

ELECTROPLATING APPARATUS

FIELD OF THE INVENTION

The present invention relates to the technical field of semiconductor manufacture, and in particular to an electroplating apparatus.

BACKGROUND

According to FIG. 1, a schematic structural view of an electroplating apparatus is shown. The electroplating apparatus comprises an electroplating chamber, a membrane frame 100', an ion-exchange membrane 200', an electroplating power supply 800', a substrate holding device 600', and the like. The interior of the electroplating chamber includes a cathode chamber 300' and an anode chamber 400'. The side wall of the membrane frame 100' encloses and thereby forms the cathode chamber 300', and the anode chamber 400' is located below the cathode chamber 300'. The anode chamber 400' contains an anode 410'. The ion-exchange membrane 200' is disposed at the bottom of the membrane frame 100' for separating the anode chamber 400' from the cathode chamber 300'. Wherein, the anode 410' is immersed in an anode liquid and electrically connected to the positive electrode of the electroplating power supply 800' through a titanium plate 450', and a substrate 500' is immersed in a cathode liquid and electrically connected to the negative electrode of the electroplating power supply 800' through the substrate holding device 600', with the substrate 500' serving as the cathode. Metal ions in the anode liquid in the anode chamber 400' enter the cathode liquid in the cathode chamber 300' through the ion-exchange membrane 200'. During electroplating, the electroplating power supply 800' outputs a constant current, and the substrate holding device 600' clamps the substrate 500', allowing the front surface of the substrate 500' to be immersed downward in the cathode liquid in the cathode chamber 300'. Metal ions such as Cu^{2+} in the cathode liquid and anode liquid migrate to the surface of the substrate 500', the substrate 500' gains electrons, and the metal ions are plated on the surface of the substrate 500' to form an electroplating layer.

Typically, after performing multiple substrate electroplating processes (often referred to as "running wafers") on the electroplating apparatus, the voltage between the anode 410' and the substrate 500' tends to increase. This phenomenon is mostly

caused by the increase in resistance between the anode 410' and the substrate 500'. According to FIG. 2, a voltage curve graph between the anode 410' and the substrate 500' measured after running 14 substrates on the electroplating apparatus is shown. It can be seen from FIG. 2 that after running 14 substrates on the electroplating apparatus, the voltage between the anode 410' and the substrate 500' increases significantly, approaching 25 V. It is worth noting that when the voltage between the anode 410' and the substrate 500' rises to the maximum output voltage of the electroplating power supply 800', the electroplating power supply 800' will switch from the constant current output mode to the constant voltage output mode. If the resistance between the anode 410' and the substrate 500' continues to increase at this time, the output current of the electroplating power supply 800' will deviate from a set current, thereby affecting the electroplating performance, such as the uniformity of the electroplating film thickness.

SUMMARY

The purpose of the present invention is to solve the problem of an increase in voltage between an anode and a substrate after running multiple substrates on an electroplating apparatus in the prior art.

To solve the above problem, embodiments of the present invention provide an electroplating apparatus, comprising a membrane frame and an ion-exchange membrane. The ion-exchange membrane is disposed at the bottom of the membrane frame. The membrane frame includes a plurality of first spray holes for discharging cathode liquid. The liquid outlet direction of the plurality of first spray holes forms a first predetermined angle with the vertically downward direction, and the first predetermined angle is an acute angle.

As described above, the electroplating apparatus of the present invention has the following advantages:

The membrane frame adopted by the electroplating apparatus is provided with a plurality of first spray holes. The liquid outlet direction of the plurality of first spray holes forms a first predetermined angle with the vertically downward direction, and the first predetermined angle is an acute angle, so that the liquid outlet direction of the plurality of first spray holes is oriented toward the ion-exchange membrane. The

cathode liquid discharged from the first spray holes flushes the ion-exchange membrane below the membrane frame in an obliquely downward direction, and promotes the fluidity of the flow field in the lower layer of the cathode chamber, thereby reducing the crystalline precipitation on the ion-exchange membrane, avoiding the continuous increase of the resistance between the anode and the substrate, and thus improving the problem of the increase in voltage between the anode and the substrate, resulting in improved electroplating performance.

Other features and corresponding beneficial effects of the present invention are described in the subsequent part of the specification, and it should be understood that at least some of the beneficial effects are obvious from the records in the specification of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and performance of the present invention are further described by the following embodiments and the accompanying drawings of the embodiments.

FIG. 1 is a schematic structural view of an electroplating apparatus;

FIG. 2 is a voltage curve graph between the anode and the substrate measured after running 14 substrates on the electroplating apparatus shown in FIG. 1;

FIG. 3 is a schematic structural view of a membrane frame;

FIG. 4 is a cross-sectional view of a branch pipe;

FIG. 5 is a flow field distribution view of the lower layer of a cathode chamber after an electroplating apparatus uses the membrane frame shown in FIG. 3;

FIG. 6 is a schematic structural view of the membrane frame provided in Embodiment 1 of the present invention;

FIG. 7 and FIG. 8 are schematic cross-sectional views of the membrane frame provided in Embodiment 1 of the present invention;

FIG. 9 is a cross-sectional view of the branch pipe provided in Embodiment 1 of

the present invention;

FIG. 10 is a schematic partial structural view of the membrane frame provided in Embodiment 1 of the present invention;

FIG. 11 is a schematic view of the direction of cathode liquid discharged from the first spray holes of adjacent branch pipes of the membrane frame provided in Embodiment 1 of the present invention;

FIG. 12 is a schematic bottom cross-sectional view of branch pipes provided with a plurality of first spray holes only on one side wall of each branch pipe provided in Embodiment 1 of the present invention;

FIG. 13 is a schematic structural view of the membrane frame with the bottom facing upward provided in Embodiment 1 of the present invention;

FIG. 14 is a schematic bottom view of the membrane frame provided in Embodiment 1 of the present invention;

