US 20050020004A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0020004 A1**

Chopra (43) **Pub. Date: Jan. 27, 2005**

(54) **METHOD AND APPARATUS FOR SIMULTANEOUSLY REMOVING MULTIPLE CONDUCTIVE MATERIALS FROM MICROELECTRONIC SUBSTRATES**

(76) Inventor: **Dinesh Chopra**, Boise, ID (US)

Correspondence Address:
PERKINS COIE LLP
PATENT-SEA
P.O. BOX 1247
SEATTLE, WA 98111-1247 (US)

(21) Appl. No.: **10/923,359**

(22) Filed: **Aug. 20, 2004**

Related U.S. Application Data

(62) Division of application No. 10/230,602, filed on Aug. 29, 2002.

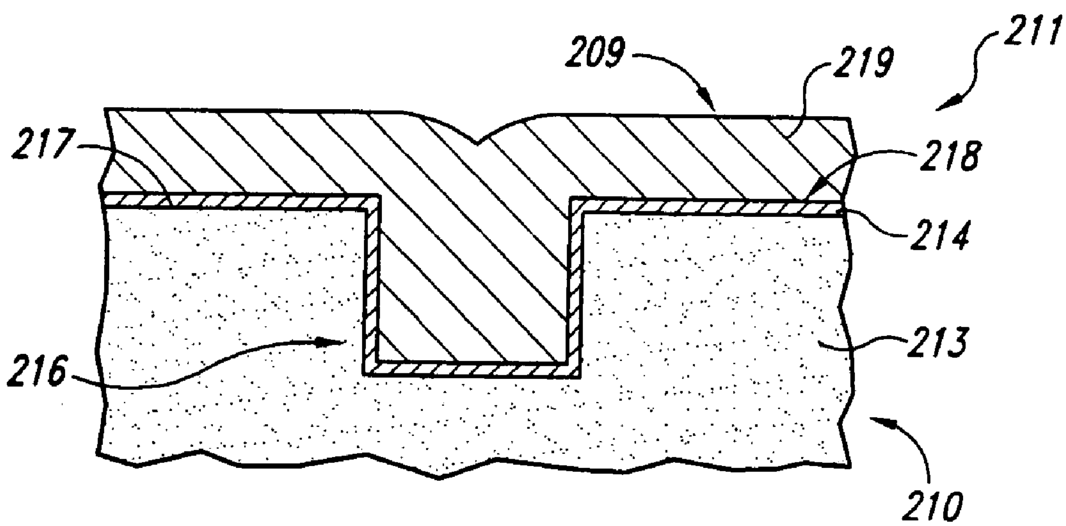
Publication Classification

(51) **Int. Cl.**^{7} **H01L 21/8238**

(52) **U.S. Cl.** **438/222**

(57) **ABSTRACT**

A method and apparatus for simultaneously removing conductive materials from a microelectronic substrate. A method in accordance with one embodiment of the invention includes contacting a surface of a microelectronic substrate with an electrolytic liquid, the microelectronic substrate having first and second different conductive materials. The method can further include controlling a difference between a first open circuit potential of the first conducive material and a second open circuit potential of the second conductive material by selecting a pH of the electrolytic liquid. The method can further include simultaneously removing at least portions of the first and second conductive materials by passing a varying electrical signal through the electrolytic liquid and the conductive materials. Accordingly, the effects of galvanic interactions between the two conductive materials can be reduced and/or eliminated.



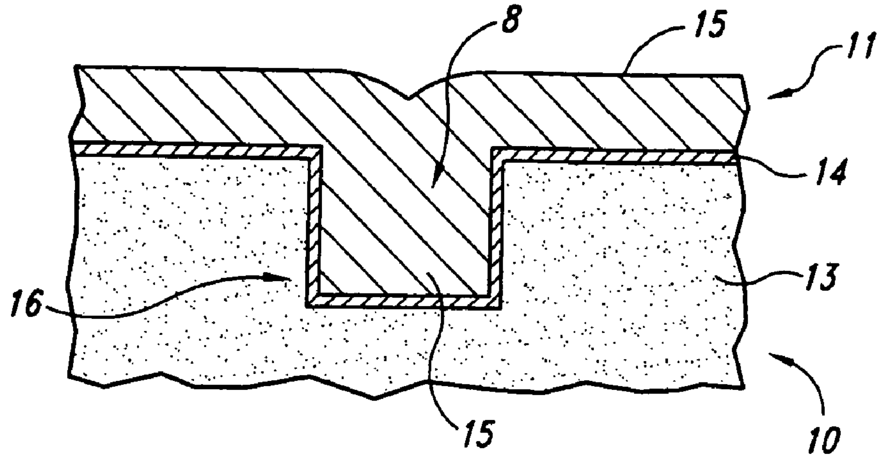


Fig. 1
(Prior Art)

