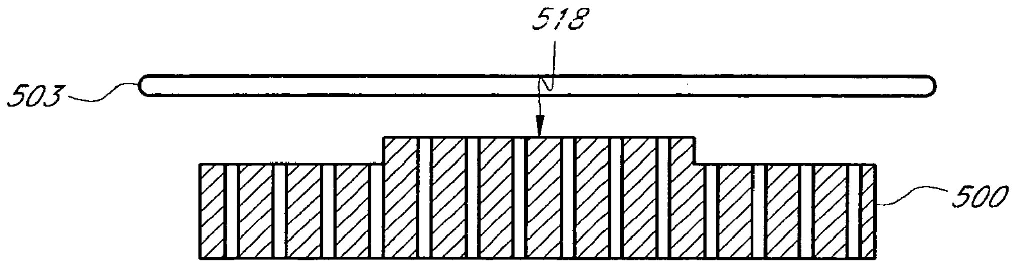


FIG. 18F

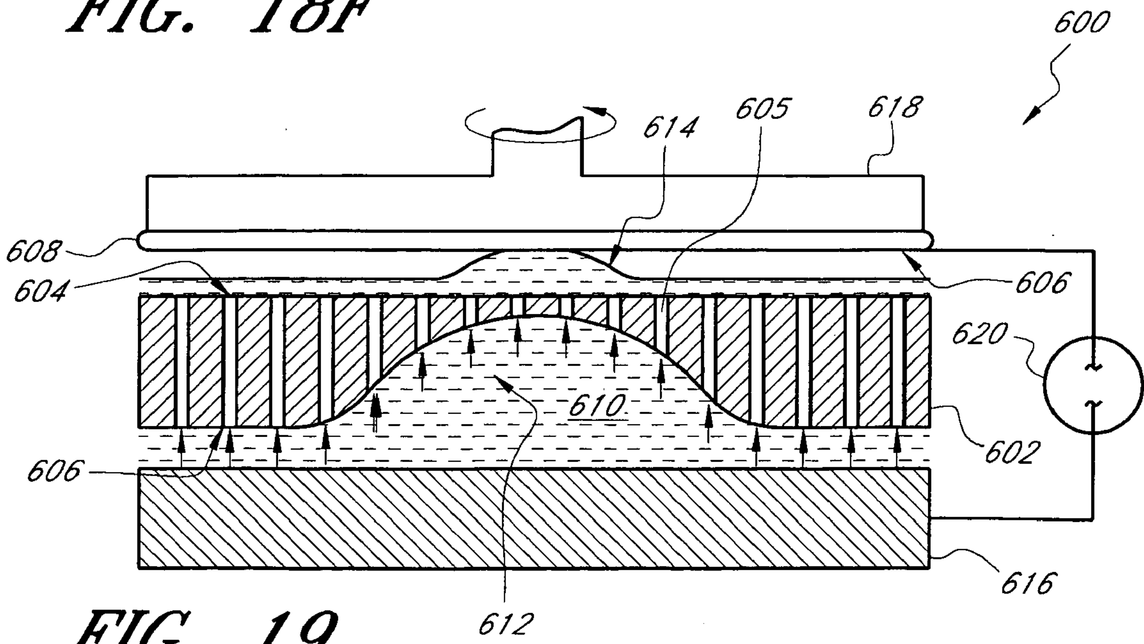


FIG. 19

MEANS TO ELIMINATE BUBBLE ENTRAPMENT DURING ELECTROCHEMICAL PROCESSING OF WORKPIECE SURFACE

REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit under 35 U.S.C. § 119(e) of U.S. provisional application No. 60/635,112, filed Nov. 19, 2004, and is a continuation-in-part (CIP) of U.S. application Ser. No. 10/816,340, filed Mar. 31, 2004 (attorney docket No. ASMNUT.2DVCP1; NT-295), which is a CIP of U.S. application Ser. No. 10/252,793, filed May 23, 2002 (attorney docket No. ASMNUT.041DV1; NT-102D), which is a divisional of U.S. application Ser. No. 10/511,278, filed Feb. 23, 2000 (issued as U.S. Pat. No. 6,413,388, issued Jul. 2, 2002). This Application also claims priority to U.S. provisional application No. 60/462,919, filed Apr. 4, 2003 by way of application Ser. No. 10/816,340.

FIELD

[0002] The present invention generally relates to semiconductor integrated circuit technology and, more particularly, to a device for electrotreating or electrochemically processing a workpiece.

BACKGROUND

[0003] Conventional semiconductor devices such as integrated circuits (IC) generally comprise a semiconductor substrate, usually a silicon substrate, and a plurality of conductive material layers separated by insulating material layers. Conductive material layers, or interconnects, form the wiring network of the integrated circuit. Each conductor in the wiring network is isolated from the neighboring conductors by the insulating layers, also known as interlayer or interlevel dielectrics (ILDs). One dielectric material that is commonly used in silicon integrated circuits is silicon dioxide, although there is now a trend to replace at least some of the standard dense silicon dioxide material in IC structures with low-k dielectric materials such as organic, inorganic, spin-on and CVD candidates.

[0004] Conventionally, IC interconnects are formed by filling a conductor such as copper in features or cavities etched into the dielectric interlayers by a metallization process. Copper is becoming the preferred conductor for interconnect applications because of its low electrical resistance and good electromigration property. The preferred method of copper metallization is electroplating. In an integrated circuit, multiple levels of interconnect networks laterally extend with respect to the substrate surface. Interconnects formed in sequential layers can be electrically connected using features such as vias or contacts. In a typical interconnect fabrication process, first an insulating layer is formed on the semiconductor substrate, and patterning and etching processes are then performed to form features or cavities such as trenches, vias, and pads etc., in the insulating layer. Then copper is electroplated to fill all the features. In such electroplating processes, the wafer is placed on a wafer carrier and a cathodic (−) voltage with respect to an electrode is applied to the wafer surface while a deposition electrolyte wets both the wafer surface and the electrode.

