US 20080271995A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2008/0271995 A1**

(43) **Pub. Date: Nov. 6, 2008**

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(54) **AGITATION OF ELECTROLYTIC SOLUTION IN ELECTRODEPOSITION**

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(21) Appl. No.: **11/744,046**

(22) Filed: **May 3, 2007**

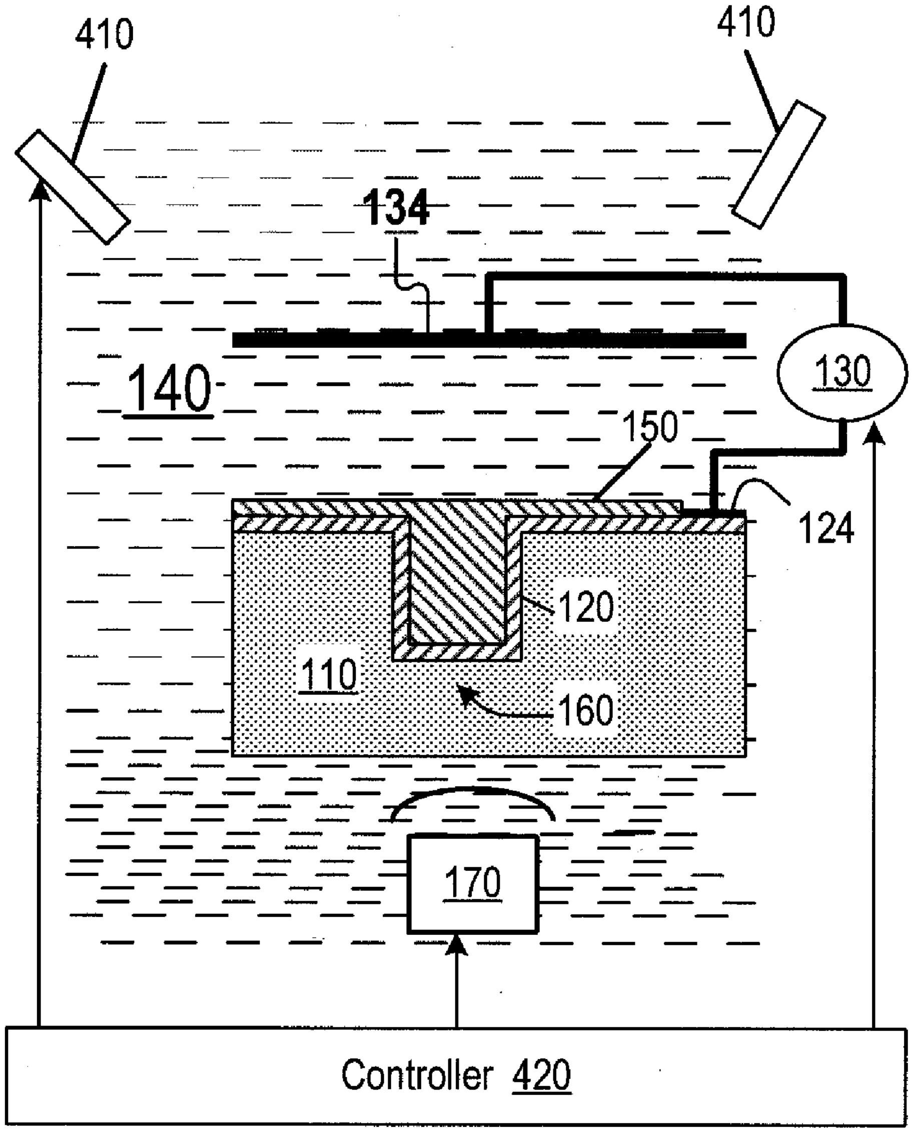
Publication Classification

(51) **Int. Cl.**
C25D 21/10 (2006.01)
C25D 17/00 (2006.01)
C25D 21/12 (2006.01)

(52) **U.S. Cl.** **204/273**; 205/148; 700/296

(57) **ABSTRACT**

In a reverse pulse plating of a substrate (**110**), the electrolytic solution is agitated with a greater power on forward pulses (**210**) than on reverse pulses (**220**). An ultrasound agitation source (**170**) can be positioned at the bottom of the substrate (**110**) if the anode (**134**) is at the top. The ultrasound source may contact the substrate's bottom. Other features are also provided.



