Jan. 28, 1969 G. A. FRANK 3,424,667

APPARATUS FOR ELECTROPLATING APERTURED AND IRREGULARLY SHAPED SUBSTRATES

Filed April 5, 1966 Sheet 1 of 5

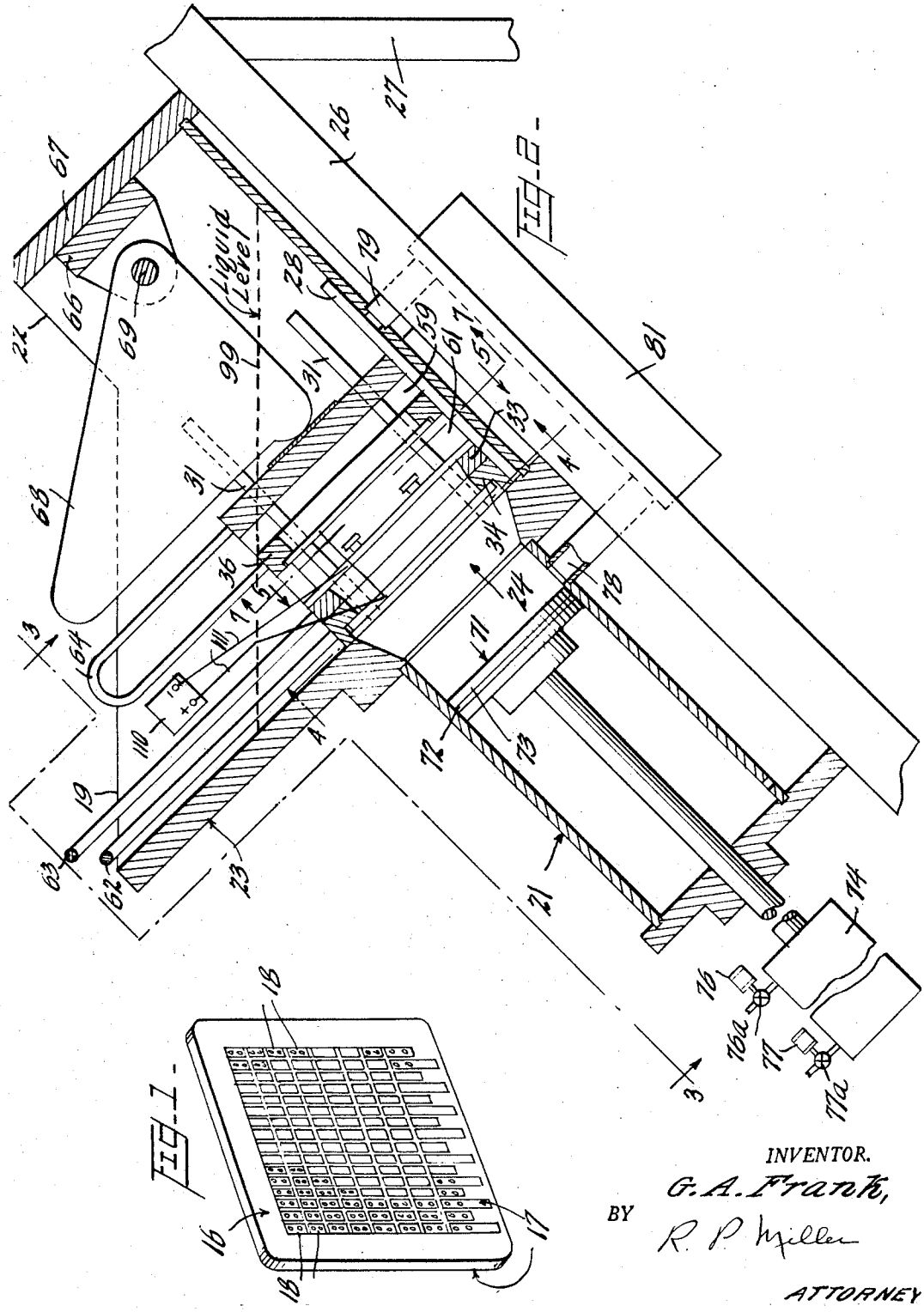


FIG. 2

FIG. 1

INVENTOR.
G. A. Frank,
BY R. P. Miller
ATTORNEY