FIG. 15 is a flow field distribution view of the lower layer of the cathode chamber provided in Embodiment 1 of the present invention;

FIG. 16 is a voltage curve graph between the anode and the substrate measured after running 14 substrates on the electroplating apparatus provided in Embodiment 1 of the present invention;

FIG. 17 is a schematic cross-sectional view of the membrane frame with through holes provided in Embodiment 1 of the present invention;

FIG. 18 is a schematic bottom view of the membrane frame with through holes provided in Embodiment 1 of the present invention;

FIG. 19 is a flow field distribution view of the lower layer of the cathode chamber after the electroplating apparatus provided in Embodiment 1 of the present invention uses a membrane frame with through holes;

FIG. 20 is a schematic structural view of the membrane frame provided in

Embodiment 2 of the present invention;

FIG. 21 is a cross-sectional view of the branch pipe provided in Embodiment 2 of the present invention;

FIG. 22 is another cross-sectional view of the branch pipe provided in Embodiment 2 of the present invention;

FIG. 23 is a schematic partial structural view of the membrane frame provided in Embodiment 2 of the present invention;

FIG. 24 is a schematic view of the direction of cathode liquid discharged from the second spray holes of adjacent branch pipes of the membrane frame provided in Embodiment 2 of the present invention; and

FIG. 25 is a flow field distribution view of the lower layer of the cathode chamber provided in Embodiment 2 of the present invention.

PREFERRED EMBODIMENTS OF THE INVENTION

The implementation of the present invention will be described below with specific embodiments, and those skilled in the art can easily understand other advantages and effects of the present invention from the content disclosed in this specification. Although the description of the present invention will be made in conjunction with the preferred embodiments, it does not mean that the features of the present invention are limited to these embodiments. On the contrary, the purpose of introducing the invention in conjunction with the embodiments is to cover other options or modifications that may be extended based on the claims of the present invention. In order to provide a thorough understanding of the present invention, many specific details will be included in the following description. The present invention can also be implemented without using these details. In addition, some specific details will be omitted from the description to avoid confusing or obscuring the focus of the present invention. It should be noted that the embodiments in the present invention and the features in the embodiments can be combined with each other, provided no conflict arises.

It should be noted that in this specification, similar reference numerals and letters

denote similar items in the following drawings, so once an item is defined in one drawing, the item does not need to be further defined and explained in subsequent drawings.

The technical solutions of the present invention will be clearly and completely described below with reference to the accompanying drawings. Obviously, the described embodiments are part of the embodiments of the present invention, but not all of the embodiments. Based on the embodiments of the present invention, all other embodiments obtained by those of ordinary skill in the art without making creative efforts shall fall within the protection scope of the present invention.

In the description of the present invention, it should be noted that the terms "center," "upper," "lower," "left," "right," "vertical," "horizontal," "inner," "outer," and the like indicate the orientation or positional relationship based on the orientation or positional relationship shown in the drawings, which are only for the convenience of describing the present invention and simplifying the description, and do not indicate or imply that the device or element referred to must have a specific orientation, be constructed and operated in a specific orientation, and thus should not be construed as limiting the present invention. In addition, the terms "first," "second," and "third" are only used for the descriptive purpose, and should not be construed as indicating or implying relative importance.

In the description of the present invention, it should be noted that unless otherwise clearly specified and limited, the terms "installation," "interconnection," and "connection" should be understood in a broad sense, for example, the connection can be a fixed connection, a detachable connection, or an integral connection; the connection can be a mechanical connection or an electrical connection; the connection can be a direct connection, an indirect connection through an intermediate medium, or an internal connection of two elements. For those of ordinary skill in the art, the specific meanings of the above terms in the present invention can be understood according to specific situations.

In order to further clarify the purpose, technical solutions, and advantages of the present invention, the embodiments of the present invention will be further described in detail below with reference to the accompanying drawings.

FIG. 1 shows a schematic structural view of an electroplating apparatus in an embodiment. The electroplating apparatus comprises an electroplating chamber, a membrane frame 100', an ion-exchange membrane 200', a substrate holding device 600', an electroplating power supply 800', an ammeter 910', and a voltmeter 920'. The interior of the electroplating chamber includes a cathode chamber 300' and an anode chamber 400'. The side wall of the membrane frame 100' encloses and thereby forms the cathode chamber 300' for containing cathode liquid, and the anode chamber 400' is located below the cathode chamber 300' for containing an anode 410' and anode liquid. The ion-exchange membrane 200' is disposed at the bottom of the membrane frame 100' for separating the anode chamber 400' from the cathode chamber 300'. Wherein, the anode 410' is immersed in the anode liquid and electrically connected to the positive electrode of the electroplating power supply 800' through a titanium plate 450', and a substrate 500' is immersed in the cathode liquid and electrically connected to the negative electrode of the electroplating power supply 800' through the substrate holding device 600', with the substrate 500' serving as the cathode. The ammeter 910' is used to measure the current in the entire circuit, and the voltmeter 920' is used to measure the voltage between the anode 410' and the substrate 500'. It should be pointed out that the anode liquid and cathode liquid can be collectively referred to as electroplating solution, and the electroplating solution includes, for example, copper sulfate.

When multiple substrate electroplating processes (referred to as "running wafers") are continuously performed in the electroplating apparatus, the voltage between the anode 410' and the substrate 500' will increase. For example, when running the 14th substrate on the electroplating apparatus, the voltage increases from the set 21 V to nearly 25 V (according to FIG. 2). This phenomenon is mostly caused by the increase in resistance between the anode 410' and the substrate 500'. The inventors of the present application found that one of the reasons for the increase in the resistance is the crystalline precipitation on the ion-exchange membrane 200', such as copper sulfate crystals precipitated from the electroplating solution, which passivates the ion-exchange membrane 200'. To reduce the crystalline precipitation, the fluidity of the flow field in the cathode chamber 300' can be enhanced.