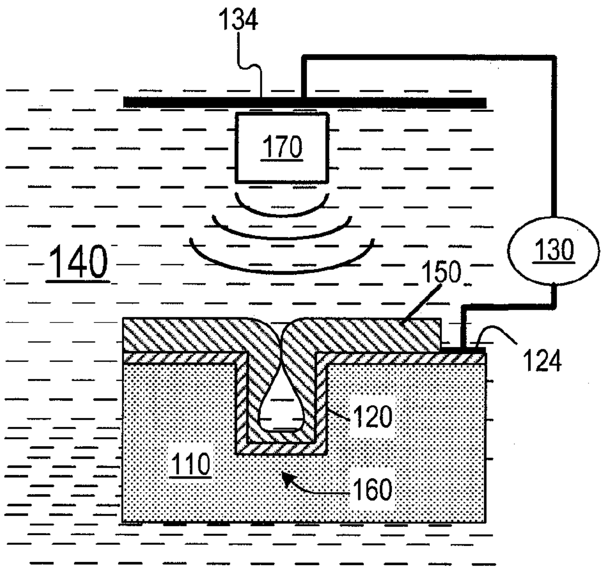


FIG. 1 PRIOR ART

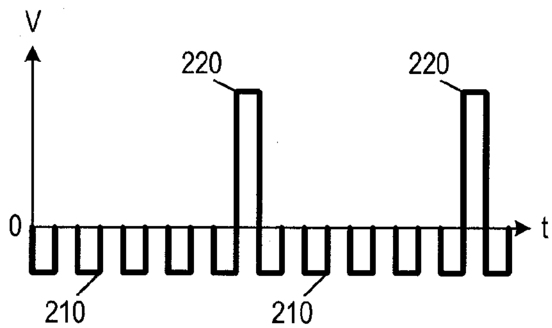


FIG. 2 PRIOR ART

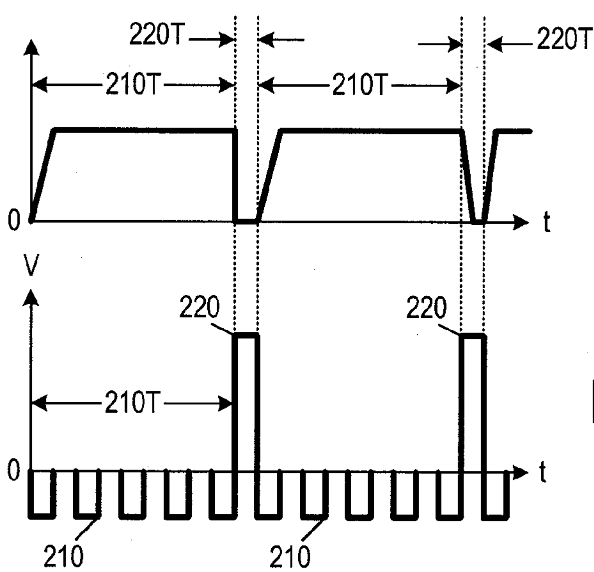


FIG. 3

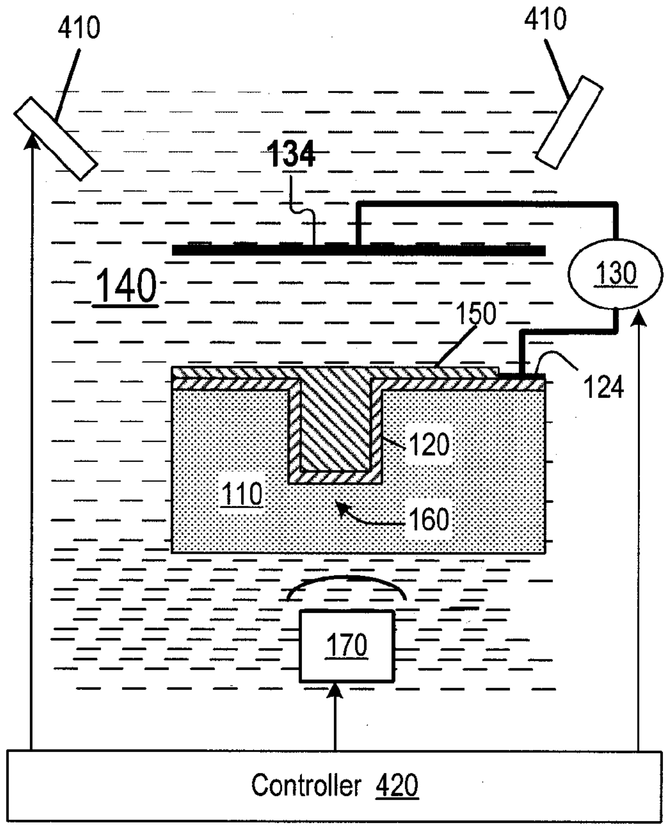

410
410
134
140
130
150
124
120
110
160
170
Controller 420

FIG. 4

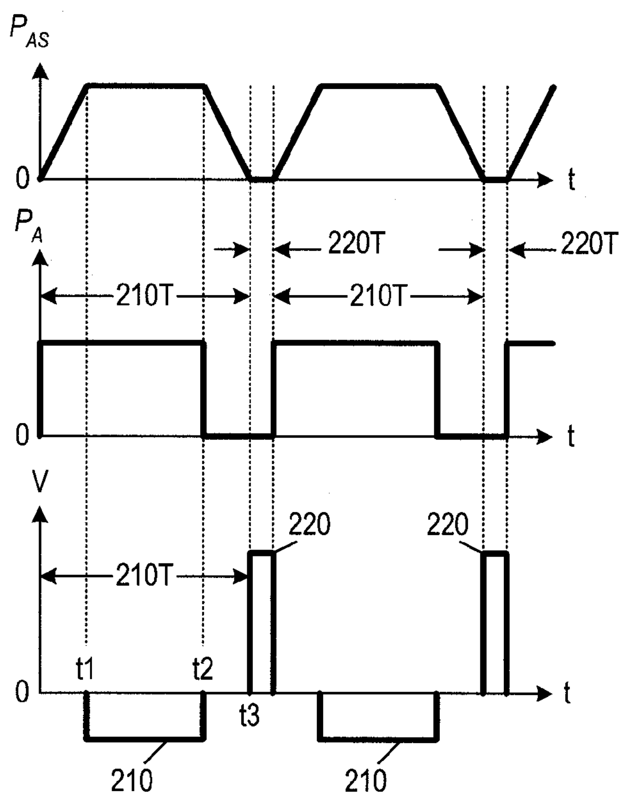

P_AS
0
t
P_A
220T
220T
210T
210T
0
t
V
220
220
210T
t1
t2
0
t3
t
210
210

FIG. 5

AGITATION OF ELECTROLYTIC SOLUTION IN ELECTRODEPOSITION

BACKGROUND OF THE INVENTION

[0001] The present invention relates to agitation of electrolytic solution in electrodeposition.

[0002] FIG. **1** illustrates electrodeposition (electroplating) of metal (e.g. copper) onto a substrate **110**, e.g. a silicon wafer or a printed circuit board. Seed layer **120** is formed on the substrate areas to be electroplated. Cathode terminal **124** of electric power supply **130** is connected to the seed layer, and anode terminal **134** is placed at a distance from substrate **110**. The substrate and the terminals **124**, **134** are immersed into an electroplating solution **140**. As a result, metal layer **150** is deposited on seed layer **120** from metal ions supplied by salts in the electroplating solution and by anode terminal **134**.

[0003] If the metal is to be electroplated into a via **160** in the substrate surface, the electrodeposition rate near the via bottom can be lower than at the top, and the metal **150** may close the via at the top before a desired amount of metal **150** is deposited into the via. An unwanted closed void may occur in the via as a result.