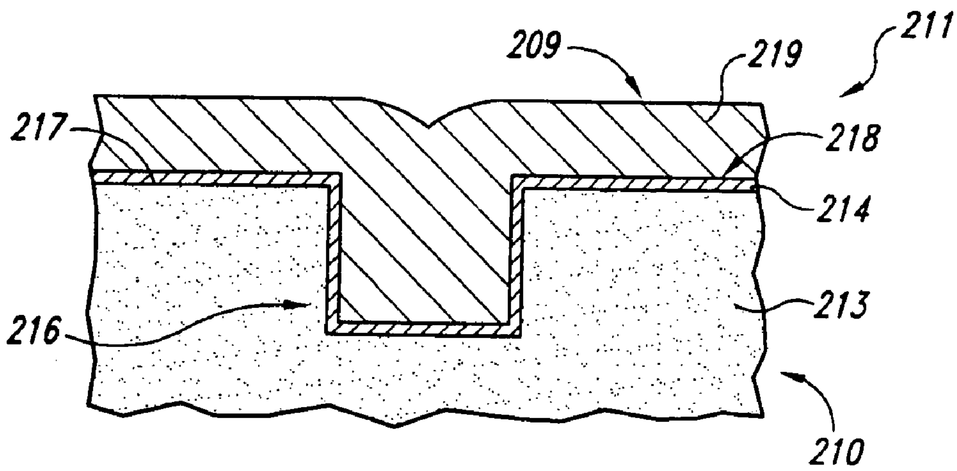


Fig. 2A

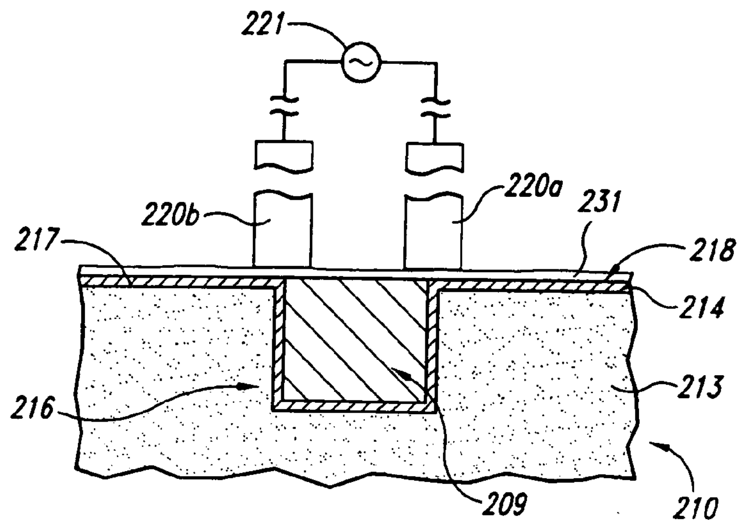


Fig. 2B

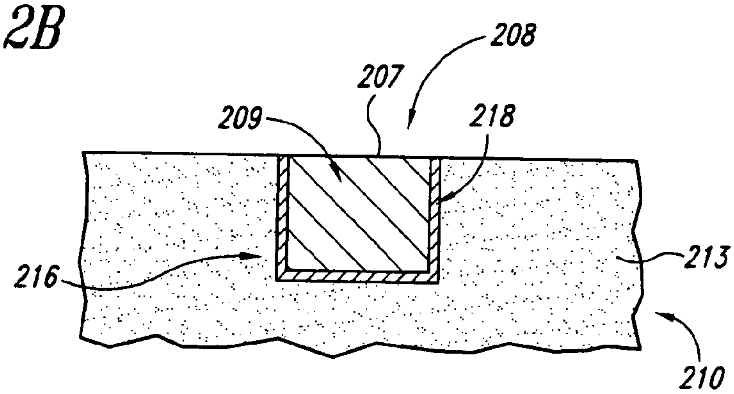


Fig. 2C

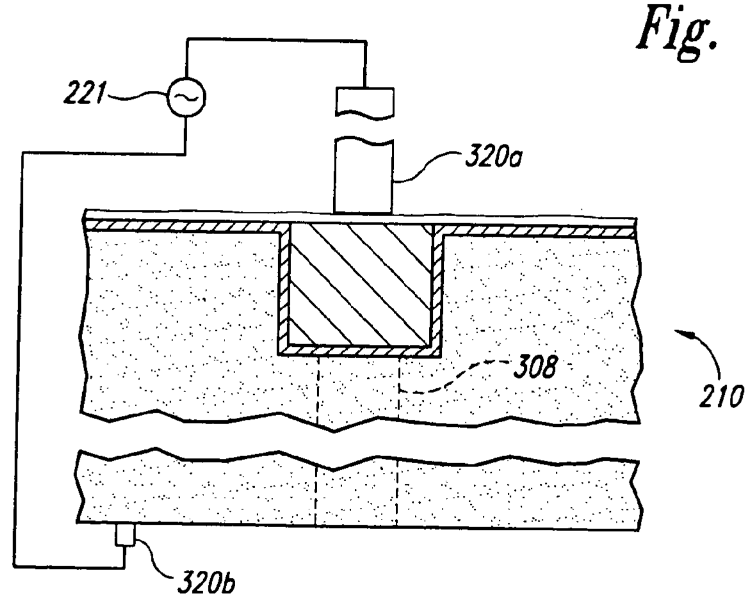


Fig. 3

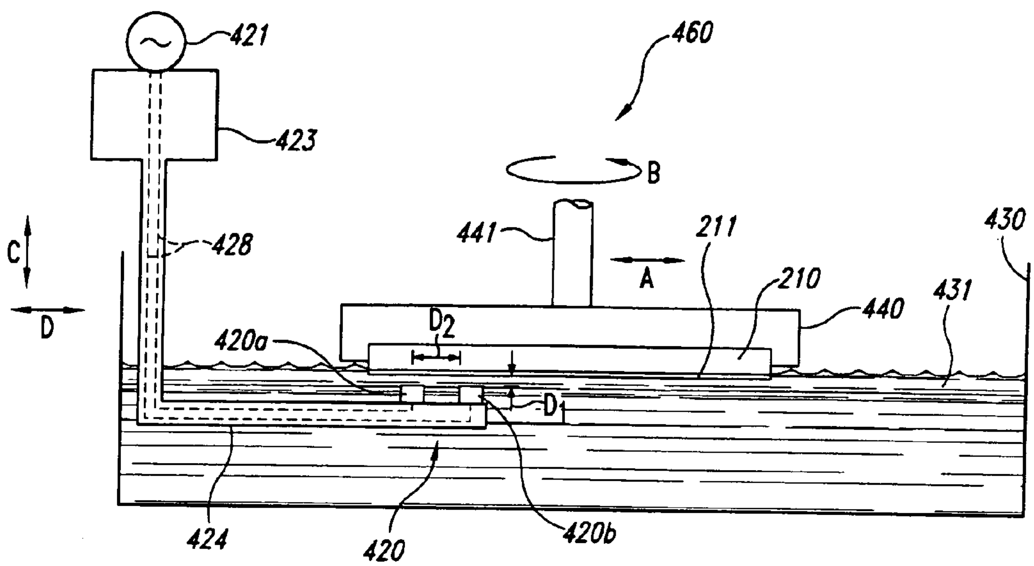

421
460
423
B
441
211
430
428
C
A
210
D
440
431
420a
D_2
D_1
424
420
420b

Fig. 4

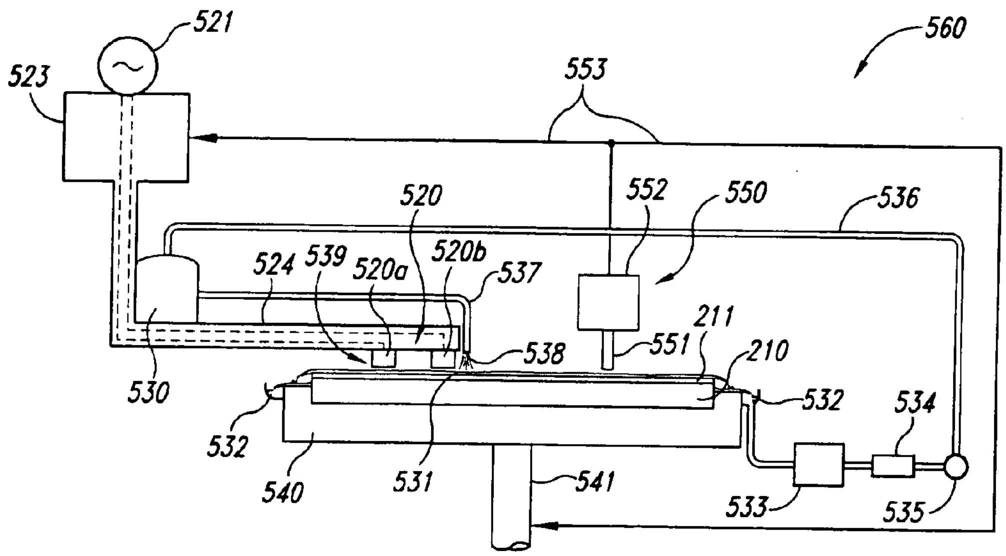

521
560
523
553
552
550
520
536
524
539
520a
520b
537
211
538
551
210
530
532
534
532
540
531
541
533
535