FIG-3-

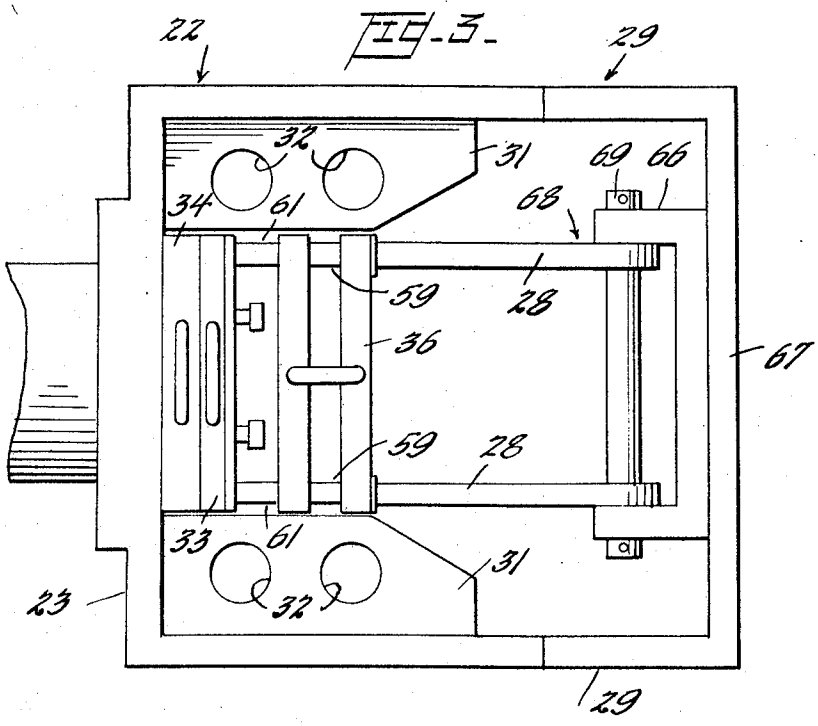

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FIG-4-

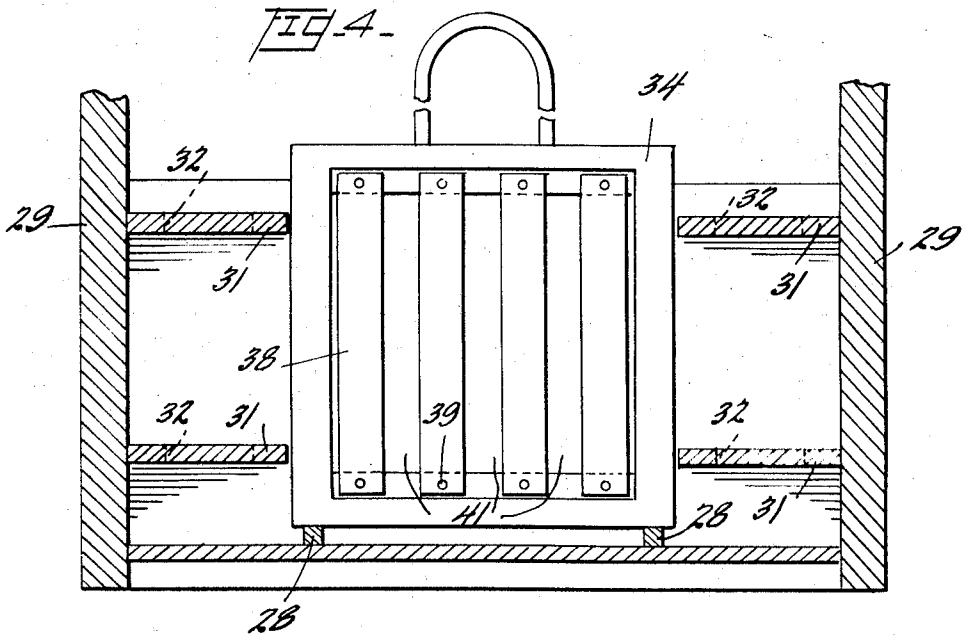

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FIG. 5

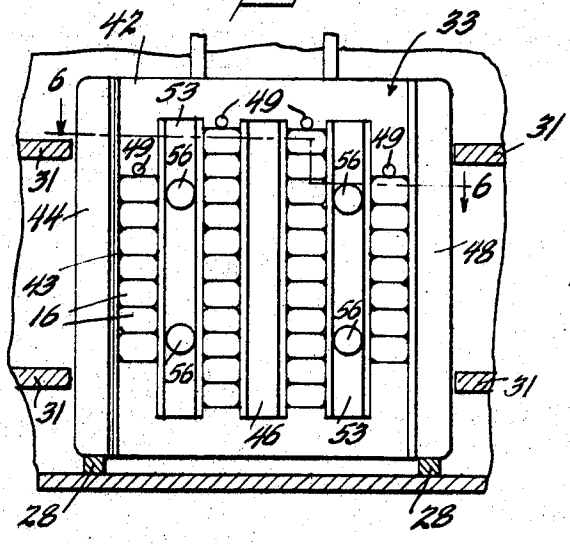