[0004] To increase the plating rate at the via bottom, the solution **140** can be agitated during the plating process to improve the metal ion delivery into the via **160**. Agitation may involve mechanical stirring (e.g. using air bubbles or eductors) or ultrasonic energy. For example, ultrasonic energy source **170** can be positioned between the anode **134** and the substrate **110** so as to align the axis of ultrasound propagation with the central axis of via **160**, thus allowing the ultrasonic energy to reach the via bottom. See U.S. Pat. No. 6,746,590 B2 issued Jun. 8, 2004 to Zhang et al.

[0005] Another technique used to improve the electrodeposition uniformity is periodic reverse pulse plating. This technique slows down the electrodeposition rate at the top relative to the via bottom. FIG. **2** shows the voltage at cathode **124** relative to anode **134** as a function of time in this technique. The plating occurs when the voltage is negative (the negative pulses are shown at **210**), but periodically the voltage polarity is reversed to deplate some of the metal. The reverse pulses are shown at **220**. Deplating proceeds faster at the top of the substrate than at the via bottom. The negative pulses ("forward pulses") **210** and the positive pulses ("reverse pulses") **220** are selected so that the net plating rate becomes more uniform, i.e. the ratio of the plating rate at the top to the plating rate at the bottom decreases. See "Acid copper plating pulse processes" at http://www.electrochemicals.com/p_pulse.html (web site of Electrochemicals Inc.) describing "Electro-Brite PC-695 Acid Copper Plating Process". See also European patent application EP 1 667 507 A1 filed by IBIDEN CO., LTD.

