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NUCH, Voha [US/US]; 3855 Gardie Place, San Jose, CA 95121 (US). GUTMAN, Felix [US/US]; 5237 Mill Creek Lane, San Jose, CA 95136 (US).

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(74) Agents: YIM, Peter, J. et al.; Morrison & Foerster LLP, 425 Market Street, San Francisco, CA 94105-2482 (US).

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(71) Applicant (for all designated States except US): ACM RESEARCH, INC. [US/US]; Suite 610, 46520 Fremont Boulevard, Fremont, CA 94538 (US).

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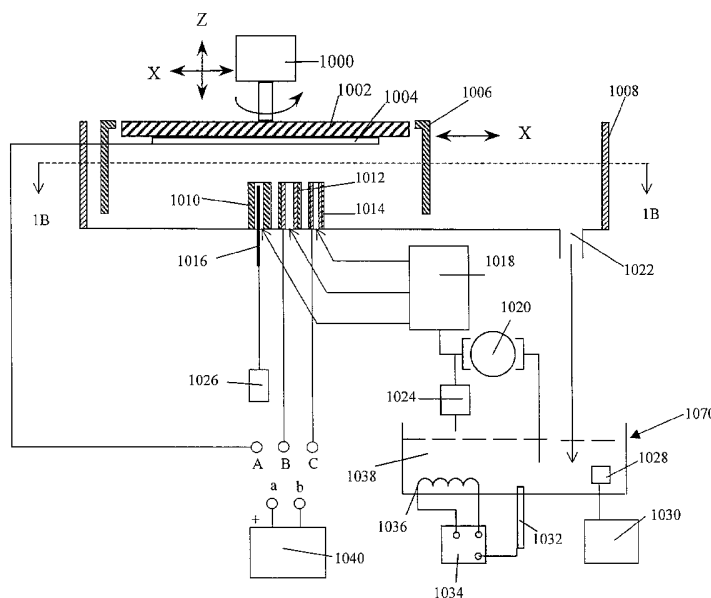
(72) Inventors; and

(75) Inventors/Applicants (for US only): WANG, Hui [CN/US]; 38855 Litchfield Circle, Fremont, CA 94536 (US). YIH, Peihau [—/US]; 37171 Sycamore Street #824, Newark, CA 94560 (US). AFNAN, Muhammed [US/US]; 1048 Vuelta Olives, Fremont, CA 94539 (US).

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(54) Title: ELECTROPOLISHING ASSEMBLY AND METHODS FOR ELECTROPOLISHING CONDUCTIVE LAYERS



(57) Abstract: In one aspect of the present invention, an exemplary apparatus and method are provided for electropolishing a conductive film on a wafer (1004). An apparatus includes a wafer chuck (1002) for holding a wafer, an actuator (1000) for rotating the wafer chuck, and a nozzle (1010) configured to electropolish the wafer. The apparatus may further include a conductive ring or a shroud (1006). A method of electropolishing a conductive film on a wafer includes rotating a wafer chuck with sufficient speed such that electrolyte fluid incident upon the wafer flows on the surface of the wafer towards the edge of the wafer.

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ELECTROPOLISHING ASSEMBLY AND METHODS FOR
ELECTROPOLISHING CONDUCTIVE LAYERS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority of earlier filed provisional applications U.S. Application No. 60/332,417, entitled ELECTROPOLISHING ASSEMBLY, filed on November 13, 2001, and U.S. Application No. 60/372,567, entitled METHOD AND APPARATUS FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE, filed on April 14, 2002, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field:

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

2. Description of the Related Art:

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

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

process may then be performed to deposit a metal layer over the semiconductor wafer thereby depositing metal both in the trenches and vias and also on the non-recessed areas of the semiconductor wafer. To isolate the interconnections, such as patterned trenches and vias, the metal deposited on the non-recessed areas of the semiconductor wafer is removed.

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

[0006] In a CMP process, a wafer assembly is positioned on a CMP pad located on a platen or web. The wafer assembly includes a substrate having one or more layers and/or features, such as interconnection elements formed in a dielectric layer. A force is then applied to press the wafer assembly against the CMP pad. The CMP pad and the substrate assembly are moved against and relative to one another while applying the force to polish and planarize the surface of the wafer. A polishing solution, often referred to as polishing slurry, is dispensed on the CMP pad to facilitate the polishing. The polishing slurry typically contains an abrasive and is chemically reactive to selectively remove from the wafer the unwanted material, for example, a metal layer, more rapidly than other materials, for example, a dielectric material.

[0007] CMP methods, however, can have several deleterious effects on the underlying semiconductor structure because of the relatively strong mechanical forces involved. For example, as interconnection geometries move to 0.13 microns and below, there can exist a large difference between the mechanical properties of the conductive materials, for example copper and the low k films used in typical damascene processes. For instance, the Young Modulus of a low k dielectric film may be greater than 10 orders of magnitude lower than that of copper. Consequently, the relatively strong mechanical force applied on the dielectric films and copper in a CMP process, among other things, can cause stress related defects on the semiconductor structure that include delamination, dishing, erosion, film lifting, scratching, or the like.

[0008] New processing techniques are therefore desired. For example a metal layer may be removed or etched from a wafer using an electropolishing process. In general, in an electropolishing process the portion of the wafer to be polished is immersed within an electrolyte fluid solution and an electric charge is then applied to the wafer. These conditions result in copper being removed or polished from the wafer.

BRIEF SUMMARY OF THE INVENTION

[0009] In one aspect of the present invention, an exemplary apparatus and method are provided for electropolishing a conductive film on a wafer. One exemplary apparatus includes a wafer chuck for holding a wafer, an actuator for rotating the wafer chuck, a nozzle configured to electropolish the wafer, and a shroud positioned around the edge of the wafer. One exemplary method of electropolishing a conductive film on a wafer includes rotating a wafer chuck with sufficient speed such that electrolyte fluid incident upon the wafer flows on the surface of the wafer towards the edge of the wafer.

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

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figs. 1A and 1B are cross-sectional and top views respectively of an exemplary semiconductor processing apparatus including a shroud;

[0012] Figs. 1C, 1D, and 1E are cross-sectional views of exemplary nozzles of a semiconductor processing apparatus;

[0013] Fig. 2 is a cross-sectional view of exemplary nozzles of a semiconductor process apparatus;

[0014] Fig. 3 is a cross-sectional view of exemplary nozzles of a semiconductor process apparatus;

- [0015] Fig. 4 is a cross-sectional view of exemplary nozzles and a block of a semiconductor process apparatus;
- [0016] Figs. 5A through 5H illustrate cross-sectional views of various exemplary nozzle shapes and configurations;
- [0017] Figs. 6A and 6B illustrate cross-sectional and top views of an exemplary nozzle structure;
- [0018] Figs. 6C through 6I illustrate top views of various exemplary nozzles structures;
- [0019] Fig. 7 illustrates a cross-sectional view of an exemplary semiconductor processing apparatus including a conductive member;
- [0020] Figs. 8A and 8B illustrate cross-sectional views of an exemplary semiconductor processing apparatus including a conductive member;
- [0021] Fig. 8C illustrates an exploded view of an exemplary wafer chuck assembly including a conductive member;
- [0022] Figs. 9A and 9B illustrate cross-sectional views of exemplary semiconductor processing apparatus including a conductive member;
- [0023] Figs. 10A and 10B illustrate cross-sectional views of exemplary semiconductor processing apparatus including one and two optical sensors respectively;
- [0024] Figs. 11A and 11B illustrate a top view and cross-sectional view of an exemplary semiconductor processing apparatus;
- [0025] Fig. 12 illustrates a cross-sectional view of an exemplary semiconductor processing apparatus;

[0026] Figs. 13A-13E illustrate an exemplary electropolishing assembly with a multiple rotary assembly;

[0027] Figs. 14A and 14B illustrate cross-sectional views of exemplary multiple rotary nozzle assemblies;

[0028] Fig. 14C illustrates an exemplary process for electropolishing a conductive layer on a wafer;

[0029] Fig. 15 illustrates a cross-sectional view of an electropolishing chamber with an exemplary multiple linearly movable nozzle assembly; and

[0030] Figs. 16A-16E illustrate exemplary views of an electropolishing apparatus with a linearly movable and multiple rotary nozzles.

DETAILED DESCRIPTION

[0031] In order to provide a more thorough understanding of the present invention, the following description sets forth numerous specific details, such as specific materials, parameters, and the like. It should be recognized, however, that the description is not intended as a limitation on the scope of the present invention, but is instead provided to enable a better description of the exemplary embodiments.

[0032] I. Exemplary Electropolishing Apparatus:

[0033] Figs. 1A and 1B illustrate a cross-sectional and top view of an exemplary wafer electropolishing apparatus that may be used to polish wafer 1004. Broadly speaking, the exemplary electropolishing apparatus operates by directing a stream of electrolyte fluid towards a metal film on a wafer while an electric charge is applied to the wafer. The electric charge and electrolyte fluid cause metal ions in the metal film to dissolve in the electrolyte fluid. The current density of the electrolyte fluid and concentration of metal ions in the electrolyte fluid determine, at least in part, the rate of polishing. Thus, by

controlling the current density, the electrolyte solution concentrations, and the like, the electropolishing apparatus may precisely polish metal layers disposed on semiconductor wafers.

[0034] As shown in Fig. 1A, the electropolishing apparatus may include chuck 1002, actuator 1000, and polishing receptacle 1008. Polishing receptacle 1008 can be formed from any material electrically insulated and resistant to acid and corrosion, such as polytetrafluoroethylene (commercially known as TEFLON), PolyVinyl Chloride (PVC), PolyVinylidene Fluoride (PVDF), Polypropylene, and the like. Preferably, polishing receptacle 1008 can be formed from PVDF. It should be recognized, however, that polishing receptacle 1008 can be formed of different materials depending on the application.

[0035] As shown in Fig. 1A, electrolyte fluid 1038 can flow into polishing receptacle 1008 through nozzles 1010, 1012, and/or 1014. More particularly, pump 1020 pumps electrolyte fluid 1038 from electrolyte fluid reservoir 1070 past return valve 1024 to pass filter 1018. Pass filter may include Liquid Mass Flow Controllers (LMFCs) that can control the amount and rate of electrolyte fluid 1038 delivered to nozzles 1010, 1012, and 1014. Additionally, pass filter 1018 can filter contaminants from electrolyte fluid 1038 in order to reduce the amount of contaminants that could possibly enter polishing receptacle 1008 through nozzles 1010, 1012, or 1014 and possibly degrade the electropolishing process or clog the LMFCs if used. In this manner, contaminants are prevented from entering polishing receptacle 1008 and/or from clogging the LMFCs. In the present example, pass filter 1018 suitably removes particles larger than about 0.05 to about 0.1 micrometers. It should be recognized, however, that various filtering systems could be used depending on the particular application. Additionally, although filtering contaminants is advantageous, pass filter 1018 can be omitted from the wafer polishing assembly in some applications.

[0036] Electrolyte fluid 1038 can include any convenient electropolishing fluid, such as phosphoric acid, and the like. Preferably, electrolyte fluid 1038 includes orthophosphoric acid (H_3PO_4) having a concentration between about 60 percent by weight and about 85 percent by weight, and more preferably about 76 percent by weight.

Additionally, electrolyte fluid 1038 preferably includes glycol at about 10 to 40 percent by weight, with the remainder including water and H_3PO_4 acid having about 1 percent aluminum metal (against weight of the acid). However, the concentration and composition of electrolyte fluid 1038 can vary depending on the particular application.

[0037] Pump 1020 can include any suitable hydraulic pump, such as a centrifugal pump, a diaphragm pump, a bellows pump, and the like. Additionally, pump 1020 can be resistant to acid, corrosion, and contamination. Although one pump 1020 is shown, it should be recognized that any number of pumps 1020 could be used. For example, a separate pump might be used for each nozzle 1010, 1012, and 1014. Additionally, electrolyte fluid 1038 can flow into polishing receptacle 1008 through nozzles 1010, 1012, and 1014 without pump 1020 in some applications. For example, electrolyte fluid 1038 can be maintained at a pressure within electrolyte fluid reservoir 1070. Alternatively, the supply lines between electrolyte fluid reservoir 1070 and nozzles 1010, 1012, and 1014 can be maintained at a pressure.

[0038] LMFCs can include any convenient mass flow controller, which is further preferably resistant to acid, corrosion, and contamination. Additionally, LMFCs deliver electrolyte fluid 1038 at set flow rates to nozzles 1010, 1012, and 1014. Additionally, LMFCs may suitably deliver electrolyte fluid 1038 at flow rates proportionate to the cross-section area of nozzles 1010, 1012, and 1014. For example, if nozzle 1012 is larger in diameter than nozzle 1014, then it might be advantageous for LMFCs to deliver electrolyte fluid 1038 at a greater flow rate to nozzle 1012. In the present exemplary embodiment, LMFCs are preferably configured to deliver electrolyte fluid 1038 at a flow rate between 0.5 liters per minute and 40 liters per minute depending on the nozzle sizes, distance between the nozzle and the wafer, and the like.

[0039] Fluid reservoir 1070 may further include a heat exchanger 1036, cooler/heater 1034, and a temperature sensor 1032 for controlling the temperature of electrolyte fluid 1038 within fluid reservoir 1070. Further, one or more electrodes 1028 may be included in reservoir 1070 and coupled to power supply 1030. Applying electric charges to electrodes 1028 removes metal ions from the electrolyte fluid 1038 thereby

adjusting the metal ion concentration of electrolyte fluid 1038. An opposite charge may be applied to electrode 1028 to add metal ions to electrolyte fluid 1038.

[0040] The exemplary wafer polisher assembly further includes electrodes disposed within nozzles 1012 and 1014. As will be described in greater detail below, although the present exemplary embodiment includes two nozzles with two electrodes therein, any number of nozzles and electrodes per nozzle, whether fewer or greater than two, may be used. In general, increasing the surface area of the electrodes within a nozzle increases the current density and the electropolishing rate across the profile of the stream of electrolyte fluid 1038.

[0041] As shown in Figs. 1D and 1E, nozzles 1012 and 1014 include electrodes 1056 and 1060, respectively. Electrodes 1056 and 1060 may include any electrically conducting material, such as copper, stainless steel, Tatanium (Ta), Titanium (Ti), TaN, TiN, lead, platinum, and the like.

[0042] During the electropolishing process, some of the metal ions, which migrate out of metal layer on wafer 1004, may accumulate on electrodes 1056 and 1060. As will be described in greater detail below, the metal accumulation or plating may be removed in a deplating process. For example, when electrodes 1056 and 1060 are charged positively and wafer 1002 is charged negatively, wafer 1004 is electroplated rather than electropolished. In this and similar manners, the metal plated on electrodes 1056 and 1060 may be removed, i.e., deplated. Alternatively, electrodes 1056 and 1060 can be suitably replaced at any appropriate time. For example, electrodes 1056 and 1060 could be replaced after processing about 100 wafers.

[0043] In some examples, the metal layer may include copper. Accordingly, during the electropolishing process, some of the copper ions from the metal layer being polished migrate to electroplate electrodes 1056 and 1060. If, however, electrodes 1056 and 1060 include copper, electrodes 1056 and 1060 may dissolve during the deplating process and become deformed. Therefore, in some examples, it is desirable that electrodes 1056 and 1060 include materials that are resistant to being dissolved during the deplating process. For example, electrodes 1056 and 1060 may include platinum or platinum alloys.

Alternatively, electrodes 1056 and 1060 may include titanium suitably coated with a layer of platinum, for example, with a thickness of about 50 microns to about 400 microns.

[0044] In the present exemplary apparatus, wafer chuck 1002 suitably holds and positions wafer 1004 within or above receptacle 1008. More particularly, wafer 1004 is suitably positioned opposite nozzles 1010, 1012, and 1014 and within shroud 1006. Shroud 1006 may optionally be included around wafer 1004 to prevent splashing and the like as will be described in greater detail below.

[0045] After wafer 1004 is suitably positioned within polishing receptacle 1008, electrodes 1056 and 1060 are electrically charged by power supply 1040. Additionally, wafer 1004 is electrically charged by power supply 1040. Alternatively, more than one power supply may be used to charge electrodes 1056 and 1060 and wafer 1004. When appropriately charged and electrolyte fluid 1038 flows between the electrodes 1056 and 1060 within nozzles 1012 and 1014 and the surface of wafer 1004, an electrical circuit is formed. More particularly, electrodes 1056 and 1060 are electrically charged to have negative electric potential in comparison to wafer 1004. In response to this negative electric potential at electrodes 1056 and 1060, metal ions migrate away from wafer 1004 into electrolyte fluid 1038, thus electropolishing wafer 1004. When the polarity of the circuit is reversed, however, metal ions migrate toward wafer 1004, thus electroplating wafer 1004.

[0046] Additionally, as shown in Figs. 1A and 1C, nozzle 1010 includes injection nozzle 1052 and end-point detector 1016. During the electropolishing process, injection nozzle 1052 can be configured to supply electrolyte fluid 1038 and end-point detector 1016 can be configured to detect the thickness of the metal layer on wafer 1004. End-point detector 1016 can include various sensors, such as ultrasonic sensors, optical reflection sensors, electromagnetic sensors such as Eddy-current sensors, and the like. Electrolyte fluid 1038 supplied by injection nozzle 1052 can act as a medium through which the end-point detector 1016 emits signals and measures the metal film thickness. Using electrolyte fluid 1038 as a single medium to transmit signals increases the accuracy of the measurements taken by end-point detector 1016 because electrolyte fluid 1038 provides a single phase. In contrast, if injection nozzle 1052 does not provide electrolyte fluid 1038,

emissions and measurements from end-point detector may pass through various other media, such as air and the like, before passing through electrolyte fluid 1038 that is applied to wafer 1004 by nozzle 1012 or nozzle 1014. As will be described below, having updated or real-time characteristics of electrolyte fluid 1038 that may change over time may also increase the accuracy of the end-point measurement. Further, although one nozzle 1010 is shown having an end-point detector 1016, any number of nozzles having any number of end-point detectors may be used.

[0047] As further shown in Fig. 1A, actuator 1000 can rotate chuck 1002 and wafer 1004 about the z-axis. Furthermore, in some applications, actuator 1000 can move chuck 1002 and wafer 1004 along the x-direction, while nozzles 1010, 1012, and 1014 remain stationary. In other applications, nozzles 1010, 1012, and 1014 can move along the x-direction, while chuck 1002 and wafer 1004 remain stationary along the x-direction. In yet other applications, actuator 1000 can move chuck 1002 and wafer 1004 along the x-direction, while nozzles 1010, 1012, and 1014 also move along the x-direction.

[0048] Furthermore, the electroplating apparatus may be oriented in alternative fashions. For example, nozzles 1010, 1012, and 1014 may be positioned above wafer 1004, such that electrolyte fluid is directed downward towards wafer 1004. Additionally, wafer 1004 may be oriented vertically with nozzles 1010, 1012, and 1014 directing electrolyte fluid towards wafer 1004.

[0049] For additional discussions of exemplary wafer electropolishing apparatus, see U.S. Patent Serial No. 6,395,152, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on July 2, 1999, which is incorporated in its entirety herein by reference. Furthermore, for additional discussions of exemplary end-point detectors, see U.S. Patent Application No. 6,447,688, entitled METHODS AND APPARATUS FOR END-POINT DETECTION, filed on May 12, 2000, which is incorporated in its entirety herein by reference.

[0050] II. Electrolyte Fluid Splash Protection

[0051] An exemplary electropolishing method includes rotating wafer 1004 while electrolyte fluid 1038 is directed to the surface of wafer 1004. Wafer 1004 is rotated at a rate sufficient to create centrifugal forces that cause incident electrolyte fluid 1038 to flow across the surface of wafer 1004 toward the edge of wafer 1004. Preferably, the electrolyte fluid 1038 flows to the edge of the wafer 1004 before falling from the surface. By directing the flow across the surface of wafer 1004 the fluid can be prevented from falling from the wafer surface and disrupting the stream of electrolyte fluid 1038 or forming a continuous column of electrolyte fluid in receptacle 1008. The process, however, may cause electrolyte fluid to splash within the receptacle and escape the apparatus or disrupt the stream of electrolyte fluid. Therefore, an exemplary electropolishing apparatus includes a shroud 1006 positioned around wafer 1004 to diminish or prevent the liquid that has been acted upon by the centrifugal forces from splashing within receptacle 1008 or escaping from receptacle 1008.

[0052] Figs. 1A and 1B illustrate shroud 1006 configured to surround wafer 1004 and chuck 1002. As shown in Fig. 1A, nozzle 1012 can supply a stream of electrolyte fluid to the surface of wafer 1004. In order to polish a metal film on wafer 1004 more uniformly, wafer 1004 can be rotated in a manner to cause electrolyte fluid 1038 to flow across wafer 1004 to the exposed portion of chuck 1002 without allowing the electrolyte fluid to fall from the surface of wafer 1004 into polishing receptacle 1008. Any electrolyte fluid that falls from wafer 1004 and forms a continuous column of electrolyte fluid between wafer 1004 and polishing receptacle 1008 may cause over-polishing of wafer 1004 where the column is formed. The additional polishing may lead to uneven and unpredictable polishing rates of the metal layer.