FIG. 6

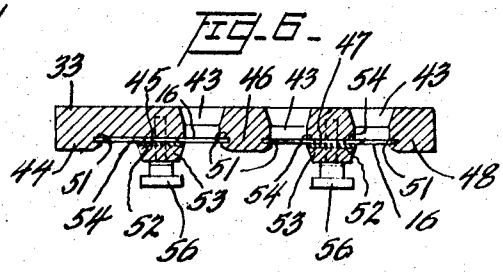


FIG. 7

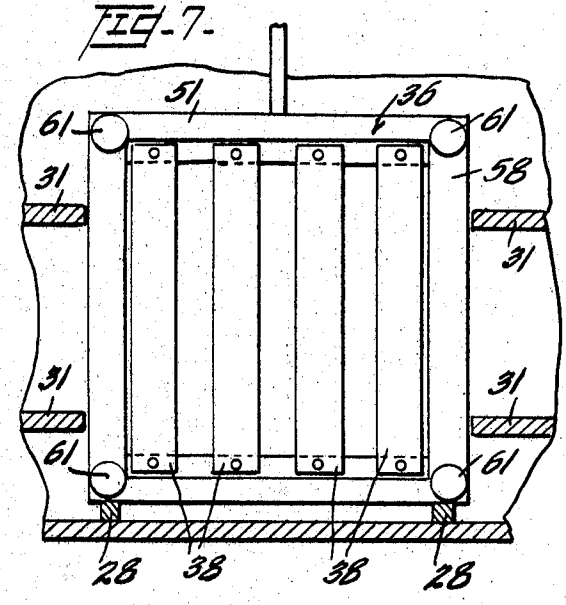
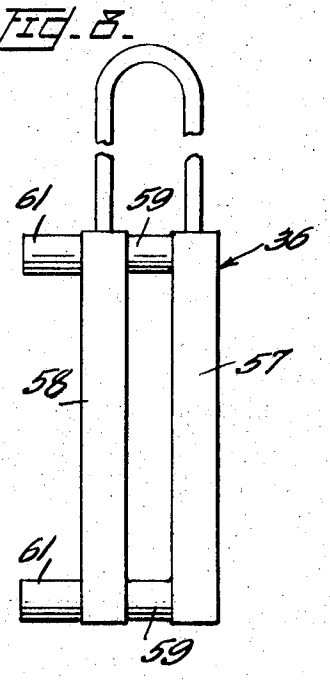


FIG. 8



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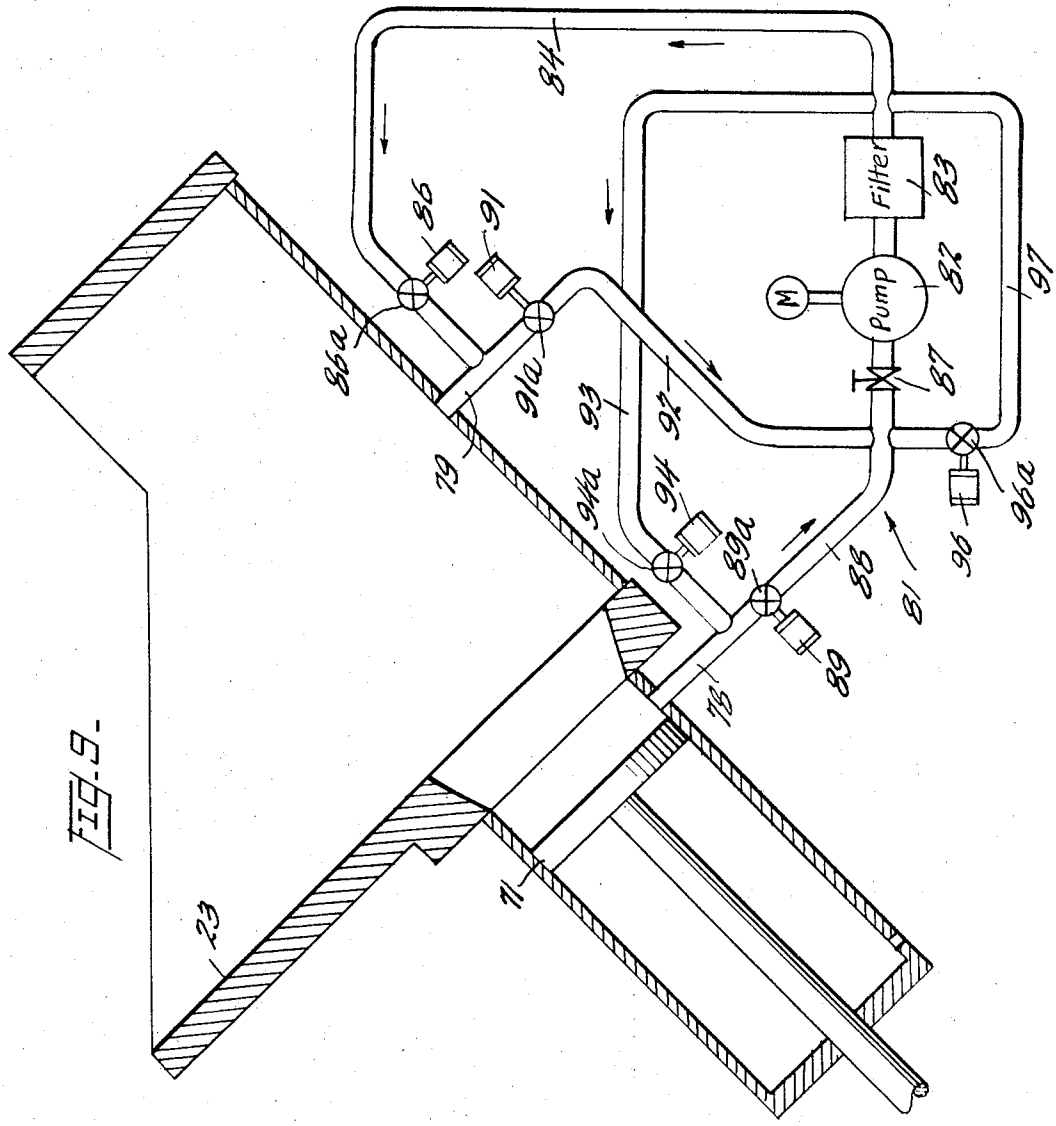


FIG. 9.