SUMMARY

[0006] This section summarizes some features of the invention. Other features are described in the subsequent sections. The invention is defined by the appended claims which are incorporated into this section by reference.

[0007] In some embodiments of the invention, the net plating rate is made more uniform by turning off agitation during the positive pulses or at least reducing the agitation power during the positive pulses. Turning off or reducing the agitation power during deplating makes the deplating rate less uniform, i.e. the ratio of the deplating rate at the top to the deplating rate at the via bottom increases. Hence, more metal can be deplated at the top per a given amount of metal deplated at the via bottom. The deplating non-uniformity provides better compensation for the plating non-uniformity during the negative pulses.

[0008] In some embodiments, the agitation source is placed at the substrate's side opposite to anode terminal **134** not to interfere with the metal ions' movement at the side adjacent to terminal **134**. The agitation energy source (e.g. ultrasound source) can be placed close to the substrate, possibly in contact with the substrate.

[0009] The invention is not limited to the features and advantages described above. Other features are described below. The invention is defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** schematically illustrates an electroplating operation.

[0011] FIG. **2** is a timing diagram of the electroplating voltage according to prior art.

[0012] FIG. **3** is a timing diagram of the electroplating voltage and the agitation power according to some embodiments of the present invention.

[0013] FIG. **4** illustrates an electroplating operation according to some embodiments of the present invention.

[0014] FIG. **5** is a timing diagram of the electroplating voltage and the agitation power according to some embodiments of the present invention.

DESCRIPTION OF SOME EMBODIMENTS

[0015] The embodiments described in this section illustrate but do not limit the invention. The invention is defined by the appended claims.

[0016] FIG. **3** illustrates timing diagrams for the electroplating voltage (the voltage at terminal **124** relative to terminal **134**) and the agitation power in some embodiments of the present invention. The electroplating voltage is as in FIG. **2**, with one or more negative pulses **210** delivered in each time period **210**T, then one or more positive pulses **220** delivered in a time period **220**T. The agitation power P_A is positive during at least a portion of each time period **210**T, but the agitation is turned off during each positive-pulse period **220**T, or at least the maximum value of the agitation power in each period **220**T is below the maximum value in each period **210**T. Consequently, the deplating rate inside the via is lowered relative to the top of substrate **110**.

[0017] The agitation can also be provided by mechanical stirring or perhaps in other ways. FIG. **4** illustrates mechanical stirring sources **410** in addition to source **170**. The mechanical stirring sources **410** provide a low frequency agitation (lower frequency than ultrasound). In some embodiments, both the mechanical stirring and the ultrasonic agitation are provided during the negative pulses **210**, but only the mechanical stirring or only the ultrasonic agitation are provided during the positive pulses **220**. For example, during the positive pulses, the mechanical stirring may be turned on to speed up deplating at the top of the substrate, but the ultrasound may be turned off to impede deplating at the via bottom. Further, the agitation power of any one or more of the agitation sources may vary from one pulse **210** to the next, or from one pulse **220** to the next. The agitation does not have to be provided throughout the electroplating process. For example, in some embodiments, the agitation is provided only during a middle phase of the electroplating process, or only at the beginning and/or end. For example, if the electroplating process fills the via **160** except for a wide shallow opening at the top of the via, the electroplating process may be continued with just negative DC current without agitation to fill the wide shallow opening. Using the negative DC current increases the electroplating speed. Note also the aforementioned U.S. Pat. No. 6,746,590 B2, incorporated herein by reference. While each of pulses **210**, **220** is shown as a single pulse, a sequence of negative pulses can be used instead of a single pulse **210**, and/or a sequence of positive pulses can be used instead of a single pulse **220**. The pulses do not have to be square, but may have other shapes. See the aforementioned European patent application EP 1 667 507 A1, incorporated herein by reference.