[0053] Additionally, any electrolyte fluid that falls from wafer 1004 or splashes within receptacle 1008 can disturb the stream of electrolyte fluid supplied by nozzle 1012. The shape, or more specifically the profile of the stream of electrolyte fluid 1038, in turn affects the current density and the polishing rate of the electropolishing apparatus. It is therefore desirable to have electrolyte fluid 1038 flow along the surface of wafer 1004 towards the edge of wafer 1004 and away from the stream of electrolyte fluid 1038 directed at wafer 1004.

[0054] Wafer 1004 can be rotated at an appropriate rotational speed, depending on the viscosity of the electrolyte fluid used, to cause the electrolyte fluid to flow across wafer 1004 towards the edge of wafer 1004 or to the exposed portion of chuck 1002. The rotational speed should be such that the electrolyte fluid 1038 may flow across wafer 1004 without falling from the surface of wafer 1004 and forming a continuous column or interfere with the stream of electrolyte fluid 1038. In particular, the lower the viscosity of the electrolyte fluid, the higher the centrifugal acceleration needed. For instance, for 85% phosphoric acid, the centrifugal acceleration can be chosen above about 1.5 meter/sec². In one exemplary method, a 300 mm diameter wafer is rotated within a range of about 100 rotations-per-minute (rpm) to about 2,000 rpm or more, and preferably, in a range of about 1,500 rpm to about 2,000 rpm.

[0055] Typically, nozzle 1012 or 1014 will scan the entire surface of the wafer 1004 to more uniformly polish wafer 1004. Wafer 1004 can be rotated to create a constant centrifugal acceleration on the incident electrolyte fluid 1038 when nozzle 1012 is scanning different portions of wafer 1004. For example, the centrifugal acceleration is directly proportional to the radial distance from the center of the wafer and the square of the rotational speed. Therefore, the speed at which wafer 1004 is rotated may be decreased when nozzle 1012 or 1014 is polishing portions of wafer 1004 near the edge of wafer 1004, i.e., a large radius, and increased when polishing portions near the center of wafer 1004, i.e., a small radius.

[0056] Typically, when electrolyte fluid is supplied to wafer 1004 in the manner described above, electrolyte fluid may flow towards the edge of wafer 1004 and past the edge of wafer 1004 toward the wall of polishing receptacle 1008. Without shroud 1006, the electrolyte fluid 1038 may contact the wall of polishing receptacle 1008 and splash within receptacle 1008 thereby disrupting the stream of electrolyte fluid 1038 or escape from polishing receptacle 1008.

[0057] As illustrated in Figs. 1A and 1B, shroud 1006 may be placed around wafer 1004 and chuck 1002 to decrease or prevent the electrolyte fluid 1038 from splashing within or escaping from polishing receptacle 1008. Furthermore, shroud 1006 can move together in the x-direction with chuck 1002 and actuator 1000 during the polishing process.

In particular, shroud 1006 can be attached to chuck 1002 and/or actuator 1000 with a mechanical attachment, joint, and the like. Alternatively, another actuator that synchronizes the movement of shroud 1006 with chuck 1002 and actuator 1000 may drive shroud 1006 separately. Shroud 1006 may also be rotated in unison or otherwise with chuck 1002.

[0058] Shroud 1006 can be formed in any suitable shape, such as a circle, polygon, and the like. Preferably shroud 1006 is shaped to decrease the splashing of the electrolyte fluid 1038 after it flows from wafer 1004 and contain the electrolyte fluid 1038 within receptacle 1008. The gap between chuck 1002 and shroud 1006 can be, for example, in the range of about 1 mm to about 10 mm, and preferably about 5 mm. Additionally, as shown in Fig. 1A, the cross section of the side-wall of shroud 1006 can be formed in the shape of an L in order to prevent electrolyte fluid from splashing above shroud 1006 or chuck 1002. However, the cross-section of shroud 1006 can have various other shapes. For instance, the sidewall of shroud 1006, i.e., the vertical portion of the L-shape, can be formed in other shapes such as a C-shape and the like. Further, shroud 1006 may be tapered in or out to diminish splashing and the like. Shroud 1006 may also extend farther above or below wafer 1004 and chuck 1002 than is shown in Fig. 1A.

[0059] Shroud 1006 can be made from plastics, ceramics, and the like, or anticorrosive metals or alloys such as Tantalum, Titanium, stainless steel in the 300 series, and the like. Additionally, shroud 1006 can be coated with electrolyte fluid-resistant materials such as Teflon, and the like.

[0060] It should be recognized, however, that the method of electropolishing described does not require that electrolyte fluid 1038 flow past the edge of the wafer and be incident upon shroud 1006. The problems of electrolyte fluid 1038 forming a continuous column with the receptacle 1008 and splashing within or out of receptacle 1008 may be decreased or prevented without electrolyte fluid flowing completely across wafer 1004. For example, merely by rotating wafer 1004 such that electrolyte fluid flows along a portion of the surface of wafer 1004 toward the edge of wafer 1004 before falling from wafer 1004 may diminish or prevent the undesirable effects.

[0061] III. Reduction of Edge Over-Polishing

[0062] In another aspect, an electropolishing method and apparatus for reducing over-polishing at or near the edges of a wafer is described. Typically, a portion of the metal layer at or near the edge of a wafer is polished faster than the portions of the metal layer on other areas of the wafer. An electrode connected to the edge of a wafer may increase the current density within electrolyte fluid near the edge region of the wafer resulting in an increased polishing rate. In general, the higher current density and polishing rate near the edges of the wafer may be reduced by absorbing a portion of the current density through the electrolyte fluid with a conductive member such as a ring or the like placed at or near the edge of the wafer. The current density near the edges may also be adjusted by charging the conductive member to vary the amount of current that is absorbed thereby controlling the current density to a greater degree.

[0063] With reference to Fig. 7, an exemplary apparatus and method are shown for reducing edge over polishing. A stream of electrolyte fluid 7080 is applied to wafer 7004 from nozzle 7054. Wafer 7004 is rotated at a sufficient rotational speed to form a thin layer of electrolyte fluid 7081 that can polish a metal layer on wafer 7004. Typically, if an electrode is connected to the edge of wafer 7004 the metal layer at or near the edge of wafer 7004 is polished by the thin layer of electrolyte fluid 7081 faster than the metal on other areas of wafer 7004. Accordingly, the metal layer at or near the edge of wafer 7004 can become over polished.

[0064] Chuck 7002 includes a conductive member 7114 that can reduce the amount of over-polishing at or near the edges of wafer 7004. For example, both wafer 7004 and conductive member 7114 can be connected to power supply 7110 and charged such that a portion of the polishing current in the thin layer of electrolyte fluid 7081 is absorbed by conductive member 7114. By absorbing a portion of the polishing current, conductive member 7114 can reduce the polishing rate of the metal layer at or near the edges of wafer 7004 and reduce or prevent the over-polishing.

[0065] Conductive member 7114 may include a single ring positioned near or at the edge of wafer 7004. Alternatively conductive member may include two or more sections that are arranged at or near the edge of wafer 7004. Conductive member 7114 can include

metals or alloys such as Tantalum, Titanium, stainless steel, and the like, as well as other conductive materials suitable for contact with electrolyte fluid 7081.

[0066] Further, wafer 7004 may be positioned between wafer chuck 7002 and conductive member 7114 as shown in Fig. 7. For example, a robot arm or the like, may position wafer 7004 adjacent wafer chuck 7002 or between wafer chuck 7002 and conductive member 7114. Wafer chuck 7002 and conductive member 7114 may then be brought together or closed to hold wafer 7004 therebetween. The exemplary assembly may therefore include additional elements, such as holders or positioners to align and hold wafer chuck 7002 and conductive member 7114 together as well as insulative members between conductive member 7114 and contacts made to charge wafer 7004.

[0067] It should be understood that the exemplary apparatus depicted in Fig. 7 may also include other features such as those shown in Fig. 1A, but have been omitted to illustrate the specific example. For instance, shroud 1006 (Fig. 1A, 1B) may be used with the exemplary apparatus as well as various pumps, nozzles, filters, and the like.

[0068] Fig. 8A illustrates another exemplary electropolishing apparatus useful for reducing the polishing rate near the edges of a wafer. A chuck 8002 with a conductive member 8114 is illustrated that may reduce the amount of over-polishing at or near the edges of wafer 8004. Fig. 8A is similar to Fig. 7 except that conductive member 8114 is separated from wafer 8004 by a spacer element 8118. Spacer element 8118 includes, for example, an o-ring. Spacer element 8118 may further be formed of a material that is electrically insulative and further resistant to acid and corrosion, such as ceramic, polytetrafluoroethylene (commercially known as TEFLON), PolyVinyl Chloride (PVC), PolyVinylidene Fluoride (PVDF), Polypropylene, silicon rubber, Viton rubber, and the like. Conductive member 8114 is coupled to power supply 8112, and a second conductive member or electrode, such as spring member 8119 is coupled to power supply 8110. As shown, current flowing through conductive member 8114 can be adjusted or controlled by power supply 8112 in order to control the polishing rate of the metal layer at or near the edge of wafer 8004. Generally, as the amount of current absorbed by bottom chuck 8114 increases, the polishing rate of the metal layer at or near the edge of wafer 8004 decreases.

[0069] Power supply 8112 can be a DC power supply, an AC power supply synchronized with main polishing power supply 8110, and the like. An AC power supply can also include a forward pulse power supply, and a forward and backward power supply. Furthermore, power supply 8112 can be operated at a constant current mode, a constant voltage mode, or a combination of constant current and constant voltage mode, wherein a constant current mode is applied during a portion of the polishing time and a constant voltage mode is applied during the other portion of the polishing time. One could also replace the power supply 8112 with a variable resistor thereby applying a varying charge to conductive member 8114 (See Fig. 9A, for example). Further, a variable resistor may be included between both conductive member 8114 and spring member 8119.

[0070] Conductive member 8114 may similarly include metals or alloys such as Tantalum, Titanium, stainless steel, and the like as well as other conductive materials. Further, conductive member 8114 may include one or more sections positioned near or at the edge of wafer 8004.

[0071] Therefore, in this exemplary electropolishing apparatus, the electric charge applied to the wafer 8004 through spring member 8119 and conductive member 8114 can be independently controlled by power supplies 8110 and 8112 respectively. This allows for greater control of the current density near the edge region of wafer 8004 to control and reduce over-polishing of the edge region.

[0072] Fig. 8B illustrates an enlarged view of the configuration and connections made with conductive member 8114 and wafer 8004 of Fig. 8A. In particular, conductive member 8114 is charged by power supply 8112 and is spaced from wafer 8004 by spacer element 8118. Wafer 8004 is charged separately by power supply 8110 that is coupled to spring member 8119 positioned around the edge of wafer 8004. Spring member 8119 provides a charge to wafer 8004 that is more uniformly distributed around wafer 8004 than, for example, several electrodes positioned around the edge of wafer 8004. An insulative member 8121 may be positioned between conductive member 8114 and spring member 8119 when separate charges are applied to conductive member 8114 and spring member 8119. Spring member 8119 may be formed as a coil spring formed in a ring (see, e.g., Fig. 8C), however, other cross-sectional profiles, such as an elliptical cross-sectional profile are

possible. Further, any number of coil springs may be used depending on the application. Spring member can be formed from any convenient electrically conducting material, such as stainless steel, spring steel, titanium, and the like. Spring member 8119 may also be formed of corrosion-resistant material or coated with a corrosion resistant material such as platinum, TiN, TaN, and the like.

[0073] The number of contact points formed between wafer 8004 and the power supply can be varied by varying the number of coils in spring member 8119. In this manner, the electric charge applied to wafer 8004 may be more evenly distributed around the outer perimeter of wafer 8004. For example, for a 200-millimeter wafer, an electric charge having about 1 to about 10 amperes is typically applied. Configuring spring member 8119 to create approximately 1,000 contact points with wafer 8004 reduced the electric charge to about 1 to about 10 milli-amperes per contact point.

[0074] It should be recognized, however, that the wafer 8004 may also be charged by one or more electrical contacts. Further, any means to distribute electrical charge around wafer 8004 may advantageously be used.

[0075] When conductive member 8114 is separated from wafer 8004 by spacer element 8118 shorting may result if spring member 8119 is exposed to the electrolyte fluid. The shorting of spring member 8119 may reduce the uniformity of the polishing rate near the edge portions of wafer 8004. Therefore, in one example, spacer element 8118 serves as a seal to isolate spring member 8119 from the electrolyte fluid. Spacer element 8118 may be formed of anti-corrosive material, such as Viton (fluorocarbon) rubber, silicone rubber, and the like. Further, spacer element 8118 may have various shapes and configuration depending on the particular application.

[0076] Fig. 8C illustrates an exploded view of an exemplary wafer chuck holder for use with the exemplary electropolishing apparatus useful for reducing the polishing rate near the edges of a wafer. The exemplary wafer chuck includes a body with a base section 8002 in an upper portion of the body and a conductive member 8114, where wafer 8004 is held between base section 8002 and conductive member 8114 of the body. The wafer chuck may further include a top holder (not shown) to clamp or otherwise hold wafer 8004 and the assembly together. In addition to the first conductive member 8114, the wafer

chuck includes a second conductive member, such as spring member 8119, to apply a charge to wafer 8004. In some examples, the wafer chuck may further include insulator member 8121 and spacer member 8118 disposed between base section 8002 and conductive member 8114 included in a lower portion of the body. It should be recognized, however, that in some examples spring member 8119 and spacer member 8118 may be omitted, for example, as illustrated in Fig. 7. In an instance where spring member 8119 is omitted, an electrode or the like may be included as a second conductive member to apply a charge to wafer 8004.

[0077] In the present example, spring member 8119 is disposed between wafer 8004 and spacer member 8118. When pressure is applied to hold conductive member 8114 and base section 8002 together, spring member 8119 conforms to maintain electrical contact to wafer 8004 (see Fig. 8B). Further, spacer member 8118 conforms between conductive member 8114 and wafer 8004 to form a seal that protects spring member 8119 from electrolyte fluid and provides electrical insulation between spring member 8119 and conductive member 8118 if desired.

[0078] Semiconductor wafers are typically substantially circular in shape. Accordingly, the various components of the wafer chuck are depicted as having substantially circular shapes. It should be recognized, however, that the various components of the wafer chuck may include various shapes depending on the particular application and/or shape of the wafer. For example, a semiconductor wafer may have a truncated shape for which the components of the wafer chuck conform with.

[0079] Other exemplary configuration of a wafer chuck assembly for holding and applying a charge to a wafer suitable in the apparatus and methods described can be found in U.S. Patent Serial No. 6,248,222 entitled METHODS AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, issued on June 19, 2001, and incorporated herein by reference in its entirety.

[0080] Fig. 9A illustrates another exemplary electropolishing apparatus useful for reducing the polishing rate near the edges of a wafer. In particular, wafer chuck 9002 includes conductive member 9114 that may reduce the amount of over-polishing at or near

the edges of wafer 9004 as described above. Fig. 9A is similar to Fig. 8A, except that conductive member 9114 includes an insulating ring 9115 and a conducting ring 9116 formed in insulating ring 9115. Insulating ring 9115 can include non-corrosive insulating materials such as plastics, ceramics, and the like. Conducting ring 9116 can include metals or alloys such as Platinum, Tantalum, Titanium, stainless steel, and the like. Conducting ring 9116 may be connected to power supply 9110 through variable resistor 9112 or the like. Additionally, spacer element 9118, for example, an o-ring or the like, can be placed between conductive member 9114 and wafer 9004 to prevent electrolyte fluid from contacting the portion of wafer 9004 that is connected through one or more electrodes to power supply 9110. Further, a spring member or the like (not shown) may also be included to more uniformly distribute the electrical charge to the wafer 9004.

[0081] The exemplary apparatus of Fig. 9A allows for a smaller amount of conductive material to be used with conductive member 9114. This allows the apparatus to be cheaper, lighter, and consume less power during operation. Further, the smaller surface area of conductive member 9114, compared to conductive member 8114 (Figs. 8A, 8B) may allow for greater control of the current density in the edge region of wafer 8004. Further, the configuration of Fig. 9A (and Fig. 7) may be advantageously used with those of Figs. 7 and 8A through 8C.

[0082] Fig. 9B illustrates an enlarged view of another example of an electropolishing apparatus. This example is similar to Fig. 9A, except that the conductive member 9114 includes an insulative member 9121 formed on the lower portion of conductive member 9114, i.e., the side opposite of wafer 9004. Further, the configuration of the wafer assembly is such that metal layer 9005 on wafer 9004 is charged near the edge through a conductive spacer element 9118.

[0083] Thus, as seen in Fig. 9B, as electrolyte fluid 9080 is directed near the edge of wafer 9004 a portion of the current I_1 flows to the metal layer 9005 and a second portion of the current I_2 flows to conductive member 9114. Insulative member 9121 formed on the lower portion of conductive member 9114 serves to reduce current I_2 and increase current I_1 flowing to the metal layer 9005. The relative thickness of insulative member 9121 and conductive member 9114 may therefore be adjusted to adjust currents I_1 and I_2 accordingly.

[0084] IV. Method for Electropolishing a Fragmented Metal Layer on a Wafer

[0085] A metal layer formed over a wafer may become fragmented during an electropolishing process. For example, there may become one or more discontinuous regions of metal on the surface of the wafer. When this occurs some fragments of the metal layer may become isolated from the edges of the wafer where the electrodes are located. In such instances, traditional electropolishing methods are unable to efficiently polish these fragmented sections because the electrodes do not charge the fragmented metal layers. In one exemplary method, by rotating a wafer with a conductive member disposed around the fragmented portions of the metal layer at sufficient rotational speeds, a thin layer of electrolyte fluid may be formed over the fragmented portions and in contact with the conductive member. The thin layer of electrolyte fluid and conductive ring allow the fragmented portions to be electropolished.

[0086] As shown in Figs. 11A and 11B, metal layer 11150 has become fragmented, for example, during a polishing process. The fragments of metal layer 11150 are not connected to or located at the edges of wafer 11004 where an electrode (not shown) is connected to power supply 11110. Because the fragments of metal layer 11150 are not located at the edge of wafer 11004 or connected to these edges by metal, electric current cannot be conducted through the fragments to an electrode at the edge of wafer 11004. Thus, traditional polishing methods, such as submersing the wafer in a polishing bath, and the like are generally ineffective in polishing these fragments.

[0087] Fragments of metal layer 11150 of the metal layer, for example, may include the exposed portions of a barrier layer that remain on the non-trenched portions of a semiconductor device after a copper layer is polished away. Further, fragments of metal layer 11150 may be a result of uneven polishing or over-polishing in edge regions, for example.

[0088] With reference to Fig. 11B an exemplary electropolishing apparatus is illustrated for electropolishing fragments of metal layer 11150 on wafer 11004. The system includes chuck 11002, actuator 11000, stationary nozzle 11054, and power supply 11110. As stationary nozzle 11054 applies a stream of electrolyte fluid 11080 to wafer 11004, actuator 11000 can rotate chuck 11002 such that electrolyte fluid 11080 flows across the

surface of wafer 11004, as described above, and forms a thin layer 11081 extending over the fragmented portions of metal layer 11150. For example, wafer chuck 11002 can be rotated at a rate in the range of about 100 rpm to about 2000 rpm, and preferably about 1500 rpm for a 300 mm diameter wafer. Thin layer 11081 provides a path across the fragments of metal layer 11150 to conduct current between the stream of electrolyte fluid 11080 and the conductive member 11114 of chuck 11002. This current allows the apparatus to electrically polish isolated fragments of metal layer 11150 on wafer 11004.

[0089] Additionally, the exemplary apparatus depicted in Figure 11B may be a part of a larger electropolishing assembly such as the one depicted in Fig. 1A. For example, a shroud 1006 (Fig. 1) may be included to prevent splashing, uneven polishing, or disruption of the polishing stream of electrolyte fluid 1038. Further, various exemplary embodiments of conductive member 11114 described in regard to the reduction of edge polishing may be used with the apparatus of Fig. 11B.

[0090] Fig. 12 shows another system that can be used to electropolish fragments of metal layer on wafer 12004. Fig. 12 is similar to Fig. 11, except that actuators 12180 and 12182 can move nozzle 12054 along the x-direction while actuator 12000 rotates chuck 12002 in a stationary location.

[0091] Although Figs. 11B and 12 show systems in which either the chuck or the nozzle moves along the x-direction, it should be recognized that both the chuck and the nozzle can be moved in varying directions depending on the particular application.

[0092] V. Metal Concentration Measurement and End Detection Control

[0093] One factor in achieving more consistent and acceptable polishing quality of wafers in a mass production environment is controlling the concentration of metal in the supply of electrolyte fluid used to polish the wafers. When the concentration of metal in the supply of electrolyte fluid reaches a certain value, the electrolyte fluid can become very active even when no current is applied. This may cause, for example, chemical etching or corrosion of the wafers during the post-electropolishing process. Therefore, it is desirable to monitor the concentration of metal in the electrolyte fluid during a process run and make adjustments on a real-time basis as desired.