FIG. 10.

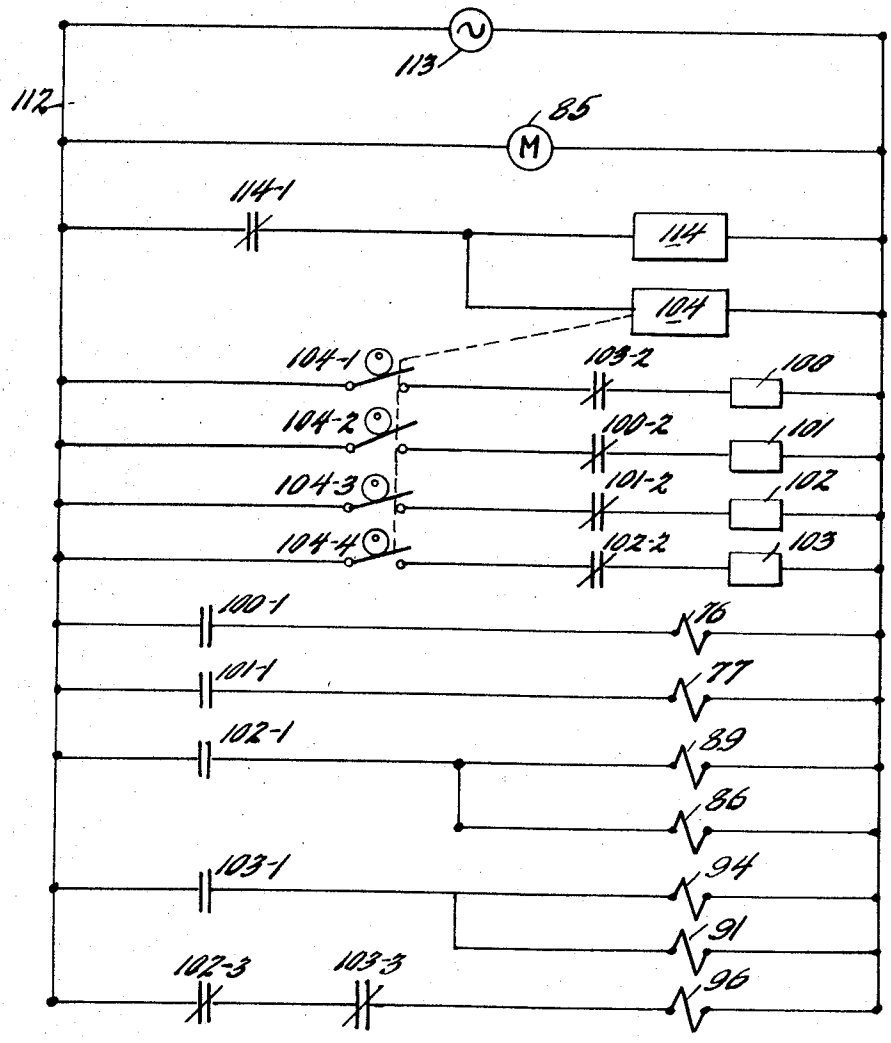


FIG. 11.

Cam Timing Chart

Approx. Time		0 sec.	15	30	45	60
Design-nation	Wired	0%	25	50	75	100
104-1	* No Nc					
104-2	* No Nc					
104-3	* No Nc					
104-4	* No Nc					

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APPARATUS FOR ELECTROPLATING APERTURED AND IRREGULARLY SHAPED SUBSTRATES

Gerard A. Frank, Allentown, Pa., assignor to Western Electric Company, Incorporated, New York, N.Y., a corporation of New York

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U.S. Cl. 204—237 7 Claims
Int. Cl. C23b 5/48

This invention relates to an apparatus for electroplating apertured and irregularly shaped substrates, more particularly to an apparatus in which an electrolyte is flushed back and forth through the apertured substrate, thereby purging any gas bubbles, formed during plating, from crevices in the substrate.

It is known in the art of electroplating that if the electrolyte is not agitated the ion density immediately surrounding the substrate becomes substantially lower than the average ion density through the remaining electrolyte thereby limiting the maximum current density obtainable. Therefore, it has become common practice to agitate the electrolyte at an optimum flow rate during the plating process to increase the maximum current density for best plating. It is also known that gas bubbles tend to form during the plating process at the surface of the substrate being plate. When the substrate has small apertures, crevices, or other surface irregularities, the bubbles tend to congregate in these irregularities thereby further preventing uniform plating. Agitating the electrolyte at a higher rate than that optimum for plating will cause turbulent flow and purge the bubbles from the substrate but the effect of maximum current density is lost. Existing apparatus for electroplating employ pumps, propellers, paddlewheels and the like to circulate or agitate the electrolyte at a flow rate which is a compromise between the optimum for plating and the optimum for purging bubbles. Another problem exists when a substrate is to be plated on both sides in that a flow of electrolyte in one direction over, around and/or through the substrate will improve the plating on one side but will result in inferior plating on the other.

Therefore, it is an object of this invention to provide a new and improved apparatus for electroplating apertured and irregularly shaped substrates.