[0018] FIG. **5** illustrates another possible timing. As in FIG. **3**, P_A is agitation power provided by ultrasonic source or sources **170** or **410**. Due to the propagation delay of the agitation energy from source **170** or **410**, the agitation power increases relatively slowly at the surface of substrate **110**. P_{AS} is the agitation power of the solution at the substrate surface onto which the electrodeposition is being performed (top surface in FIG. **4**) inside or outside of via **160**. The agitation power P_A is turned on at time **0** at the start of a period **210**T, and almost immediately reaches its maximum value for that period **210**T. The power PAS reaches its maximum at some later time t**1**. The negative pulse or pulses **210** are delayed until at least the time t**1** to provide greater uniformity for electrodeposition. To provide greater non-uniformity during deplating, the agitation power P_A is turned off at some time t**2** before the start of period **220**T (at a later time t**3**) so that the solution agitation power P_{AS} would have time to decrease to about zero by the start of pulse **220**. The negative pulse or pulses **210** are terminated at time t**2** or earlier not to allow electrodeposition to proceed with less than the maximum agitation P_{AS}.

[0019] The embodiment of FIG. **5** is particularly suitable for filling large vias **160**, of a diameter of a few tens of microns. In an exemplary embodiment, the length of each pulse **210** is about 9.9 seconds, and the pulse current is −2 A. The length of each pulse **220** is about 1 second, and the pulse current is 6 A. The times t**1** and (t**3**-t**2**) are each about 100 ms. Other values are also possible for the lengths of the pulses **210**, **220**, their currents, the times t**1**, t**2**, t**3**. These parameters may depend on the via geometry, plating area, desired plating thickness, and other factors. The layer **150** can be quite thin on top of the wafer outside of via **160**, and so can be quickly polished away from the top by CMP (chemical mechanical polishing) if needed.

[0020] The invention is not limited to a particular placement of agitation energy sources. In FIG. **4**, ultrasonic source or sources **170** are placed at the bottom of substrate **110**, at the side opposite from the via opening and the terminal **134**. Ultrasonic energy propagates through substrate **110** to reach and agitate the electroplating solution inside via **160** and, possibly, at the top side of the substrate. Since the source **170** is closer to the via bottom than to the top of the substrate, the ultrasonic energy density can be higher at the via bottom than at the top of the substrate. In some embodiments, the substrate **110** is a better conductor of ultrasound than the electrolytic solution **140**. For example, substrate **110** may be a semiconductor wafer (e.g. a silicon wafer) with or without other materials providing integrated circuit elements (such materials may include metal, semiconductor and dielectric materials), or substrate **110** may be a printed wiring substrate made of BT (bis-maleimide triazine), PPE (polyphenylene-ether), and/or other materials. In some embodiments, the via bottom is closer to the bottom of the substrate than to the top, and hence the source **170** is closer to the via bottom than would be possible if the source **170** were located above the substrate. In some embodiments, the source **170** is positioned very close to substrate **110**, possibly in physical contact with the substrate's bottom, to reduce the ultrasonic energy losses between the source **170** and the substrate. It is believed that the plating rate ratio of the top to the via bottom can be improved with the FIG. **4** arrangement. Further, the source **170** advantageously does not interfere with the metal ion movement between terminal **134** and substrate **110**.

[0021] The source **170** may be moved relative to substrate **170** during electroplating. See the aforementioned U.S. Pat. No. 6,746,590 B2. Multiple sources **170**, some moving and some not, can be provided.

[0022] The power supply **130** and the agitation energy sources **170**, **410** can be controlled by a controller **420**. Controller **420** may be a hardwired circuit and/or may include a computer processor or processors executing computer instructions to control the devices **170**, **410**. Controller **420** may include a computer readable medium storing computer instructions and/or data to control the devices **170**, **410**.

[0023] The invention is not limited to the embodiments described above. For example, the invention is not limited to flat substrates **110**. If the substrate is flat, it can be positioned horizontally as in FIG. **4** or at an angle, with the terminal **134** being either above the substrate or in some other position. The electroplating may be conducted onto any one side of the substrate or on multiple sides, depending on the seed layer position and masking (the seed layer may be masked as known in the art). The positions of terminal **134** and/or source **170** can be adjusted as needed. Via **160** can be a through via, and may have any suitable shape (e.g. elongated, damascene, etc.). Multiple vias can be provided. The invention is particularly suitable for high aspect ratio vias but is not limited thereto. Of note, the aspect ratio may increase during electroplating, and the techniques of FIG. **3** may be used only during a later portion of the plating process. The seed layer may be absent.