Fig. 5

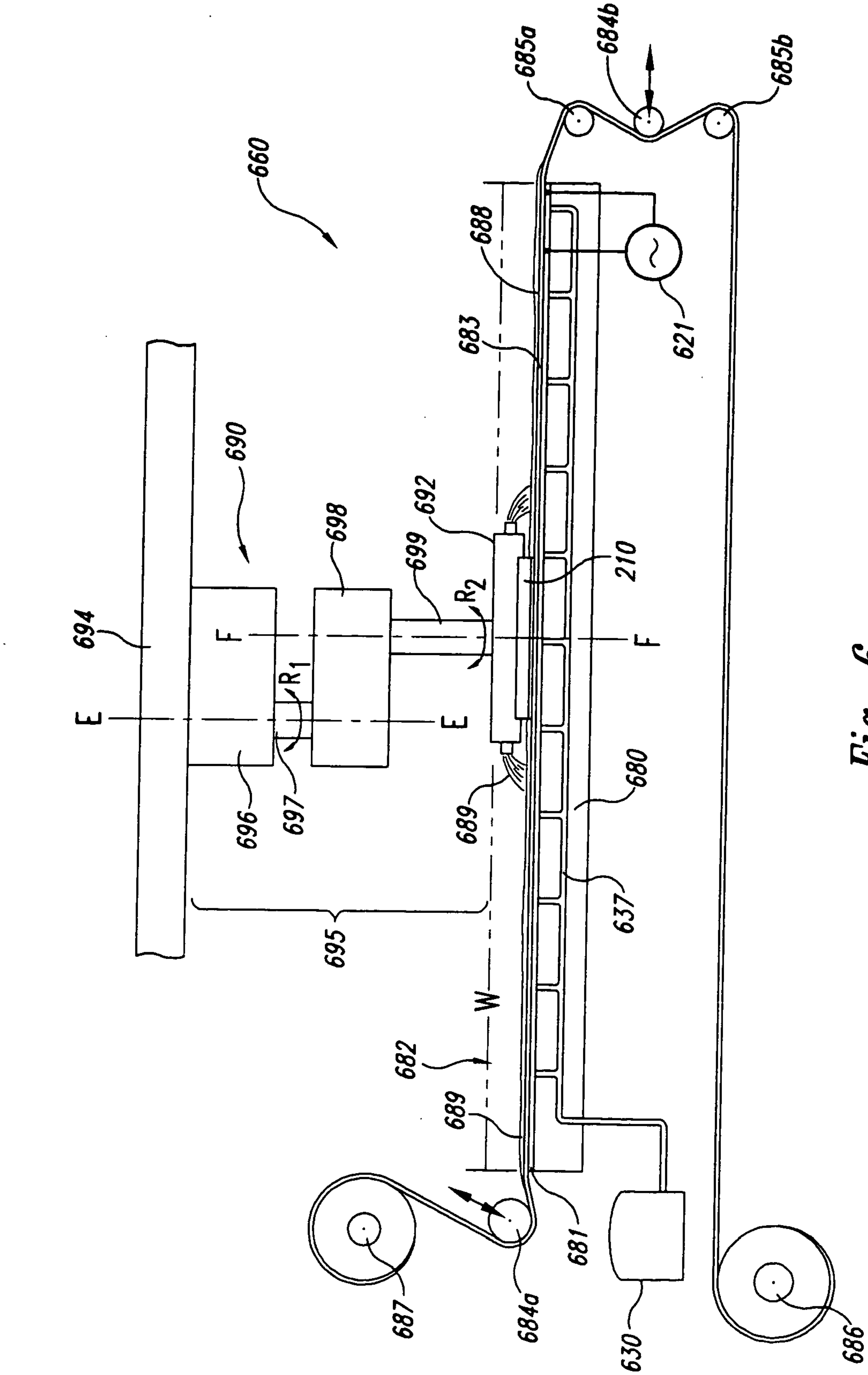

660
694
690
696
697
698
699
692
210
695
689
682
W
683
688
621
685a
684b
685b
680
637
681
684a
687
630
686
E
F
R_1
R_2