[0005] Once the plating is over, a material removal step such as a chemical mechanical polishing (CMP) process step is conducted to remove the excess copper layer, which is also called copper overburden, from the top surfaces (also called the field region) of the workpiece, leaving copper only in the features. An additional material removal step is then employed to remove the other conductive layers such as the barrier/glue layers that are on the field region. Fabrication in this manner results in copper deposits within features that are physically as well as electrically isolated from each other. Another important material removal technique, especially for wafers with low-k dielectrics, is the electrochemical polishing (electropolishing) or electrochemical etching process. In electropolishing, an anodic voltage is applied to the wafer surface with respect to a cathodic electrode in an electropolishing electrolyte. Excess conductor, such as overburden copper is removed without physically touching and stressing the interconnect structure. It is possible to perform electropolishing on a wafer surface while physically touching the surface with a pad material. Such techniques are called electrochemical mechanical polishing or etching methods.

[0006] One technique used for planar deposition and removal of materials is collectively referred to as Electrochemical Mechanical Processing (ECMPR), which term is used to include Electrochemical Mechanical Deposition (ECMD) processes as well as Electrochemical Mechanical Polishing (ECMP) (also known as Electrochemical Mechanical Etching (ECME)). It should be noted that in general both ECMD and ECMP processes are referred to as electrochemical mechanical processing (ECMPR) since both involve electrochemical processes and physical touching of, or mechanical action on, the workpiece surface. All electrochemical techniques for material deposition and removal may be referred to as "electrotreatment."

[0007] In one aspect of an ECMPR method, a workpiece-surface-influencing-device (WSID) such as a mask, pad or a sweeper is used during at least a portion of the electrotreatment process when there is physical contact or close proximity and relative motion between the workpiece surface and the WSID. Descriptions of various planar deposition and planar etching methods and apparatus can be found in the following patents and pending applications, all commonly owned by the assignee of the present invention. U.S. Pat. No. 6,176,992, issued Jan. 23, 2001, entitled "Method and Apparatus for Electrochemical Mechanical Deposition." U.S. Pat. No. 6,534,116, issued Mar. 18, 2003, entitled "Plating Method and Apparatus that Creates a Differential Between Additive Disposed on a Top Surface and a Cavity Surface of a Workpiece Using an External Influence," filed on Dec. 18, 2000 and U.S. Pat. No. 6,951,551, issued Jul. 26, 2005, entitled "Plating Method and Apparatus for Controlling Deposition on Predetermined Portions of a Workpiece". These methods can deposit metals in and over cavity sections on a workpiece in a planar manner. The disclosures of these patents are incorporated herein by reference. They also have the capability of yielding novel structures with excess amount of metals over the features irrespective of their size, if desired.

[0008] In ECMD methods, the surface of the workpiece is wetted by the electrolyte and is rendered cathodic with respect to an electrode, which is also wetted by the electrolyte. During ECMD, the wafer surface is pushed against or in close proximity to the surface of the WSID or vice versa when relative motion between the surface of the workpiece

and the WSID results in sweeping of the workpiece surface. Planar deposition is achieved due to this sweeping action as described in the above-cited patent applications.

[0009] In ECMP methods, the surface of the workpiece is wetted by the electropolishing electrolyte or etching solution, but the polarity of the applied voltage is reversed, thus rendering the workpiece surface more anodic compared to the electrode. A WSID touches the surface during removal of the layer from the workpiece surface.

[0010] Very thin planar films can be obtained by first depositing a planar layer using an ECMD technique and then applying an ECMP technique on the planar film in the same electrolyte by reversing the applied voltage. Alternatively, the ECMP step can be carried out in a separate machine and a different etching electrolyte or electropolishing solution. This way the thickness of the deposit may be reduced in a planar manner. In fact, an ECMP technique may be continued until all the metal on the field regions is removed. It should be noted that a WSID may or may not be used during the electroetching process since substantially planar etching can be achieved either way as long as the starting layer surface is planar.

[0011] **FIG. 1** is a schematic illustration of an exemplary conventional ECMPR system **10** used for processing wafers. In **FIG. 1**, a WSID **12** having openings **14** in it, is disposed in close proximity of a workpiece or wafer **16** to be processed. The wafer **16** is a silicon wafer to be plated with a conductor metal, preferably copper or copper alloy. The wafer may or may not have a previously plated copper layer on it. The wafer **16** is retained by a wafer carrier **18** so as to position front surface **20** of the wafer against top surface **22** of the WSID **12**. The openings **14** are designed to assure uniform deposition of copper from an electrolyte solution **24**, depicted by arrows, onto the front surface **22**, or uniform electropolishing from the front surface **22**. The top surface **22** of the WSID **12** facing the front surface **20** of the wafer is used as the sweeper and the WSID **12** itself establishes appropriate electrolyte flow and electric field flow to the front surface **22** for globally uniform deposition or electroetching. Such an ECMPR system **10** also includes an electrode **26**, which is immersed in the electrolyte **24**. The electrolyte solution **24** is contained in a process chamber **25**. The electrolyte **24** is in fluid communication with the electrode **26** and the front surface **20** of the wafer **16** through the openings **14** in the WSID **12**.

[0012] It should be noted that the electrode **26** is only schematically shown in **FIG. 1**. In actual practice, the electrodes are shielded with a particle filter and other precautions are taken to avoid bubble accumulation under the WSID and to avoid particles generated on the electrode **26** to reach the surface of the wafer **16**. An exemplary copper electrolyte may be copper sulfate solution with additives such as accelerators, suppressors, leveler, chloride and such, which are commonly used in the industry. The top surface **22** of the WSID **12** sweeps the front surface **20** the wafer while an electrical potential is established between the electrode **26** and the front surface **20** of the wafer. For deposition of a planar film such as copper, the front surface of the wafer **12** is made more cathodic (negative) compared to the electrode **26**, which becomes the anode. For electropolishing in the same system the wafer surface is made more anodic than the electrode.