[0024] Some embodiments of the present invention provide an electrodeposition method comprising: (1) immersing a substrate into an electrolytic solution; (2) providing a voltage between at least a portion of the substrate and an electrode (e.g. **134**) spaced from the substrate to effect the electrodeposition onto the substrate, wherein providing the voltage comprises: (2A) providing one or more voltage pulses (e.g. **210**) of a first polarity (e.g. negative polarity) in each of a plurality of first periods of time (e.g. **210**T) to provide a net electrodeposition of metal onto the substrate in each first period of time (even though the voltage may become positive in a single period **210**T between the negative pulses **210** or before the first pulse **210** or after the last pulse **210**, the negative pulses dominate in each period **210** in the sense that the net result is electrodeposition); and (2B) providing one or more voltage pulses of a second polarity in each of a plurality of second periods of time (**220**T) alternating with the first periods of time to provide a net deplating off the substrate in each second period of time; (3) during a first time interval comprising a plurality of the first periods of time and a plurality of the second periods of time (the first interval of time may include a whole or a part of the electrodeposition time), operating one or more agitation sources (e.g. **170** and/or **410**) to agitate said solution, wherein at least one of the one or more agitation sources is operated in a first mode during each first period of time and in a second mode during each second period of time. For example, an agitation source **170** or **410** (or both) may provide agitation power P_A for the solution in each first period of time but not in the second periods of time. In another example, an agitation source provides agitation power for the solution both in each first period of time and in at least one of the second periods of time, but a maximum of the agitation power in each first period of time is greater than in any of the second periods of time.

[0025] In some embodiments, in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are provided only while the at least one of the agitation sources agitates said solution. For example, in FIG. **5**, in each period **210**T, the pulses **210**T are provided only while the power P_A is positive. The same is true for FIG. **3**. The invention is not limited to such embodiments as the power P_A could be zero part of a period **210**T.

[0026] In some embodiments, in each first period of time in the first time interval, the at least one of the agitation sources starts agitating said solution before a start of the one or more voltage pulses of the first polarity. For example, in FIG. **5**, in each period **210**T, the power P_A becomes positive before the start of pulse **210**.

[0027] In some embodiments, in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are started only when the solution agitation at the substrate has reached its maximum in the first period of time. For example, in FIG. **5**, pulse **210** starts (at time t**1**) only when P_{AS} has reached its maximum value.

[0028] In some embodiments, in each first period of time in the first time interval, the one or more voltage pulses of the first polarity stop no later than the at least one of the agitation sources stops providing agitation power to said solution. For example, in FIG. **5**, the pulse **210** stops (at time t**2**) no later than P_A becomes zero. In some embodiments, the solution agitation at the substrate is zero throughout each second period of time (e.g. P_{AS} is zero throughout each period **220**T).

[0029] In some embodiments, in each first period of time in the first time interval, the solution agitation at the substrate becomes zero by the end of the first period of time (e.g. P_{AS} becomes zero by the end of period **210**T).

[0030] In some embodiments, at least some of ultrasound provided by an ultrasound source is coupled from the ultrasound source directly into the substrate (for example, when source **170** contacts the substrate **110**), propagating through the substrate to reach the solution.

[0031] In some embodiments, the substrate comprises a via, and the electrodeposition comprises electrodeposition into the via. In some embodiments, at a start of the electrodeposition, the via has an aspect ratio of at least 1:1.

[0032] Some embodiments provide an electrodeposition method comprising: (1) immersing a substrate into an electrolytic solution; (2) providing a voltage between at least a portion of the substrate and an electrode spaced from the substrate to effect the electrodeposition onto the substrate, wherein providing the voltage comprises: (2A) providing one or more voltage pulses of a first polarity but no pulses of a second polarity opposite to the first polarity in each of a plurality of first periods of time; and (2B) providing one or more voltage pulses of the second polarity but no pulses of the first polarity in each of a plurality of second periods of time alternating with the first periods of time; (3) during a first time interval comprising a plurality of the first periods of time and a plurality of the second periods of time, providing a greater maximum agitation power for the solution in each first period of time than in any of the second periods of time.

[0033] In some embodiments, the agitation power is zero in each second period of time.

[0034] Some embodiments provide an electrodeposition method comprising: (1) immersing a substrate into an electrolytic solution; (2) providing a voltage between at least a portion of the substrate and a first electrode spaced from the substrate to effect the electrodeposition onto the substrate, the first electrode being positioned at a first side of the substrate (e.g. top side in FIG. **4**); (3) during at least a part of operation (2), operating an ultrasound source to emit ultrasound at a second side of the substrate (e.g. bottom side in FIG. **4**) opposite to the first side of the substrate. In some embodiments, the substrate comprises a via in a first side of the substrate, the via is not a through via, and the electrodeposition comprises electrodeposition into the via. In some embodiments, the deepest point of the via (the via's bottom in FIG. **4**) is closer to the second side (e.g. bottom side) of the substrate than to the via's opening at the first side of the substrate. In some embodiments, at least some of the ultrasound enters the substrate before entering the solution (e.g. if the source **170** contacts the substrate), and reaches the solution through the substrate.