An additional object of this invention resides in electroplating apparatus wherein an electrolyte is circulated at a first rate to insure maximum plating, and then the electrolyte is circulated at a second rate to insure maximum purging of trapped gas bubbles.

It is a further object of this invention to provide an electroplating apparatus in which there is a novel arrangement of the component parts such that trapped gasses upon being purged are effectively conveyed out of the solution.

It is still another object of this invention to provide an improved apparatus for electroplating which reciprocates the electrolyte back and forth alternately at different flow rates to insure uniformed plating on both sides of an article to be plated.

With these and other objects in view, the present invention contemplates an electroplating apparatus in which two fluid-forcing systems cooperate to provide alternate flow at first a rate for optimum plating at a high current density and then at a second rate optimized for effectively purging gas bubbles from surface irregularities on the substrate. More particularly, a plating container is mounted on an incline and electrodes, together with an apertured substrate, are mounted and arranged therein to provide an exit path along with trapped gas bubbles are purged and conveyed from the plating chamber.

The first fluid-forcing system includes a pumping device for reciprocating the electrolyte back and forth past the substrate, thereby obtaining optimum plating on both sides of the substrate and in the surface irregularities and apertures.

The second fluid-forcing system includes a ram mounted in a lower portion of the inclined container for reciprocating between a first and a second position to force the electrolyte through the apertures in the substrate. On the upward stroke purged gas bubbles rise and leave the container. On the downward stroke, however, the gas bubbles are forced down into the inclined container and are trapped and congregate in a space or pocket behind the substrate. On the next upward stroke these trapped bubbles are forced and conveyed along the exit path, together with the bubbles purged on that stroke.

Other objects and advantages will become apparent by reference to the following detailed description and drawings, wherein:

FIG. 1 shows a perspective view of a substrate susceptible of being plated by the novel apparatus of this invention;

FIG. 2 is an assembly view partially in section, of a plating apparatus which embodies the principles of the invention;

FIG. 3 is a sectional view taken along line 3—3 of FIG. 2 showing the relationship of plating electrodes in an upper section of an electrolyte container;

FIG. 4 is a sectional view taken along line 4—4 of FIG. 2 showing the detail of a first anode positioned in the upper section of the container;

FIG. 5 is a sectional view taken along line 5—5 of FIG. 2 showing the detail of a substrate rack with the substrates to be plated mounted thereon and the position of the rack in the upper section of the container;

FIG. 6 is a sectional view taken along line 6—6 of FIG. 5 showing the cross-section of the substrate rack;

FIG. 7 is a sectional view taken along line 7—7 of FIG. 2 showing the detail of a second anode positioned in the upper section of the container;

FIG. 8 is a side view of a second anode assembly showing spacers which form an integral part thereof;

FIG. 9 is a schematic diagram of a fluid-forcing system employed in the plating process;

FIG. 10 is a diagram of a circuit for controlling the plating apparatus; and

FIG. 11 is a cam timing chart illustrating the relative times of operation of various circuit components illustrated in FIG. 10.

Referring now to FIG. 1, there is shown a substrate or workpiece **16** made from an insulating material which is susceptible of being selectively copper plated on both of its surfaces **17** and inside of small apertures **18** therethrough by the novel apparatus of this invention. As is known in the art, an insulator is rendered susceptible of being selectively electroplated by vapor depositing a conducting material through a mask onto the areas of the insulator which are to be plated.

Considering now the plating apparatus shown in FIG. 2, a container or plating tank **19** is divided into a lower, cylindrical section **21** and an upper, rectangular section **22** by a wall **23** having a connecting orifice **24** therethrough. The container is mounted on an incline by a support base **26** secured to a leg **27**.

As can best be seen in FIGS. 2 and 3, the upper section of the container **22** has two runners or electrode supports **28** spaced from each other along the bottom of the upper section **22**. Extending from opposite sides **29** of the upper section **22**, are pairs of guide plates **31**. Each guide plate **31** has two holes **32** therein. These runners **28** and guide plates **31** serve to support a substrate rack or electrode

assembly 33 and a pair of anodes or electrode assemblies 34 and 36.

Referring now to FIG. 4, the first anode or electrode assembly 34 is depicted as comprising a frame 37, which is open and generally rectangular in shape. A plurality of copper strips 38 are secured across the opening in the frame 37 by fasteners 39 in a spaced arrangement to provide passageways 41 for the flow of an electrolyte. The copper strips 38 form the active portion of the anode, serving as a source of copper ions.

The substrate rack or electrode assembly 33, as shown in FIGS. 5 and 6, comprises a flat sheet-like body member 42 with four elongated slotted passageways 43 formed by five bars 44–48. The bars 44, 46 and 48 are thicker than bars 45 and 47. Above each passageway 43 is a vent hole 49. Bars 44, 46 and 48 have grooves 51 formed on the sides which are adjacent the passageways 43. The grooves 51 are level with upper surfaces 52 of bars 45 and 47. Clamping plates 53 having edge grooves 54 are affixed to the upper surfaces 52 of bars 45 and 47 by locking screws 56. The substrate rack 33 is loaded with a plurality of substrates 16 by loosening the locking screws 56 and sliding one side of each substrate 16 into one of the grooves 51 and the other side of each substrate 16 into an adjacent edge groove 54. The substrates 16 are positioned so that none of the surfaces to be plated are covered by the bars 44–48 or the clamping plates 53 and the four vent holes 49 are not covered. The clamping plates 53 are then tightened to secure the substrates 16 in position.