[0094] Further, end-point detection sensors typically use optical detectors that measure through the electrolyte fluid. The measurements therefore depend, at least in part, on the optical characteristics of the electrolyte fluid. The optical characteristics of the electrolyte fluid, however, may change over time depending on the concentration of the metal dissolved in the electrolyte fluid as well as on other factors, such as contaminant particles, hydrogen gas bubble formation within the electrolyte fluid, and the like. Thus, as the optical characteristics of the electrolyte fluid changes during a process run, the measurements from the end-point detector can be adjusted accordingly to increase the accuracy of the end-point detection measurements.

[0095] Fig. 10A depicts an exemplary system that may be used to measure the concentration of metal in a supply of electrolyte fluid 10038, such as electrolyte fluid reservoir 1070 (Fig. 1A), and the like. The exemplary system includes fiber probe 10102, fiber optical sensor 10104, and reflector 10100. Fiber probe 10102 and reflector 10100 can be immersed in electrolyte fluid 10038, and fiber probe 10102 can be positioned with respect to reflector 10100 in a manner that allows light emitted from fiber probe 10102 to be reflected by reflector 10100 back to fiber probe 10102 with a maximum light intensity. For instance, fiber probe 10102 can be positioned to emit light in a direction perpendicular to the surface of reflector 10102, as shown in Fig. 10A.

[0096] Additionally, the distance H between reflector 10100 and fiber probe 10102 may effect the accuracy of the measurement of the concentration of metal in the electrolyte fluid. Accordingly, distance H can be chosen such that the intensity of light received by optical sensor 10104 reaches a maximum value when the metal concentration reaches a minimum concentration in the supply of electrolyte fluid 10038. It should be recognized that other paths between a optical sensor 10104 and reflector 10100 may be chosen, including a path with multiple paths and multiple reflections depending on the application and desired path length. The fiber probe 10102 may also be placed exterior to the fluid reservoir with a path traversing a portion of the electrolyte fluid 1038. Further, an optical sensor positioned to detect a light intensity that is received by optical sensor 10104 may replace reflector 10100.

[0097] Generally, the color of the electrolyte fluid depends on the type and concentration of metal ions that are dissolved in the electrolyte fluid. For example, copper ions in Phosphoric acid (H_3PO_4) have a blue color. Additionally, the intensity of light passing through the electrolyte fluid can decay depending on the color of the electrolyte fluid. In general, as the concentration of metal ions in the electrolyte fluid increases, the decay of light intensity increases.

[0098] For the system depicted in Fig. 10A, the relationship between the concentration of metal in the electrolyte fluid and the decay of light intensity can be tabulated for a particular metal and electrolyte fluid used with the system as follows:

Metal Concentration (wt %)	Light Intensity Decay
0	Y1
0.2	Y2
0.4	Y3
0.6	Y4
0.8	Y5
1.0	Y6

[0099] This tabulated information can be stored in computer 10105. Using the tabulated information, the computer can automatically calculate the concentration of metal in the electrolyte fluid based on the intensity of light detected by optical sensor 10104, by using interpolation, rounding, or other approximation methods. Although certain values are listed in the above table for Metal Concentration (wt %), any values can be used, and any number of values can be used.

[00100] The color of light emitted by fiber probe 10102 can be chosen to increase the sensitivity of the measurements detected by optical sensor 10104. In particular, the color of light emitted by fiber probe 10102 can be different from the color of the metal ions in the electrolyte fluid supply in order to increase the sensitivity to the particular metal ions. For example, for copper ions in a supply of phosphoric acid, emitting red light provides a higher sensitivity to copper ion concentration than emitting green light, and emitting green

light provides a higher sensitivity than emitting blue light. However, for any color of metal ions in an electrolyte fluid, white light may be emitted.

[00101] Fig. 10A also depicts another aspect of an exemplary system described above that can be used to remove metal ions from the supply of electrolyte fluid 10038. The system further includes two electrodes 10028 and 10029, and power supply 10030. When optical sensor 10104 measures that the metal ion concentration in the supply of electrolyte fluid 10038 has reached a first pre-set value, computer 10105 can instruct power supply 10030 to apply voltage to electrodes 10028 and 10029 in order to remove metal ions from the electrolyte fluid supply. When voltage is applied to electrodes 10028 and 10029, metal ions from the supply of electrolyte fluid 10038 begin plating onto electrode 10029. When optical sensor 10104 detects that the metal ion concentration has fallen below a second pre-set value, computer 10105 can instruct power supply 10030 to stop applying voltage to electrodes 10028 and 10029 in order to stop the removal of metal ions from the supply of electrolyte fluid 10038. In this manner, the concentration of metal ions in the supply of electrolyte fluid 10038 can be maintained between the first and second pre-set values, for example, during an electropolishing process.

[00102] The concentration values of the metal ions in electrolyte fluid 10038 may also be used to aid end-point detector 1016 (Fig. 1A, 1B). End-point detector 1016 may be used to determine the thickness of the metal layer on wafer 1004. The information may be used by the electropolishing apparatus to determine when to continue or discontinue an electropolishing process on a particular area of wafer 1004. It may also be used to determine a suitable polishing rate. End-point detector 1016 may include various sensors, such as ultrasonic sensors, optical sensors, electromagnetic sensors, and the like. Using the electrolyte fluid 1038 as a medium to transmit signals and take measurements increases the accuracy of the measurement because medium interfaces, for example, air to electrolyte fluid 1038, do not have to be considered. If properties of the electrolyte fluid 1038 that may affect the sensors change, however, the measurements may not be accurate over time. Therefore, the end-point detector measurements may be improved by taking into consideration the changing properties of electrolyte fluid 1038.

[00103] Fig. 10B shows another exemplary system for monitoring the optical characteristics of the electrolyte fluid, which may be used, for example, to adjust an end-point detector measurement. Fig. 10B is similar to Fig. 10A except that a second optical sensor 10204 and optical fiber 10202 are included. Optical sensor 10104, optical fiber 10102 and reflector 10100 operate in a similar manner as described in reference to Fig. 10A. The second optical sensor 10204 and optical fiber 10202 also operate similar to optical sensor 10104 and optical fiber 10102; however, optical sensor 10204 and optical fiber 10202 measure other optical characteristics of the electrolyte fluid. For example, during an electropolishing process, hydrogen bubbles often form on the electrodes. The bubbles may adversely affect the end-point detector by diffracting and decreasing the intensity of the measurement beams in the electrolyte fluid. The decrease in intensity may affect the measurements of metal ion concentration, but, by using multiple detectors sensitive to different characteristics the metal ion concentration can be accurately determined.

[00104] In the example of determining the optical characteristics of the electrolyte fluid due to bubbles, the color of light emitted by fiber probe 10202 can again be chosen to increase the sensitivity of the measurements detected by optical sensor 10204. In this instance, the color of light emitted by fiber probe 10202 can be chosen as the same color of the metal ions in the electrolyte fluid supply in order to increase sensitivity to the bubbles and decrease the sensitivity to the metal ions. For example, for copper in a supply of phosphoric acid, emitting blue light provides a higher sensitivity to bubbles and lower sensitivity to copper ions than emitting white light, and emitting white light provides a higher sensitivity to bubbles and a lower sensitivity to copper ions than emitting red light.

[00105] Additionally, the intensity of red light from fiber probe 10102 will also be reduced due to any bubbles in electrolyte fluid such that the measurement of copper ion concentration will be inaccurate. The second optical sensor 10204, however, will indicate the portion of the decrease in intensity due primarily to the bubbles and not the copper ion concentration because the sensitivity of fiber probe 10202 was chosen to be insensitive to the copper ion concentration. The decrease in intensity of the red light may therefore be determined by considering the portion due to bubbles determined by the second optical sensor 10204. Further, the end-point detector 1010 (Fig. 1A) will be able to retrieve the

optical characteristics of the electrolyte fluid from computer 10105 and make accurate measurements of the metal thickness on wafer 1004 (Fig. 1A). Thus, second optical sensor 10204 may increase the accuracy of both the end-point detector measurements and the metal ion concentration measurements.

[00106] It should be recognized that any number of sensors may be used to measure various properties of the electrolyte fluid. The various properties, for example, the optical properties and the like, may then be stored and used to adjust or determine end-point detector measurements and the like.

[00107] VI. Nozzle Configurations

[00108] According to another aspect, an exemplary method and apparatus for electropolishing a metal film on a wafer includes using multiple sized nozzles with different polishing rates. In general, a large nozzle allows for higher polishing rates of a metal film, for example, copper, formed on a wafer and a small nozzle produces lower polishing rates. A large nozzle can therefore be used as a rough polish of the metal layer followed by using a small nozzle to more precisely control the electropolishing process. Multiple nozzles are therefore advantageous for more precisely polishing different regions of a wafer. However, because of the limited space within a clean room, for example, an apparatus with multiple nozzles is desirably compact. An exemplary apparatus with a number of nozzles configured on a rotating nozzle holder therefore allows for the use of multiple nozzles in a compact space.

[00109] Figs. 13A, 13B, 13C, 13D, and 13E illustrate an exemplary electropolishing assembly including a multiple rotary nozzle assembly. Figs. 13A through 13E are similar to Figs. 1A through 1E, except for the addition of rotary nozzle 1012 with multiple nozzles positioned adjacent optical end-point detector 1016, and Eddy-current thickness/end-point detector 1009. As indicated by the arrow in Fig. 1A, rotary nozzle 2012 may rotate and position different sized and/or shaped nozzles 1014 to direct a stream of electrolyte fluid 1038 to the wafer 1004. Thus, pump 1018 only directs electrolyte fluid 1038 to nozzle 1010 of the end detector 1016 and a single nozzle 1014, whereas in Fig. 1A electrolyte fluid 1038 is directed to each individual nozzle used therein.

[00110] End-point detector 1009 may operate to measure the thickness of a metal film formed on wafer 1004. Detector 1009 may measure the thickness of the metal film prior, during, and after an electropolishing process. In one exemplary method, end-point detector 1009 is used to determine the thickness of the metal film over the entire wafer 1004 prior to electropolishing, using for example, an eddy current end-point detector. The metal film thickness may then be used to control the local polishing rate for various positions on wafer 1004 by controlling the current density and/or stream profile. The distance between the end-point detector 1009 and wafer 1004 is, for example, in the range of about 5 to about 1000 microns. The film thickness over the entire wafer may be determined by rotating wafer 1004 and moving chuck 1002 in a horizontal direction while simultaneously allowing the end-point detector 1009 to scan the entire surface of wafer 1004. It should be understood, however, that alternatively end detector 1009 could scan a stationary wafer 1004.

[00111] Rotary nozzle 2012 may then rotate to select a desired nozzle 1014 depending on the portion of wafer 1004 that is being polished, the metal film thickness and the like. For example, in areas where metal layer is thick a larger nozzle may be used, and in areas where metal layer is thin a small nozzle may be used. Including numerous nozzles of varying sizes and profiles within a simple compact electropolish assembly that may be quickly and easily interchanged thus enhances the precision of the polishing.

[00112] With reference to Fig. 14A a cross-sectional view of an exemplary multiple rotary nozzle holder 2012 is shown. Rotary nozzle holder 2012 holds nozzles 2014. Driving means 2070 rotates the rotary nozzle 2012 through driving joint 2068 for positioning a new nozzle to direct a stream of electrolyte fluid. An o-ring 2066 seals driving joint 2068, for example. The driving means 2070 may be a stepper motor, servomotor, pneumatic (compressed gas or liquid) driving rotation means, and the like. Nozzles 2014 in rotary nozzle holder 2012 include electrodes 2056 that may be electrically coupled to outside power supply 1040 (Fig. 13A) through electrical current feed-throughs 2062. Rotary nozzle holder 2012 rests on plate 2084, which is sealed with chamber 1008 by o-ring 2072 and bolt 2074.

[00113] Nozzle holder 2012 may be made of plastics such as PVC, PVD, TEFLON, polypropylene, and the like or coated with a material that is generally insulative and non-corrosive. Nozzles 2014 may be made of tantalum, titanium, platinum, stainless steel, and the like.

[00114] Figure 14C illustrates an exemplary process for electropolishing a metal film from a wafer 1002 using the apparatus of Figure 14A. In block 1 the metal film thickness profile is determined, for example, by end-point detector 1009 translating in the x-direction as the wafer 1004 is rotated as described above. In block 2, the metal film can be polished initially with a high polishing rate using a large nozzle 2014. Following the high polishing rate the nozzle holder 2012 may be rotated to use a lower polishing rate using a small nozzle 2014 in block 3. After the initial polishing in block 1 and/or block 2 the remaining metal thickness profile may be determined in block 4 using end-point detector 1009, for example, an eddy current end-point detector, optical end-point detector, or the like. Based on the remaining metal thickness profile determined in block 4, the polishing current may be adjusted or tuned in block 5 to polish thick film locations at a higher rate, polish thin film locations at a low rate, and stop the polish at zero film thickness locations. The polishing current may be tuned, for example, by using different nozzles 2014 and/or varying the charge supplied by the power supply. In block 6, measurements of the thickness profile are repeated, i.e., block 4. If the thickness of the metal layer reaches a pre-set value the polishing process may be stopped. If, however, the thickness of the metal has not reached a pre-set value, then block 5 may be repeated until a desired thickness is reached.

[00115] It should be recognized that numerous modifications and variations may be made to the process described with reference to Figure 14C. Further, numerous other processes may be used in conjunction with the exemplary apparatus of Fig. 14A.

[00116] With reference to Fig. 14B, another exemplary multiple rotary nozzle assembly is illustrated. The rotary nozzle assembly shown in Fig. 14B is similar to that shown in Fig. 14A except that driving joint 2068 is replaced by magnetically coupled joints 2078 and 2082. An advantage of using magnetically coupled joints 2078 and 2082 is that driving joint 2078 does not make a direct connection to nozzle holder 2012 and o-ring 2066

of Fig. 14A may be omitted. This reduces the possible occurrence of electrolyte fluid 1038 leaking through to driving joint 2068. It should be recognized therefore that various methods of coupling driving joint 2068 to rotary nozzle 2012 are possible.

[00117] With reference to Fig. 15, an exemplary linearly movable multiple nozzle assembly is illustrated. The multiple linearly movable nozzle assembly operates similar to the rotary nozzle 2012 of Figs. 13A through 13E except that the nozzles move in a linear motion as opposed to rotational motion. The multiple linear movable nozzle assembly includes nozzle 3054, nozzle 3222, and nozzle 3226 including electrodes 3056, 3220, and 3224 respectively. The three nozzles 3054, 3222, and 3226 may be configured to have different profiles, for example, different diameters, and therefore may provide different polishing rates.

[00118] Nozzles 3054, 3222, and 3226 are movable in a horizontal direction, i.e., x-direction, through nozzle holder 3180 and moving guide 3182. Electrodes 3056, 3220, and 3224 are further connected with power supply 3110 through electrical feed-throughs (not shown). Electrolyte fluid 3080 is supplied to nozzles 3054, 3222, and 3226 through nozzle holder 3180. As described with reference to Fig. 14C, different sized nozzles 3054, 3222, and 3226 may be used interchangeably during an electropolishing process to remove a metal film disposed on wafer 1004. In general, a large nozzle may be used to polish the metal film at a higher polish rate when the metal film is thick, and a small nozzle may be used to polish the metal film at a lower polish rate if the metal film is thin, or a small amount of metal is desired to be removed.

[00119] Figs. 16A through 16E illustrate an exemplary electropolishing assembly including a multiple rotary nozzle assembly. Figs. 16A through 16E are similar to Figs. 13A through 13E, except for the addition of a linear movable base 4180 and moving guide 4182 with rotary nozzles 4012 and 4014 mounted thereon.

[00120] In particular, rotary multiple nozzles 4014, optical end-point detector 4016, and eddy current thickness/end-point detector 4060 are mounted on linearly movable base 4180. The linearly movable base member may be moved in a horizontal direction, i.e., x-direction, along moving guide 4182. This assembly allows for multiple nozzles to be included within a compact space.

[00121] The structure and operation of the multiple nozzles 4014 is similar to those shown in Figs 14A and 14B, however, structures such as the rotating driving means, driving joint, electrical current feed-through, and electrolyte feed-throughs have been omitted for illustrative purposes.

[00122] VII. Nozzle Self-Cleaning Processes

[00123] According to another aspect, an exemplary process for self-cleaning electropolishing nozzles is described. During a typical electropolishing process metal dissolved in the electrolyte fluid may become plated on the nozzle electrodes. The plated metal may restrict or deform the opening of the nozzle thereby altering the shape and/or direction of the stream of electrolyte fluid. Changing the shape of the stream may change the current density of the stream and consequently alter the polishing rate of the electropolishing apparatus. The nozzles may be depleted, or cleaned, by applying a reverse voltage to the nozzles that cause metal ions to dissolve back into the electrolyte solution. For example, the metal may be plated to another nozzle, a sacrificial material, or the like.

[00124] With reference again to Figs. 1A through 1E, metal from a metal layer that is polished from wafer 1004 becomes dissolved in electrolyte fluid 1038 and may result in a portion of the dissolved metal becoming plated onto nozzle electrodes 1056 and/or 1060. In order to remove the metal from nozzle electrodes 1056 and/or 1060, a reverse voltage can be applied to nozzle electrodes 1056 and/or 1060. Either a DC or an AC power supply can be used to apply the reverse voltage. In one exemplary process, a reverse voltage is applied to dissolve the metal buildup into the electrolyte fluid. In another exemplary process, a reverse voltage is applied to plate the metal buildup onto a disposable wafer. In yet another example, a reverse voltage is applied to plate the metal buildup onto a block.

[00125] A. Dissolving Metal Buildup into Electrolyte fluid Using a DC Power Supply

[00126] With reference to Fig. 1A, metal buildup on nozzle 1012 can be polished off and dissolved into electrolyte fluid 1038 using a DC power supply. More particularly, lead C can be connected to lead b and lead B can be connected to lead a, such that nozzle electrode 1056 (Figs. 1B-1E) acts as an anode and nozzle electrode 1060 acts as a cathode.

Electrolyte fluid 1038 can be supplied through nozzles 1012 and 1014 in order to form an electrical circuit between electrode 1056 and 1060 that allows metal buildup on nozzle 1012 to be removed from nozzle 1012 and dissolved into electrolyte fluid 1038. A portion of the metal dissolved into electrolyte fluid 1038 may become plated onto nozzle 1014.

[00127] Although it appears that the process simply moves the metal from one nozzle and plates it to another, the majority of the metal removed from nozzle 1012 remains dissolved in electrolyte fluid 1038. The metal concentration in the electrolyte fluid 1038 for an exemplary electropolishing process is typically low, for example, less than 3% by weight, such that the electropolishing is driven by electrically charging electrodes 1012 and 1014 and not by the chemistry of the electrolyte solution 1038. Thus, the amount of metal polished from nozzle 1012 is greater than the amount of metal plated to nozzle 1014. For example, ten metal ions might be removed from nozzle 1012 for every one metal ion plated to nozzle 1014 resulting in the majority of the metal ions being dissolved into the electrolyte fluid 1038.

[00128] With continued reference to Fig. 1A, the process can be reversed such that metal buildup on nozzle 1014 is polished off and dissolved into electrolyte fluid 1038 using a DC power supply. More particularly, lead B can be connected to lead b and lead C can be connected to lead a, such that nozzle electrode 1060 (Figs. 1B-1E) acts as an anode and nozzle electrode 1056 acts as a cathode. Electrolyte fluid 1038 can be supplied through nozzles 1012 and 1014 in order to form an electrical circuit that allows metal buildup on nozzle 1014 to be removed from nozzle 1014 and dissolved into electrolyte fluid 1038. Again, a portion of the metal dissolved into electrolyte fluid 1038 can become plated onto nozzle 1012.

[00129] By repeating this process, i.e., reversing the voltage for each nozzle used in the apparatus, the nozzles can be cleaned. In one exemplary process, the nozzles are quickly cleaned by electropolishing successive wafers by first deplating nozzle 1012 and plating nozzle 1014, followed by deplating nozzle 1014 and plating 1012. Both nozzles are effectively cleaned because, as discussed, most of the metal is dissolved in the electrolyte fluid 1038 as opposed to being plated to the opposing nozzle.

[00130] Figs. 2 and 3 show two exemplary configurations of nozzles 1012 and 1014 during a cleaning process. Nozzles 1012 and 1014 are positioned near each other and electrolyte fluid is allowed to flow through nozzle 1012 and 1014 and form a film or path of electrolyte fluid therebetween. When nozzles 1012 and 1014 are placed closer together, as shown in Fig. 3, the two films or paths of electrolyte fluid 1080 flowing between nozzle 1012 and 1014 can join to form a single path. This single path reduces the length of the electrical circuit, thereby increasing the efficiency of the metal buildup removal process. It should be recognized of course that the exemplary method may also be employed with more than two nozzles.