[0013] U.S. application Ser. No. 09/960,236 filed on Sep. 20, 2001, entitled "Mask Plate Design," assigned to the assignee of the present invention, discloses various WSID embodiments. Also, U.S. application Ser. No. 10/155,828 filed on May 23, 2002, entitled Low Force Electrochemical Mechanical Deposition Method and Apparatus, also assigned to the same assignee of the present invention teaches means of applying force to the wafer surface by a WSID for ECMPR.

[0014] To this end, there is still a need for further development of high-throughput electrochemical processes and apparatus that can yield deposits with less defect and high yield, and methods and apparatus that provide more uniform material removal from workpiece surfaces.

SUMMARY OF THE INVENTION

[0015] In accordance with one aspect of the invention, a method is provided for immersing a surface of a wafer in a solution for processing the surface. The method included flowing the solution through openings of a rigid plate having a protruding region to form a raised solution surface over the protruding region. A selected portion of the wafer surface is contacted with the raised solution surface. The wafer surface is immersed fully into the solution.

[0016] In accordance with another aspect of the invention, a system is provided for eliminating bubble entrapment under a surface of a wafer when the surface is immersed into a process solution to process the surface of a wafer. The system includes a rigid plate, having a protruded region and fluid openings. The plate is configured such that when the solution flows through the rigid plate, a raised solution surface forms over the protruded region. The system also includes a moving mechanism configured to move the wafer such that, as the wafer is moved towards the solution, a selected portion of the surface of the wafer contacts the raised solution surface before immersing the surface of the wafer fully into the solution.

[0017] In accordance with another aspect of the invention, a method of processing a conductive surface of a wafer using a process solution is provided. The method includes flowing the solution through openings of a plate having a protruding region to form a raised solution surface over the protruding region. A selected portion of the conductive surface is contacted with the raised solution surface. The conductive surface is fully immersed into the solution and the conductive surface is processed.

[0018] In accordance with another aspect of the invention, a system is provided for electroprocessing a conductive surface of a wafer using a process solution. The system includes an electrode configured to be placed in the process solution. A rigid plate, having a protruded region and fluid openings, is configured to be immersed in the solution and positioned between the electrode and the conductive surface. The plate is configured such that as the solution flows through the rigid plate, a raised solution surface forms over the protruded region. A moving mechanism is configured to move the wafer such that as the wafer moves towards the solution, a selected portion of the conductive surface contacts the raised solution surface before immersing the surface fully into the solution.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] **FIG. 1** is a schematic illustration of an exemplary conventional electrochemical mechanical processing system;

[0020] **FIG. 2** is an exemplary portion of a wafer surface with a planar conductive layer;

[0021] **FIG. 3** is a schematic illustration of an electrochemical mechanical processing system where a force is applied to the back surface of the wafer;

[0022] **FIG. 4** is a graph showing the distribution of the applied force over the wafer surface as the force is applied in the manner shown in **FIG. 3**;

[0023] **FIG. 5** is a schematic illustration of interaction between a wafer front surface and the workpiece surface influencing device (WSID) as the center region of the wafer back surface is pressed against the WSID;

[0024] **FIGS. 6A-6D** are schematic illustrations of various force sources to apply force on the back surface of a wafer;

[0025] **FIG. 7** is a schematic illustration of the electrochemical mechanical processing system where a force is applied to the back surface of the workpiece surface influencing device;

[0026] **FIG. 8** is a schematic illustration of the interaction between a wafer front surface and the workpiece surface influencing device as the surface of the workpiece surface influencing device is pressed against the center region of the wafer front surface;

[0027] **FIG. 9** is a graph showing the distribution of the applied force over the wafer surface as the force is applied in the manner shown in **FIG. 8**;

[0028] **FIG. 10** is a schematic illustration of an embodiment of a smart electrochemical mechanical processing system where a force is applied to the back surface of the workpiece surface influencing device;

[0029] **FIG. 11A-11B** are schematic illustrations of various combinations of support plate and workpiece influencing device having convex profiles;

[0030] **FIGS. 12A-14B** are schematic illustrations of various plates having varying thickness and resulting degrees of bowing under applied pressure;

[0031] **FIG. 15A-15B** are schematic illustrations of removing entrapped bubbles by bowing the WSID towards the center of a wafer during a process;

[0032] **FIG. 16A** is a schematic illustration of the relative positions of a wafer and an embodiment of a rigid plate having a protruding region in top view;

[0033] **FIG. 16B** is a schematic illustration of an alternative electrochemical mechanical processing system including the rigid plate shown in **FIG. 16A**, wherein the surface of the wafer contacts a raised solution surface formed over the protruding region;

[0034] **FIG. 16C** is a schematic illustration of system shown in **FIG. 16B**, after the surface of the wafer has been moved to be immersed into the solution;

[0035] **FIG. 17A-17B** are schematic illustrations of the relative positions of a wafer and another embodiment of a rigid plate having a protruding region in top view and side views;

[0036] **FIGS. 18A-18F** are schematic illustrations of various embodiments of rigid plates; and

[0037] **FIG. 19** is a schematic illustration of an electrochemical mechanical processing system including an embodiment of a rigid plate having a cavity.

DETAILED DESCRIPTION

[0038] The preferred embodiments will now be described using the example of fabricating interconnects for integrated circuit applications. It should, however, be recognized that present invention can be used to operate on any workpiece with various electroplated materials such as Au, Ag, Ni, Pt, Pd, Fe, Sn, Cr, Pb, Zn, Co and their alloys with each other or other materials, for many different applications such as packaging, flat panel displays, magnetic heads and such. In the examples provided below, the example material that is electroplated or electropolished will be copper, but it will be understood that other materials can instead be used.