The second anode or electrode assembly 36, see FIGS. 7 and 8, is composed of two plates 57 and 58. The front plate 58 is similar in construction to the first anode assembly 34, that is, it is open and there are a plurality of copper strips 38 fastened across the opening. The front anode plate 58 is spaced from the solid rear plate 57 by spacers 59. As shown in FIGS. 2 and 3, a second set of spacers 61 are attached to the front of plate 58 for positioning the second anode assembly 36 in the upper section 22 of the container 19 from the substrate rack 33.

As can best be seen in FIGS. 2 and 3, the three electrode assemblies 33, 34 and 36 are mounted in the upper section 22 of the container 19 and rest on the runners 28 between the guide plates 31. The electrode and rack assemblies 33, 34 and 36 have handles 62, 63 and 64, respectively, for placing the assemblies on the runners 28 and between the guide plates 31. A bracket 66 is secured to a rear wall 67 of the upper section 22. A locking member 68 is pivotally secured to the bracket 66 by a pin 69. Upon placing the electrode assemblies 33, 34 and 36 in the upper section 22, the locking member 68 is pivoted to lock the assemblies 33, 34 and 36 against a face of the dividing wall 23 so that an electrolyte flowing from the lower section 21 to the upper section 22 of the container 19 will pass through the connecting orifice 24 in the dividing wall 23, the passageways 41 and the vent holes 49 provided in the electrode assemblies 33, 34 and 36 and the apertures 18 provided in the substrates 16.

Referring again to FIG. 2 a ram 71 is mounted in sliding engagement with the lower section 21 of the container 19. An O-ring 72 is placed in a circumferential slot 73 formed in the periphery of ram 71, thereby providing a dynamic fluid seal with the wall of the cylindrical section 21. The ram 71 is reciprocated between an upper position as shown in FIG. 2 and a lower position by an air cylinder 74. The ram 71 flushes an electrolyte through the apertures 18 in the substrates 16 at a rate which produces turbulence, thereby purging bubbles from the apertures 18. The air cylinder 74 is operated by selective actuation of normally closed valves 76*a* and 77*a* connected to a source of compressed air, not shown. The valves 76*a* and 77*a*, respectively, are actuated by solenoids 76 and 77.

In the floor of the lower section 21 of the container 19 is a first fluid outlet 78 adjacent to and above the face of the ram 71 where it is in the upper position. A second fluid outlet 79 is extended through a bottom wall of the upper section 22 adjacent to the right hand side of the electrode assembly 36. A fluid-pumping system 81 is connected to the fluid outlets 78 and 79 for flushing an electrolyte back and forth past substrates 16 and through the apertures 18 therein at a rate which produces laminar flow thereby continuously supplying ion rich electrolyte to the surface being plated.

FIG. 9 shows the details of the fluid-pumping system 81. One side of a pump 82 is connected through a filter 83, a conduit 84 and a valve 86*a* to the second fluid outlet 79. The other side of pump 82 is connected to the first fluid outlet 78 through a throttle valve 87, a conduit 88 and a valve 89*a*. The second fluid outlet 79 is also connected to the conduit 88 by a valve 91*a* and a conduit 92. Further, the conduit 84 is also connected through a conduit 93 and a valve 94*a* to the first fluid outlet 78. A return bypass path around the throttle valve 87, the pump 82 and the filter 83 is provided through valve 96*a* and conduit 97. The valves 86*a*, 89*a*, 91*a* and 94*a* may be considered as being normally closed, and valve 96*a* as being normally open to allow the pump 82 to continuously operate to circulate a portion of the electrolyte through the bypass conduit 98. During a cycle of operation each valve 86*a*, 89*a*, 91*a*, 94*a*, and 96*a*, respectively, has a control solenoid 86, 89, 91, 94 and 96 to control the flow of electrolyte through either the outlet 78, the outlet 79 or by bypass conduit 98.

Considering now the overall operation of the apparatus with particular reference to FIGS. 2, 9 and 10, the ram 71 is initially in its upper position. The first anode assembly 34, the substrate rack 33 loaded with substrates 16, and the second anode assembly 36 are mounted on the runners 28 in the upper section 22 of the container 19. The container is filled with an appropriate electrolyte, such as a solution of a copper salt, up to a level designated 99 in FIG. 2. A source of electrical energy 110 is connected through leads 111 to the substrates 16 and the anodes 34 and 36.

Referring particularly to FIG. 10, the plating cycle is started by closing a main power or start switch 112 to apply current from a source 113 through normally closed contact 114–1, through a pair of timers 114 and 104. A second current path is closed through start switch 112 and motor 85, energizing motor 85 to start pump 82 pumping fluid. A third current path is also closed through start switch 112, normally closed contact 100–3, normally closed contact 101–3 and solenoid 96 thereby energizing solenoid 96 to open valve 96*a* to allow the pump 82 to continuously pump fluid through the return path while valves 86*a*, 89*a*, 91*a* and 94*a* remain in the normally closed position. The timer 104 drives a series of four cams to control the operation of four contacts 104–1 through 104–4. The action of the cams in controlling the associated contact closure sequence is shown in the chart in FIG. 11. The timer 104 continuously cycles as long as power is applied. The timer 114 controls normally closed contact 114–1 to open after a predetermined interval thereby ending the overall plating cycle by opening the current path from timers 114 and 104. When the current path is broken by the opening of contact 114–1, the timer 104 is returned to its initial state opening contacts 104–1 through 104–4.