[00131] B. Plating Metal Buildup onto Wafer Using a DC Power Supply

[00132] With reference to Fig. 1A, metal buildup on nozzle 1012 can be polished off and plated onto wafer 1004 using a DC power supply according to another exemplary process. More particularly, lead A can be connected to lead b and lead B can be connected to lead a, such that wafer 1004 acts as a cathode and nozzle electrode 1056 (Figs. 1B-1E) acts as an anode. Electrolyte fluid 1038 can be supplied through nozzle 1012 to wafer 1004 in order to form an electrical circuit allowing metal buildup on nozzle 1012 to be plated onto wafer 1004. Wafer 1004 can be discarded after the metal buildup on nozzle 1012 is removed.

[00133] Similarly, with reference to Fig. 1A, metal buildup on nozzle 1014 can be polished off and plated onto wafer 1004 using a DC power supply. More particularly, lead A can be connected to lead b and lead C can be connected to lead a, such that wafer 1004 acts as a cathode and nozzle electrode 1060 (Figs. 1B-1E) acts as an anode. Electrolyte fluid 1038 can be supplied through nozzle 1014 to wafer 1004 in order to form an electrical circuit that allows metal buildup on nozzle 1014 to be plated onto wafer 1004. Nozzle 1012, or other nozzles in the electropolishing apparatus, may be cleaned in parallel or in series with nozzle 1014. Wafer 1004 can be discarded after the metal buildup on nozzle 1014 is removed.

[00134] C. Plating Metal Buildup onto a Block Using a DC Power Supply

[00135] With reference to Fig. 4, metal buildup 1057 on nozzle 1012 can be polished off and plated onto block 1082 using a DC power supply according to another exemplary process. More particularly, lead B can be connected to lead a and lead D can be connected to lead b, such that block 1082 acts as a cathode and nozzle electrode 1056 acts as an anode. Electrolyte fluid 1038 (Fig. 1) can be supplied through nozzle 1012 and allowed to contact block 1082 in order to form an electrical circuit through electrolyte fluid 1038 allowing metal buildup on nozzle 1012 to be plated onto block 1082. Block 1082 can be discarded after the metal buildup on nozzle 1012 is removed, or when otherwise convenient.

[00136] Similarly, with reference to Fig. 4, metal buildup 1057 on nozzle 1014 can be polished off and plated onto block 1082 using a DC power supply. More particularly, lead C can be connected to lead a and lead D can be connected to lead b, such that block 1082 acts as a cathode and nozzle electrode 1060 acts as an anode. Electrolyte fluid 1038 (Fig. 1) can be supplied through nozzle 1014 and allowed to contact block 1082 in order to form an electrical circuit that can allow metal buildup on nozzle 1014 to be plated onto block 1082. Block 1082 can be discarded after the metal buildup on nozzle 1014 is removed, or when otherwise convenient. Further, electrode 1056 and 1060 may be cleaned in series or in parallel.

[00137] D. Removing Metal Buildup Using an AC Power Supply

[00138] In another exemplary nozzle cleaning process, an AC power supply, as opposed to a DC power supply, may be used with any of the above configurations to remove metal buildup from nozzles 1012 and 1014. In particular, an AC power supply is used to dissolve the metal buildup into the electrolyte fluid, plate the metal buildup onto a wafer to be discarded, or plate the metal buildup onto a block or other sacrificial material.

[00139] Removing metal buildup from the nozzles with an AC power supply becomes more efficient as the concentration of the metal in the electrolyte fluid decreases. Accordingly, the metal concentration can be typically in the range of about 0.1% to about 5% wt, and preferably less than about 0.5% wt during the removal process.

[00140] VIII. Nozzle Shapes

[00141] In any of the exemplary embodiments described, nozzles of various shapes may be advantageously employed. Different types of nozzles, for example, different sizes, profiles, cross-sectional shapes, and the like, provide different polishing characteristics and may be advantageously used depending on the particular application. For example, as seen in Fig. 1B, the exemplary electropolishing apparatus may include two different sized nozzles 1012 and 1014 that may be used to electropolish different sections of wafer 1004.

[00142] Additionally, Figs. 5A through 5H illustrate various exemplary nozzles having a variety of shapes and configurations. The shape of a nozzle, for example, the channel and the distal end, can change the profile of the electrolyte fluid flowing from the nozzle, the current density within the stream of electrolyte fluid, and the like. Figs. 5A through 5E illustrate various nozzle configurations and shapes that include insulator 5054 and an electrode 5056. Figs. 5F through 5H illustrate nozzles without an insulator. Several of the nozzle configurations have a curved electrode 5056 near the opening. The curved electrode 5056 prevents an electrical peak at a sharp point in the electrode, which helps produce a more uniform current density in the stream of electrolyte fluid. Fig. 5H depicts a nozzle including electrode 5056 and rod 5058 located near the center of the nozzle to increase the surface area of the electrode and create a more uniform current density.

[00143] For each of the above-described nozzles, electrode 5056 can include a metal or alloy such as Tantalum, Titanium, stainless steel, and the like. Additionally, insulator 5054 can include plastics such as PVC, PVD, Teflon, and the like, or ceramics such as Al_2O_3 , ZrO_2 , SiO_2 , and the like. Accordingly, because metals and alloys are typically easier to form into various shapes than plastics and ceramics, nozzles having electrodes with curved or tapered shapes and insulators with straight shapes can be less expensive to manufacture than other shapes. Furthermore, nozzles having only an electrode 5056, such as those shown in Figs. 5F, 5G, and 5H, can have a simpler design and more surface area. Additionally, the nozzle shown in Fig. 5H includes rod 5058 as part of electrode 5056, which provides the electrode with more surface area and may distribute more uniformly the electric potential across electrolyte fluid 1038 (Fig. 1A) flowing from the nozzle. A more uniformly distributed electric potential leads to more uniform electropolishing of wafer 1004.

[00144] Figs. 6A and 6B illustrates another exemplary nozzle having insulator 6054, electrode 6056, and conductive inner structure 6086. Inner structure 6086 includes a metal or alloy such as Tantalum, Titanium, stainless steel, and the like. Additionally, inner structure 6086 includes multiple channels that can increase the surface area of the electrode, and can distribute the electric potential across nozzle 6056 more uniformly. The size of the channels can be in the range of about 0.1 mm to about 10 mm, depending on the diameter of the nozzle and the particular application. Preferably, the size of each of the channels can be about one tenth of the nozzle diameter.

[00145] The channels can be formed in various cross-sectional shapes, such as those shown in Figs. 6B to 6I. For example, channels can be square, fiber-shaped, straight slots, metal rods, waved slots, rectangular, honeycomb, and the like. In addition, although particular cross-sectional shapes are shown in Figs. 6B to 6I, the channels can be formed in any cross-sectional shape, such as a triangle, polygon, ellipse, and the like.

[00146] The above detailed description is provided to illustrate exemplary embodiments and is not intended to be limiting. It will be apparent to those skilled in the art that numerous modifications and variations within the scope of the present invention are possible. For example, the different exemplary electropolishing apparatuses, for example, the shroud, the conductive member, the various nozzles, end-point detectors, and the like may be used together in a single assembly or may be used separately to enhance a conventional electropolishing apparatus. Accordingly, the present invention is defined by the appended claims and should not be limited by the description herein.

CLAIMS

1. An apparatus for electropolishing a wafer, comprising:
a wafer chuck for holding the wafer;
an actuator for rotating the wafer chuck;
a nozzle configured to electropolish the wafer; and
a shroud positioned around the edge of the wafer.
2. The apparatus of claim 1, wherein the actuator is configured to rotate the wafer chuck with sufficient rotational speed such that a stream of electrolyte fluid incident on the wafer flows towards the edge of the wafer.
3. The apparatus of claim 2, wherein the electrolyte fluid flows past the edge of the wafer and is incident upon the shroud.
4. The apparatus of claim 2, wherein the wafer is oriented facing down and the stream of electrolyte fluid incident on the wafer flows to the edge of the wafer before falling from the surface of the wafer.
5. The apparatus of claim 1, wherein the actuator is configured to vary the rotation of the chuck depending on the portion of the wafer that is being electropolished.
6. The apparatus of claim 5, wherein the actuator is configured to rotate the chuck at a higher speed when electropolishing portions of the wafer near the center.
7. The apparatus of claim 1, wherein the wafer chuck is configured to translate in relation to the nozzle.
8. The apparatus of claim 7, wherein the shroud is configured to move with the wafer chuck in relation to the nozzle.
9. The apparatus of claim 7, wherein the shroud and the wafer chuck are mechanically coupled to move together in relation to the nozzle.

10. The apparatus of claim 1, wherein the nozzle is configured to move in relation to the wafer chuck.
11. The apparatus of claim 1, wherein the shroud is positioned about 1 mm to about 10 mm from the edge of the chuck.
12. The apparatus of claim 1, wherein the shroud is positioned about 5 mm from the edge of the chuck.
13. The apparatus of claim 1, wherein the sidewall of the shroud includes an L-shape cross-section.
14. The apparatus of claim 1, wherein the sidewall of the shroud is tapered.
15. The apparatus of claim 1, wherein the sidewall of the shroud extends above or below the chuck.
16. The apparatus of claim 1, wherein the shroud includes plastic or ceramic material.
17. The apparatus of claim 1, wherein the shroud includes anticorrosive metals or alloys.
18. The apparatus of claim 1, wherein the shroud is coated with an electrolyte fluid-resistant material.
19. A method for electropolishing a semiconductor wafer, comprising the acts of:
electropolishing the wafer with a stream of electrolyte fluid;
rotating the wafer such that the electrolyte fluid incident upon the wafer flows across the surface of the wafer towards the edge of the wafer; and
positioning a shroud adjacent the edge of the wafer.

20. The method of claim 19, wherein the wafer is rotated with sufficient rotational speed such that electrolyte fluid incident on the wafer flows to the edge of the wafer without leaving the surface of the wafer.
21. The method of claim 19, wherein the electrolyte fluid flows past the edge of the wafer and is incident upon the shroud.
22. The method of claim 19, further including varying the rotation of the chuck depending on the portion of the wafer that is being electropolished.
23. The method of claim 22, wherein the wafer is rotated at a higher speed when electropolishing portions of the wafer near the center.
24. The method of claim 19, further including translating the wafer in relation to the nozzle.
25. The method of claim 19, further including moving the shroud in relation to the nozzle.
26. The method of claim 19, further including moving the shroud and the wafer together in relation to the nozzle.
27. The method of claim 19, further including moving the nozzle in relation to the wafer.
28. An apparatus for holding a wafer, comprising:
 - a body to support the wafer and expose one side of the wafer to a stream of electrolyte fluid;
 - a first conductive member configured to apply a charge to the wafer; and
 - a second conductive member configured to be exposed to the stream of electrolyte fluid.

29. The apparatus of claim 28, wherein the first conductive member is further configured to be isolated from the stream of electrolyte fluid.
30. The apparatus of claim 28, wherein an electric charge is applied to the second conductive member.
31. The apparatus of claim 28, wherein the electric charge applied to the second conductive member is not equal to the conductive charge applied to the wafer.
32. The apparatus of claim 28, wherein the second conductive member is a ring.
33. The apparatus of claim 28, wherein the second conductive member is positioned near a perimeter of the wafer.
34. The apparatus of claim 28, wherein the second conductive member includes metal.
35. The apparatus of claim 28, wherein the second conductive member is in contact with the wafer.
36. The apparatus of claim 28, wherein an insulative member is positioned between the wafer and the second conductive member.
37. The apparatus of claim 36, wherein the insulative member forms a seal between the conductive member and the wafer.
38. The apparatus of claim 36, wherein the insulative member includes an o-ring.
39. The apparatus of claim 36, wherein the insulative member includes synthetic rubber.

40. The apparatus of claim 28, wherein the first conductive member includes a spring member
41. The apparatus of claim 40, wherein the spring member is configured to contact an outer perimeter of the wafer.
42. The apparatus of claim 40, wherein the spring member includes a spring.
43. The apparatus of claim 40, wherein the spring member includes a plurality of coiled springs arranged around the perimeter of the wafer.
44. The apparatus of claim 40, wherein a second insulative member is inserted between the spring member and the second conductive member.
45. The apparatus of claim 28, wherein one of the electrical charge applied by the first conductive member and a electrical charge applied by the second conductive member may be varied with respect to each other.
46. The apparatus of claim 28, further including a DC power supply configured to apply the electrical charge.
47. The apparatus of claim 28, further including an AC power supply configured to apply the electrical charge.
48. The apparatus of claim 28, wherein the second conductive member is positioned within an insulative member.
49. The apparatus of claim 48, wherein the insulative member is a ring.
50. The apparatus of claim 28, further including at least one resistor to vary the electric charge applied to the wafer or an electric charge applied to the second conductive member.

51. The apparatus of claim 28, wherein the second conductive member has an insulative coating layer.
52. The apparatus of claim 28, wherein a second insulative member is positioned on a side of the second conductive member opposite of the wafer.
53. A method for holding a semiconductor wafer during an electropolishing process, comprising the acts of:
 - positioning a surface of the wafer in a stream of electrolyte fluid;
 - applying an electric charge to the wafer with a first conductive member; and
 - applying an electric charge to a second conductive member, wherein the second conductive member is configured to draw a current from the electrolyte fluid on the surface of the wafer.
54. The method of claim 53, wherein the second conductive member draws current near the edge of the wafer to reduce the polishing rate.
55. The method of claim 53, wherein the wafer is rotated such that the electrolyte fluid flows towards the edge of the wafer.
56. The method of claim 53, wherein the second conductive member is positioned near the edge of the wafer.
57. The method of claim 53, wherein the second conductive member is a ring of metal.
58. The method of claim 53, further including an insulative member positioned between the wafer and the second conductive member.
59. The method of claim 53, wherein the conductive member is positioned adjacent the wafer.

60. The method of claim 53, further including adjusting one of the electric charge applied to the wafer and the electric charge applied to the second conductive member relative to the other.
61. The method of claim 53, wherein the electric charges are applied with a DC power supply.
62. The method of claim 53, wherein the electric charges are applied with an AC power supply.
63. The method of claim 53, wherein the second conductive member is positioned within an insulative member.
64. The method of claim 53, wherein the insulative member is a ring.
65. An apparatus for monitoring the end-point of an electropolishing process of a metal layer formed on a wafer, comprising:
a nozzle configured to electropolish the metal layer;
an end-point detector disposed adjacent to said nozzle;
a reservoir containing an electrolyte fluid and coupled to said nozzle;
a fluid detector disposed in the reservoir, wherein
the fluid detector measures a property of the fluid, and
the end-point detector is configured to measure wafer properties taking into consideration the measured property of the fluid.
66. The apparatus of claim 65, wherein said apparatus is further configured to end the electropolishing process when a measured property of the wafer reaches a target value.
67. The apparatus of claim 65, wherein the nozzle and the end-point detector are configured to move together to electropolish discrete portions of the wafer.

68. The apparatus of claim 65, wherein the nozzle is configured as a stationary nozzle and the wafer is translated relative to the nozzle.
69. The apparatus of claim 65, further comprising a wafer chuck configured to rotate the wafer.
70. The apparatus of claim 65, wherein the fluid detector measures a metal ion concentration in the fluid.
71. The apparatus of claim 70, further including electrodes immersed in the electrolyte fluid configured to remove metal ions from the electrolyte fluid if the metal ion concentration reaches a pre-set value.
72. The apparatus of claim 71, wherein if the metal ion concentration reaches a second pre-set value the electrodes are configured to stop removing metal ions from the electrolyte fluid.
73. The apparatus of claim 65, wherein the fluid detector includes an optical detector.
74. The apparatus of claim 73, wherein the optical detector includes a red light.
75. The apparatus of claim 73, wherein the optical detector includes a white light.
76. The apparatus of claim 73, further including a reflector wherein the optical detector reflects light from.
77. The apparatus of claim 65, wherein the end-point detector includes an optical reflection detector.

78. The apparatus of claim 65, wherein the end-point detector includes an ultrasonic detector.
79. The apparatus of claim 65, wherein the end-point detector includes an electromagnetic detector.
80. The apparatus of claim 65, wherein the end-point detector includes an Eddy-current detector.
81. The apparatus of claim 65, further comprising a second fluid detector to measure a second property of the fluid.
82. The apparatus of claim 81, wherein the end-point detector is configured to measure wafer properties taking into consideration the second measured property of the fluid.
83. The apparatus of claim 81, wherein the second fluid detector includes an optical detector.
84. The apparatus of claim 81, wherein the optical detector includes a blue light.
85. The apparatus of claim 81, wherein the optical detector includes a white light.
86. The apparatus of claim 81, wherein the optical detector detects bubbles in the electrolyte fluid.
87. A method of detecting the end-point of an electropolishing process of a wafer, comprising the acts of:
 electropolishing the wafer using an electrolyte fluid;
 measuring properties of the wafer using an end-point detector;
 measuring properties of the electrolyte fluid using a fluid detector; and

evaluating the properties of the wafer measured by the end-point detector taking into consideration the properties of the fluid measured by the fluid detector.

88. The method of claim 87, wherein the act of electropolishing is ended when a measured property of the wafer reaches a target value.
89. The method of claim 87, wherein a nozzle and the end-point detector are configured to move together to electropolish discrete portions of the wafer.
90. The method of claim 87, further including translating the wafer relative to a stationary nozzle.
91. The method of claim 87, further including rotating the wafer with a wafer chuck.
92. The method of claim 87, further including measuring a metal ion concentration of the fluid with the fluid detector.
93. The method of claim 92, further including removing metal ions from the electrolyte fluid if the metal ion concentration reaches a pre-set value.
94. The apparatus of claim 92, wherein if the metal ion concentration reaches a second pre-set value metal ions are no longer removed from the electrolyte fluid.
95. The method of claim 87, wherein the fluid detector includes an optical detector.
96. The method of claim 87, wherein the optical detector includes a red light.
97. The method of claim 96, wherein the optical detector includes a white light.

98. The method of claim 96, further including reflecting light from a reflector to the optical detector.
99. The method of claim 87, wherein the end-point detector includes an optical reflection detector.
100. The method of claim 87, wherein the end-point detector includes an ultrasonic detector.
101. The method of claim 87, wherein the end-point detector includes an electromagnetic detector.
102. The method of claim 87, further including measuring a second property of the fluid.
103. The method of claim 102, wherein the end-point detector is configured to measure wafer properties taking into consideration the second measured property of the fluid.
104. The method of claim 103, wherein the second property of the fluid is measured with a second detector.
105. The method of claim 102, wherein the second fluid detector includes an optical detector.
106. The method of claim 102, wherein the second optical detector includes a blue light.
107. The method of claim 102, wherein the second optical detector includes a white light.

108. The method of claim 102, wherein the second optical detector detects bubbles in the electrolyte fluid.
109. An apparatus for electropolishing a fragmented metal layer on a semiconductor wafer, comprising:
a wafer chuck for holding the wafer;
a conductive member around the perimeter of the wafer chuck;
a nozzle configured to direct a stream of electrolyte fluid to a surface of the wafer; and
an actuator configured to rotate the wafer chuck with sufficient rotational speed to form a thin film of electrolyte fluid across the surface of the wafer to electrically connect the fragmented metal layer.
110. The apparatus of claim 109, wherein the thin film of electrolyte fluid forms a path to conduct a current between the electrolyte fluid and the conductive member.
111. The apparatus of claim 109, wherein the wafer is oriented facing down and the stream of electrolyte fluid incident on the wafer flows to the edge of the wafer before falling from the surface of the wafer.
112. The apparatus of claim 109, wherein the actuator is configured to vary the rotation of the chuck depending on the portion of the wafer that is being electropolished.
113. The apparatus of claim 112, wherein the actuator is configured to rotate the chuck at a higher speed when electropolishing portions of the wafer near the center.
114. The apparatus of claim 109, wherein the wafer chuck is configured to translate the wafer in relation to the nozzle.

115. The apparatus of claim 109, wherein the nozzle is configured to move in relation to the wafer chuck.
116. The apparatus of claim 109, further including a shroud surround the wafer chuck.
117. The apparatus of claim 116, wherein the shroud moves with the wafer chuck in relation to the nozzle.
118. The apparatus of claim 116, wherein the shroud and the wafer chuck are mechanically coupled to move together in relation to the nozzle.
119. The apparatus of claim 116, wherein the shroud is positioned about 1 mm to about 10 mm from the edge of the wafer chuck.
120. The apparatus of claim 116, wherein the shroud is positioned about 5 mm from the edge of the chuck.
121. The apparatus of claim 116, wherein the sidewall of the shroud includes an L-shape cross-section.
122. The apparatus of claim 116, wherein the sidewall of the shroud is tapered.
123. The apparatus of claim 116, wherein the sidewall of the shroud extends above or below the chuck.
124. The apparatus of claim 116, wherein the shroud includes plastic or ceramic material.
125. The apparatus of claim 116, wherein the shroud includes anticorrosive metals or alloys.