[0039] In electrochemical mechanical processing (ECMPR) such as electrochemical mechanical deposition (ECMD) and electrochemical mechanical polishing (ECMP) or etching (ECME), since the mechanical action on wafer surface assists planarization of the surface of the wafer, uniformity of this mechanical action is important to obtain uniform process results, such as a uniformly planarized wafer surface.

[0040] **FIG. 2** shows an exemplary portion of a substrate or workpiece **100** such as a wafer having a front and a back surface **101** and **102**. The wafer **100** comprises a semiconductor substrate **103** and an insulation or dielectric layer **104** on which a planar conductive layer **106** such as a planar copper layer is formed in accordance with embodiments described herein. The copper layer **106** maintains a uniform overburden thickness over the entire wafer surface. The copper layer **106** is plated to fill features in the dielectric layer using an ECMD process in which the wafer surface is mechanically swept with a pad mask or WSID during plating. Further, in an exemplary process the copper layer **106** may be electropolished using ECMP. Before the plating process, the dielectric layer **104** is processed to form features such as vias **108** and trenches **109** and **110**. The features **108**, **109** and **110** and top surface **112** of the dielectric layer, which is often referred to as a field region or surface, are lined with one or more conductive layers such as a barrier layer **114** and a copper seed layer (not shown) before forming the copper layer **106**. Interconnects are formed when the copper layer **106** is removed down to the level of field regions **112** and the barrier layer **144** covering the field regions **112** is also removed. Overall efficiency of this process depends on the thickness uniformity of the copper layer **106** over the entire wafer surface. As will be described more fully below, the present invention provides a method of forming a planar conductive layer while maintaining its thickness uniformity.

[0041] During ECMD and ECMP processes, wafers are typically rotated and may additionally be moved laterally. As can be appreciated, on a rotating wafer surface the linear

velocity due to rotation is zero right at the center of the wafer and it increases linearly towards the edge of the wafer in proportion to the distance to the center. The linear velocity is highest right at the edge of the wafer and it is given by the relationship: $V=(2\pi rR/60)$ cm/second, where "r" is the radius of the wafer in centimeters and "R" is the rotation in revolution per minute (rpm). As can be seen from this relationship, velocity "V" increases as the radius of the wafer "r" increases. Mechanical action delivered by a WSID (see **FIG. 1**) onto wafer surface increases with the relative velocity between the WSID and wafer surface as well as the force applied onto the surface by the WSID. Therefore, in an electrochemical mechanical process, in one method, the uniformity of the mechanical action on the wafer surface may be improved by keeping the relative velocity between the WSID and the whole wafer surface substantially the same while keeping the force applied by the WSID onto the wafer surface substantially constant. An example of this method can be found in U.S. patent application Ser. No. 10/288,558, entitled Electrochemical Mechanical Deposition with Advancible Sweeper, filed Nov. 4, 2002. In that application, a belt-type WSID is used for ECMD and ECMP processes. The belt WSID or the wafer may be moved linearly. The high linear velocity of the belt WSID is constant everywhere on the wafer surface as long as the velocity on the wafer surface due to rpm is much lower than the linear velocity of the belt WSID. For example, if the wafer is rotated with 5 rpm and belt linear velocity is 100 cm/sec, the linear velocity at the edge of the wafer due to rpm would be about 5 cm/sec for an 8" wafer. This is negligible compared to the belt speed of 100 cm/sec.

[**0042**] In another method, if the relative velocity between the WSID and the wafer surface is not constant, the force applied by the WSID is adjusted such that a higher force is applied onto certain surface regions, such as the central region of the wafer, where the relative velocity is low. As previously mentioned, in exemplary ECMD or ECMP processes, the wafer is rotated and also translated over a stationary WSID surface. If the velocity of the lateral motion is lower than the motion near the edge of the wafer due to rotation, velocity near the center of the wafer would be lower than at the edge. Therefore, additional force should be applied near the center of the wafer to improve process results.

[**0043**] There are various approaches that may be used to apply additional force on the wafer surface near its center. One such approach involves shaping of the wafer surface. When such shaped wafer surface is pushed against a pad structure, its center gets the highest force. An example of shaping wafer **100** while it is processed may be described in connection with **FIG. 3**, which illustrates a partial view of an ECMPR system **200**. In **FIG. 3**, only components such as a wafer carrier **202** and a WSID **204** of the system **200** are illustrated for the purpose of clarity. The wafer carrier **202** holds the wafer **100** by the back surface **102** while exposing the front surface **101** of the wafer to the WSID **204**. The wafer is held on a chuck face **203** of the wafer carrier **202**.

[**0044**] The WSID **204** may have a compressible layer **206** having a top surface **208**. The top surface **208** may be made of a flexible material and may be abrasive or it may contain a polishing pad material. The top surface **208** is brought to physical contact with the front surface **101** of the wafer during the ECMD or ECMP processes. The WSID **204** comprises openings **210**, such as holes with various geometrical shapes or slits with varying width, or may be made of a porous material that allows a process solution (not shown) to flow through the WSID and wet the surface of the wafer. The WSID **204** is supported by a support plate **212**, which has a top surface **213** and a back surface **214**. The WSID **204** is placed on the top surface **213** of the support plate **212**. The support plate **212** is fixed on sidewalls **25** of a process chamber, which is not shown in **FIG. 3** but can be seen in **FIG. 1**. The openings **210** may continue through the support plate **214** as support plate openings **216**, although size and location of the openings **216** may be different from the openings **210** in the WSID. For example, support plate openings **216** may be made of narrow slits or very small holes. Alternately, support plate openings **216** may be larger than openings **210** of the WSID. Optionally a flow restrictor such as a filter **218** may be placed under the support plate. This filter **218** also reduces the number of particles that may reach the wafer surface. A process solution **217** in the process chamber is delivered to the front surface **101** of the wafer **100**. Process solution **217** flows through the pores of the filter **218**, openings **216**, **210** of the support plate **212** and the WSID **204** to reach the front surface during the process.

