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(54) **PLATING DEVICE**

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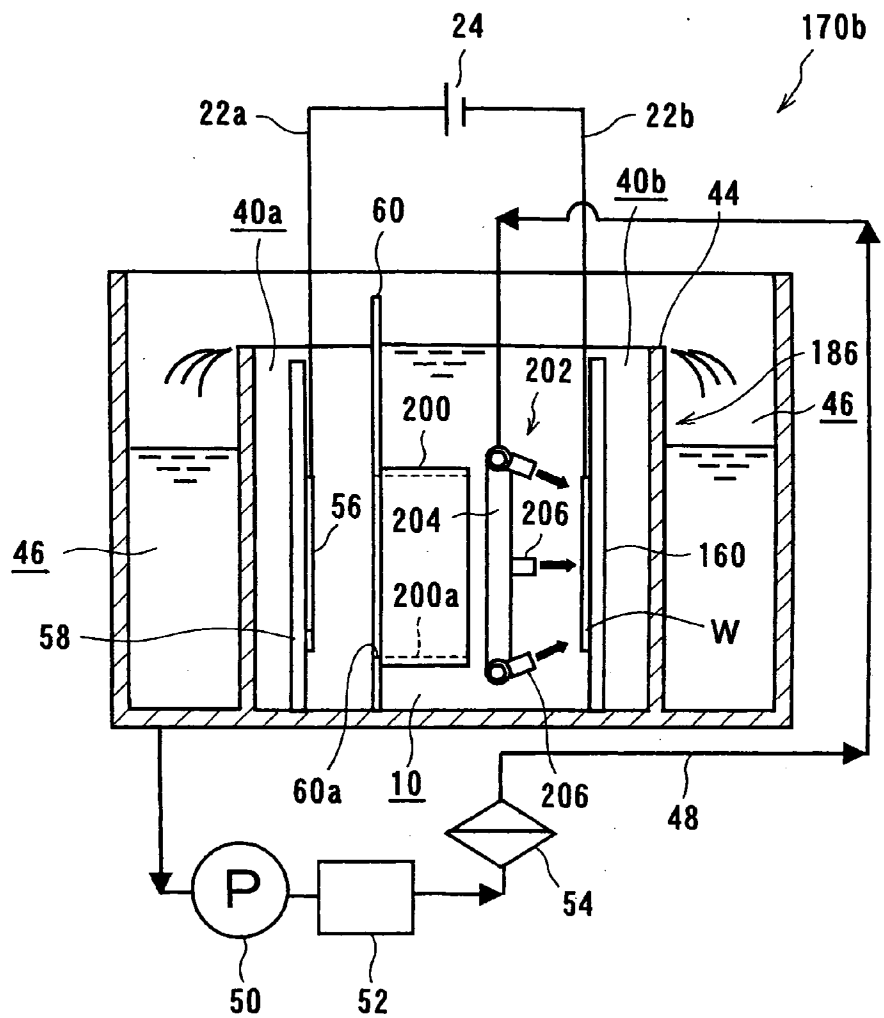
(57) **ABSTRACT**

A plating apparatus according to the present invention has a plating tank **(40)** for holding a plating solution **(10)**, an anode **(56)** disposed so as to be immersed in the plating solution **(10)** in the plating tank **(40)**, a regulation plate **(60)** disposed between the anode **(56)** and a plating workpiece (W) disposed so as to face the anode **(56)**, and a plating power supply **(24)** for supply a current between the anode **(56)** and the plating workpiece (W) to carry out plating. The regulation plate **(60)** is disposed so as to separate the plating solution **(10)** held in the plating tank **(40)** into a plating solution on the anode side and a plating solution on the plating workpiece side, and a through-hole group **(68)** having a large number of through-holes **(66)** is formed in the regulation plate **(60)**.



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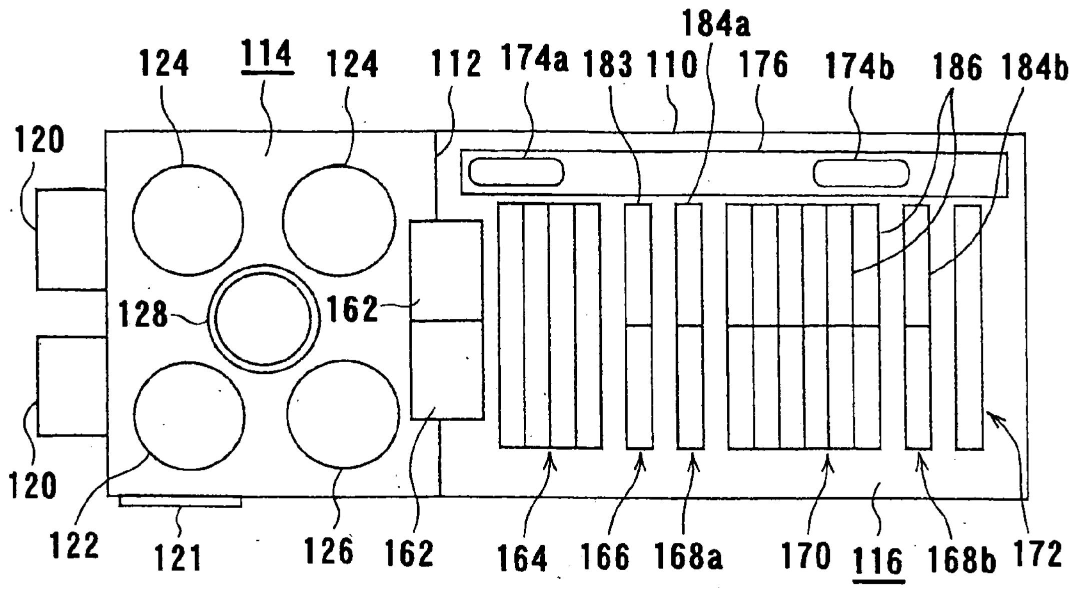
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168a
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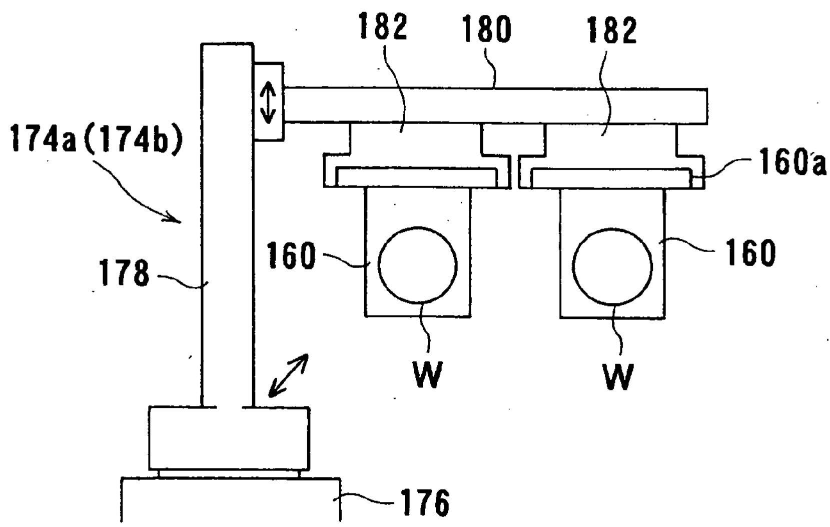
168b
172