126. The apparatus of claim 116, wherein the shroud is coated with an electrolyte fluid-resistant material.
127. A method for electropolishing a fragmented metal layer on a semiconductor wafer, comprising the acts of:
 holding a wafer with a wafer chuck that includes a conductive member positioned around the perimeter of the wafer;
 electropolishing the wafer with a stream of electrolyte fluid; and
 rotating the wafer such that the electrolyte fluid incident upon the wafer forms a thin film of electrolyte fluid on the surface of the wafer.
128. The method of claim 127, wherein the wafer is rotated with sufficient rotational speed such that electrolyte fluid incident on the wafer flows to the edge of the wafer without leaving the surface of the wafer.
129. The method of claim 127, further including varying the rotation of the chuck depending on the portion of the wafer that is being electropolished.
130. The method of claim 129, wherein the wafer is rotated at a higher speed when electropolishing portions of the wafer near the center.
131. The method of claim 127, further including translating the wafer in relation to the nozzle.
132. The method of claim 127, further including positioning a shroud around the wafer chuck.
133. The method of claim 127, wherein the electrolyte fluid flows past the edge of the wafer and is incident upon the shroud.
134. The method of claim 127, further including moving the shroud in relation to the nozzle.

135. The method of claim 127, further including moving the shroud and the wafer together in relation to the nozzle.
136. The method of claim 127, further including moving the nozzle in relation to the wafer.
137. An apparatus for electropolishing a wafer, comprising:
a nozzle holder configured to hold one two or more nozzles adjacent to a supply line of electrolyte fluid, wherein
at least one of the nozzle holder and the supply line move relative to the other to couple one of the two or more nozzles to the supply line of electrolyte fluid.
138. The apparatus of claim 137, further including an actuator, wherein the actuator is configured to rotate the nozzle holder to couple one of the two or more nozzles.
139. The apparatus of claim 137, wherein the nozzle holder includes an insulative material.
140. The apparatus of claim 137, wherein the nozzle holder includes a non-corrosive material.
141. The apparatus of claim 137, wherein the nozzle holder is made of plastic.
142. The apparatus of claim 137, wherein the nozzle holder and the one or more nozzles are integrally formed.
143. The apparatus of claim 137, wherein the two or more nozzles include at least two different profiles.

144. The apparatus of claim 137, further including an end-point detector positioned adjacent the nozzle holder.
145. The apparatus of claim 137, further including a movable base, wherein said nozzle holder is coupled to said movable base.
146. The apparatus of claim 145, wherein the movable base is configured to move in a linear direction and the nozzle holder is configured to rotate.
147. A method for electropolishing a semiconductor wafer, comprising the acts of:
providing a wafer;
providing a supply of electrolyte fluid;
providing two or more nozzles that are mechanically coupled together;
movably positioning one of the two or more nozzles to the supply of electrolyte fluid to direct a stream of electrolyte fluid towards the wafer.
148. The method of claim 147, wherein the two or more nozzles are mechanically coupled through a nozzle holder.
149. The method of claim 148, wherein the act of movably positioning one of the two or more nozzles includes rotating the nozzle holder.
150. The method of claim 148, wherein the act of movable positioning the nozzles includes translating the nozzle holder in a linear direction.
151. The method of claim 147, wherein the two or more nozzles include at least two different nozzle profiles.
152. The method of claim 147, further including:
determining the profile of a metal layer on the wafer; and

directing a stream of electrolyte fluid at the metal layer with varying nozzle profiles depending on the particular profile of the metal layer.

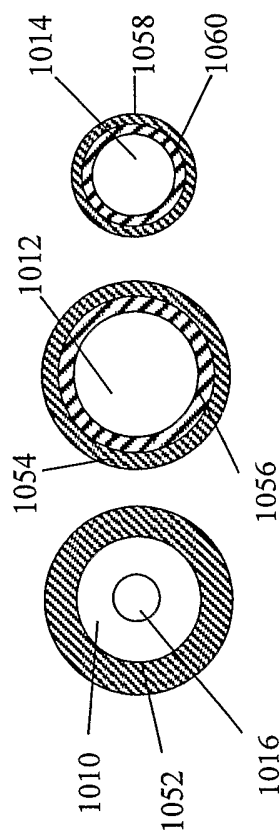
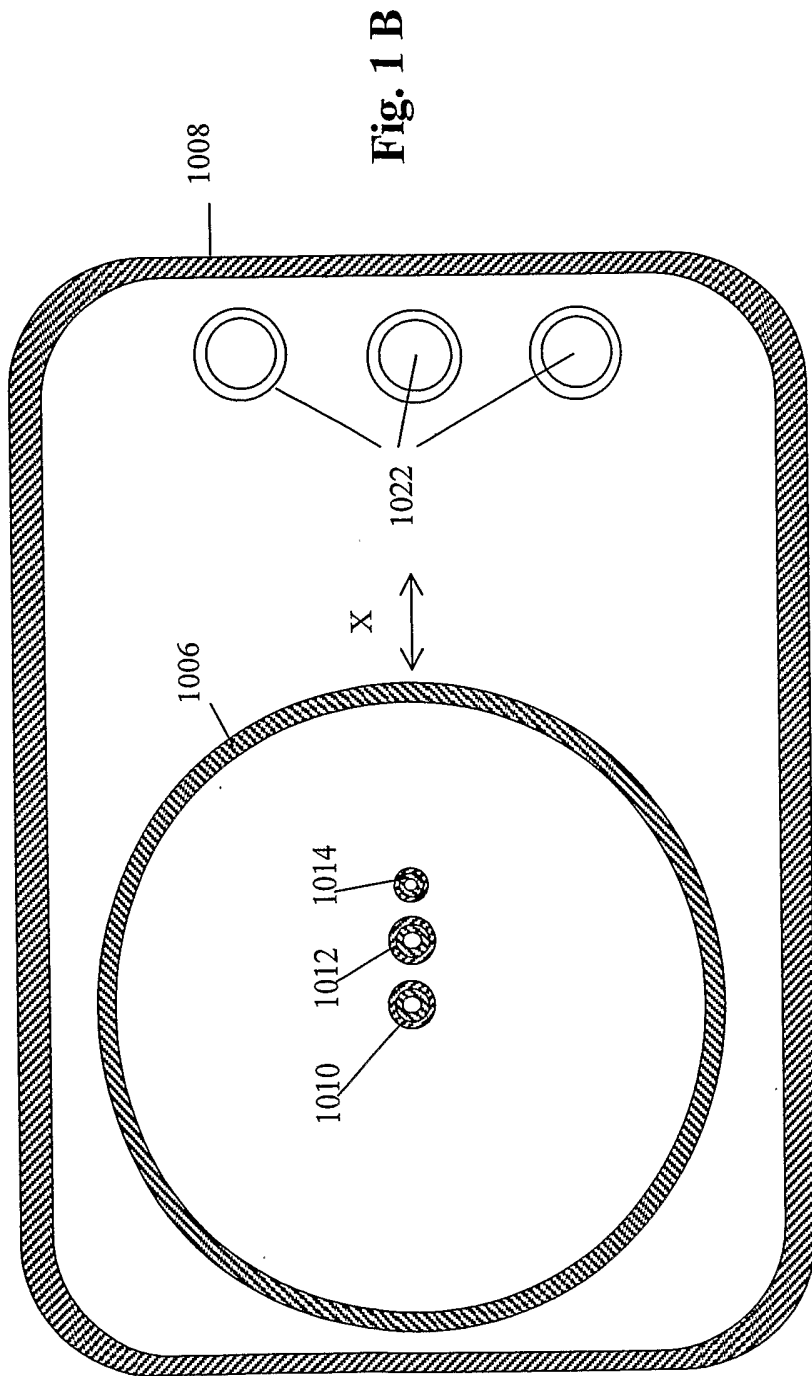
153. The method of claim 152, wherein the varying nozzles include two or more different nozzle profiles.
154. The method of claim 152, wherein the varying nozzles produce varying polishing rates.
155. The method of claim 152, wherein the varying nozzles are selected to include relatively high polishing rates on thick portions of the metal layer and relatively low polishing rates on thin portions of the metal layer.
156. The method of claim 152, wherein the profile of the metal layer is determined with an end-point detector positioned adjacent the two or more nozzles.
157. A nozzle for electropolishing a semiconductor wafer, comprising:
a channel with sidewalls and a distal opening for directing a stream of electrolyte fluid, wherein
the channel includes a conductive material, and
the sidewalls are curved near the distal opening.
158. The nozzle of claim 157, further including an insulator disposed on an exterior of the sidewalls in relation to the channel.
159. The nozzle of claim 157, wherein the channel includes a cylindrical shape.
160. The nozzle of claim 157, wherein the channel includes a conical cylindrical shape.

161. The nozzle of claim 157, further including a conductive structure disposed within the channel.
162. The nozzle of claim 161, wherein the conductive structure includes a rod.
163. The nozzle of claim 161, wherein the conductive structure includes a rod positioned within the channel.
164. The nozzle of claim 161, wherein the conductive structure includes a plurality of channels.
165. The nozzle of claim 164, wherein the cross-sectional size of the plurality of channels are in the range of about 0.1 to 10 mm.
166. The nozzle of claim 164, wherein the cross-sectional size of the plurality of channels are about one-tenth the size of the diameter of the channel.
167. A method for deplating a nozzle used in an electropolishing apparatus, comprising the acts of:
providing an electrolyte fluid through the nozzle; and
applying an electric charge to the nozzle, wherein the electric charge is configured to remove metal ions from the nozzle.
168. The method of claim 167, further including applying a second opposite electric charge to a second nozzle, wherein said electrolyte fluid forms a path between the first nozzle and the second nozzle.
169. The method of claim 168, wherein the nozzle and the second nozzle are brought closer together during the deplating process.
170. The method of claim 168, wherein the nozzle is an anode and the second nozzle is a cathode.

171. The method of claim 168, wherein a portion of the depleted metal is dissolved into the electrolyte fluid.
172. The method of claim 168, wherein a concentration of metal ions in the electrolyte fluid is about 3% or less by weight.
173. The method of claim 168, further including reversing the electric charges applied to the nozzle and the second nozzle to deplete the second nozzle.
174. The method of claim 168, wherein the nozzle is an anode and the second nozzle is a cathode.
175. The method of claim 167, wherein the nozzle is charged with a DC power supply.
176. The method of claim 167, wherein the nozzle is charged with an AC power supply.
177. The method of claim 167, further including applying a second opposite electric charge to a wafer.
178. The method of claim 177, wherein a portion of the depleted metal is dissolved into the electrolyte fluid.
179. The method of claim 177, wherein a concentration of metal ion in the electrolyte fluid is about 3% or less by weight.
180. The method of claim 177, wherein the nozzle is charged with a DC power supply.