When contact 104–1 is closed by its associated timer cam a current path is established through start switch 112, through normally closed contact 103–2 and through relay 100, energizing relay 100, thereby closing normally opened contact 100–1 and opening normally closed contacts 100–2. The closing of relay contact 100–1 closes a current path through start switch 112 and solenoid 76 thereby opening normally closed valve 76*a*, to supply compressed air to cylinder 74 which draws ram 71 to the lower position. The electrolyte following the ram flows through the apertures 18 in substrates 16 thereby purging any gas bubbles which have formed due to the plating that has taken place thus far. These bubbles are forced down into the inclined container 19 and are trapped in a pocket behind the sub-

strate rack 33. After an interval, as shown in the timing chart of FIG. 11 elapses, contact 104–2 is closed by its associated timer cam. The cam associated with contact 104–1 then releases contact 104–1, thereby deenergizing relay 100 by opening the current path thereto, returning the contact 100–2 to its normally closed position and returning contact 100–1 to the normally opened position. The closing of contact 100–2 closes a circuit through relay 101, through contact 104–2 and start switch 112. Relay 101 opens normally closed contact 101–2 and closes normally opened contact 101–1.

The opening of contact 100–1 deenergizes solenoid 76, closing vlave 76*a*. The closing of contact 101–1 closes a current path through start switch 112 and solenoid 77, opening valve 77*a* to apply compressed air from a source, not shown, to air cylinder 74, thereby returning ram 71 to its upper position. The ram 71 pushes the electrolyte past the anodes 34 and 36 and the substrates 16 and through the apertures 18 therein. The gasses purged on the previous stroke and trapped behind the substrate rack are now pushed through vent holes 49 and are expelled from the upper section 22 along with the gas purged on that stroke. Some plating does occur during these two portions of the cycle, however, the prime purpose for actuating the ram is to clear gas bubbles from the apertures 18 in the substrates 16 to provide gas free surfaces which can be effectively plated.

With ram 71 in its upper position, contact 104–3 is closed by its associated timer cam. At this time, contact 104–2 is opened by its associated timer cam, opening the current path through relay 101. Relay 101 is deenergized thereby opening contact 101–1 and closing normally closed contacts 101–2. The opening of contact 101–1 opens the current path through solenoid 77 whereupon valve 77*a* is again closed. The closing of normally closed contact 101–2 completes a current path through start switch 112, contact 104–3 and relay 102. Relay 102 closes contact 102–1 and opens normally closed contacts 102–2, and 102–3. The opening of contact 102–3 deenergizes solenoid 96 so that valve 96*a* is closed to interrupt the bypass path around pump 82. The closing of contact 102–1 completes an energizing circuit through start switch 112 and solenoids 86 and 89 which respectively opens normally closed valves 86*a* and 89*a*. The opening of valves 86*a* and 89*a* provides a path for the electrolyte to flow from pump 82 through filter 83, through conduit 84, through valve 86*a*, through second fluid outlet 79, past the electrode assemblies 33, 34 and 36 and through the apertures 18 of substrates 16, through first fluid outlet 78, through valve 89*a*, through conduit 88, through throttle valve 87, back to pump 82. The rate of flow of electrolyte is optimized for best plating by controlling throttle valve 87. The electrolyte flowing in the container 19 from right to left provides ion rich electrolyte to the surface 17 of the right hand side of substrates 16 mounted in substrate rack 33 and to the apertures 18 in substrates 16.

Next, the contact 104–4 is closed by its associated timer cam and contact 104–3 is opened by its associated timer cam. The opening of contact 104–3 de-energizes relay 102, thereby opening contact 102–1 and closing contacts 102–2 and 102–3. The opening of contact 102–1 deenergizes solenoids 86 and 89 whereupon valves 86*a* and 89*a* are closed. The closing of contact 104–2 completes an energizing circuit through start switch 112, contact 104–4 and relay 103. Energized relay 103 opens normally closed contacts 103–2 and 103–3 and closes normally opened contact 103–1. The opening of contact 103–2 maintains solenoid 96 deenergized which maintains valve 96*a* closed, thereby maintaining the return path closed. The closing of normally opened contact 103–1 completes an energizing circuit through start switch 112, through solenoids 91 and 94 which function to open valves 91*a* and 94*a*. The opening of valves 91*a* and 94*a* provides a flow path for the electrolyte from the pump 82, through filter 83, through conduit 93, through valve 94*a*, through first fluid outlet 78, from left to right, through the container 19, past the electrode assemblies 33, 34 and 36, through second fluid outlet 79, through valve 91*a*, through conduit 92, through throttle valve 87 back to the pump 82. The rate at which pump 82 operates and the setting of the throttle valve 87 are not altered, therefore, the rate of flow of electrolyte from left to right in the container is the same rate for optimum plating as when the electrolyte was flowing from right to left. It is to be understood that the setting of throttle valve 87 may be cyclically varied so that the flow rate may be at a first rate through outlet 71 and at a second rate through outlet 72 to obtain maximum plating during the plating portion of the overall cycle of the apparatus. The flow from left to right provides ion rich electrolyte to the left hand surface 17 of the substrates 16 mounted in substrate rack 33 and the apertures 18 in substrate 16, thereby optimally plating the substrates 16 on the left hand side and in the apertures 18. Contact 104–4 is opened by its associated timer cam and contact 104–1 is again closed by its associated cam repeating the cycle as above described until timer 114 opens contact 114–1, thereby completing the plating cycle. As can be seen in FIG. 11, the plating portion of the cycle is substantially longer than the portion of the cycle devoted to purging the gas.