According to FIG. 3 and FIG. 4, FIG. 3 shows a schematic structural view of a

membrane frame, and FIG. 4 shows a cross-sectional view of a branch pipe of a membrane frame. The liquid outlet direction of spray holes 152' of the membrane frame 100' forms a predetermined angle α with the vertically upward direction (as shown in FIG. 4). The cathode liquid in a liquid supply channel 140' of each branch pipe 120' is discharged obliquely upward through the spray holes 152', which can promote the fluidity of the flow field in the upper layer of the cathode chamber 300'. However, the fluidity of the flow field in the lower layer of the cathode chamber 300' is very low, and it is easy to cause the electroplating solution to crystallize and precipitate on the ion-exchange membrane 200' (as shown in FIG. 1), leading to an increase in the resistance between the anode 410' and the substrate 500', and thus an increase in the voltage between the anode 410' and the substrate 500'.

According to FIG. 5, FIG. 5 shows a flow field distribution view of a lower layer of the cathode chamber after an electroplating apparatus uses the membrane frame shown in FIG. 3. It can be seen from FIG. 5 that the dark-colored area in the flow field region is large, indicating that there are many flow-field dead zones in the lower layer of the cathode chamber 300'; the light-colored area in the flow field region is small, indicating that the fluidity of the flow field in the lower layer of the cathode chamber 300' is very low.

To improve the fluidity of the flow field in the lower layer of the cathode chamber 300' and prevent the voltage between the anode 410' and the substrate 500' from increasing after running multiple substrates, the present invention improves the design of the membrane frame 100' of the above electroplating apparatus, as detailed in the following embodiments.

Embodiment 1

According to FIGS. 6 to 9, FIG. 6 shows a schematic structural view of a membrane frame in an embodiment of the present application; FIGS. 7 and 8 show schematic cross-sectional views of a membrane frame in an embodiment of the present application; FIG. 9 shows a cross-sectional view of a branch pipe in an embodiment of the present application, and the cross-sectional view is taken along the section line DD in FIG. 6.

As shown in FIG. 6, the membrane frame 100 includes a membrane frame side wall 110 and a plurality of branch pipes 120. Wherein, each branch pipe 120 has a first end and a second end. The first end of each branch pipe 120 extends to an intermediate channel 130 in the middle of the membrane frame 100, and the second end of each branch pipe 120 is connected to the membrane frame side wall 110. As shown in FIGS. 7 and 8, the bottom of the membrane frame 100 is provided with an ion-exchange membrane 200, and the liquid outlet direction of the plurality of first spray holes 151 is oriented toward the ion-exchange membrane 200. Specifically, as shown in FIG. 9, the liquid outlet direction of the first spray holes 151 of the branch pipe 120 forms a first predetermined angle β_1 with the vertically downward direction, and the first predetermined angle β_1 is an acute angle, such as 30° to 60° , or 45° . In other embodiments, the angle of the first predetermined angle β_1 can be designed according to specific needs.

As shown in FIG. 8, each branch pipe 120 is provided with a liquid supply channel 140 and a plurality of first spray holes 151. The liquid supply channel 140 is disposed inside the branch pipe 120 and extends along the length direction of the branch pipe 120. The liquid supply channel 140 is in fluid communication with the plurality of first spray holes 151 and with a cathode liquid inlet 111 disposed on the membrane frame side wall 110. When supplying cathode liquid to a cathode chamber 300, the cathode liquid flows into the liquid supply channel 140 from the cathode liquid inlet 111, and the cathode liquid in the liquid supply channel 140 enters the cathode chamber 300 through the plurality of first spray holes 151. The cathode liquid discharged from the first spray holes 151 flushes the ion-exchange membrane 200 in an obliquely downward direction, so that the fluidity of the flow field in the lower layer of the cathode chamber 300 is increased, thereby reducing the crystalline precipitation on the ion-exchange membrane 200, preventing the continuous increase of the resistance between an anode and a substrate, which would otherwise lead to an increase in the voltage between the anode and the substrate, and thus ensuring improved electroplating performance and uniform electroplating film thickness. It should be noted that the lower layer of the cathode chamber 300 refers to a region in the cathode chamber 300 close to the ion-exchange membrane 200, especially the region in the cathode chamber 300 located below the first spray holes 151.

According to FIGS. 10 and 11, FIG. 10 shows a schematic partial structural view of the membrane frame; FIG. 11 shows a schematic view of the direction of cathode liquid discharged from the first spray holes of adjacent branch pipes of the membrane frame; wherein the dashed arrows in FIG. 11 indicate the direction of cathode liquid discharged from the first spray holes.

As shown in FIG. 10, each branch pipe 120 has two opposite side walls, namely a first side wall 1201 and a second side wall 1202. Along the circumferential direction of the membrane frame 100, the side wall on the same side of each branch pipe 120 is the first side wall 1201, and the second side wall 1202 is on the opposite side of the first side wall 1201. Specifically, according to FIG. 9 and FIG. 10, the first side wall 1201 has a straight wall and chamfered structures 12013, 12014, and the straight wall is connected to the chamfered structures 12013, 12014. The second side wall 1202 has a straight wall and chamfered structures 12023, 12024, and the straight wall is connected to the chamfered structures 12023, 12024. The plurality of first spray holes 151 are disposed on the first side wall 1201 and/or the second side wall 1202. Specifically, the first spray holes 151 of this embodiment are disposed on the straight wall of the side wall where the first spray holes 151 are located. In some embodiments, the first spray holes 151 may be disposed at the chamfered structure 12014 formed on the first side wall 1201 and the chamfered structure 12024 formed on the second side wall 1202.