Fig. 6

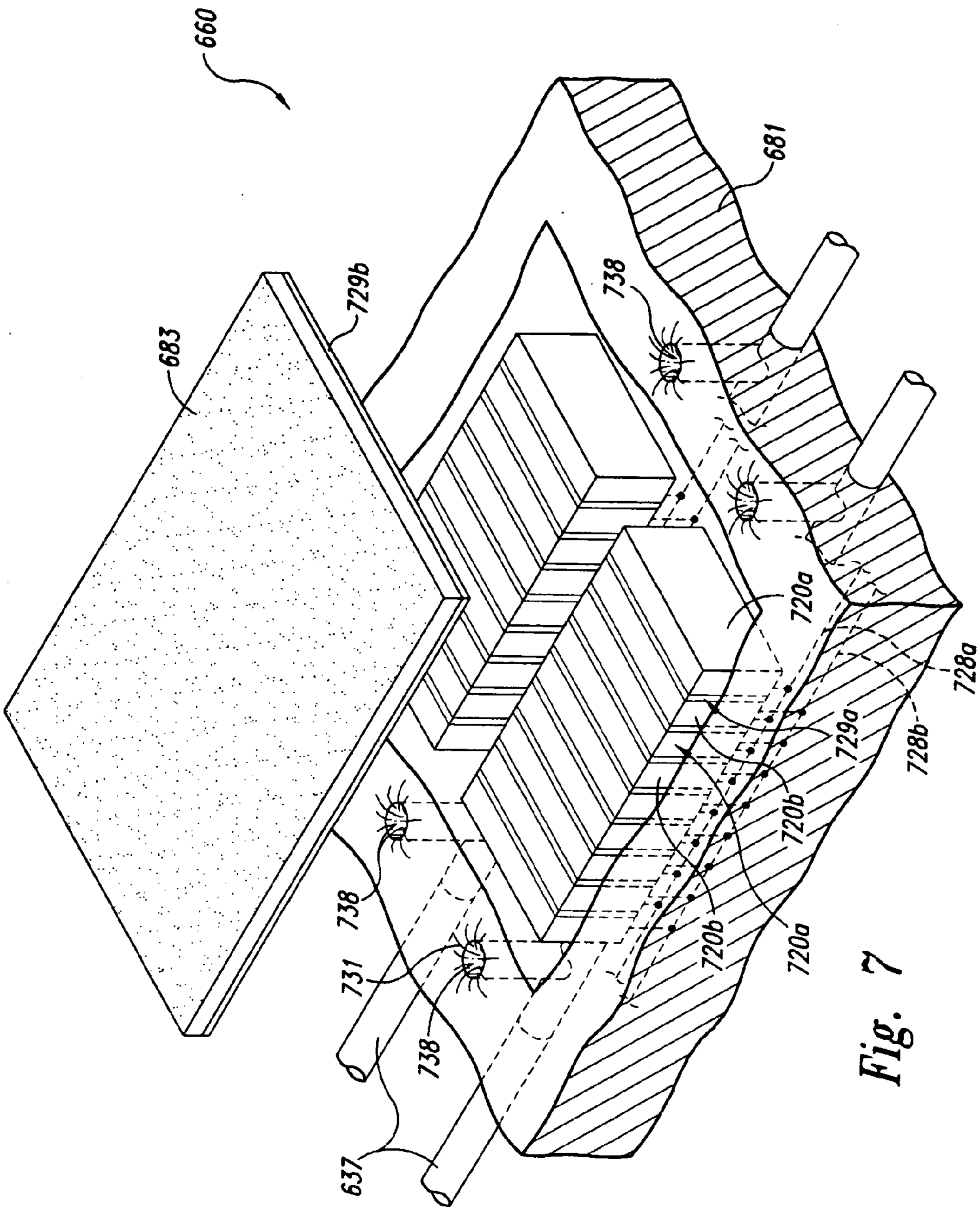

660
683
729b
681
738
720a
728a
729a
728b
720b
720b
720a
738
731
738
637

Fig. 7

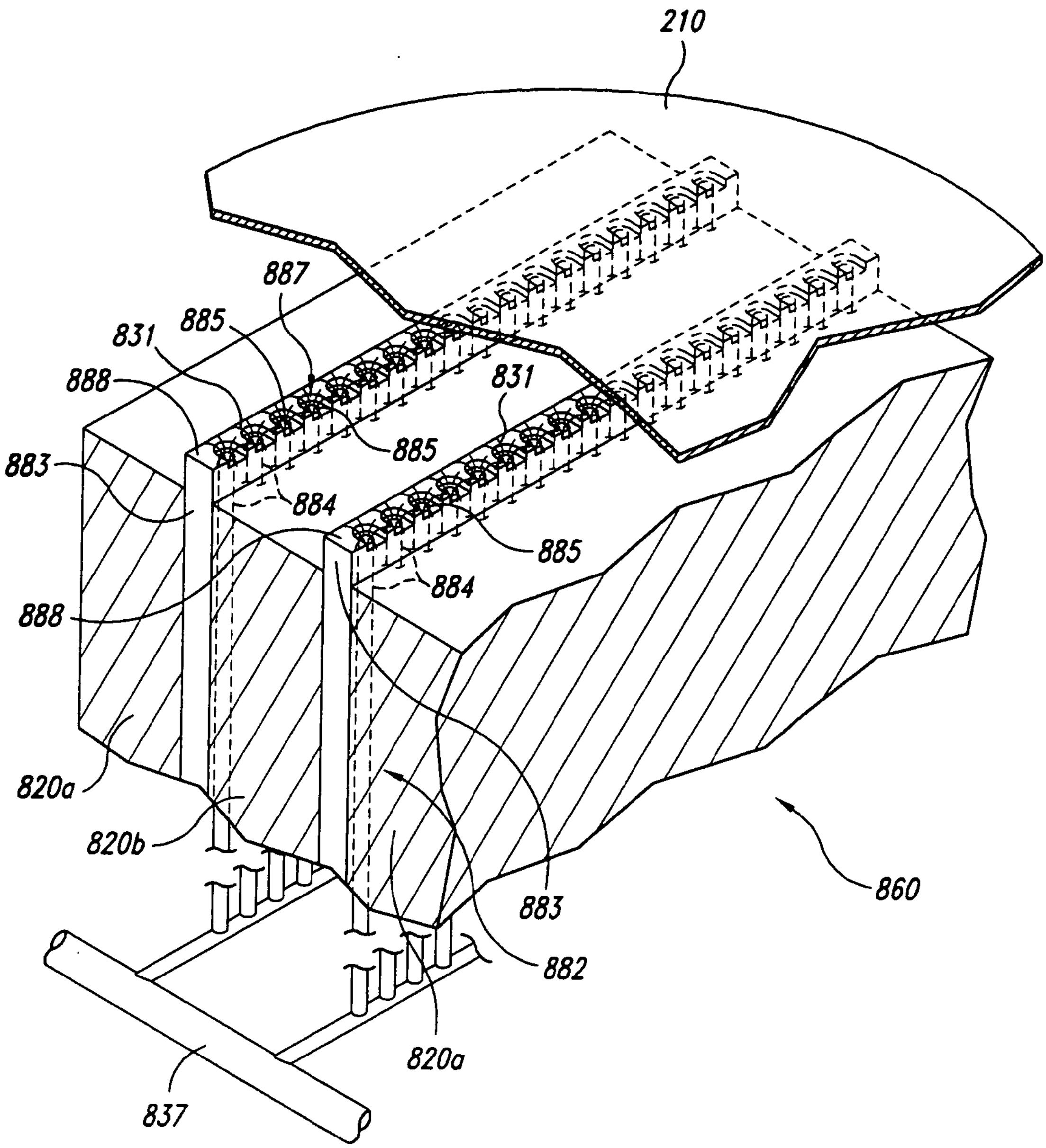

210
887
885
831
888
883
885
884
831
885
888
884
820a
820b
883
860
882
820a
837

Fig. 8

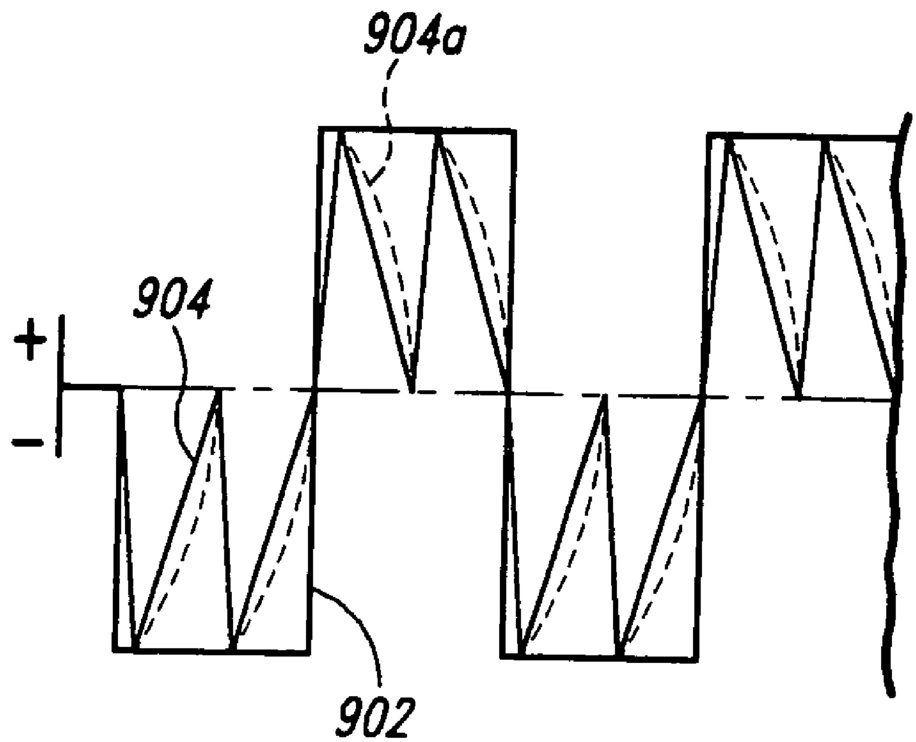


Fig. 9

METHOD AND APPARATUS FOR SIMULTANEOUSLY REMOVING MULTIPLE CONDUCTIVE MATERIALS FROM MICROELECTRONIC SUBSTRATES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to the following pending U.S. Patent Applications, all of which are incorporated herein by reference: Ser. No. 09/651,779 (Attorney Docket 10829.8515US), filed Aug. 30, 2000; Ser. No. 09/651,808 (Client Docket 00-0036), filed Aug. 30, 2000; Ser. No. 09/653,392 (Client Docket 00-0130), filed Aug. 31, 2000; Ser. No. 09/888,084 (Attorney Docket 10829.8515US01), filed Jun. 21, 2001; Ser. No. 09/887,767 (Attorney Docket 10829.8515US02), filed Jun. 21, 2001; and Ser. No. 09/888,002 (Attorney Docket 10829.8515US03) filed Jun. 21, 2001. Also incorporated herein by reference are the following U.S. Patent Applications filed simultaneously herewith: 10/______ (Attorney Docket 10829.8515US06); 10/______ (Attorney Docket 10829.8515US07); 10/______ (Attorney Docket 10829.8515US08); 10/______ (Attorney Docket 10829.8672); and 10/______ (Attorney Docket 10829.8673).

TECHNICAL FIELD

[0002] The present disclosure is directed toward methods and apparatuses for simultaneously removing multiple conductive materials from microelectronic substrates.

BACKGROUND

[0003] Microelectronic substrates and substrate assemblies typically include a semiconductor material having features, such as memory cells, that are linked with conductive lines. The conductive lines can be formed by first forming trenches or other recesses in the semiconductor material and then overlaying a conductive material (such as a metal) in the trenches. The conductive material is then selectively removed to leave conductive lines or vias extending from one feature in the semiconductor material to another.

[0004] **FIG. 1** is a partially schematic illustration of a portion of a microelectronic substrate **10** having a conductive line formed in accordance with the prior art. The microelectronic substrate **10** includes an aperture or recess **16** in an oxide material **13**. A barrier layer **14**, formed from materials such as tantalum or tantalum compounds, is disposed on the microelectronic substrate **10** and in the aperture **16**. A conductive material **15**, such as copper, is then disposed on the barrier layer **14**. The barrier layer **14** can prevent copper atoms from migrating into the surrounding oxide **13**.

[0005] In a typical existing process, two separate chemical-mechanical planarization (CMP) steps are used to remove the excess portions of the conductive material **15** and the barrier layer **14** from the microelectronic substrate **10**. In one step, a first slurry and polishing pad are used to remove the conductive material **15** overlying the barrier layer **14** external to the aperture **16**, thus exposing the barrier layer **14**. In a separate step, a second slurry and a second polishing pad are then used to remove the barrier layer **14** (and the remaining conductive material **15**) external to the aperture **16**. The resulting conductive line **8** includes the conductive material **15** surrounded by a lining formed by the barrier layer **14**.

[0006] One drawback with the foregoing process is that high downforces are typically required to remove copper and tantalum from the microelectronic substrate **10**. High downforces can cause other portions of the microelectronic substrate **10** to become dished or eroded, and/or can smear structures in other parts of the microelectronic substrate **10**. A further drawback is that high downforces typically are not compatible with soft substrate materials. However, it is often desirable to use soft materials, such as ultra low dielectric materials, around the conductive features to reduce and/or eliminate electrical coupling between these features.