It is to be understood that the above described arrangements of apparatus and construction of elemental parts are simply illustrative of an application of the principles of the invention and many other modifications may be made without departing from the invention.

What is claimed is:

1. In an apparatus for electroplating an article having apertures therethrough:
- a tank for supporting said article immersed in in electrolyte,
- a pair of anodes of plating material immersed in said tank on opposite sides of said article,
- means for applying plating energy through said anodes, said electrolyte, and said article,
- means periodically operated for cyclically forcing said electrolyte back and forth through the apertures in said article at a first rate sufficient to obtain a plating of the article, and
- means rendered effective between said periodic operation of said electrolyte forcing means for forcing said electrolyte through said apertures in said article at a second rate sufficient to obtain a purging of gases generated during the plating of said article.

2. In an apparatus for electroplating metal from an electrolyte onto a substrate susceptible of being electroplated, said substrate having two sides and one or more apertures extending from one of said sides to the other of said sides;
- a container for receiving said electrolyte,
- means for mounting an apertured substrate in said container,
- an anode means mounted in said container adjacent said one side of said substrate,
- means for energizing said anode and said substrate with potentials of opposite polarity,
- a first means operable at a first rate for forcing said electrolyte past said anode and through said apertures of said workpiece,
- a second means operable at a second rate for forcing said electrolyte past said anode and through said apertures of said substrate, and
- means for alternately operating said first and second forcing means.

3. An apparatus as set forth in claim 2 including:
- a second anode means mounted adjacent said other side of said apertured substrate, and
- said second forcing means including facilities for reciprocating said electrolyte back and forth past said anodes and through said apertures of said substrate.

4. In an apparatus for electroplating metal from an electrolytic solution onto a substrate susceptible of being electroplated, said substrate having apertures extending therethrough;

a container for receiving a predetermined quantity of said electrolytic solution,

a ram mounted for movement in said container to flush said electrolyte from a first section of said container to a second section of said container,

means for mounting a substrate in said second section of said container with the apertures therein positioned to pass said flushed electrolyte,

an anode means mounted in said second section of said container and spaced from said substrate,

means for reciprocating said ram between a first position and a second position in said first section of said container, to flush electrolyte through said apertures, and

means for energizing said substrate and anode to complete an electroplating circuit through said electrolyte.

5. An apparatus as set forth in claim 4:

said container being mounted on an incline so that said first section is lower than said second section, and said first position is lower than said second position,

said predetermined quantity of electrolyte being sufficient to cover said anode and said substrate when said ram is in said second position,

a first fluid outlet in said container adjacent to and above said second position of said ram,

a second fluid outlet in said container above said anode and said substrate,

means rendered effective following movement of said ram to said second position for forcing said electrolyte back and forth between said first fluid outlet and said second fluid outlet past said anode and through said apertures, and

means for alternatively operating said reciprocating means and said forcing means.

6. An apparatus as described in claim 5, wherein said forcing means comprises:

a pump means having an intake port and an output port,

means including a first valve for connecting said first fluid outlet to said intake port of said pump means,

means including a second valve for connecting said second fluid outlet to said output port of said pump means,

means including a third valve for connecting said first fluid outlet to said output port of said pump means,

means including a fourth valve for connecting said second fluid outlet to said intake port of said pump means, and

means for alternately opening said first and second valves and said third and fourth valves to pump fluid back and forth between said first fluid outlet and said second fluid outlet past said anode and through said apertures.

7. In an apparatus for electroplating a metal from an electrolyte onto both sides of a substrate and inside apertures therethrough, said substrate capable of being electroplated:

a container mounted on an incline for receiving said electrolyte,

a first anode means mounted in said container and having openings for said electrolyte to pass through,

a second anode means mounted in said container higher than said first anode means, said second anode means having openings for said electrolyte to pass through,

means for mounting a rack to hold said apertured substrate between said first and second anode means whereupon said electrolyte will pass through said apertures, said rack having holes therethrough above the center of said rack for gas bubbles formed during plating to pass through,

means for supplying energizing potential to said anodes and said substrate, and

means for reciprocating said electrolyte back and forth through said anode and said apertured substrate to purge gas formed during plating from said apertures and convey said purged gas through said hole and out of said container.

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JOHN H. MACK, *Primary Examiner.*

D. R. VALENTINE, *Assistant Examiner.*

U.S. Cl. X.R.

204—278, 238, 24, 273