The plurality of first spray holes 151 form at least one row on the side wall where the plurality of first spray holes 151 are located along the height direction of the branch pipe 120, and the plurality of first spray holes in each row of first spray holes 151 are spaced apart along the length direction L of the branch pipe 120 to form one row. For example, FIG. 10 shows one row of first spray holes 151 on the corresponding side wall of the branch pipe 120, and the plurality of first spray holes in this row of first spray holes 151 are spaced apart along the length direction L of the branch pipe 120 to form one row. It should be noted that the height direction of the branch pipe 120 is the vertical direction in this embodiment, which is perpendicular to the length direction L.

As shown in FIG. 10, in some embodiments, for each branch pipe 120, the plurality of first spray holes 151 are disposed on the first side wall 1201 and the second side wall 1202, and form one row on the first side wall 1201 and the second side wall

1202, respectively. The row of first spray holes 151 disposed on the first side wall 1201 and the row of first spray holes 151 disposed on the second side wall 1202 are located at the same height of the branch pipe 120 and are arranged in a staggered manner along the length direction L of the branch pipe 120.

In some embodiments, for each branch pipe 120, the plurality of first spray holes 151 are disposed on the first side wall 1201 and the second side wall 1202, and the plurality of first spray holes 151 form a plurality of rows on the first side wall 1201 and the second side wall 1202, respectively, along the height direction of the branch pipe 120. The plurality of rows of first spray holes 151 disposed on the first side wall 1201 correspond to the plurality of rows of first spray holes 151 disposed on the second side wall 1202 respectively along the height direction of the branch pipe 120, wherein the first spray holes 151 located on different side walls but at the same height are arranged in a staggered manner along the length direction L of the branch pipe 120.

In some embodiments, the plurality of first spray holes 151 form at least two rows on the side wall where the plurality of first spray holes 151 are located along the height direction of the branch pipe 120, and adjacent two rows of first spray holes 151 on the same side wall of the branch pipe 120 are arranged in a staggered manner along the length direction L of the branch pipe 120.

In some embodiments, according to FIG. 11, the first spray holes 151 on the opposite side walls of adjacent branch pipes 120 are staggered from each other. In this example, the first side wall 1201 of each branch pipe 120 is opposite to the second side wall 1202 of the adjacent branch pipe 120. When the first spray holes 151 on the first side wall 1201 and the first spray holes 151 on the second side wall 1202 of each branch pipe 120 discharge cathode liquid respectively, the direction of cathode liquid discharged from the first spray holes 151 on the first side wall 1201 of the branch pipe 120 is staggered from the direction of cathode liquid discharged from the first spray holes 151 on the second side wall 1202 of the adjacent branch pipe 120, which can weaken the mutual impact of the cathode liquid discharged from the opposite side walls, making the flow rate of the electroplating solution near the substrate in the cathode chamber gentle.

In some embodiments, the plurality of first spray holes 151 are disposed on the

side wall of each branch pipe 120 located on the same side along the circumferential direction of the membrane frame 100. According to FIG. 12, FIG. 12 shows a schematic bottom cross-sectional view of the branch pipes 120 provided with a plurality of first spray holes 151 only on the first side wall 1201 of each branch pipe 120. As shown in FIG. 12, the plurality of first spray holes 151 are disposed on the first side wall 1201 of each branch pipe 120, wherein the first side wall 1201 is located on the same side of each branch pipe 120 along the circumferential direction of the membrane frame 100 (for example: the right side along the clockwise direction of the membrane frame 100). In other examples, the plurality of first spray holes 151 are disposed on the second side wall 1202 of each branch pipe 120, wherein the second side wall 1202 is located on the same side of each branch pipe 120 along the circumferential direction of the membrane frame 100.

According to FIG. 10, FIG. 13, and FIG. 14, FIG. 13 and FIG. 14 show schematic bottom views of the membrane frame. The membrane frame 100 further includes an intermediate baffle 131 and an intermediate channel 130. The intermediate baffle 131 defines the intermediate channel 130 extending along the vertical direction, and the intermediate baffle 131 is connected to the first end of each branch pipe 120. A first groove 123 is disposed at the bottom of the first end of each branch pipe 120. The plurality of first grooves 123 disposed at the bottom of the first ends of the branch pipes 120 can form an intermediate annular zone for liquid circulation on the outer periphery of the intermediate baffle 131 (according to the dashed circle on the outer periphery of the intermediate baffle 131 shown in FIG. 14), so that the electroplating solution circulates in the intermediate annular zone, enhances the fluidity of the flow field in the corner region between the intermediate baffle 131 and each branch pipe 120, reduces the flow-field dead zones in the corner region, and further enhances the overall fluidity of the lower layer of the cathode chamber.

In some embodiments, a second groove 124 is disposed at the bottom of the second end of each branch pipe 120 connected to the membrane frame side wall 110. The plurality of second grooves 124 can allow the electroplating solution on both sides of the second ends of the branch pipes 120 to circulate, enhance the fluidity of the flow field in the corner region between the membrane frame side wall 110 and each branch pipe 120, reduce the flow-field dead zones in the corner region, and also further

enhance the overall fluidity of the lower layer of the cathode chamber.

As shown in FIG. 13 and FIG. 14, the membrane frame 100 further includes an outer peripheral baffle 160. The outer peripheral baffle 160 is arranged around and between the first ends and the second ends of the plurality of branch pipes 120 for dividing the cathode chamber 300 into at least two independent cathode regions. In this embodiment, the membrane frame 100 includes one outer peripheral baffle 160, which divides the cathode chamber 300 into two cathode regions. The region enclosed by the outer peripheral baffle 160 is a first cathode region 310, and the region between the outer peripheral baffle 160 and the membrane frame side wall 110 is a second cathode region 320. The first ends of the plurality of branch pipes 120 are located in the first cathode region 310, and the second ends of the plurality of branch pipes 120 are located in the second cathode region 320.