SUMMARY

[0007] The present invention is directed toward methods and apparatuses for simultaneously removing multiple conductive materials from a microelectronic substrate. A method in accordance with one aspect of the invention includes contacting a surface of a microelectronic substrate with an electrolytic liquid, the microelectronic substrate having a first conductive material and a second conductive material different than the first. The method can still further include controlling an absolute value of a difference between a first open circuit potential of the first conductive material and a second open circuit potential of the second conductive material by selecting a pH of the electrolytic liquid. The method can further include simultaneously removing at least portions of the first and second conductive materials by passing a varying electrical signal through the electrolytic liquid and the conductive materials while the electrolytic liquid contacts the microelectronic substrate.

[0008] In a further aspect of the invention, wherein the first conductive material includes tungsten and the second conductive material includes copper, the method can include controlling an absolute value of a difference between the first open circuit potential and the second open circuit potential to be about 0.50 volts or less by selecting the pH of the electrolytic liquid to be from about 2 to about 5. The conductive materials can be removed simultaneously by passing an electrical signal from a first electrode spaced apart from the microelectronic substrate, through the electrolytic liquid to the first and second conductive materials and from the first and second conductive materials through the electrolytic liquid to a second electrode spaced apart from the first electrode and spaced apart from the microelectronic substrate.

[0009] A method in accordance with another aspect of the invention includes providing a microelectronic substrate having a first conductive material and a second conductive material different than the first. The method can further include disposing on the microelectronic substrate an electrolytic liquid having a pH that controls a difference between a first open circuit potential of the first conductive material and a second open circuit potential on the second conductive material. The method can further include simultaneously removing at least portions of the first and second conductive materials by passing a variable electrical signal through the electrolytic liquid and the conductive materials while the electrolytic liquid contacts the microelectronic substrate.

[0010] An electrolytic liquid in accordance with another embodiment of the invention can include a liquid carrier and an electrolyte disposed in the liquid carrier. The electrolyte can be configured to transmit electrical signals from an electrode to the first and second conductive materials of the microelectronic substrate. A pH of the electrolytic liquid can be from about 2 to about 5.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] **FIG. 1** is a partially schematic, cross-sectional view of a portion of a microelectronic substrate having multiple conductive materials processed in accordance with the prior art.

[0012] **FIGS. 2A-2C** are partially schematic, cross-sectional illustrations of a portion of a microelectronic substrate having multiple conductive materials processed in accordance with an embodiment of the invention.

[0013] **FIG. 3** is a partially schematic, cross-sectional view of a portion of a microelectronic substrate having multiple conductive materials processed in accordance with another embodiment of the invention.

[0014] **FIG. 4** is a partially schematic illustration of an apparatus for electrolytically removing conductive materials from a microelectronic substrate in accordance with an embodiment of the invention.

[0015] **FIG. 5** is a partially schematic illustration of an apparatus for electrolytically removing conductive materials from a microelectronic substrate in accordance with another embodiment of the invention.

[0016] **FIG. 6** is a partially schematic illustration of an apparatus for electrolytically, chemically-mechanically and/or electrochemically-mechanically removing conductive material from a microelectronic substrate in accordance with still another embodiment of the invention.

[0017] **FIG. 7** is a partially schematic, isometric view of a portion of an embodiment of the apparatus shown in **FIG. 6**.

[0018] **FIG. 8** is a partially schematic, isometric illustration of a portion of an apparatus for removing conductive material from a microelectronic substrate in accordance with yet another embodiment of the invention.

[0019] **FIG. 9** is a schematic illustration of a waveform for electrolytically processing a microelectronic substrate in accordance with still another embodiment of the invention.

DETAILED DESCRIPTION

[0020] The present disclosure describes methods and apparatuses for removing conductive materials from a microelectronic substrate. The term "microelectronic substrate" is used throughout to include a substrate upon which and/or in which microelectronic circuits or components, data storage elements or layers, and/or micro-mechanical elements are fabricated. Features in the substrate can include submicron features (having submicron dimensions ranging from, for example, 0.1 micron to 0.75 micron) such as trenches, vias, lines and holes. It will be appreciated that several of the details set forth below are provided to describe the following embodiments in a manner sufficient to enable a person skilled in the relevant art to make and use the disclosed embodiments. Several of the details and advantages described below, however, may not be necessary to practice certain embodiments of the invention. Additionally, the invention can include other embodiments that are within the scope of the claims but are not described in detail with respect to **FIG. 2A-9**.

[0021] One approach for addressing some of the drawbacks described above with reference to **FIG. 1** is to remove conductive materials from the microelectronic substrate with electrolytic processes. Accordingly, a voltage is applied to the conductive material in the presence of an electrolytic liquid to remove the conductive material. However, many existing electrolytic liquids cannot simultaneously remove copper and tantalum, once the tantalum barrier layer has been exposed. Accordingly, chemical-mechanical planarization (CMP) techniques are typically used to remove the exposed tantalum barrier layer and the adjacent copper material. However, this approach typically re-introduces the high downforces that the initial electrolytic process was intended to avoid. Accordingly, another approach has been to replace the tantalum barrier layer with a tungsten barrier layer. However, tungsten (and tungsten compounds) typically form a galvanic couple with copper, which results in one or the other of these materials corroding and dissolving at an uncontrolled rate. The following disclosure describes methods and apparatuses for overcoming this drawback.

[0022] **FIG. 2A** is a partially schematic, cross-sectional side view of a microelectronic substrate **210** prior to electrolytic processing in accordance with an embodiment of the invention. In one aspect of this embodiment, the microelectronic substrate **210** includes a substrate material **213**, such as an oxide or a low dielectric constant material. The substrate material **213** includes a substrate material surface **217** having an aperture **216** formed by conventional processes, such as selective etch processes. A first conductive material **218** is disposed on the substrate material **213** and can form a barrier layer **214** along the walls of the aperture **216**. A second conductive material **209**, such as a blanket fill material, can be disposed on the first conductive material **218** to form a fill layer **219**. In one embodiment, the first conductive material **218** can include tungsten (W) or a tungsten compound, such as tungsten nitride (WN_x), and the second conductive material **209** can include copper or copper alloys such as alloys that include at least 50% copper. In other embodiments, these conductive materials can include other elements or compounds. In any of these embodiments, the first conductive material **218** and the second conductive material **209** can collectively define a conductive portion **211** of the microelectronic substrate **210**.

[0023] To form an isolated conductive line within the aperture **216**, the first conductive material **218** and second conductive material **219** external to the aperture **216** are typically removed. In one embodiment, the second conductive material **209** is removed using a CMP process. In other embodiments, an electrochemical-mechanical polishing (ECMP) process or an electrolytic process is used to remove the second conductive material **209**. An advantage of electrolytic and ECMP processes is that the downforce applied to the microelectronic substrate **210** during processing can be reduced or eliminated. Apparatuses for performing these processes are described in greater detail below with reference to **FIGS. 4-9**. In any of these embodiments, the result after completing this portion of the process is a microelectronic substrate **210** having the second conductive material

209 external to the aperture **216** and external to the barrier layer **214** removed, as is shown in **FIG. 2B**.

[**0024**] Referring now to **FIG. 2B**, a process in accordance with one embodiment of the invention includes simultaneously, electrolytically removing the portions of the second conductive material **209** and the first conductive material **218** that extend beyond the substrate material surface **217** after the initial removal process described above with reference to **FIG. 2A**. Accordingly, in one aspect of this embodiment, an electrolytic liquid **231** can be disposed on the microelectronic substrate **210** and a pair of electrodes **220** (shown as a first electrode **220***a* and a second electrode **220***b*) can be positioned in electrical communication with the electrolytic liquid **231**. The electrodes **220** can be coupled to a variable signal transmitter **221** (such as a variable current source) to provide a varying electrical signal to both the first conductive material **218** and the second conductive material **209**. These conductive materials can be simultaneously removed via an electrolytic process

[**0025**] In a further aspect of this embodiment, the pH of the electrolytic liquid **231** is selected to control the difference between the open circuit potential of the first conductive material **218** and the open circuit potential of the second conductive material **209**. As used herein, the difference in open circuit potentials between the first conductive material **218** and the second conductive material **209** refers to the difference in electrical potential that would result when measuring the voltage difference between the first conductive material **218** and the second conductive material **209** in the presence of the electrolytic liquid **231**, but in the absence of any current applied by the signal transmitter **221**. In a particular aspect of this embodiment, for example, when the first conductive material **218** includes tungsten and the second conductive material **209** includes copper, the pH of the electrolytic liquid **231** can be selected to be from about 2 to about 5 to produce a difference in open circuit potential of from about 0.50 volts to about −0.50 volts. In other words, the absolute value of the difference in open circuit potential can be about 0.50 volts or less. In other embodiments, the absolute value of the difference in open circuit potential can be about 0.25 volts or less, for example, 0.15 volts or less. In still further embodiments, the pH of the electrolytic liquid **231** can have other values to produce near-zero open circuit potential differentials for other combinations of first conductive materials **218** and second conductive materials **209**. For example, in one embodiment, the electrolytic liquid **231** can have a pH of from about 0 to about 7.