181. The method of claim 177, wherein the nozzle is charged with an AC power supply.

182. The method of claim 167, further including applying a second opposite electric charge to a conductive material.



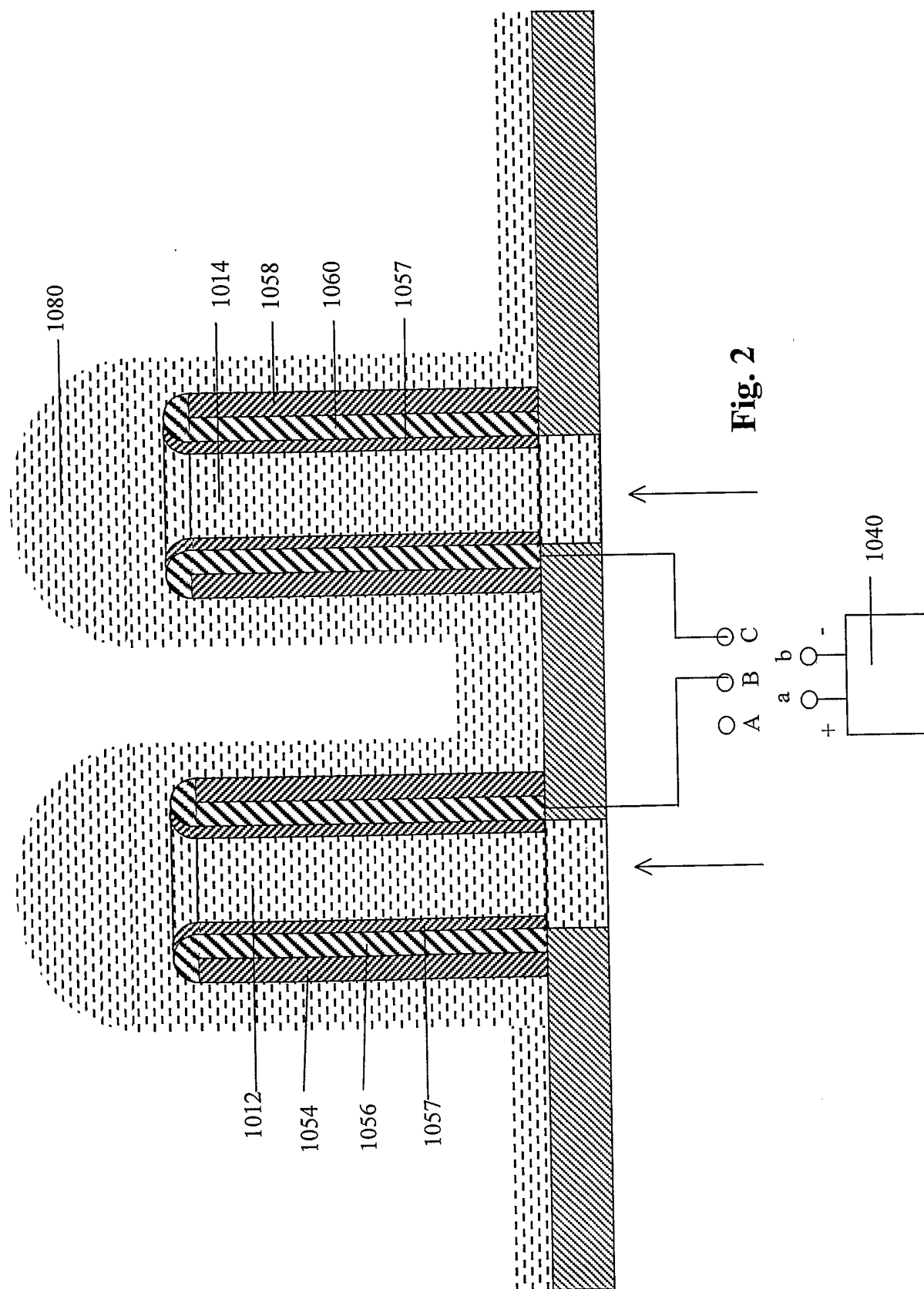


Fig. 2

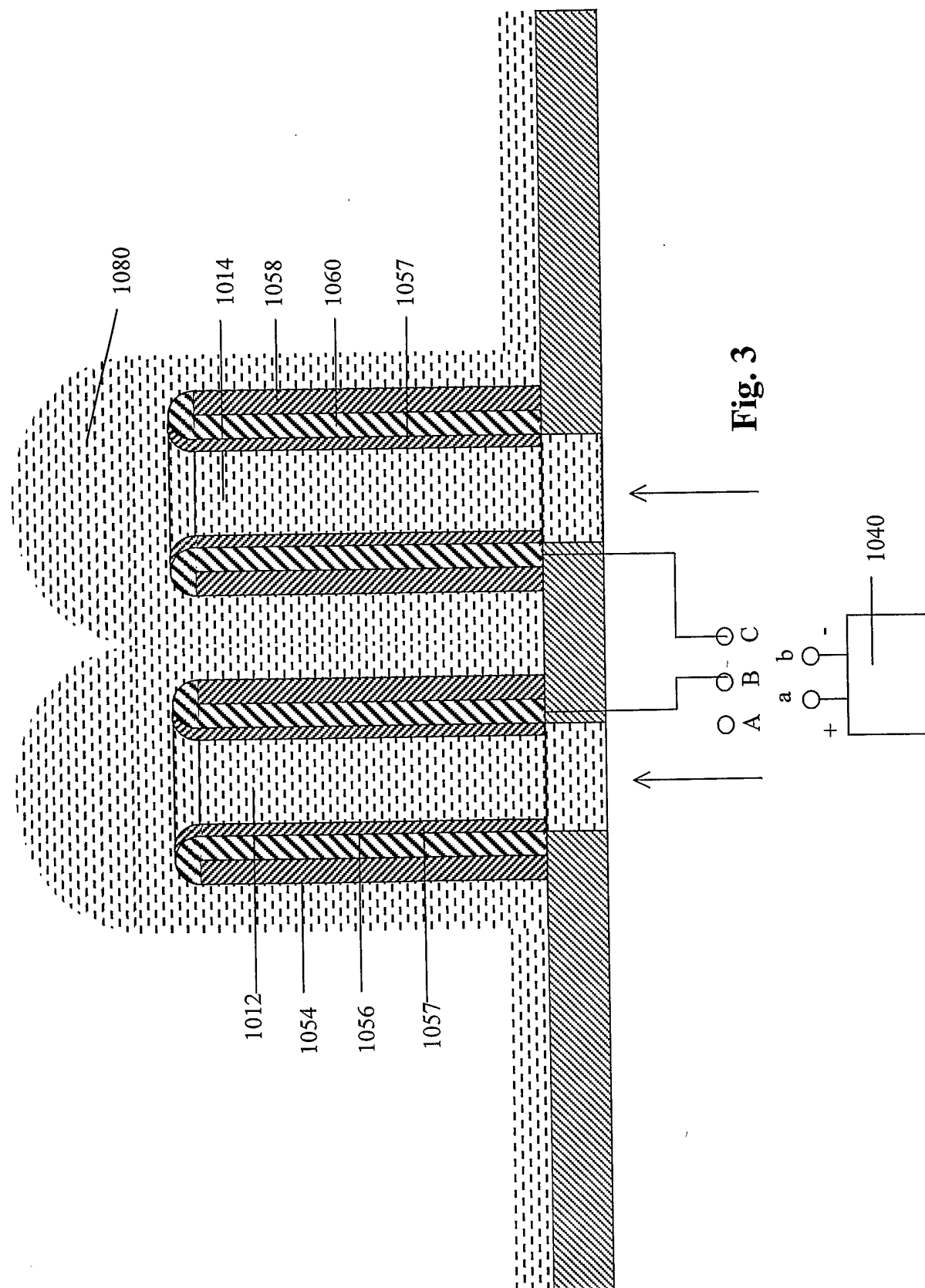


Fig. 3

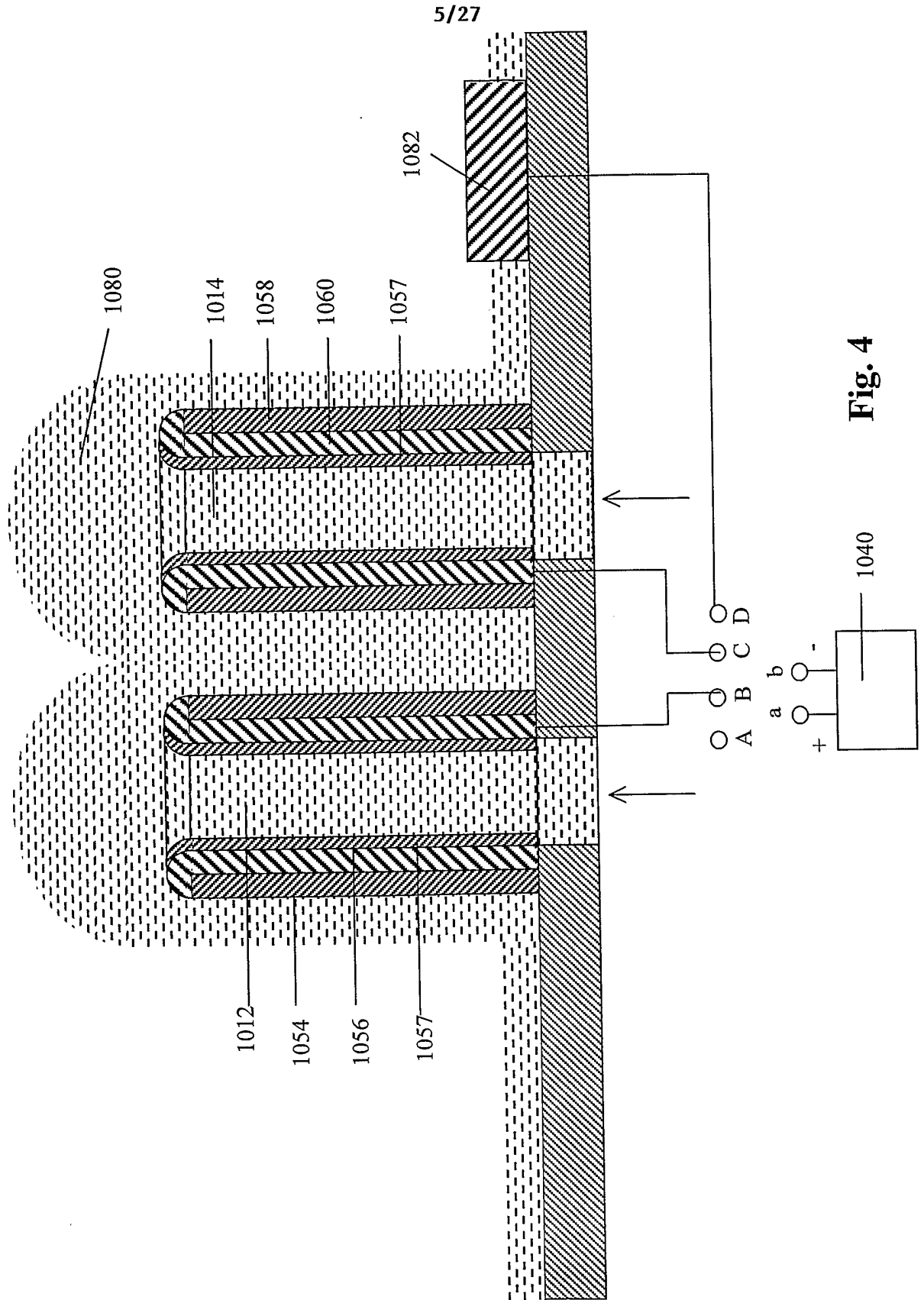


Fig. 4

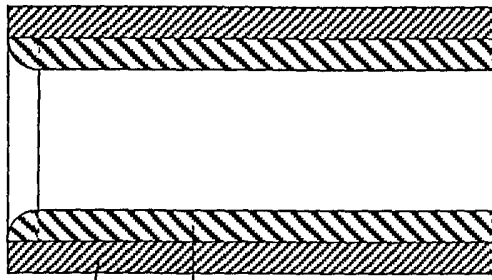


Fig. 5A

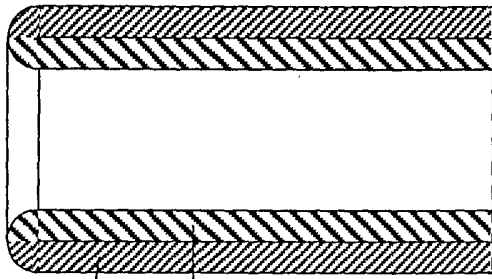


Fig. 5B

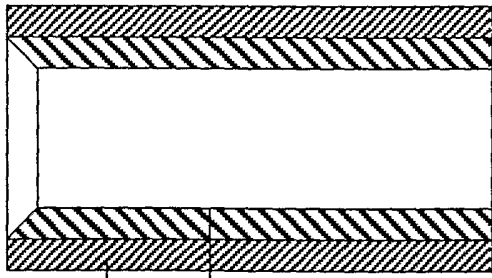


Fig. 5C

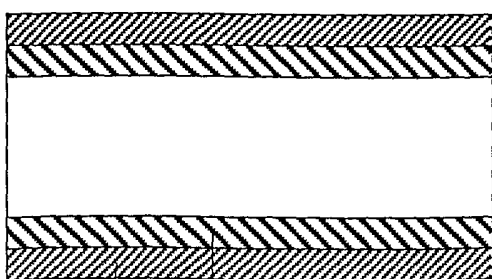


Fig. 5D

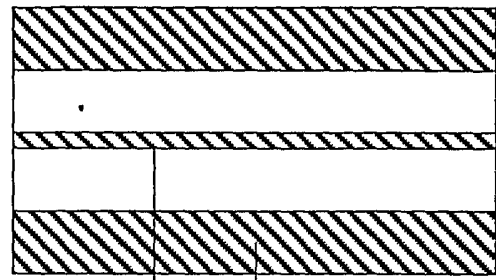


Fig. 5E

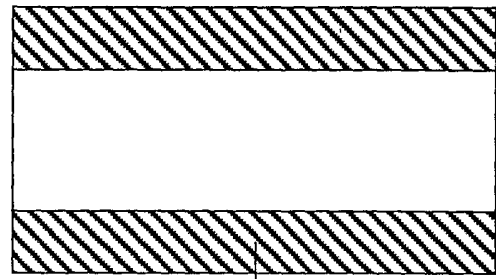


Fig. 5F

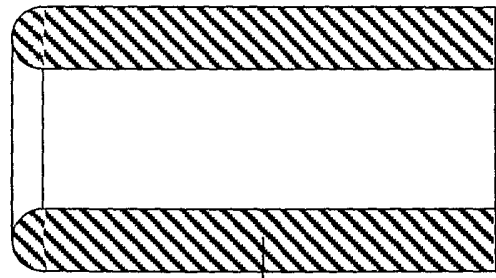


Fig. 5G

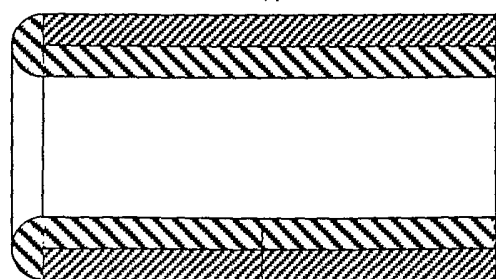


Fig. 5H

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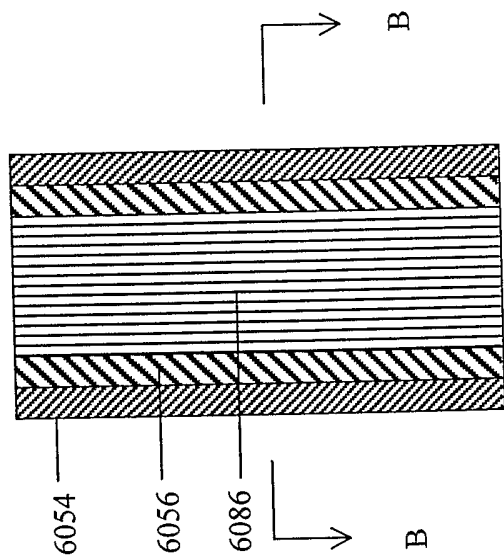


Fig. 6A

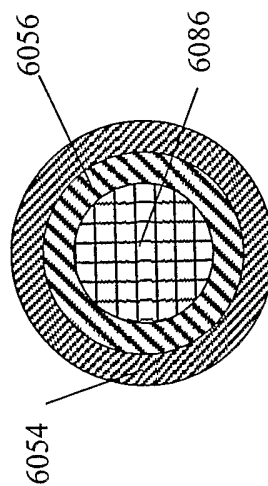


Fig. 6B

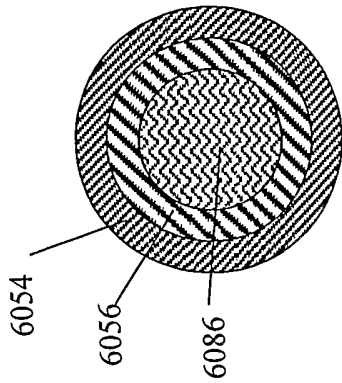


Fig. 6F

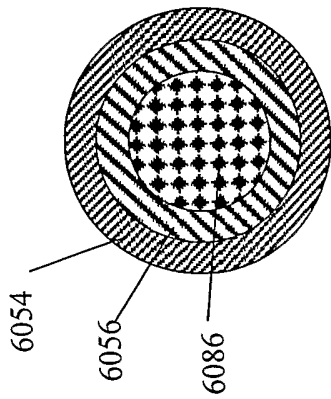


Fig. 6E

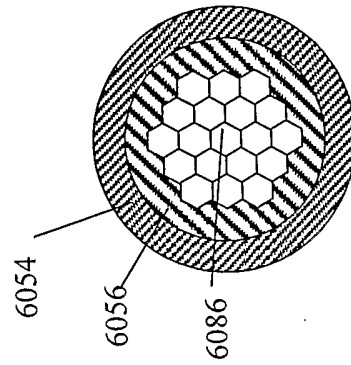


Fig. 6I

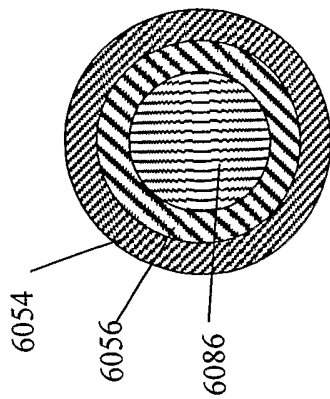


Fig. 6D

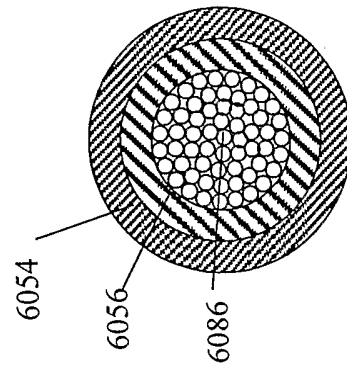


Fig. 6H

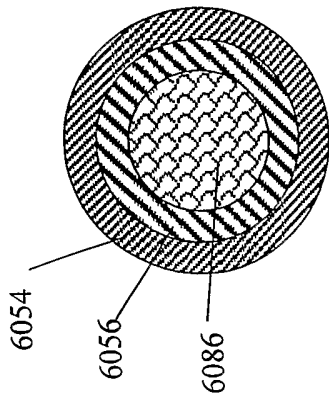


Fig. 6C

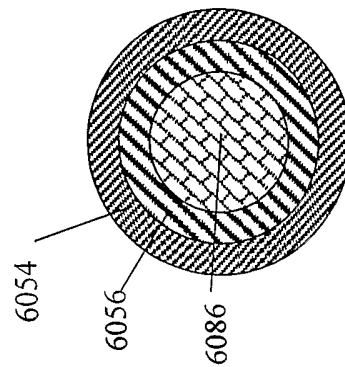


Fig. 6G

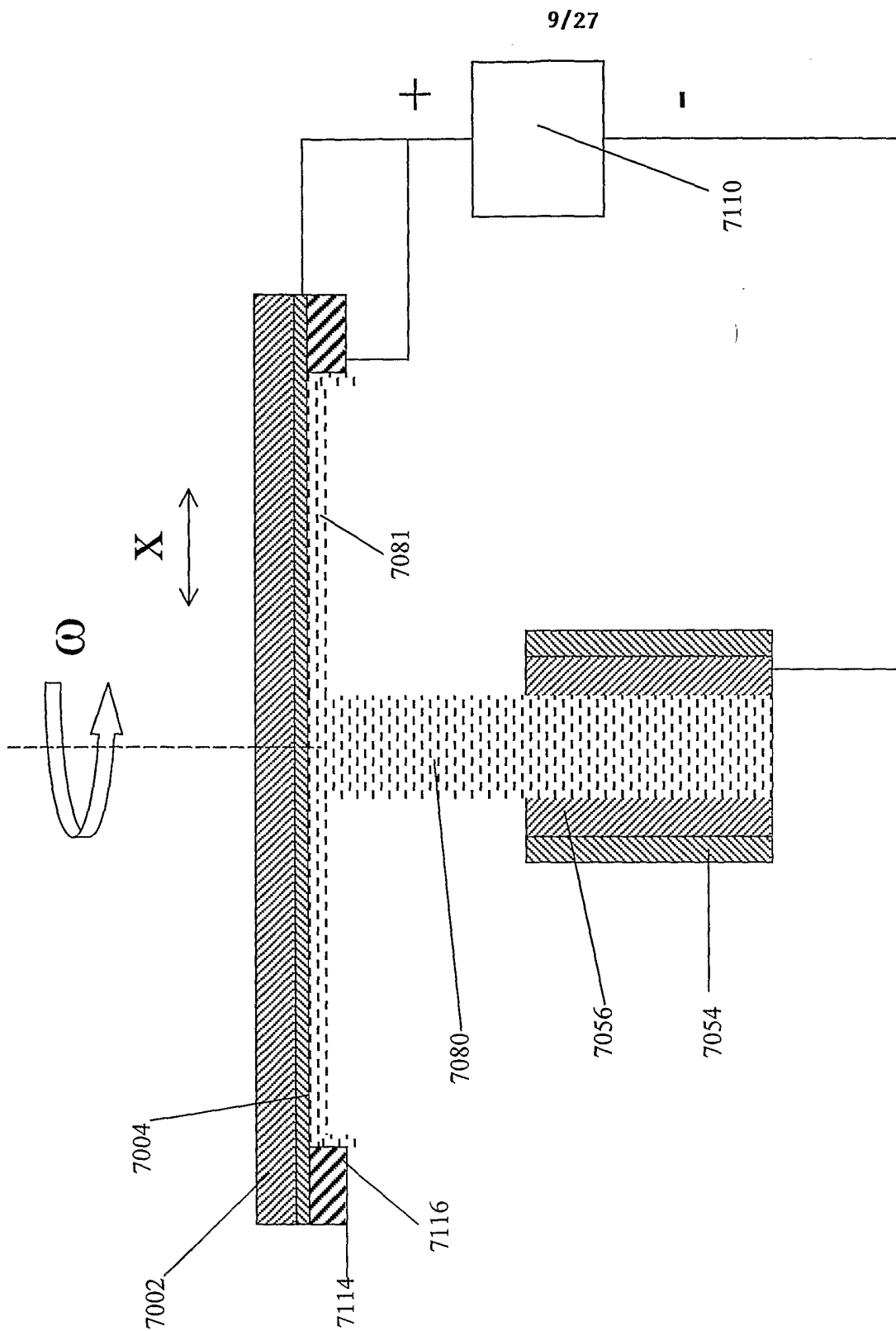


Fig. 7

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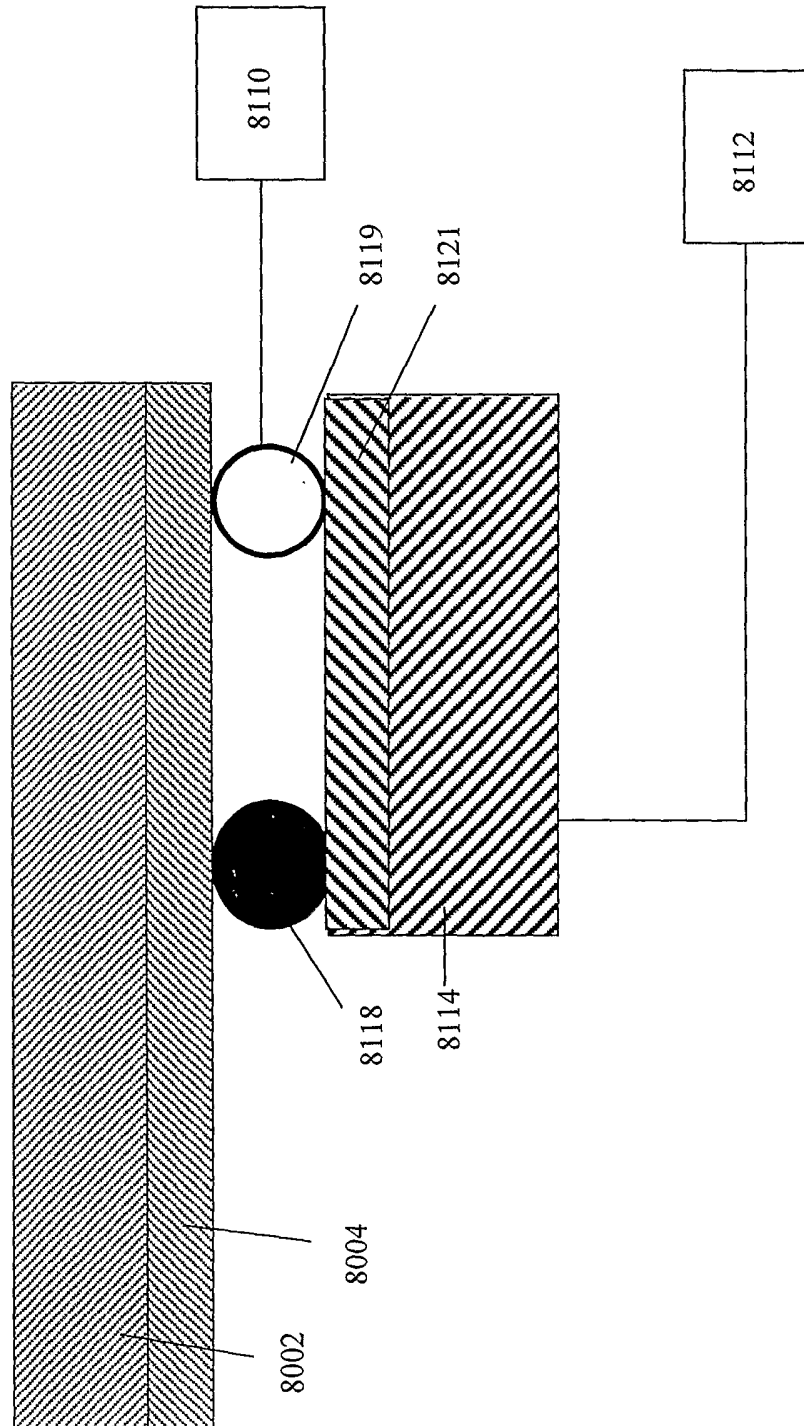


Fig. 8B

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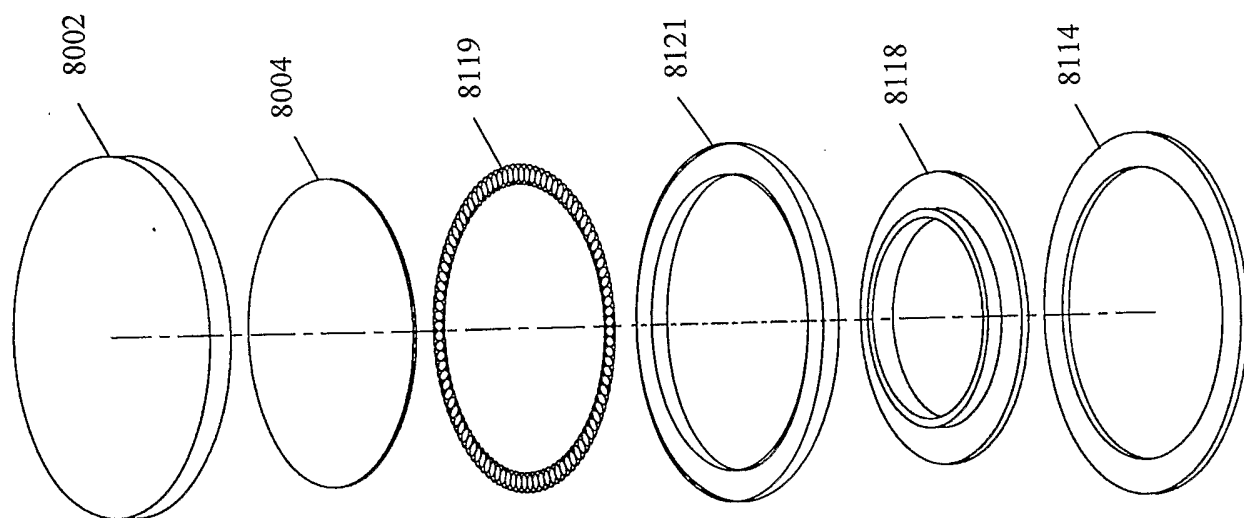