In some embodiments, in the first cathode region 310, a third groove (not shown) is disposed at the bottom of the joint between each branch pipe 120 and the outer peripheral baffle 160 to enhance the fluidity of the flow field in the corner region between the outer peripheral baffle 160 and each branch pipe 120.

In some embodiments, as shown in FIG. 13, in the second cathode region 320, the membrane frame 100 is further provided with reinforcing ribs 170. The reinforcing ribs 170 connects the outer peripheral baffle 160 to the membrane frame side wall 110, which can enhance the strength of the outer peripheral baffle 160. In this embodiment, one reinforcing rib 170 is disposed between adjacent branch pipes 120, and the reinforcing ribs 170 and the branch pipes 120 divide the second cathode region 320 into a plurality of sub-regions along the circumferential direction. To enhance the fluidity of the flow field between the plurality of sub-regions, a fourth groove 171 is disposed at the bottom of each reinforcing rib 170. Wherein, as shown in FIG. 13, each sub-region is defined by the outer peripheral baffle 160, the branch pipe 120, the membrane frame side wall 110 of the membrane frame 100, and the reinforcing rib 170.

By disposing the second groove 124 at the bottom of the second end of each branch pipe 120 and the fourth groove 171 at the bottom of each reinforcing rib 170, an edge annular region for liquid circulation is formed along the circumferential

direction of the second cathode region 320. The electroplating solution in any adjacent sub-regions of the second cathode region 320 circulates with each other, which enhances the fluidity of the flow field in the second cathode region 320 and reduces the flow-field dead zones in the second cathode region 320.

According to FIG. 15, FIG. 15 shows a flow field distribution view of the lower layer of the cathode chamber after the electroplating apparatus uses the membrane frame of Embodiment 1. Compared with the flow field distribution of the lower layer of the cathode chamber 300' shown in FIG. 5, the light-colored area in the flow field region in FIG. 15 is significantly increased, indicating that the overall fluidity of the flow field in the lower layer of the cathode chamber 300 is significantly enhanced.

According to FIG. 16, FIG. 16 shows a voltage curve graph between the anode and the substrate measured after running 14 substrates on the electroplating apparatus adopting the membrane frame of this embodiment. Compared with the voltage curve between the anode and the substrate shown in FIG. 2, the voltage curves during running all substrates shown in FIG. 10 are basically similar, and after running 14 substrates, the voltage is stably maintained at approximately 22 V.

Therefore, according to FIG. 15 and FIG. 16, it can be seen that after the electroplating apparatus adopts the membrane frame of Embodiment 1, the fluidity of the flow field in the lower layer of the cathode chamber 300 is significantly enhanced, which can reduce the crystalline precipitation on the ion-exchange membrane 200, thereby reducing the voltage increase between the anode and the substrate after running multiple substrates.

As shown in FIG. 15, in the first cathode region 310, the fluidity of the flow field at the positions of the plurality of first grooves disposed at the bottom of the first ends of the branch pipes (refer to the position indicated by a1) is slightly weak. Based on this situation, to further improve the fluidity of the fluid, a through hole can be disposed at the first end of each branch pipe. According to FIG. 17 and FIG. 18, a through hole 1231 is disposed at the first end of each branch pipe 120. The through hole 1231 connects the liquid supply channel 140 to the first groove 123 at the bottom of the first end of the corresponding branch pipe 120, so that the cathode liquid in the liquid supply channel 140 flows downward to flush the ion-exchange membrane 200 below the first

groove 123, thereby enhancing the fluidity of the flow field at the position of the first groove 123 at the bottom of the first end of each branch pipe 120 and further enhancing the fluidity of the flow field in the corner region between the intermediate baffle 131 and each branch pipe 120. FIG. 19 shows a flow field distribution view of the lower layer of the cathode chamber after the electroplating apparatus uses the membrane frame with through holes. It can be seen from FIG. 19 that the fluidity of the flow field at the position of the first groove at the bottom of the first end of each branch pipe (refer to the position indicated by a2) is significantly enhanced.

Similarly, according to FIG. 17 and FIG. 18, in the second cathode region 320, a through hole 1231 can also be disposed at the second end of each branch pipe 120. The through hole 1231 connects the liquid supply channel 140 to the second groove 124 at the bottom of the second end of each branch pipe 120, so as to enhance the fluidity of the flow field at the position of the second groove 124 and further enhance the fluidity of the flow field in the corner region between the membrane frame side wall 110 and each branch pipe 120. Compared with the fluidity of the flow field at the position of the second groove at the bottom of the second end of each branch pipe in FIG. 15 (refer to the position indicated by b1), the fluidity of the flow field at the position of the second groove at the bottom of the second end of each branch pipe shown in FIG. 19 (refer to the position indicated by b2) is relatively enhanced.

In some embodiments, the through hole (not shown) can also be disposed at the joint between each branch pipe 120 and the outer peripheral baffle 160. The through hole connects the liquid supply channel 140 to the third groove, so that the cathode liquid in the liquid supply channel 140 flows downward to flush the ion-exchange membrane 200 below the third groove, thereby enhancing the fluidity of the flow field at the position of the third groove.

In this embodiment, since the liquid outlet direction of the first spray holes 151 on the branch pipes 120 of the membrane frame 100 is oriented toward the ion-exchange membrane 200 at the bottom of the membrane frame 100 and is in an obliquely downward direction, the first spray holes 151 can be drilled from bottom to top, that is, a tool is inserted from the bottom of the membrane frame 100 to drill the branch pipes 120, which is convenient for drilling, and the tool is not easy to break.