[**0026**] In any of the foregoing embodiments, the first and second conductive materials **218**, **209** can be removed simultaneously without necessarily being removed at the same rates. For example, in one embodiment for which the first conductive material **218** includes tungsten or a tungsten compound and the second conductive material **209** includes copper, the copper can be removed at about four times the rate at which the tungsten or tungsten compound is removed. In other embodiments, the first and second conductive materials **218**, **209** can be removed at rates that vary by greater or lesser amounts.

[**0027**] In one embodiment, the pH of the electrolytic liquid **231** can be controlled by disposing an acid in the electrolytic liquid **231**. Accordingly, the electrolytic liquid **231** can include a liquid carrier (such as deionized water) and an acid such as nitric acid, acetic acid, hydrochloric acid, sulfuric acid, or phosphoric acid. In other embodiments, the electrolytic liquid **231** can include other acids. In addition to reducing the pH of the electrolytic liquid **231**, the acid can provide ions to enhance the electrolytic action of the electrolytic liquid **231**. In any of these embodiments, the electrolytic liquid **231** can also optionally include an inhibitor, such as benzotriazole (BTA) to produce more uniform material removal. The electrolytic liquid **231** can also include oxidizers, such as hydroxylamine, peroxide or ammonium persulfate. In another embodiment, the oxidizers can be eliminated, for example, when the electrolytic action provided by the electrodes **220** is sufficient to oxidize the conductive materials **218** and **209**.

[**0028**] In any of the foregoing embodiments, the first conductive material **218** and the second conductive material **209** external to the recess **216** can be removed, producing a microelectronic substrate **210** having an embedded conductive structure **208**, as shown in **FIG. 2C**. In one embodiment, the conductive structure **208** can include a conductive line and in other embodiments, conductive structure **208** can include a via or other feature in the microelectronic substrate **210**. In any of these embodiments, the foregoing processes can provide a conductive structure **208** having a smooth external surface **207** that includes smooth external surface portions for both the first conductive material **218** and the second conductive material **209**.

[**0029**] One feature of an embodiment of the method described above with reference to **FIGS. 2A-2C** is that the pH of the electrolytic liquid **231** can be selected to reduce or eliminate the open circuit potential differential between the first conductive material **218** and the second conductive material **209**. An advantage of this feature is that the likelihood for a galvanic reaction, which can preferentially pit, dissolve, or otherwise remove one of the conductive materials more readily than the other, can be reduced and/or eliminated. Accordingly, the resulting external surface **207** that includes the first conductive material **218** and the second conductive material **209** can be clean and uniform, as shown in **FIG. 2C**. Another advantage of this feature is that the first conductive material **218** and the second conductive material **209** can be removed simultaneously without requiring high downforces which can damage structures and features of the microelectronic substrate **210**.

[**0030**] In the embodiments described above with reference to **FIGS. 2A-2C**, the first and second electrodes **220***a*, **220***b* are spaced apart from the microelectronic substrate **210** as they remove conductive materials from the microelectronic substrate **210**. An advantage of this arrangement is that the conductive material removal process can be relatively uniform. In other embodiments, one or more of the electrodes can be positioned in direct contact with the microelectronic substrate **210**. For example, as shown in **FIG. 3**, a first electrode **320***a* can be positioned in a spaced apart orientation relative to the microelectronic substrate **210**, and a second electrode **320***b* can be connected to a rear surface of the microelectronic substrate **210**. A conductive path **308** (such as an internal via) between the rear surface and the conductive portion **211** of the microelectronic substrate can complete the circuit between the electrodes **320***a*, **320***b*, allowing the signal transmitter **221** to remove conductive material in a manner generally similar to that described above. In still another embodiment, the second electrode **320***b* can be connected directly to the microelectronic substrate **210**. Such arrangements can be used when material removal nonuniformities which may result from the direct contact between the electrode and the microelectronic substrate are remote from regions that might be adversely affected by such nonuniformities.

[**0031**] **FIGS. 4-9** illustrate apparatuses for electrolytically, chemically-mechanically, and/or electrochemically-mechanically removing material from microelectronic substrates to perform the processes described above with reference to **FIGS. 2A-3**. Beginning with **FIG. 4**, an apparatus **460** can electrolytically remove conductive material from the microelectronic substrate **210** in accordance with an embodiment of the invention. In one aspect of this embodiment, the apparatus **460** includes liquid support, such as a vessel **430** containing an electrolytic liquid or gel **431**. A support member **440** supports the microelectronic substrate **210** relative to the vessel **430** so that the conductive portion **211** of the microelectronic substrate **210** contacts the electrolytic liquid **431**. In another aspect of this embodiment, the support member **440** can be coupled to a substrate drive unit **441** that moves the support member **440** and the substrate **210** relative to the vessel **430**. For example, the substrate drive unit **441** can translate the support member **440** (as indicated by arrow "A") and/or rotate the support member **440** (as indicated by arrow "B").

[**0032**] The apparatus **460** can further include a first electrode **420***a* and a second electrode **420***b* (referred to collectively as electrodes **420**) supported relative to the microelectronic substrate **210** by a support arm **424**. In one aspect of this embodiment, the support arm **424** is coupled to an electrode drive unit **423** for moving the electrodes **420** relative to the microelectronic substrate **210**. For example, the electrode drive unit **423** can move the electrodes **420** toward and away from the conductive portion **211** of the microelectronic substrate **210**, (as indicated by arrow "C"), and/or transversely (as indicated by arrow "D") in a plane generally parallel to the conductive portion **211**. In other embodiments, the electrode drive unit **423** can move the electrodes **420** in other fashions, or the electrode drive unit **423** can be eliminated when the substrate drive unit **441** provides sufficient relative motion between the substrate **210** and the electrodes **420**.

[**0033**] In either embodiment described above with reference to **FIG. 4**, the electrodes **420** can be coupled to a signal transmitter **421** with leads **428** for supplying electrical current to the electrolytic liquid **431** and the conductive portion **211**. In operation, the signal transmitter **421** can supply an alternating current (signal phase or multi-phase) to the electrodes **420**. The current passes through the electrolytic liquid **431** and reacts electrochemically with the conductive portion **211** to remove material (for example, atoms or groups of atoms) from the conductive portion **211**. The electrodes **420** and/or the microelectronic substrate **210** can be moved relative to each other to remove material from select regions of the conductive portion **211**, or from the entire conductive portion **211**.

[**0034**] In one aspect of an embodiment of the apparatus **460** shown in **FIG. 4**, a distance D_1 between the electrodes **420** and the conductive portion **211** is set to be smaller than a distance D_2 between the first electrode **420***a* and the second electrode **420***b*. Furthermore, the electrolytic liquid **431** generally has a higher resistance than the conductive portion **211**. Accordingly, the alternating current follows the path of least resistance from the first electrode **420***a*, through the electrolytic liquid **431** to the conductive portion **211** and back through the electrolytic liquid **431** to the second electrode **420***b*, rather than from the first electrode **420***a* directly through the electrolytic liquid **431** to the second electrode **420***b*. In one aspect of this embodiment, the resistance of the electrolytic liquid **431** can be increased as the thickness of the conductive portion **211** decreases (and the resistance of the conductive portion **211** increases) to maintain the current path described above. In another embodiment, a low dielectric material (not shown) can be positioned between the first electrode **420***a* and the second electrode **420***b* to decouple direct electrical communication between the electrodes **420** that does not first pass through the conductive portion **211**.