[0035] Some embodiments provide an apparatus for performing electrodeposition onto a substrate, the apparatus comprising: a first electrode (e.g. **124**) for connection to the substrate; a second electrode (e.g. **134**); and at least one ultrasound source; wherein a region for containing the substrate is located between the first electrode and the ultrasound source (in FIG. **4**, the substrate **110** is located between the electrode **124** and the source **170**).

[0036] Other embodiments and variations are within the scope of the invention, as defined by the appended claims.

1. An electrodeposition method comprising:

(1) immersing a substrate into an electrolytic solution;

(2) providing a voltage between at least a portion of the substrate and an electrode spaced from the substrate to effect the electrodeposition onto the substrate, wherein providing the voltage comprises:

(2A) providing one or more voltage pulses of a first polarity in each of a plurality of first periods of time to provide a net electrodeposition of metal onto the substrate in each first period of time; and

(2B) providing one or more voltage pulses of a second polarity in each of a plurality of second periods of time alternating with the first periods of time to provide a net deplating of the metal off the substrate in each second period of time;

(3) during a first time interval comprising a plurality of the first periods of time and a plurality of the second periods of time, operating one or more agitation sources to agitate said solution, wherein at least one of the one or more agitation sources is operated in a first mode during each first period of time and in a second mode during each second period of time.

2. The method of claim **1** wherein in operation (3), the at least one of the agitation sources provides agitation power for the solution in each first period of time but not in the second periods of time.

3. The method of claim **2** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are provided only while the at least one of the agitation sources agitates said solution.

4. The method of claim **2** wherein in each first period of time in the first time interval, the at least one of the agitation sources starts agitating said solution before a start of the one or more voltage pulses of the first polarity.

5. The method of claim **4** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are started only when the solution agitation at the substrate has reached its maximum in the first period of time.

6. The method of claim **2** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity stop no later than the at least one of the agitation sources stops providing agitation power to said solution.

7. The method of claim **2** wherein in each first period of time in the first time interval, the solution agitation at the substrate becomes zero by the end of the first period of time.

8. The method of claim **1** wherein in operation (3), the at least one of the agitation sources provides agitation power for the solution both in each first period of time and in at least one of the second periods of time, but a maximum of the agitation power in each first period of time is greater than in any of the second periods of time.

9. The method of claim **1** wherein the at least one of the agitation sources is an ultrasound source.

10. The method of claim **9** wherein at least some of ultrasound provided by the ultrasound source is coupled from the ultrasound source directly into the substrate, propagating through the substrate to reach the solution.

11. The method of claim **1** wherein the substrate comprises a via, and the electrodeposition comprises electrodeposition into the via.

12. The method of claim **11** wherein at a start of the electrodeposition, the via has an aspect ratio of at least 1:1.

13. An electrodeposition method comprising:

(1) immersing a substrate into an electrolytic solution;

(2) providing a voltage between at least a portion of the substrate and an electrode spaced from the substrate to effect the electrodeposition onto the substrate, wherein providing the voltage comprises:

(2A) providing one or more voltage pulses of a first polarity but no pulses of a second polarity opposite to the first polarity in each of a plurality of first periods of time; and

(2B) providing one or more voltage pulses of the second polarity but no pulses of the first polarity in each of a plurality of second periods of time alternating with the first periods of time;

(3) during a first time interval comprising a plurality of the first periods of time and a plurality of the second periods of time, providing a greater maximum agitation power for the solution in each first period of time than in any of the second periods of time.

14. The method of claim **13** wherein in operation (3), the agitation power is zero in each second period of time.

15. The method of claim **14** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are started only while the agitation power is positive.

16. The method of claim **14** wherein in each first period of time in the first time interval, the agitation power becomes positive before a start of the one or more voltage pulses of the first polarity.

17. The method of claim **16** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are provided only when the solution agitation at the substrate has reached its maximum in the first period of time.

18. The method of claim **14** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity stop while the agitation power is at its maximum for the first period of time.

19. The method of claim **14** wherein the solution agitation at the substrate is zero throughout each second period of time in the first time interval.

20. The method of claim **13** wherein the agitation power is ultrasonic.

21. The method of claim **20** wherein at least some of the agitation power is coupled directly into the substrate, propagating through the substrate to reach the solution.