Embodiment 2

According to FIGS. 20 to 22, FIG. 20 is a schematic structural view of the membrane frame 100A of the electroplating apparatus provided in Embodiment 2 of the present invention; FIG. 21 is a cross-sectional view of the branch pipe provided in Embodiment 2 of the present invention; FIG. 22 is another cross-sectional view of the branch pipe provided in Embodiment 2 of the present invention. Compared with Embodiment 1, the present embodiment differs in that: (1) a branch pipe 120A includes not only a plurality of first spray holes 151A but also a plurality of second spray holes 152A. When a substrate is immersed in the cathode liquid in a cathode chamber 300A for electroplating, the liquid outlet direction of the first spray holes 151A is oriented toward an ion-exchange membrane 200A, and the liquid outlet direction of the second spray holes 152A is oriented toward the substrate, that is, the liquid outlet direction of the second spray holes 152A is opposite to the ion-exchange membrane 200A. (2) No groove is disposed at the bottom of each branch pipe 120A (refer to the first groove 123 and the second groove 124 in FIG.13 of Embodiment 1, and the third groove not shown), and no groove is disposed at the bottom of each reinforcing rib 170A (refer to the fourth groove 171 in FIG. 13 of Embodiment 1).

As shown in FIG. 21 and FIG. 22, the liquid outlet direction of the first spray holes 151A forms a first predetermined angle β_2 with the vertically downward direction, and the liquid outlet direction of the second spray holes 152A forms a second predetermined angle β_3 with the vertically upward direction. Both the first predetermined angle β_2 and the second predetermined angle β_3 are acute angles. The first predetermined angle β_2 is identical to the second predetermined angle β_3 , such as 30° to 60° , or 45° .

According to FIG. 20, each branch pipe 120A has two opposite side walls, namely a first side wall 1201A and a second side wall 1202A. Specifically, as shown in FIG. 21 and FIG. 22, the first side wall 1201A has a straight wall and chamfered structures 12013A, 12014A, wherein the straight wall is connected to the chamfered structures 12013A, 12014A, and the second side wall 1202A has a straight wall and chamfered structures 12023A, 12024A, wherein the straight wall is connected to the chamfered structures 12023A, 12024A. The plurality of first spray holes 151A and the plurality of second spray holes 152A are disposed on the first side wall 1201A and/or the second

side wall 1202A of each branch pipe 120A. Specifically, the first spray holes 151A of this embodiment are disposed on the straight wall of the side wall where the first spray holes 151A are located, and the second spray holes 152A are disposed at the chamfered structure (i.e., the chamfered structure 12013A or the chamfered structure 12023A) of the side wall where the second spray holes 152A are located. In some embodiments, both the first side wall 1201A and the second side wall 1202A may have straight walls, and at this time, both the first spray holes 151A and the second spray holes 152A are disposed on the straight wall of the side wall where the first spray holes 151A and the second spray holes 152A are located.

The plurality of first spray holes 151A and the plurality of second spray holes 152A respectively form at least one row on the side walls where the plurality of first spray holes 151A and the plurality of second spray holes 152A are located along the height direction of the branch pipe 120A. The plurality of first spray holes in each row of first spray holes 151A are spaced apart along the length direction L of the branch pipe 120A to form one row, and the plurality of second spray holes in each row of second spray holes 152A are spaced apart along the length direction L of the branch pipe 120A to form one row.

In some embodiments, as shown in FIG. 20, each branch pipe 120A is provided with one row of first spray holes 151A and one row of second spray holes 152A on the first side wall 1201A and the second side wall 1202A, respectively. The second spray holes 152A on the same side wall are located above the first spray holes 151A, and in these embodiments, the first spray holes 151A and the second spray holes 152A on the same side wall are arranged in a staggered manner along the length direction L of the branch pipe 120. In addition, for the same branch pipe 120A, the row of first spray holes 151A disposed on the first side wall 1201A and the row of first spray holes 151A disposed on the second side wall 1202A are located at the same height of the branch pipe 120A and are arranged in a staggered manner along the length direction L of the branch pipe 120A; similarly, regarding the second spray holes 152A, the row of second spray holes 152A disposed on the first side wall 1201A and the row of second spray holes 152A disposed on the second side wall 1202A are located at the same height of the branch pipe 120A and are arranged in a staggered manner along the length direction L of the branch pipe 120A.

In some embodiments, along the height of each branch pipe 120A, a plurality of rows of first spray holes 151A and a plurality of rows of second spray holes 152A are formed on the first side wall 1201A and the second side wall 1202A of the branch pipe 120A, respectively. In the same branch pipe 120A, the plurality of rows of first spray holes 151A disposed on the first side wall 1201A correspond to the plurality of rows of first spray holes 151A disposed on the second side wall 1202A respectively along the height direction of the branch pipe 120A, wherein the first spray holes 151A located on different side walls but at the same height are arranged in a staggered manner along the length direction L of the branch pipe 120A. Similarly, regarding the second spray holes 152A, in the same branch pipe 120A, the plurality of rows of second spray holes 152A disposed on the first side wall 1201A correspond to the plurality of rows of second spray holes 152A disposed on the second side wall 1202A respectively along the height direction of the branch pipe 120A, wherein the second spray holes 152A located on different side walls but at the same height are arranged in a staggered manner along the length direction L of the branch pipe 120A.

In some embodiments, the plurality of first spray holes 151A form at least two rows on the side wall where the plurality of first spray holes 151A are located along the height direction of the branch pipe 120A, and on the same side wall of the branch pipe 120A, the second spray holes 152A are located above the first spray holes 151A. The adjacent rows of first spray holes 151A on the same side wall of the branch pipe 120A are arranged in a staggered manner along the length direction L of the branch pipe 120A. Similarly, the plurality of second spray holes 152A form at least two rows on the side wall where the plurality of second spray holes 152A are located along the height direction of the branch pipe 120A, and the adjacent rows of second spray holes 152A on the same side wall of the branch pipe 120A are arranged in a staggered manner along the length direction L of the branch pipe 120A. In this embodiment, on the same side wall of the branch pipe 120A, one row of first spray holes 151A and one adjacent row of second spray holes 152A along the height direction of the branch pipe 120A are arranged in a staggered manner along the length direction of the branch pipe 120A.