[**0045**] Referring to **FIGS. 3-5**, shaping of the front surface **101** of the wafer **100** may be performed by applying a force to the back surface **102** of the wafer **100** to deflect the front surface **101**. As shown in **FIG. 5**, as the force is applied to the back surface of the wafer **100**, the wafer bows into the WSID and a higher-pressure interface **219** forms between the center region **220** of the front surface of the wafer and the top surface **208** of the WSID **204**. This is because the support plate **212** is relatively rigid in this example and extra compression of the compressible layer of the WSID in the central region applies higher force to the wafer surface in this region compared to the edge region. The size of the pressure interface depends on the applied force and depending on the force it may get smaller or larger. A force source in the wafer carrier **202** may apply a force A to the back of the wafer and cause the wafer to bow into the WSID **204**, thereby pushing a center region **220** of the wafer **100** in the direction of the arrow A. The force source may use a pressurized fluid, inflatable membranes, or a mechanism using shims or pins to physically apply force to the back surface **102** of the wafer. Application of the force A, gives the wafer **100** and hence the front surface **101** a convex shape which allows WSID to exert more force on the center region **220** than edge region **222** of the wafer **100**. In **FIG. 4**, this can be seen in the force distance graph **224**. As seen in the graph, the force applied to the center region is higher than the edge region of the wafer.

[**0046**] As shown in **FIG. 5**, as the force A is applied, the center region is pushed into the WSID **204** by a distance D at the center region **220** and a distance d at the edge region **222**. Since the force applied by the WSID onto the wafer surface is proportional to the distance the surface is pressed into the WSID, as the D distance becomes larger than the d-distance, the force, which is applied to the center region becomes higher than the edge region. It should be understood that the distances and the convex shape of the wafer are exaggerated in the figures for clarity. In practice the difference between the distance D and distance d may be in the range of 0.1-1 mm for an 8" wafer or as much as 2 mm for a 300 mm wafer. For the purpose of clarity, openings in the WSID are not shown in **FIG. 5**.

[0047] **FIGS. 6A-6D** illustrate various configurations of force source. In each configuration edges of the wafer are held by a holding mechanism on the wafer carrier and the force is applied on the back surface of the wafer. **FIG. 6A** shows a pressurized fluid source **230**, preferably air to apply pressure to the back surface of the wafer. The fluid source **230** may be in the chuck face **203** of the wafer carrier (see **FIG. 3**). **FIG. 6B** illustrates an inflatable member **232** such as a bladder to fill with pressurized air or another gas to apply pressure. The bladder may be placed between the chuck face and the back surface of the wafer **100**, and attached to the fluid source **230**. **FIG. 6C** shows a curved object **234**, which may be placed between the back surface of the wafer **100** and the chuck face to press against the back surface **102** of the wafer to shape it. **FIG. 6D** shows use of pins **236** configured to have varying lengths so that more force is applied to the center region on the back of the wafer **100**. The pins **236** may be placed in the chuck face and moved by a moving mechanism.

[0048] As shown in **FIG. 7** in system **200**, another method for achieving the same result involves applying force to the center region of the WSID **204** and thereby compressing a portion of the WSID more against the center region **220**. As shown in **FIGS. 7 and 8**, since the edges of the support plate **212** are substantially fixed on the side walls of the process chamber, by applying a force in the direction of arrow B to the back surface **214** of the support plate **212**, the support plate **212** is bowed towards the front surface **101** of the wafer. This way, a selected region **240** of the support plate **212** is brought closer to the center region **220** of the wafer **100** and forms a high-pressure interface **219**. The location of the selected region **240** is configured to correspond to the center region **220** of the wafer. The bowing effect shown in **FIG. 8** and other figures are highly exaggerated for the purpose of clarity. In practice, during bowing, the selected region may move up a distance only in the range of 0.1 to 2 millimeters. As the selected region of the support plate is moved closer to the center region **220** of the wafer, a portion **242** of the compressible layer **206** between the center region **220** and the selected region **240** is compressed between these two surfaces. This, in turn, pushes the top surface **208** of the WSID against the center region and applies more force to the center region **220** than the edge region **222**. It should be noted that in this method a relatively flexible support plate **212** may be used. By selecting the thickness and flexibility of the support plate and the magnitude of the applied force, the degree of bowing and the magnitude of the extra force applied to the central region may be controlled.

[0049] Referring back to **FIG. 7**, the force maybe applied to the support plate **212** by exerting more process solution pressure to the back surface of the support plate **212** or the filter **218** placed under it. Such pressure gives the support plate **212** a convex shape. The pressure and thus the magnitude of the applied force may be controlled by various means such as flow restrictors, filters with varying porosity or bleed valves.

[0050] One exemplary method of controlling force involves controlling the flow rate of the process solution. Depending on the porosity of the filter **218**, as the flow rate of the process solution increases, the pressure under the filter **218** increases. Since the edges of the support plate **212** are fixed, the support plate **212** bows up under increased process solution flow as shown in **FIG. 8**. It is also possible to increase or decrease the amount of bowing by keeping the flow constant but by using one or more bleed valves that can control the pressure under the filter. In this case, by controlling the amount of solution that is bled through these valves, the pressure under the filter **218** maybe increased (when valves are closed, restricting the amount of solution bleeding out through them) or decreased (when valves are opened, increasing the amount of solution bleeding out through them) or kept constant at a predetermined pressure level. It should be noted that this process may be automated using feedback control as will be discussed later. For the purpose of clarity, openings in the WSID are not shown in **FIG. 8**.