Fig. 8C

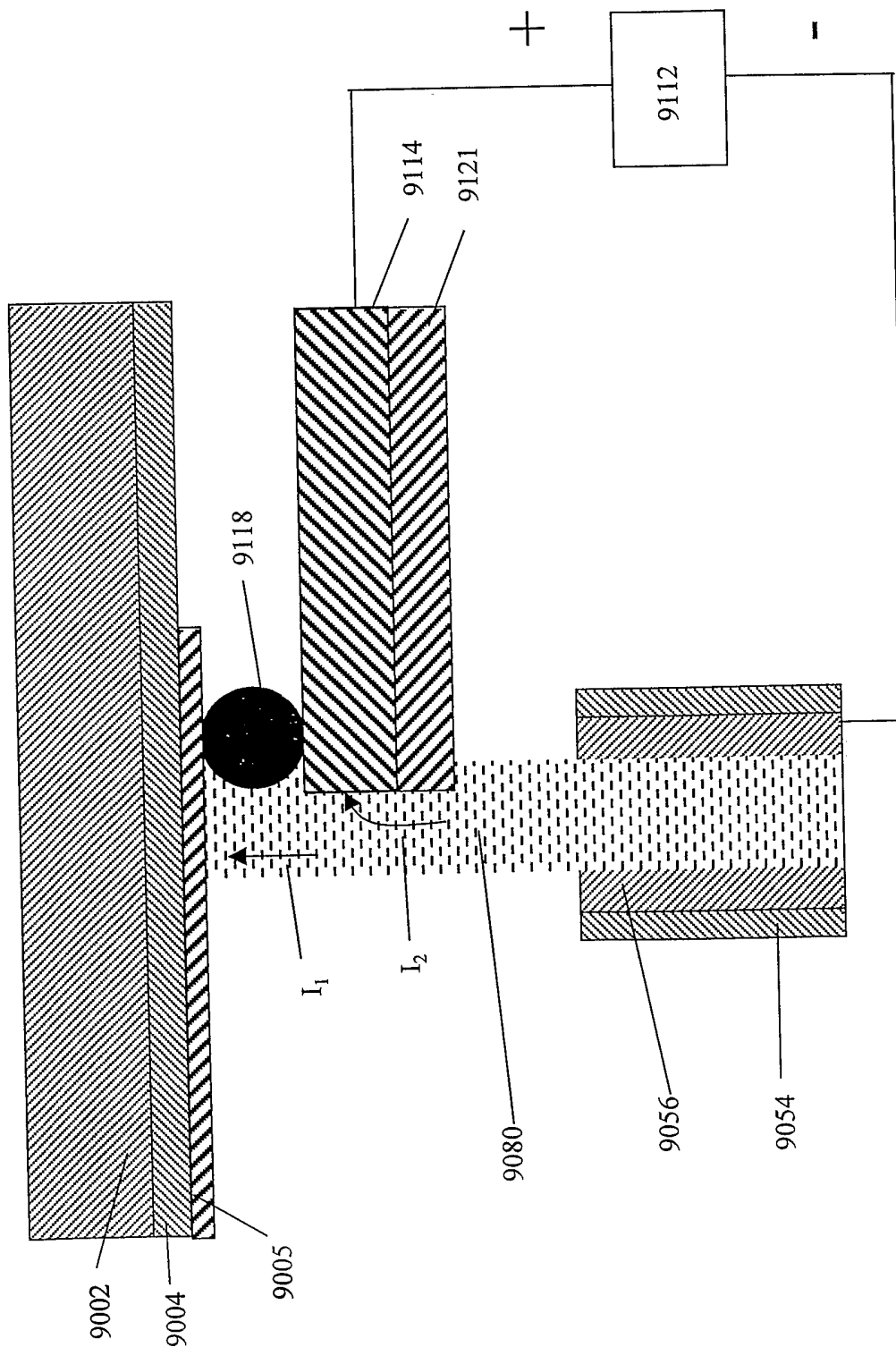


Fig. 9B

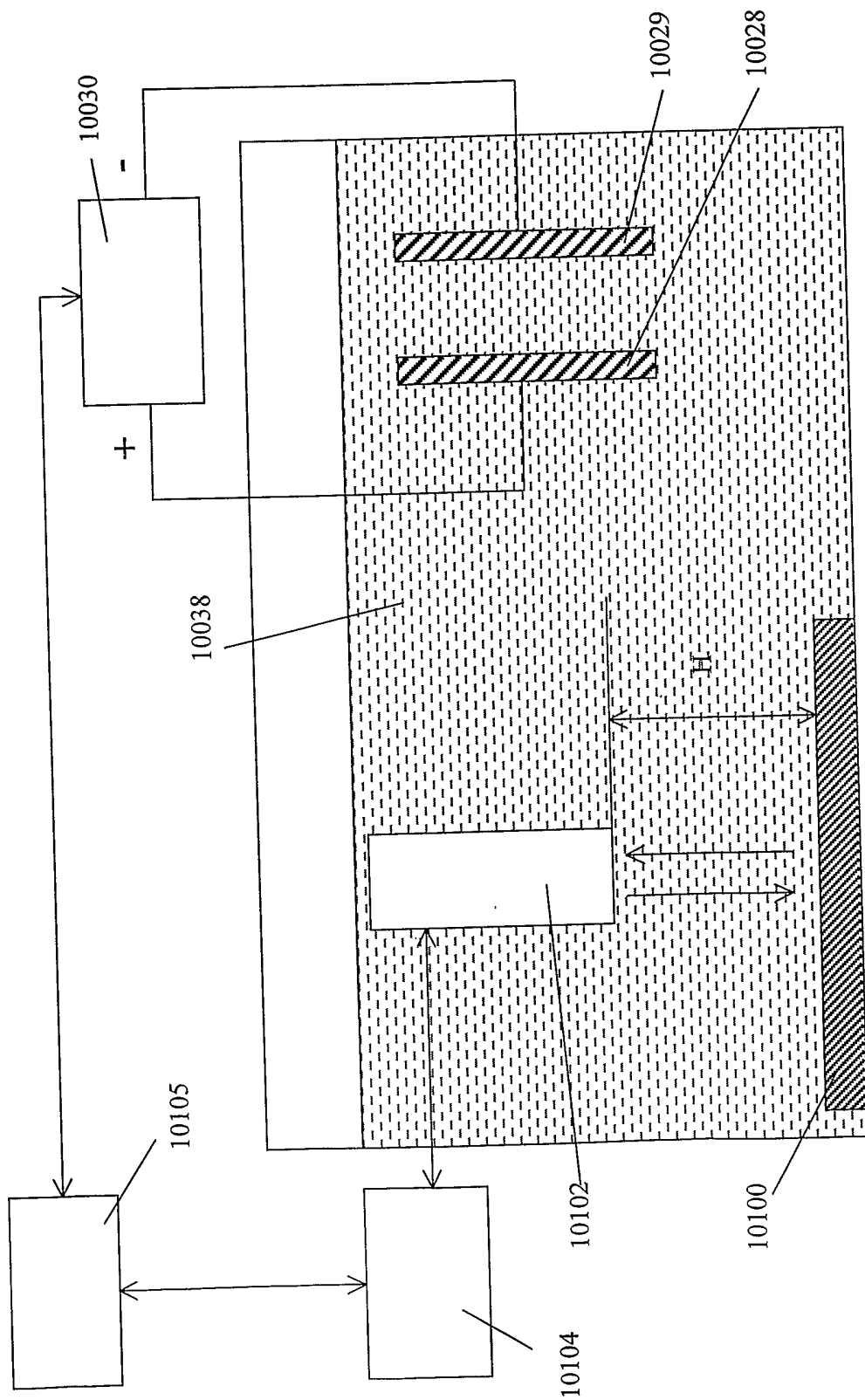


Fig. 10A

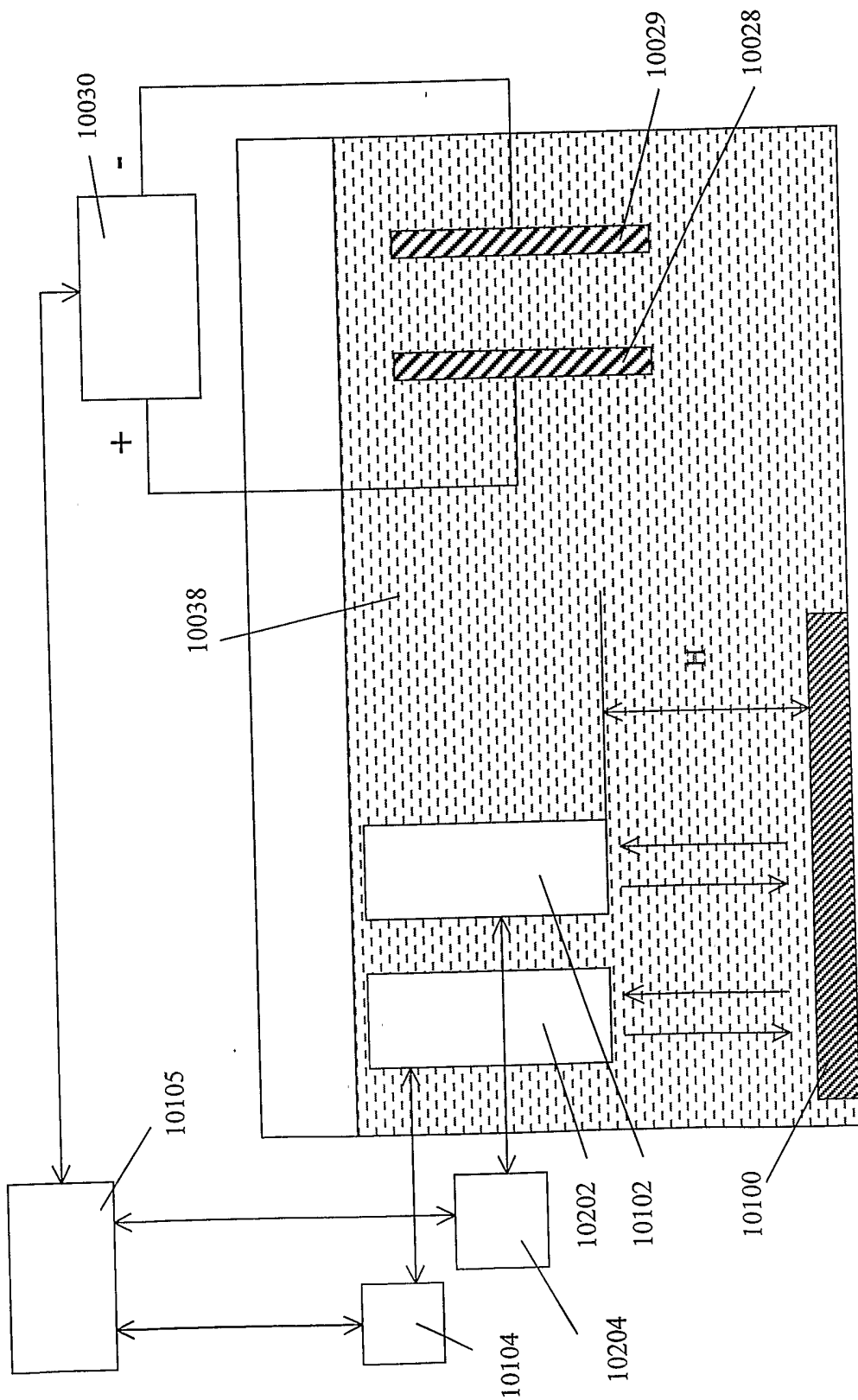
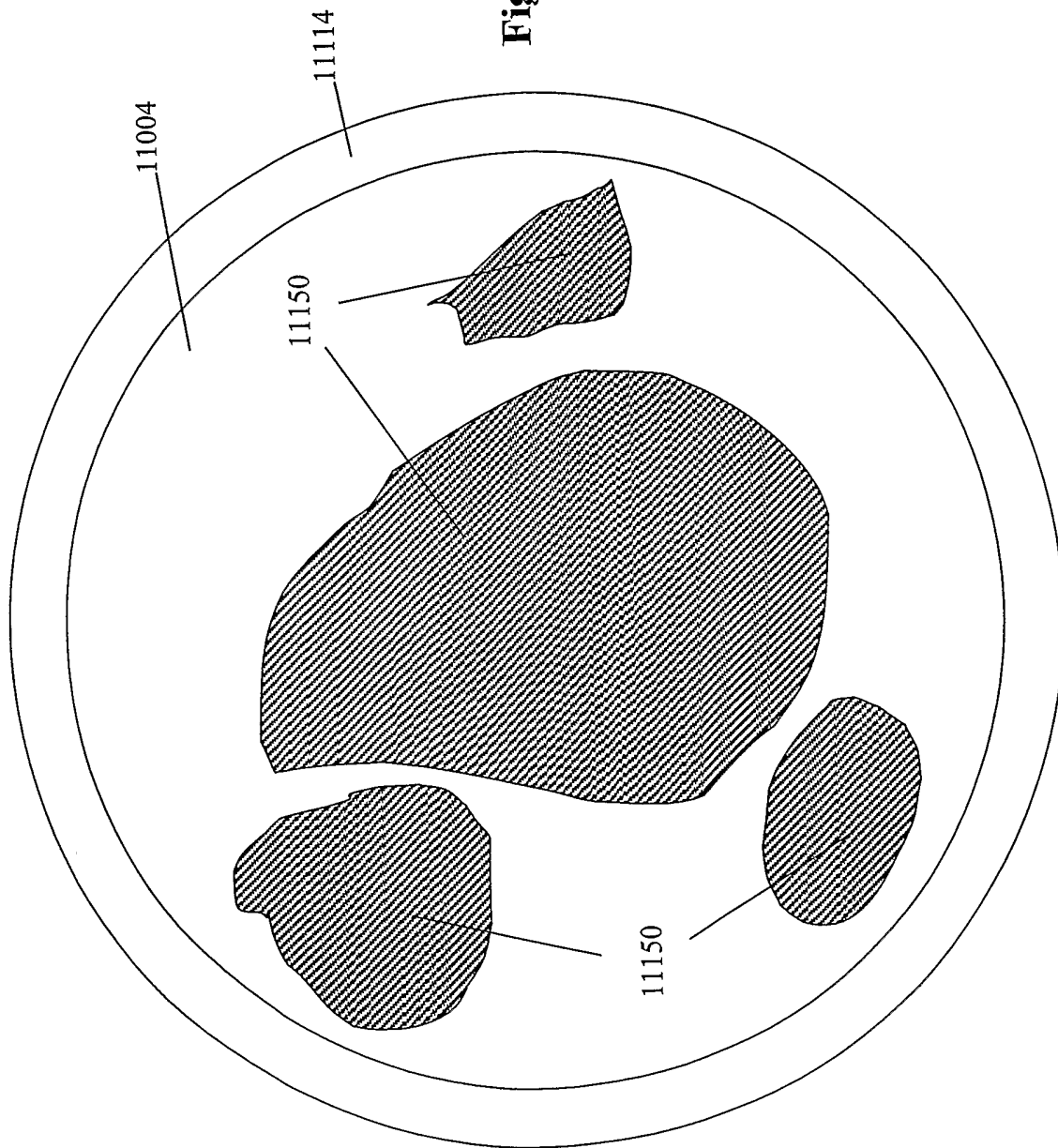


Fig. 10B

Fig. 11A



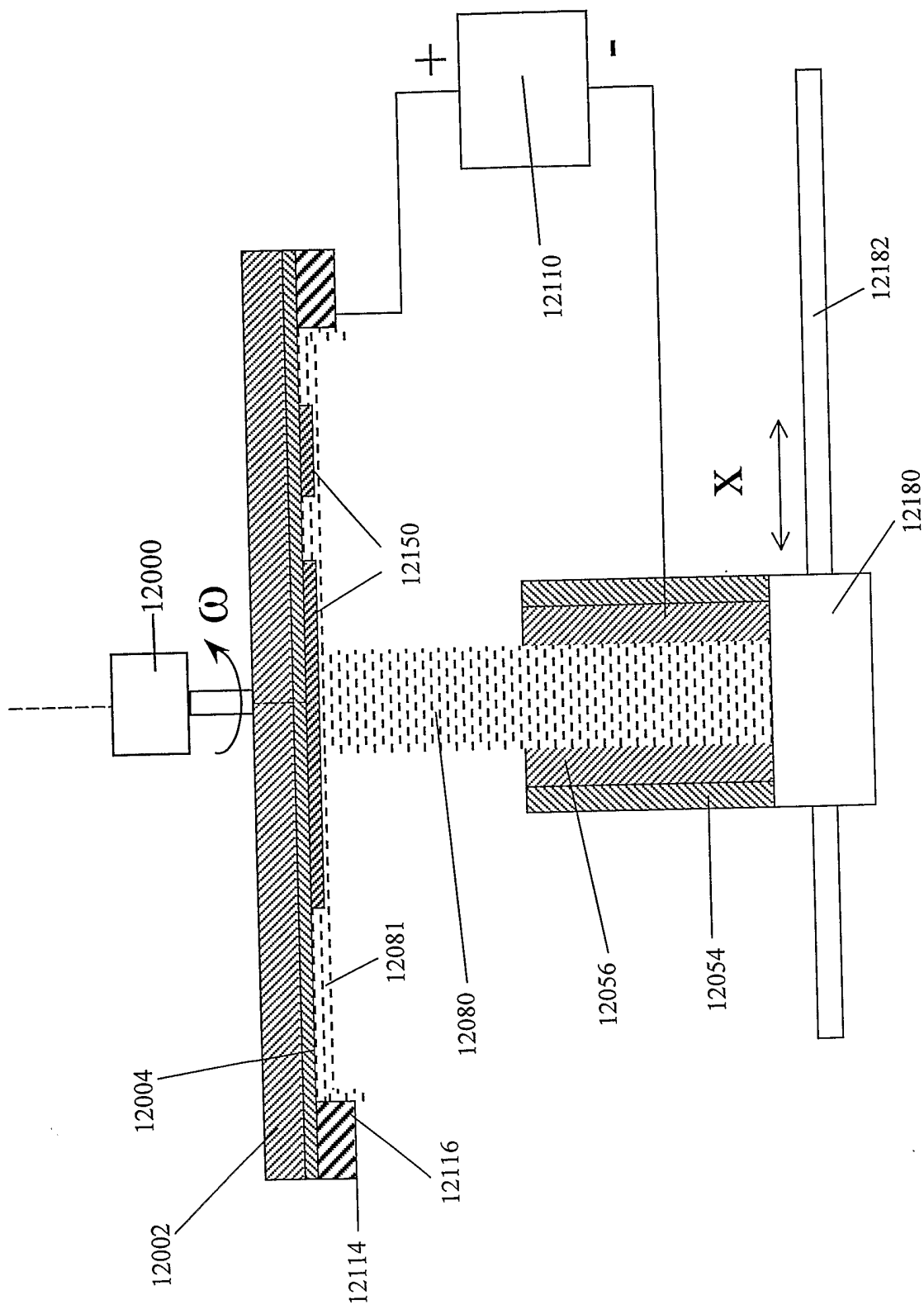


Fig. 12

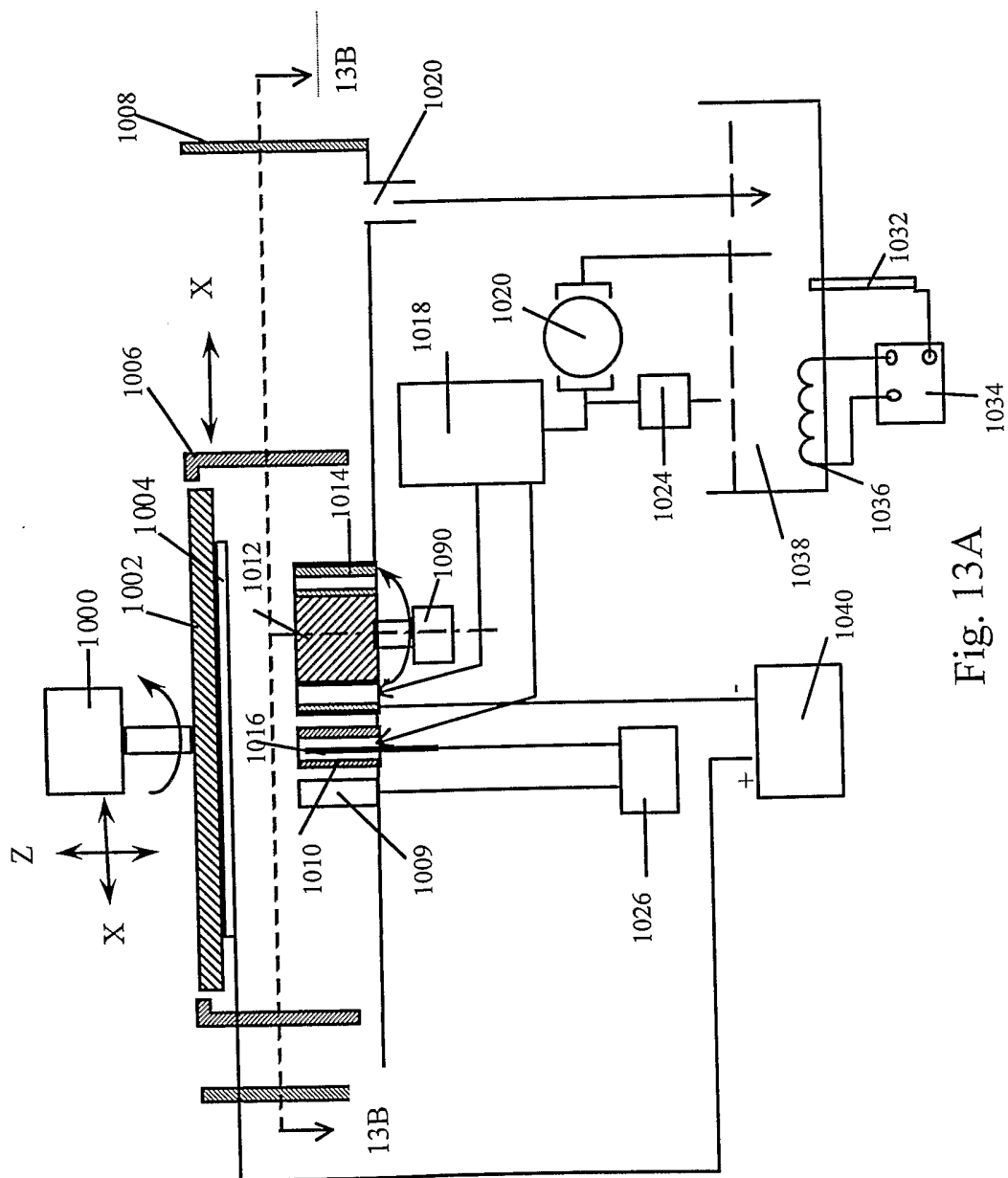
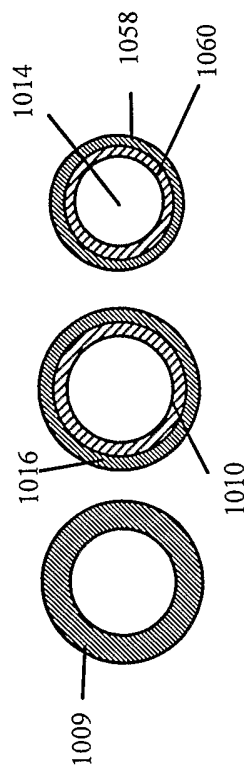
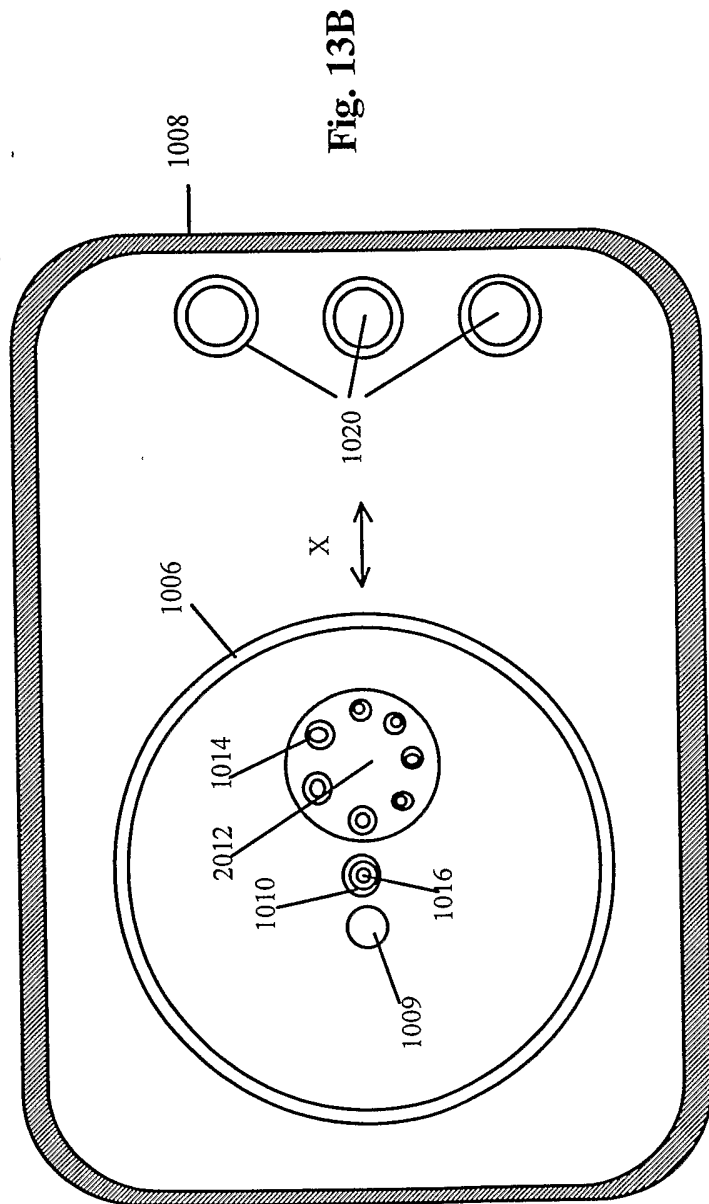