In some embodiments, according to FIG. 23, on the same side wall of the branch pipe 120A, at least one row of first spray holes 151A and at least one row of second spray holes 152A are alternately arranged along the height direction of the branch pipe

120A, wherein one row of first spray holes 151A and one adjacent row of second spray holes 152A along the height direction of the branch pipe 120A are arranged in a staggered manner along the length direction L of the branch pipe 120A, which helps to make the flow field in the cathode chamber 300A more uniform.

In some embodiments, according to FIG. 21 and FIG. 22, on the same cross-section of the branch pipe 120A, the first spray hole 151A and the second spray hole 152A respectively located on different side walls of the branch pipe 120A are coaxial, and the cross-section is taken along the section line UU in FIG. 20. The first spray hole 151A of the first side wall 1201A and the second spray hole 152A of the second side wall 1202A are coaxial, and the axis passes through the liquid supply channel 140A of the branch pipe 120A. Through this coaxial design, during the processing of the spray holes, the first spray hole 151A and the second spray hole 152A can be drilled from bottom to top, that is, a tool is inserted obliquely upward from the bottom of the membrane frame 100A to drill the branch pipe 120A, and the first spray hole 151A on one side wall and the second spray hole 152A on the other side wall are drilled at the same time, which is convenient for drilling, and the tool is not easy to break.

According to FIG. 24, FIG. 24 shows a schematic view of the direction of cathode liquid discharged from the second spray holes of adjacent branch pipes of the membrane frame 100A; wherein the dashed arrows in FIG. 24 indicate the direction of cathode liquid discharged from the second spray holes. The second spray holes 152A on the opposite side walls of adjacent branch pipes 120A are staggered from each other, and the first side wall 1201A of each branch pipe 120A is opposite to the second side wall 1202A of the adjacent branch pipe 120A. The direction of cathode liquid discharged from the second spray holes 152A on the first side wall 1201A of the branch pipe 120A is staggered from the direction of cathode liquid discharged from the second spray holes 152A on the second side wall 1202A of the adjacent branch pipe 120A, which can avoid the mutual impact of the cathode liquid discharged from the opposite side walls toward the substrate, reduce the impact of the cathode liquid on the substrate, thereby making the flow rate of the cathode liquid near the substrate gentle and ensuring improved electroplating effect. Similarly, the first spray holes 151A on the opposite side walls of adjacent branch pipes 120A are staggered from each other.

In this embodiment, by adopting a design of obliquely upward openings for the

second spray holes 152A, the cathode liquid is discharged obliquely upward to promote the fluidity of the flow field in the upper layer of the cathode chamber 300A. By adopting a design of obliquely downward openings for the first spray holes 151A, the cathode liquid flushes the ion-exchange membrane 200A in an obliquely downward direction (as shown in FIG. 20) to promote the fluidity of the flow field in the lower layer of the cathode chamber 300A, reduce the flow-field dead zones, further reduce the crystalline precipitation on the ion-exchange membrane 200A, prevent the increase of the resistance between an anode and the substrate, which would otherwise lead to the increase in the voltage between the anode and the substrate, and thus ensure improved electroplating performance.

In addition, under the condition that the flow rate of the cathode liquid supplied to each branch pipe 120A is the same, compared with the case in which only the second spray holes 152A are provided, each branch pipe 120A in the present application is provided with both the first spray holes 151A and the second spray holes 152A, so that the cathode liquid in each branch pipe 120A is discharged toward two directions at the same time, which plays a role of splitting flow. On the premise of ensuring that the total supply flow rate of the cathode liquid remains unchanged, the flow rate of the cathode liquid discharged upward from the second spray holes 152A is reduced, thereby reducing the impact of the cathode liquid on the substrate, making the flow rate of the cathode liquid near the substrate gentle, and ensuring a improved electroplating effect.

According to FIG. 25, FIG. 25 shows a flow field distribution view of the lower layer of the cathode chamber after the electroplating apparatus uses the membrane frame 100A of Embodiment 2. Compared with the flow field distribution of the lower layer of the cathode chamber 300' shown in FIG. 5, the light-colored area in the flow field region in FIG. 25 is significantly increased, indicating that the flow rate of the electroplating solution in the lower layer of the cathode chamber 300A is significantly accelerated, and the flow-field dead zones are significantly reduced.

After running multiple substrates on the electroplating apparatus with the membrane frame 100A of this embodiment, the voltage between the anode and the substrate can remain stable, and will not increase significantly due to the increase of crystalline precipitation on the ion-exchange membrane 200A.

It should be pointed out that the bottom of each branch pipe 120A of Embodiment 2 can also be configured with the first groove 123 and the second groove 124 shown in FIG. 13 of Embodiment 1, and the third groove not shown as needed, and the bottom of each reinforcing rib 170A can also be configured with the fourth groove 171 shown in FIG. 13 of Embodiment 1 as needed.

Finally, it should be noted that the above embodiments are only used to illustrate the technical solutions of the present invention, but not to limit the technical solutions of the present invention; although the present invention has been described in detail with reference to the foregoing embodiments, those of ordinary skill in the art should understand that they can still modify the technical solutions described in the foregoing embodiments, or equivalently replace some or all of the technical features of the embodiments; and these modifications or replacements do not make the essence of the corresponding technical solutions deviate from the scope of the technical solutions of the embodiments of the present invention.

What is claimed is:

1. An electroplating apparatus, comprising:

a membrane frame, including a plurality of first spray holes for discharging cathode liquid, the liquid outlet direction of the plurality of first spray holes forming a first predetermined angle with the vertically downward direction, and the first predetermined angle being an acute angle;

an ion-exchange membrane, disposed at the bottom of the membrane frame.