22. The method of claim **13** wherein the substrate comprises a via, and the electrodeposition comprises electrodeposition into the via.

23. The method of claim **22** wherein at a start of the electrodeposition, the via has an aspect ratio of at least 1:1.

24. An electrodeposition method comprising:

(1) immersing a substrate into an electrolytic solution;

(2) providing a voltage between at least a portion of the substrate and a first electrode spaced from the substrate to effect the electrodeposition onto the substrate, the first electrode being positioned at a first side of the substrate;

(3) during at least a part of operation (2), operating an ultrasound source to emit ultrasound at a second side of the substrate opposite to the first side of the substrate.

25. The method of claim **22** wherein the substrate comprises a via in a first side of the substrate, the via is not a through via, and the electrodeposition comprises electrodeposition into the via.

26. The method of claim **25** wherein a deepest point of the via is closer to the second side of the substrate than to the via's opening at the first side of the substrate.

27. The method of claim **24** wherein at least some of the ultrasound enters the substrate before entering the solution, and reaches the solution through the substrate.

28. A controller for controlling electrodeposition, the controller comprising circuitry and/or comprising a computer readable medium with computer instructions and/or data, the circuitry and/or the computer instructions and/or data being for:

(i) providing a voltage between a terminal to be connected to a substrate immersed into an electrolytic solution and an electrode to be spaced from the substrate to effect the electrodeposition onto the substrate, wherein providing the voltage comprises:

(A) providing one or more voltage pulses of a first polarity in each of a plurality of first periods of time to provide a net electrodeposition of metal onto the substrate in each first period of time; and

(B) providing one or more voltage pulses of a second polarity in each of a plurality of second periods of time alternating with the first periods of time to provide a net deplating of the metal off the substrate in each second period of time;

(ii) during a first time interval comprising a plurality of the first periods of time and a plurality of the second periods of time, operating one or more agitation sources to agitate said solution, wherein at least one of the one or more agitation sources is operated in a first mode during each first period of time and in a second mode during each second period of time.

29. The controller of claim **28** wherein in operation (ii), the at least one of the agitation sources provides agitation power for the solution in each first period of time but not in the second periods of time.

30. The controller of claim **29** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are started only while the at least one of the agitation sources agitates said solution.

31. The controller of claim **29** wherein in each first period of time in the first time interval, the at least one of the agitation sources starts agitating said solution before a start of the one or more voltage pulses of the first polarity.

32. The controller of claim **29** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity stop no later than the at least one of the agitation sources stops providing agitation power to said solution.

33. The controller of claim **28** wherein in operation (ii), the at least one of the agitation sources provides agitation power for the solution both in each first period of time and in at least one of the second periods of time, but a maximum of the agitation power in each first period of time is greater than in any of the second periods of time.

34. The controller of claim **28** wherein the at least one of the agitation sources is an ultrasound source.

35. A controller for controlling electrodeposition, the controller comprising circuitry and/or comprising a computer readable medium with computer instructions and/or data, the circuitry and/or the computer instructions and/or data being for:

(i) providing a voltage between a terminal to be connected to a substrate immersed into an electrolytic solution and an electrode to be spaced from the substrate to effect the electrodeposition onto the substrate, wherein providing the voltage comprises:

(A) providing one or more voltage pulses of a first polarity but no pulses of a second polarity opposite to the first polarity in each of a plurality of first periods of time; and

(B) providing one or more voltage pulses of the second polarity but no pulses of the first polarity in each of a plurality of second periods of time alternating with the first periods of time;

(ii) during a first time interval comprising a plurality of the first periods of time and a plurality of the second periods of time, providing a greater maximum agitation power for the solution in each first period of time than in any of the second periods of time.

36. The controller of claim **35** wherein in operation (3), the agitation power is zero in each second period of time.

37. The controller of claim **36** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity are provided only while the agitation power is positive.

38. The controller of claim **36** wherein in each first period of time in the first time interval, the agitation power becomes positive before a start of the one or more voltage pulses of the first polarity.

39. The controller of claim **36** wherein in each first period of time in the first time interval, the one or more voltage pulses of the first polarity stop while the agitation power is at its maximum for the first period of time.

40. The controller of claim **35** wherein the agitation power is ultrasonic.

41. An apparatus for performing electrodeposition onto a substrate, the apparatus comprising:

a first electrode for connection to the substrate;

a second electrode; and

at least one ultrasound source;

wherein a region for containing the substrate is located between the first electrode and the ultrasound source.

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