[0051] Another way of controlling the bowing and thus the force on the central region of the wafer involves controlling the porosity of the filter **218**. At a given solution flow rate, filters with smaller pore size would give more bowing and thus more additional force would be applied to the central section of the wafer. As can be seen in the force-distance graph in **FIG. 9**, the force applied to the center **220** of the wafer is preferably higher than the force applied to the edge **222**.

[0052] **FIG. 10** illustrates a smart system **250** which can sense the pressure under the filter element **256** using a transducer. The system **250** includes a WSID **252** supported by a support plate **254**. A filter **256** is placed under the support plate **254**. The filter **256** may not be needed if the openings in the WSID are small enough to keep the cavity **265** pressurized. However, presence of the filter **256** is preferable since it also filters out any particulates from the process solution before delivering it to the wafer surface. Process solution **258** enters chamber **260** through an inlet **262**. Differing from the previously described embodiments, a pressure-monitoring device **264** such as a pressure transducer monitors the solution pressure and turns on and off a bleed valve **266** to keep the pressure, and hence the bowing of the support plate **254** at a predetermined desired value. For example, if the flow is set to a constant value and the pressure in the cavity **265** is higher than the pre-determined value, the bleed valve **266** is automatically opened more to let more solution out and bring the pressure down to the pre-determined level. Similarly, if the actual pressure within cavity **265** is lower than the pre-determined value, then the bleed valve **266** would automatically close to restrict flow through it and bring the pressure up to the pre-determined level. This way, using feedback and computer control, a predetermined value for the pressure is selected and kept through the process. Also, by changing the pressure during the process, more or less force may be applied on the surface in a controlled manner. Bowing is a strong function of the choice of filter, flexibility of the support plate and the pressure under the support plate.

[0053] The force may also be controlled by shaping the WSID itself or by constructing the support plate to make it more or less compliant along the diameter of the wafer. Other stiffeners or flexural members can be added to WSID to produce a force curve of any desired shape for planarization, especially at the center region.

[0054] In this respect, **FIGS. 11A-11B** illustrate various support plate and WSID combined structures to create a bowing effect. As shown in **FIG. 11A** a first structure **300** includes a support plate **302** having a curved top surface

304. A WSID **306** is attached on the curved top surface **304** so that a top surface **308** of the WSID is in compliance with the curved top surface **304** of the support plate **302**. As shown in **FIG. 11B**, a support plate and WSID combined structure **310** includes a support plate **312** and a WSID **314**. In this example, a curved top surface **316** of the WSID is provided using a curved insert **318**. In **FIGS. 11A-11B**, for the purpose of clarity openings of the support plates and the WSIDs are not shown.

[**0055**] By varying the thickness of the support plate, the applied pressure and the size of the high-pressure interface may be changed. **FIGS. 12A-12B** illustrate a support plate **320** before and after the application of the force. The support plate **320** is a thin support plate; therefore, with the applied pressure it bows more in comparison to a thicker support plate. This may allow the support plate **320** to apply more localized pressure and to a smaller area of the wafer.

[**0056**] **FIGS. 13A-13B** show a support plate **322**, which is thicker than the support plate **320** described above. Since it is thicker, the support plate **322** bows less and thereby, it may apply a force to a larger (central) area on the wafer. **FIGS. 14A-14B** illustrate a support plate **324** before and after the application of the force. The support plate **324** has a thin section **326**; therefore, when a pressure is applied to the thin section, the thin section **326** protrudes more. This may allow the support plate **324** to apply more localized pressure and to a smaller area of the wafer. Again, the bowing effects in all these drawing are greatly exaggerated to clearly explain the principles, advantages and distinctions. For the purpose of clarity, openings in the support plates are not shown in **FIGS. 12A-14B**.

[**0057**] The above-noted methods and structures may also be used for eliminating bubbles that may be trapped between the wafer surface and the process solution during electroplating and electropolishing processes. As shown in **FIG. 15A**, as a wafer is first lowered towards the WSID **402** and enters the process solution **403**, bubbles **406** may get trapped under the wafer surface **404**, especially near the center of the wafer. This is a common problem in electroplating and electropolishing technologies and is generally due to the fact that the edges of the wafer may get wetted by the process solution before its center. If these bubbles stay on the wafer surface during the process, they may generate defects in the forming layers and therefore they should be removed. As shown in **FIG. 15B**, when the pressure of the solution **403** is increased to bow the support plate **408** towards the wafer **400** at least during the first stage of process when wafer is being lowered down towards the WSID **402**, the WSID **402** bows and the solution flowing from the WSID **402** also takes a convex shape. This way when the wafer is lowered towards the WSID **402**, the central region of the wafer **400** gets wetted by the process solution **403** first. Because of the convex shape of the WSID **402**, the solution from the top of the convex shape reaches the center of the conductive surface of the wafer **400** and wets the center region before the solution flowing from the rest of the WSID **402** reaches and wets the rest of the surface of the wafer **400**. This way, since the bubbles are swept away from the center, and no bubble entrapment occurs. For the purpose of clarity, openings in the WSID and the support plates are not shown in **FIGS. 15A-15B**.

[**0058**] As will be described more fully below, alternatively, from the foregoing bowed WSID surface principle, the surface of the support plate or solution supply plate through which the solution flows towards the workpiece surface can itself be given a profile to assist removal of bubbles in electrochemical processes without having a compressible layer or a pad on it, particularly in a non-contact ECMPR. Since in a non-contact ECMPR there is no need to touch the wafer surface with a WSID, there is no need for a pad, and the WSID may be formed as a rigid structure. In that respect, non-contact ECMPR may actually be called ECPR (electrochemical processing) since there is no mechanical action applied to the wafer surface during process.