[**0035**] **FIG. 5** is a partially schematic, side elevation view of an apparatus **560** that includes a support member **540** positioned to support the microelectronic substrate **210** in accordance with another embodiment of the invention. In one aspect of this embodiment, the support member **540** supports the microelectronic substrate **210** with the conductive portion **211** facing upwardly. A substrate drive unit **541** can move the support member **540** and the microelectronic substrate **210**, as described above with reference to **FIG. 4**. Electrodes **520**, including first and second electrodes **520***a* and **520***b*, are positioned above the conductive portion **211** and are coupled to a current source **521**. A support arm **524** supports the electrodes **520** relative to the substrate **210** and is coupled to an electrode drive unit **523** to move the electrodes **520** over the surface of the conductive portion **211** in a manner generally similar to that described above with reference to **FIG. 4**.

[**0036**] In one aspect of the embodiment shown in **FIG. 5**, the apparatus **560** further includes an electrolyte vessel **530** having a supply conduit **537** with an aperture **538** positioned proximate to the electrodes **520**. Accordingly, an electrolytic liquid **531** can be deposited locally in an interface region **539** between the electrodes **520** and the conductive portion **211**, without necessarily covering the entire conductive portion **211**. The electrolytic liquid **531** and the conductive material removed from the conductive portion **211** flow over the substrate **210** and collect in an electrolyte receptacle **532**. The mixture of electrolytic liquid **531** and conductive material can flow to a reclaimer **533** that removes most of the conductive material from the electrolytic liquid **531**. A filter **534** positioned downstream of the reclaimer **533** provides additional filtration of the electrolytic liquid **531**, and a pump **535** returns the reconditioned electrolytic liquid **531** to the electrolyte vessel **530** via a return line **536**.

[**0037**] In another aspect of an embodiment shown in **FIG. 5**, the apparatus **560** can include a sensor assembly **550** having a sensor **551** positioned proximate to the conductive portion **211**, and a sensor control unit **552** coupled to the sensor **551** for processing signals generated by the sensor **551**. The control unit **552** can also move the sensor **551** relative to the microelectronic substrate **210**. In a further aspect of this embodiment, the sensor assembly **550** can be coupled via a feedback path **553** to the electrode drive unit **523** and/or the substrate drive unit **541**. Accordingly, the sensor **551** can determine which areas of the conductive portion **211** require additional material removal and can move the electrodes **520** and/or the microelectronic substrate **210** relative to each other to position the electrodes **520** over those areas. Alternatively, (for example, when the removal process is highly repeatable), the electrodes **520** and/or the microelectronic substrate **210** can move relative to each other according to a pre-determined motion schedule.

[**0038**] **FIG. 6** schematically illustrates an apparatus **660** for electrolytically, chemically-mechanically and/or electrochemically-mechanically polishing the microelectronic substrate **210** in accordance with an embodiment of the invention. In one aspect of this embodiment, the apparatus **660** has a support table **680** with a top-panel **681** at a workstation where an operative portion "W" of a polishing pad **683** is positioned. The top-panel **681** is generally a rigid plate to provide a flat, solid surface to which a particular section of the polishing pad **683** may be secured during polishing.

[**0039**] The apparatus **660** can also have a plurality of rollers to guide, position and hold the polishing pad **683** over the top-panel **681**. The rollers can include a supply roller **687**, first and second idler rollers **684***a* and **684***b*, first and second guide rollers **685***a* and **685***b*, and a take-up roller **686**. The supply roller **687** carries an unused or preoperative portion of the polishing pad **683**, and the take-up roller **686** carries a used or postoperative portion of the polishing pad **683**. Additionally, the first idler roller **684***a* and the first guide roller **685***a* can stretch the polishing pad **683** over the top-panel **681** to hold the polishing pad **683** stationary during operation. A motor (not shown) drives at least one of the supply roller **687** and the take-up roller **686** to sequentially advance the polishing pad **683** across the top-panel **681**. Accordingly, clean preoperative sections of the polishing pad **683** may be quickly substituted for used sections to provide a consistent surface for polishing and/or cleaning the microelectronic substrate **210**.

[**0040**] The apparatus **660** can also have a carrier assembly **690** that controls and protects the microelectronic substrate **210** during polishing. The carrier assembly **690** can include a substrate holder **692** to pick up, hold and release the microelectronic substrate **210** at appropriate stages of the polishing process. The carrier assembly **690** can also have a support gantry **694** carrying a drive assembly **695** that can translate along the gantry **694**. The drive assembly **695** can have an actuator **696**, a drive shaft **697** coupled to the actuator **696**, and an arm **698** projecting from the drive shaft **697**. The arm **698** carries the substrate holder **692** via a terminal shaft **699** such that the drive assembly **695** orbits the substrate holder **692** about an axis E-E (as indicated by arrow "R_1"). The terminal shaft **699** may also rotate the substrate holder **692** about its central axis F-F (as indicated by arrow "R_2").

[**0041**] The polishing pad **683** and a polishing liquid **689** define a polishing medium **682** that electrolytically, chemically-mechanically, and/or electro-chemically-mechanically removes material from the surface of the microelectronic substrate **210**. In some embodiments, the polishing pad **683** may be a nonabrasive pad without abrasive particles, and the polishing liquid **689** can be a slurry with abrasive particles and chemicals to remove material from the microelectronic substrate **210**. In other embodiments, the polishing pad **683** can be a fixed-abrasive polishing pad in which abrasive particles are fixedly bonded to a suspension medium. To polish the microelectronic substrate **210** with the apparatus **660**, the carrier assembly **690** presses the microelectronic substrate **210** against a polishing surface **688** of the polishing pad **683** in the presence of the polishing liquid **689**. The drive assembly **695** then orbits the substrate holder **692** about the axis E-E and optionally rotates the substrate holder **692** about the axis F-F to translate the substrate **210** across the polishing surface **688**. As a result, the abrasive particles and/or the chemicals in the polishing medium **682** remove material from the surface of the microelectronic substrate **210** in a chemical and/or chemical-mechanical polishing process.

[**0042**] In a further aspect of this embodiment, the polishing liquid **689** can include an electrolyte for electrolytic processing or ECMP processing. In another embodiment, the apparatus **660** can include an electrolyte supply vessel **630** that delivers an electrolyte separately to the polishing surface **688** of the polishing pad **683** with a conduit **637**, as described in greater detail below with reference to **FIG. 7**. In either embodiment, the apparatus **660** can further include a current supply **621** coupled to electrodes positioned proximate to the polishing pad **683**. Accordingly, the apparatus **660** can electrolytically remove material from the microelectronic substrate **210**.

[**0043**] **FIG. 7** is a partially exploded, partially schematic isometric view of a portion of the apparatus **660** described above with reference to **FIG. 6**. In one aspect of the embodiment shown in **FIG. 6**, the top-panel **681** houses a plurality of electrode pairs, each of which includes a first electrode **720***a* and a second electrode **720***b*. The first electrodes **720***a* are coupled to a first lead **728***a* and the second electrodes **720***b* are coupled to a second lead **728***b*. The first and second leads **728***a* and **728***b* are coupled to the current supply **621** (**FIG. 6**). In one aspect of this embodiment, the first electrodes **720***a* can be separated from the second electrodes **720***b* by an electrode dielectric layer **729***a* that includes Teflon™ or another suitable dielectric material. The electrode dielectric layer **729***a* can accordingly control the volume and dielectric constant of the region between the first and second electrodes **720***a* and **720***b* to control the electrical coupling between the electrodes.