2. The electroplating apparatus according to claim 1, wherein the membrane frame includes a plurality of branch pipes, each of the branch pipes includes a liquid supply channel for providing cathode liquid and two opposite side walls, the two side walls include a first side wall and a second side wall, the plurality of first spray holes are disposed on the first side wall and/or the second side wall, the liquid supply channel extends along the length direction of the branch pipe, and the plurality of first spray holes are in fluid communication with the liquid supply channel.

3. The electroplating apparatus according to claim 2, wherein the plurality of first spray holes form at least one row on the side wall where the plurality of first spray holes are located along the height direction of the branch pipe, and the plurality of first spray holes in each row of the first spray holes are spaced apart along the length direction of the branch pipe to form one row.

4. The electroplating apparatus according to claim 3, wherein the at least one row of first spray holes respectively formed on the two side walls of each branch pipe correspond to each other along the height direction of the branch pipe, and the first spray holes located at the same height on the two side walls of each branch pipe are arranged in a staggered manner along the length direction of the branch pipe.

5. The electroplating apparatus according to claim 3, wherein the plurality of first spray holes form at least two rows on the side wall where the plurality of first spray holes are located along the height direction of the branch pipe, and the adjacent rows of first spray holes on the same side wall of the branch pipe are arranged in a staggered manner along the length direction of the branch pipe.

6. The electroplating apparatus according to claim 3, wherein the plurality of first spray holes are disposed on the first side wall and the second side wall, and the first spray holes on the opposite side walls of adjacent branch pipes are arranged in a staggered manner.

7. The electroplating apparatus according to claim 2, wherein the membrane frame further includes a membrane frame side wall, an intermediate baffle and an intermediate channel are disposed in the middle of the membrane frame, the intermediate baffle defines the intermediate channel extending along the vertical direction, each branch pipe has a first end and a second end, the first end of each branch pipe is connected to the intermediate baffle, the second end of each branch pipe is connected to the membrane frame side wall; a first groove is disposed at the bottom of the first end of each branch pipe, and/or a second groove is disposed at the bottom of the second end of each branch pipe.

8. The electroplating apparatus according to claim 7, wherein the membrane frame side wall encloses and thereby forms a cathode chamber, the membrane frame further includes an outer peripheral baffle, the outer peripheral baffle is arranged around and between the first ends and the second ends of the plurality of branch pipes for dividing the cathode chamber into at least two independent cathode regions; and a third groove is disposed at the bottom of the joint between each branch pipe and the outer peripheral baffle.

9. The electroplating apparatus according to claim 7 or 8, wherein a through hole is further disposed in each branch pipe, and the through hole connects the liquid supply channel to at least one of the first groove, the second groove, or the third groove.

10. The electroplating apparatus according to claim 8, wherein the membrane frame further includes a reinforcing rib connected between the outer peripheral baffle and the membrane frame side wall; and a fourth groove is disposed at the bottom of the reinforcing rib.

11. The electroplating apparatus according to claim 1, the membrane frame further including:

a plurality of second spray holes, for discharging cathode liquid, the liquid outlet direction of the second spray holes forming a second predetermined angle with the vertically upward direction, and both the first predetermined angle and the second predetermined angle being acute angles.

12. The electroplating apparatus according to claim 11, wherein the first predetermined angle is identical to the second predetermined angle.

13. The electroplating apparatus according to claim 11, wherein the membrane frame includes a plurality of branch pipes, each of the branch pipes includes a liquid supply channel for providing cathode liquid and two opposite side walls, the two side walls include a first side wall and a second side wall, the plurality of first spray holes and the plurality of second spray holes are disposed on the first side wall and/or the second side wall, the liquid supply channel extends along the length direction of the branch pipe, and both the plurality of first spray holes and the plurality of second spray holes are in fluid communication with the liquid supply channel.

14. The electroplating apparatus according to claim 13, wherein the plurality of first spray holes and the plurality of second spray holes respectively form at least one row on the side walls where the plurality of first spray holes and the plurality of second spray holes are located along the height direction of the branch pipe, the plurality of first spray holes in each row of the first spray holes are spaced apart along the length direction of the branch pipe to form one row, and the plurality of second spray holes in each row of the second spray holes are spaced apart along the length direction of the branch pipe to form one row.

15. The electroplating apparatus according to claim 14, wherein on the same cross-section of the branch pipe, the first spray hole and the second spray hole respectively located on different side walls of the branch pipe are coaxial.

16. The electroplating apparatus according to claim 14, wherein the at least one row of first spray holes respectively formed on the two side walls of each branch pipe correspond to each other along the height direction of the branch pipe, and the at least one row of second spray holes respectively formed on the two side walls of each branch pipe correspond to each other along the height direction of the branch pipe; the first

spray holes located at the same height on the two side walls of each branch pipe are arranged in a staggered manner along the length direction of the branch pipe; the second spray holes located at the same height on the two side walls of each branch pipe are arranged in a staggered manner along the length direction of the branch pipe.

17. The electroplating apparatus according to claim 14, wherein the plurality of first spray holes and the plurality of second spray holes respectively form at least two rows on the side walls where the plurality of first spray holes and the plurality of second spray holes are located along the height direction of the branch pipe; the adjacent rows of first spray holes on the same side wall of the branch pipe are arranged in a staggered manner along the length direction of the branch pipe; the adjacent rows of second spray holes on the same side wall of the branch pipe are arranged in a staggered manner along the length direction of the branch pipe.

18. The electroplating apparatus according to claim 14, wherein on the same side wall of the branch pipe, one row of first spray holes and one adjacent row of second spray holes along the height direction of the branch pipe are arranged in a staggered manner along the length direction of the branch pipe.

19. The electroplating apparatus according to claim 14, wherein the plurality of second spray holes are disposed on the first side wall and the second side wall, and the second spray holes on the opposite side walls of adjacent branch pipes are arranged in a staggered manner.