[**0059**] The support plate may be a rigid plate having openings and a surface profile, which will be referred to as a plate hereinbelow. In this embodiment, a surface of the plate includes a protruding profile or region, which may be any curved or protruding surface or surface portion, including but not limited to, spherical, cylindrical, conical, pyramidal, rectangular, trapezoidal, or triangular surfaces. During the process, the plate is placed in a process solution and the solution is flowed through openings of the plate. The solution flowing through the protruding region of the plate conforms to the top surface profile and forms a raised solution surface over the protruding region. When a workpiece is lowered towards the process solution, the workpiece surface first touches the raised surface of the solution which corresponds to the location of the protruding region of the plate. If so configured, the central region of the workpiece may be wetted first by the process solution, and then the solution moves towards the periphery of the wafer, sweeping any bubbles out with it. This prevents bubble entrapment under the workpiece before the rest of the surface of the workpiece is wetted by the solution. This way, since the bubbles are eliminated or swept away from the center, and no bubble entrapment occurs.

[**0060**] The protruding region may be placed about the center of the plate surface or may extend along the length or width of the plate surface. As the workpiece surface moves towards the surface of the plate, a gap filled with solution is formed between the workpiece surface and the surface of the plate. Peripheral ends of the gap are unblocked so that the solution is moved laterally to the open ends of the gap as the pressure from the moving workpiece surface pushes the solution while the workpiece surface is getting closer to the surface of the plate. At the protruding region, the surface profile of the plate locally narrows the gap and applies more pressure to the adjacent solution. For example if a protrusion on the plate is placed across from the center of the workpiece surface, the gap between the two surfaces, i.e. the wafer surface and the plate surface, will be narrower at this location. Solution between the surface about the center of the wafer and the protruding region on the plate surface will be squeezed more than the solution in the rest of the gap, which will cause solution to flow outwardly into this low pressure zone. This outwardly flow also sweeps away any remaining or forming bubbles with the solution.

[**0061**] **FIGS. 16A, 16B** and **16C** illustrate a plate **500** in top view, and in side views of a ECMPR system **502**. In **FIG. 16A**, circle W in dotted lines shows the position of a wafer **503** facing towards the plate **500**. Although in this embodiment, the plate **500** has a rectangular shape, it may have any geometrical shape, preferably allowing side electrical contacts to touch the front surface of the wafer **503**

(i.e., allowing the wafer W to overhang). Accordingly **FIGS. 16B-16C** show side views along from the short edge of the plate **500**. It should be noted that all dimensions of the plate **500** may be larger than the diameter of the wafer if other means of making electrical contact to the wafer, such as a clamp ring contact, are employed. We will, however continue to refer to the exemplary geometry shown in **FIGS. 16A, 16B** and **16C**. In **FIG. 16B**, a wafer **503** is above the surface **504** of a process solution **505**, and in **FIG. 16C** the wafer is immersed in the solution **505**. As shown in **FIGS. 16B and 16C**, the plate **500** is placed between the wafer **503** and an electrode **506**. A carrier head **508** holds the wafer **503** by its back surface while exposing a front surface **510** of the wafer **503**. The carrier head **508** may rotate and move the wafer laterally over the plate **500**. As described above, the front surface **510** includes a conductive layer, e.g., a copper seed layer, a barrier layer or a nucleation layer etc., for electrodeposition or a copper layer for electropolishing. The electrode **506** may be an anode for electrodeposition, and may be a cathode if the process is electropolishing. A power supply **512** is electrically connected to the electrode **506** and the front surface **510** to apply a potential difference while the process solution **505** is contacting the electrode **506** and the front surface **510** during the electrochemical process. As shown in **FIG. 16B**, electrical connection to the front surface **510** is made using movable electrical contacts **516** adjacent and along the long edge of the plate **500**.

[0062] During the process, the front surface **510** of the wafer to be processed is placed across from a first surface **518** of the plate **500**. Fluid openings **520** between the first surface **518** and the second surface **522** of the plate **500** allow the process solution **505** to flow between the front surface **510** of the wafer **503** and the electrode **506**. The openings **520** may be shaped as holes or slits and may have any geometrical shape. The first surface **518** includes a protruding region **524** or a protruding surface or a bump to eliminate bubble entrapment under the front surface **510**. The protruding region **524** may be a portion of the first surface or may be the entire first surface. The second surface **522** may be flat as shown in **FIG. 16B**, but it may also be curved.

[0063] As shown in **FIG. 16B**, in this embodiment, the protruding region **524** has a spherical surface and is placed at a central location of the first surface **518**. As exemplified above, the protruding region of the first surface **518** may be any three dimensional surface. As also shown in **FIGS. 17A and 17B**, the protruding region **524** may extend along the length of the first surface **518** of the plate **500** and again may have any geometrical surface such as cylindrical, rectangular, etc. Referring back to **FIG. 16B**, the process solution **505** flowing through the plate **500** forms a raised surface **526** over the protruding region **524** of the plate **500**. The raised surface **526** of the process solution **505** is closer to the front surface **510** than the rest of the surface **504** of the process solution **505**. Accordingly, as the wafer is lowered towards the process solution **505**, the center of the front surface **510** touches the raised surface **526** of the process solution **505** first and gets wet without bubble entrapment, and as the wafer **503** is further advanced towards the process solution **505** the rest of the front surface immerses into the solution without bubble entrapment. **FIG. 17B** shows the raised surface **526** of the process solution **505** over the protruding region **524** of the plate **500**. **FIGS. 18A-18F** illustrate various first or top surfaces of exemplary plates **500** placed across the wafers **503** to be processed. As shown in **FIGS. 18A, 18B**, **18D** and **18E** the first surfaces **518** are shaped to have protruded regions to form the raised solution surfaces over them. In this respect, **FIG. 18A** shows a cylindrical first surface profile; **FIG. 18B** shows a triangular first surface profile; **FIG. 18D** shows a slanted first surface profile; and **FIG. 18E** shows a curved and slanted first surface profile. However, in **FIGS. 18C and 18F** a portion of the first surfaces includes protruded regions, which is triangular in **FIG. 18C** and rectangular in **FIG. 18F**.