[**0044**] The electrodes **720***a* and **720***b* can be electrically coupled to the microelectronic substrate **210** (**FIG. 6**) by the polishing pad **683**. In one aspect of this embodiment, the polishing pad **683** is saturated with an electrolytic liquid **731** supplied by the supply conduits **637** through apertures **738** in the top-panel **681** just beneath the polishing pad **683**. Accordingly, the electrodes **720***a* and **720***b* are selected to be compatible with the electrolytic liquid **731**. In an another arrangement, the electrolytic liquid **731** can be supplied to the polishing pad **683** from above (for example, by disposing the electrolytic liquid **731** in the polishing liquid **689**, rather than by directing the electrolytic liquid upwardly through the polishing pad **683**). Accordingly, the apparatus **660** can include a pad dielectric layer **729***b* positioned between the polishing pad **683** and the electrodes **720***a* and **720***b*. When the pad dielectric layer **729***b* is in place, the electrodes **720***a* and **720***b* can be isolated from physical contact with the electrolytic liquid **731** and can accordingly be selected from materials that are not necessarily compatible with the electrolytic liquid **731**.

[**0045**] **FIG. 8** is an isometric view of a portion of an apparatus **860** having electrodes **820** (shown as a first electrode **820***a* and a second electrode **820***b*), and a polishing medium **882** arranged in accordance with another embodiment of the invention. In one aspect of this embodiment, the polishing medium **882** includes polishing pad portions **883** that project beyond the electrodes **820***a* and **820***b*. Each polishing pad portion **883** can include a polishing surface **888** and a plurality of flow passages **884** coupled to a fluid source (not shown in **FIG. 8**) with a conduit **837**. Each flow passage **884** can have an aperture **885** proximate to the polishing surface **888** to provide an electrolytic liquid **831** proximate to an interface between the microelectronic substrate **210** and the polishing surface **888**. In one aspect of this embodiment, the pad portions **883** can include recesses **887** surrounding each aperture **885**. Accordingly, the electrolytic liquid **831** can proceed outwardly from the flow passages **884** while the microelectronic substrate **210** is positioned directly overhead and remains spaced apart from the electrodes **820**. In other embodiments, the polishing pad portions **883** can be applied to other electrodes, such as those described above with reference to **FIGS. 4 and 5** to provide for mechanical as well as electromechanical material removed.

[**0046**] The foregoing apparatuses described above with reference to **FIGS. 4-8** can be used to electrolytically, chemically-mechanically and/or electrochemically-mechanically process the microelectronic substrate **210**. When the apparatuses are used to electrolytically or electrochemically-mechanically process the microelectronic substrate **210**, they can provide a varying electrical current that passes from the electrodes, through the conductive material of the microelectronic substrate **210** via the electrolytic liquid. For example, as shown in **FIG. 9**, the apparatus can generate a high-frequency wave **904** and can superimpose a low-frequency wave **902** on the high-frequency wave **904**. In one aspect of this embodiment, the high-frequency wave **904** can include a series of positive or negative voltage spikes contained within a square wave envelope defined by the low-frequency wave **902**. Each spike of the high-frequency wave **904** can have a relatively steep rise-time slope to transfer charge through the dielectric material to the electrolytic liquid, and a more gradual fall-time slope. The fall-time slope can define a straight line, as indicated by high-frequency wave **904**, or a curved line, as indicated by high-frequency wave **904***a*. In other embodiments, the high-frequency wave **904** and the low-frequency wave **902** can have other shapes depending, for example, on the particular characteristics of the dielectric material and the electrolytic liquid, the characteristics of the microelectronic substrate **210**, and/or the target rate at which conductive material is to be removed from the microelectronic substrate **210**.

[**0047**] The methods described above with reference to **FIGS. 2A-3** may be performed with the apparatuses described above with reference to **FIGS. 4-9** in a variety of manners in accordance with several embodiments of the invention. For example, in one embodiment, a single apparatus can be used to electrolytically remove first the second conductive material **209** and then the first and second conductive materials **218, 209** simultaneously. Alternatively, one apparatus can initially remove the second material **209** (e.g., via CMP) and the same or another apparatus can subsequently remove both the first and second conductive materials **218, 209**. In either embodiment, both the first an second conductive materials **218, 209** can be removed simultaneously when they are exposed. In one aspect of both embodiments, the downforce applied to the microelectronic substrate **210** can be reduced or eliminated during electrolytic processing. In another aspect of these embodiments, a selected downforce can be applied to the microelectronic substrate **210** during electrolytic processing to supplement the electrolytic removal process with a mechanical removal process. The electrolytic removal process can also be supplemented with a chemical removal process in addition to or in lieu of the mechanical removal process.

[**0048**] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

1-54. (Canceled)

55. An electrolytic liquid for removing first and second conductive materials from a microelectronic substrate, the first conductive material being different than the second conductive material, the electrolytic liquid comprising:

a liquid carrier; and

an electrolyte disposed in the liquid carrier and configured to transmit electrical signals from an electrode to the first and second conductive materials of the microelectronic substrate;

wherein a pH of the electrolytic liquid is from about 2 to about 5.

56. The electrolytic liquid of claim 55 wherein the electrolyte includes an acid.

57. The electrolytic liquid of claim 55 wherein the electrolyte includes at least one of hydrochloric acid, sulfuric acid, phosphoric acid, nitric acid and acetic acid.

58. The electrolytic liquid of claim 55 wherein the liquid carrier includes deionized water.

59. The electrolytic liquid of claim 55 wherein the pH of the electrolytic liquid is selected to control an absolute value of a difference between a first open circuit potential of the first conductive material and a second open circuit potential of the second conductive material to be about 0.50 volts or less.

60. The electrolytic liquid of claim 55 wherein the pH of the electrolytic liquid is selected to control an absolute value of a difference between a first open circuit potential of the first conductive material and a second open circuit potential of the second conductive material to be about 0.25 volts or less.

61. The electrolytic liquid of claim 55, further comprising an oxidizer.

62. The electrolytic liquid of claim 55, further comprising an oxidizer selected from hydroxylamine, peroxide and ammonium persulfate.

63. The electrolytic liquid of claim 55, further comprising a corrosion inhibitor.

64. The electrolytic liquid of claim 55, further comprising a corrosion inhibitor that includes benzotriazole.

65. A system for removing first and second conductive materials from a microelectronic substrate, the first conductive material being different than the second conductive material, the system comprising:

a substrate support configured to carry a microelectronic substrate;

at least one electrode positioned at least proximate to the substrate support;

a liquid support positioned proximate to the substrate support to carry an electrolytic liquid in contact with the microelectronic substrate; and

an electrolytic liquid carried by the liquid support, the electrolytic liquid including:

a liquid carrier;

an electrolyte disposed in the liquid carrier and configured to transmit electrical signals from the at least one electrode to the first and second conductive materials of the microelectronic substrate, wherein a pH of the electrolytic liquid is from about 2 to about 5.

66. The system of claim 65 wherein the liquid support includes a liquid vessel.

67. The system of claim 65 wherein the liquid support includes a polishing pad having a polishing surface positioned to contact the microelectronic substrate, wherein the at least one of the polishing pad and the substrate support is movable relative to the other.

68. The system of claim 65 wherein the electrode is a first electrode and wherein the system further comprises:

a second electrode spaced apart from the first electrode; and

an electrical signal transmitter coupled to the first and second electrodes, wherein the first and second electrodes are positioned to be spaced apart from the microelectronic substrate when the substrate carrier carries the microelectronic substrate.

69. The system of claim 65, further comprising a sensor positioned to detect an amount of conductive material on the microelectronic substrate.

70. The system of claim 65 wherein at least one of the at least one electrode and the substrate support is movable relative to the other.

71. The system of claim 65 wherein the electrolyte includes at least one of hydrochloric acid, sulfuric acid, phosphoric acid, nitric acid and acetic acid.

72. The system of claim 65 wherein the pH of the electrolytic liquid is selected to control an absolute value of a difference between a first open circuit potential of the first conductive material and a second open circuit potential of the second conductive material to be about 0.50 volts or less.

73. The system of claim 65 wherein the pH of the electrolytic liquid is selected to control an absolute value of a difference between a first open circuit potential of the first conductive material and a second open circuit potential of the second conductive material to be about 0.25 volts or less.

* * * * *