Fig. 13A



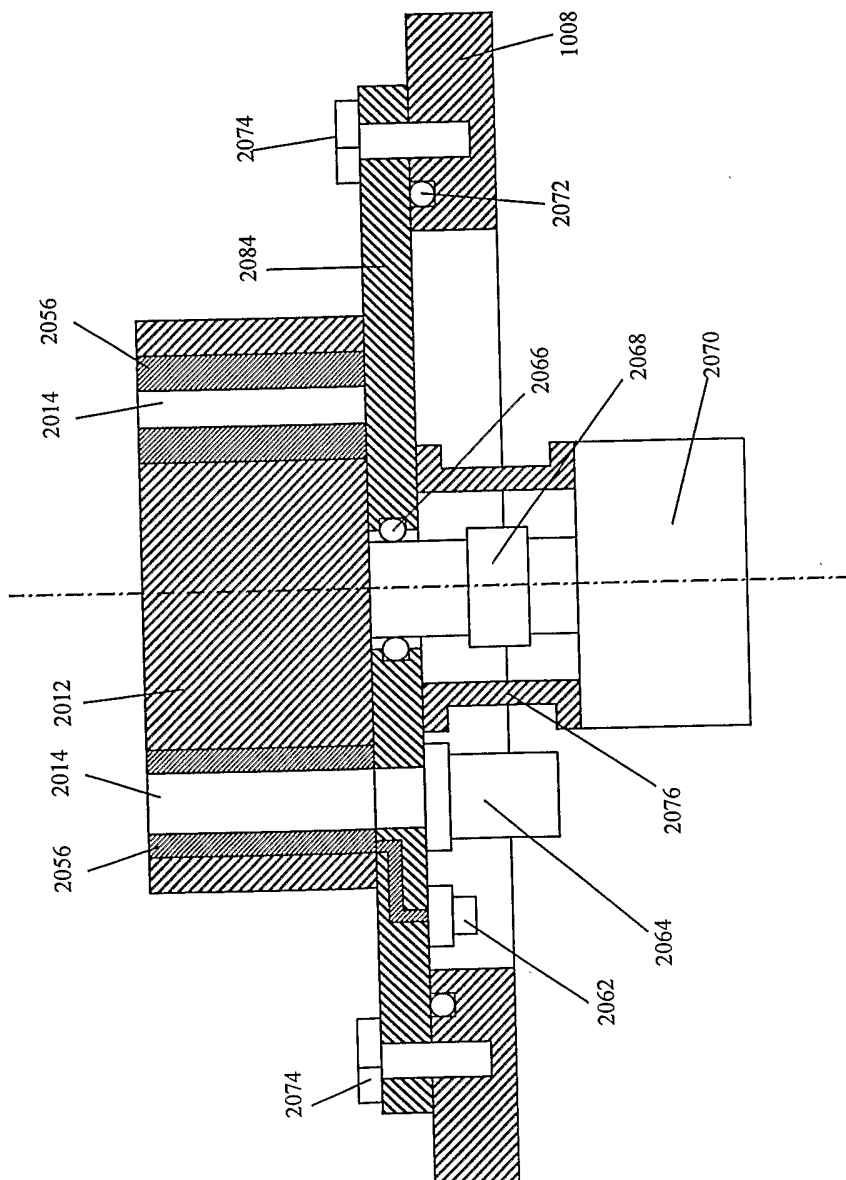


Fig. 14A

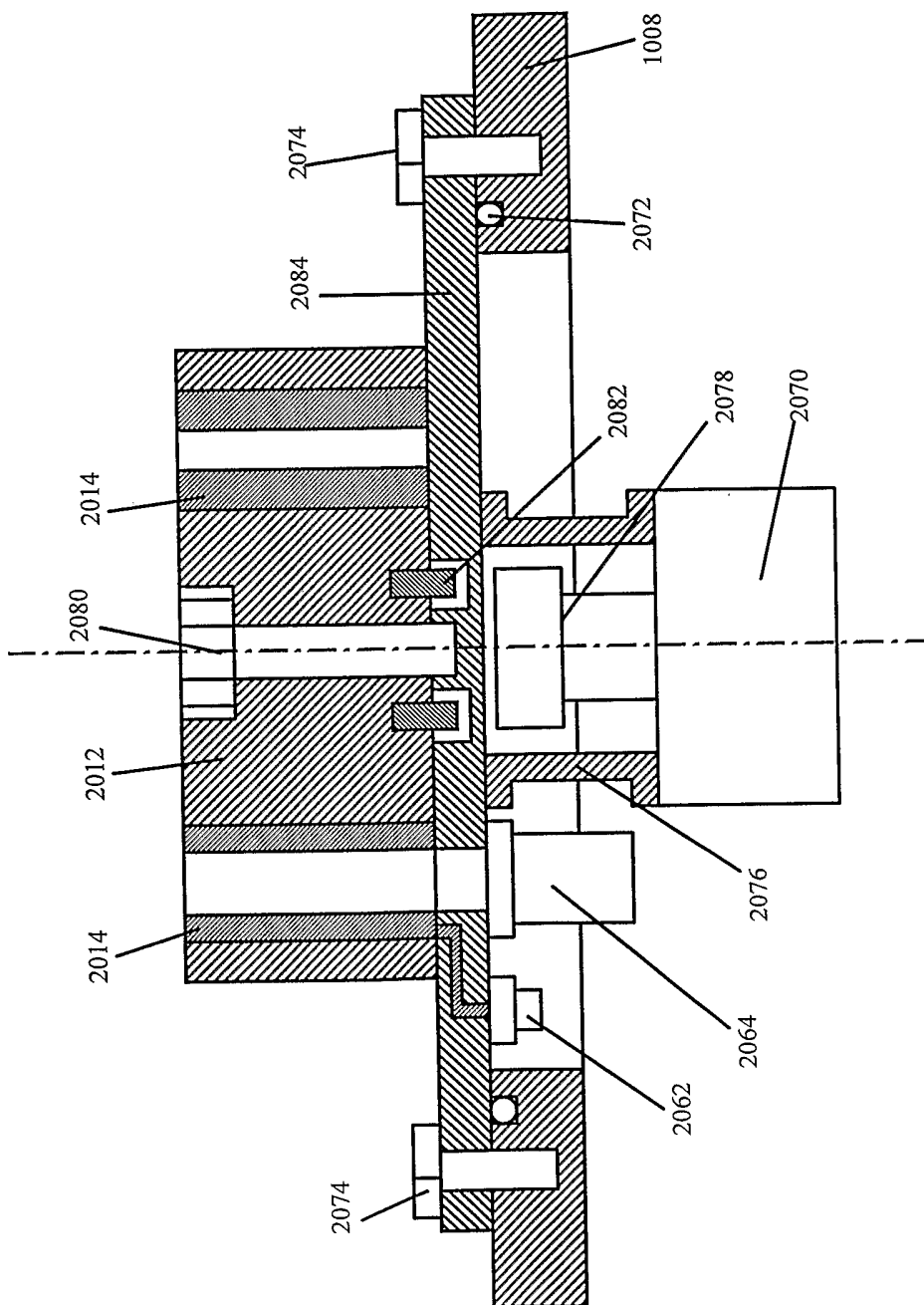


Fig. 14B

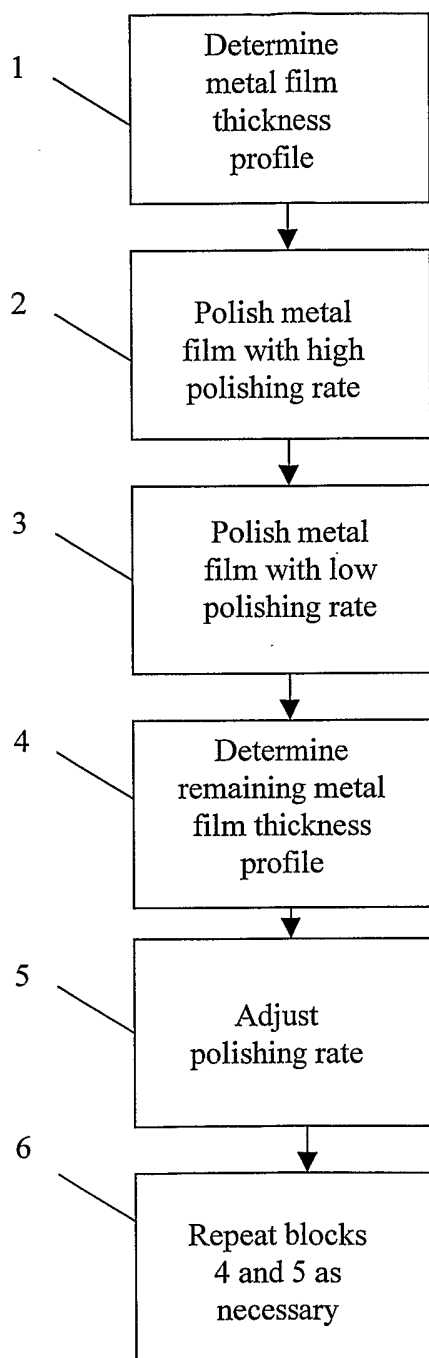


Fig. 14C

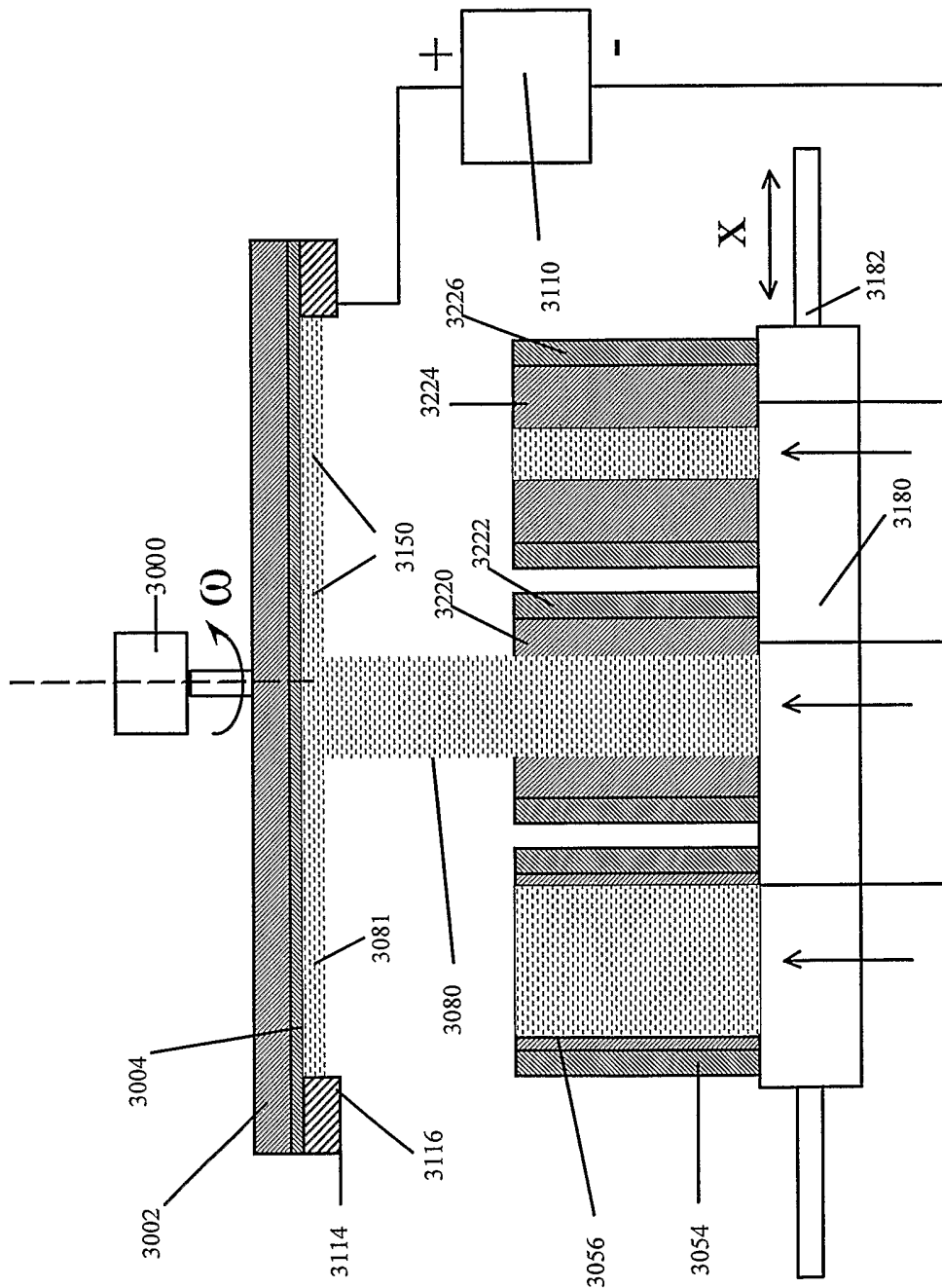


Fig. 15

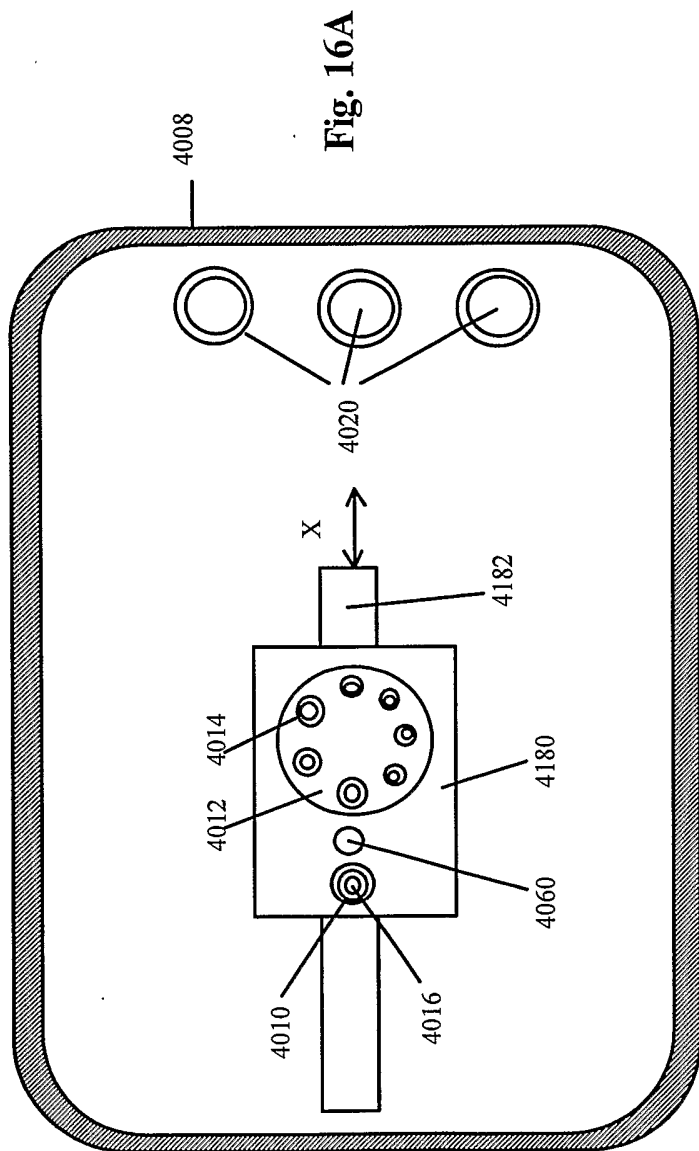


Fig. 16A

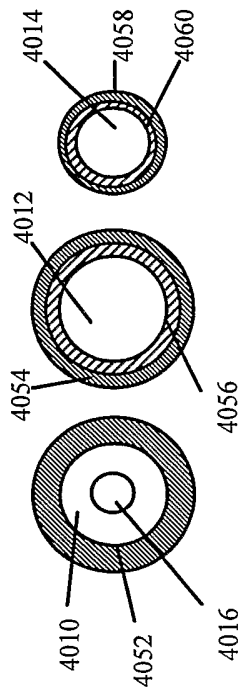


Fig. 16B Fig. 16C Fig. 16D

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/36567

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : C25B 9/00; C25D 7/12, 17/00; C25F 3/30, 7/00
 US CL : 204/212, 224M, 279, 286.1, 297.01, 297.14; 205/640, 645, 670, 672, 686

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)
 U.S. : 204/212, 224M, 279; 205/157, 670, 672, 686

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,567,300 A (DATTA et al) 22 October 1996 (22.10.1996), col. 8, lines 54-67, col. 9, lines 1-51, col. 10, lines 1-28	157, 167, 175, 176,
Y	US 4,304,641 A (GRANDIA et al) 08 December 1981 (05.12.1981), Col. 3, lines 10-68	157, 167, 175
A	US 5,217,586 A (DATTA et al) 08 June 1993 (08.06.1993) col. 5. lines 59-68 and Col. 6, lines 4-13.	87
A	US 5,421,987 A (TZANAVARAS et al) 06 June 1995 (06.06.1995)	
A	US 6,039,854 A (LIU) 21 March 2000 (21.03.2000)	

Further documents are listed in the continuation of Box C. See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent published on or after the international filing date	"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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"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
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 27 January 2003 (27.01.2003)	Date of mailing of the international search report 14 FEB 2003
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Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Donald R. Valentine Telephone No. 703-308-0661
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INTERNATIONAL SEARCH REPORT

PCT/US02/36567

Continuation of B. FIELDS SEARCHED Item 3:

EAST: shroud and wafer; and electropolishing; and 205/\$.ccls.; and 204/\$.ccls.; and semiconductor; nozzle; end?point near electropolish\$3