[0064] **FIG. 19** shows an electrochemical processing system **600** employing another embodiment of a rigid plate **602**. The rigid plate **602** has a top surface **604**, which faces a front surface **606** of a wafer **608**, and the rigid plate **502** has a back surface **606**. Fluid channels or openings **605** extend between the top surface **604** and the back surface **606** to flow a process solution **610** towards the surface **606** of the wafer **608**. Different than the above embodiments, the top surface **604** of the rigid plate **602** is substantially flat and the back surface includes a cavity **612**. In the region of the cavity **612**, the thickness of the rigid plate **602** is reduced, which is at a minimum at the top of the cavity **612**. The cavity **612** helps forming a raised solution surface **614** over the top surface **604** of the plate **602**, with the pressure of the process solution **610** filling the cavity **612**. The level of the solution above the cavity **612** is higher (highest at the top of the cavity), than its level over the rest of the rigid plate **602**, due to the fact that the resistance to fluid flow is the lowest at that location. As a selected portion of the surface of the wafer **608** (e.g. the center of the surface of the wafer) is touched to the raised surface **614**, entrapped bubbles are swept away with the solution flowing over the top surface **604** of the rigid plate **602** from the center towards the edge of the wafer. A sequence of touching the surface **606** of the wafer **608** to the raised solution surface **614** and then immersing the surface **606** into the process solution is performed as described above. In the system **600**, the rigid plate **602** is positioned between an electrode **616** and the wafer **608**, which is moved and rotated by a wafer holder **618** during the process. A power supply **620** applies a potential difference between the surface of the wafer **608** and the electrode **616** for electrochemically processing the surface **606** of the wafer **608**. The rigid plate **602** may be rectangular as in the other embodiments. The cavity **612** may be positioned under the center of the wafer or may extend along the long edge of the rigid plate (see also **FIGS. 17A-17B**). The cavity **612** may be shaped in any 3-D form, such as hemispherical, cylindrical, conical, pyramidal, rectangular.

[0065] Although various preferred embodiments and the best mode of the present invention have been described in detail above, those skilled in the art will readily appreciate that many modifications of the exemplary embodiment are possible without materially departing from the novel teachings and advantages of this invention.

What is claimed is:

1. A method of immersing a surface of a wafer in a solution for processing the surface, comprising:

flowing the solution through openings of a rigid plate having a protruding region to form a raised solution surface over the protruding region;

contacting a selected portion of the wafer surface with the raised solution surface; and

immersing the wafer surface fully into the solution.

2. The method of claim 1, further comprising rotating the wafer before contacting.

3. The method of claim 1, wherein the selected portion of the surface is a center of the surface of the wafer.

4. The method of claim 1, further comprising placing the rigid plate into the solution.

5. The method of claim 1, further comprising processing the surface of the wafer.

6. A system for eliminating bubble entrapment under a surface of a wafer when the surface is immersed into a process solution to process the surface of the wafer, comprising:

a rigid plate, having a protruded region and fluid openings, wherein the plate is configured such that as the solution flows through the rigid plate, a raised solution surface forms over the protruded region; and

a moving mechanism configured to move the wafer, wherein as the wafer is moved towards the solution, a selected portion of the surface of the wafer contacts the raised solution surface before immersing the surface fully into the solution.

7. The system of claim 6, wherein the protruded region forms a portion of a top surface of the rigid plate.

8. The system of claim 6, wherein the protruded region forms a top surface of the rigid plate.

9. The system of claim 6, further including an electrode placed in the process solution.

10. The system of claim 9, further including a power supply connected to the electrode and the surface of the wafer to apply a potential difference between the surface of the wafer and the electrode to process the surface.

11. The system of claim 9, wherein the rigid plate is placed between the electrode and the surface of the wafer.

12. The system of claim 6, wherein the rigid plate has a rectangular shape.

13. The system of claim 6, wherein the selected portion of the surface is a center of the surface of the wafer.

14. A method of processing a conductive surface of a wafer using a process solution, comprising:

flowing the solution through openings of a plate having a protruding region to form a raised solution surface over the protruding region;

contacting a selected portion of the conductive surface with the raised solution surface;

immersing the conductive surface fully into the solution; and

processing the conductive surface.

15. The method of claim 14, further comprising applying a potential difference between the conductive surface and an electrode.

16. The method of claim 15, wherein processing is electropolishing.

17. The method of claim 15, wherein processing is electrodeposition.

18. The method of claim 14, further comprising rotating the conductive surface before the step of contacting.

19. The method of claim 14, wherein the selected portion of the conductive surface is a center of the conductive surface of the wafer.

20. The method of claim 14, wherein the plate is rigid.

21. A system for electroprocessing a conductive surface of a wafer using a process solution, comprising:

an electrode configured to be placed in the process solution;

a rigid plate, having a protruded region and fluid openings, configured to be immersed in the solution and positioned between the electrode and the conductive surface, wherein the rigid plate is configured such that as the solution flows through the rigid plate, a raised solution surface forms over the protruded region; and

a moving mechanism configured to move the wafer, wherein as the wafer is moved towards the solution, a selected portion of the conductive surface contacts the raised solution surface before immersing the surface fully into the solution.

22. The system of claim 21, wherein the rigid plate is placed between the electrode and the conductive surface of the wafer.

23. The system of claim 21, wherein the rigid plate has a rectangular shape.

24. The system of claim 21, wherein the selected portion of the conductive surface is s center of the conductive surface of the wafer.

25. The system of claim 21, wherein the protruded region forms a portion of a top surface of the rigid plate.

26. The system of claim 21, wherein the protruded region forms a top surface of the rigid plate.

27. The system of claim 21, further including a power supply connected to the electrode and the surface of the wafer to apply a potential difference between the conductive surface of the wafer and the electrode to process the conductive surface of the wafer.

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