F I G. 2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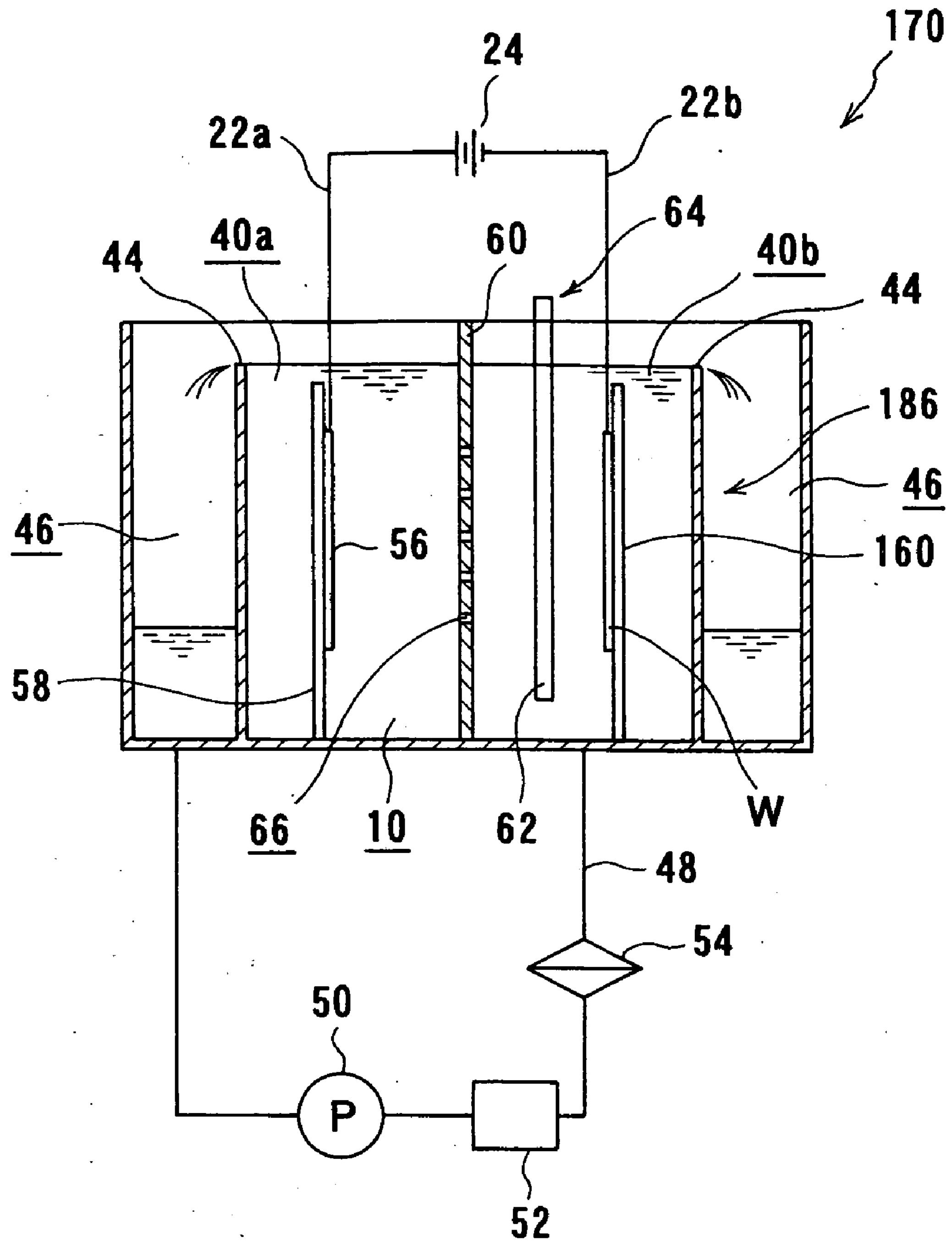
182
174a(174b)
160a
160
160
178
W
W
176

F I G. 3


170
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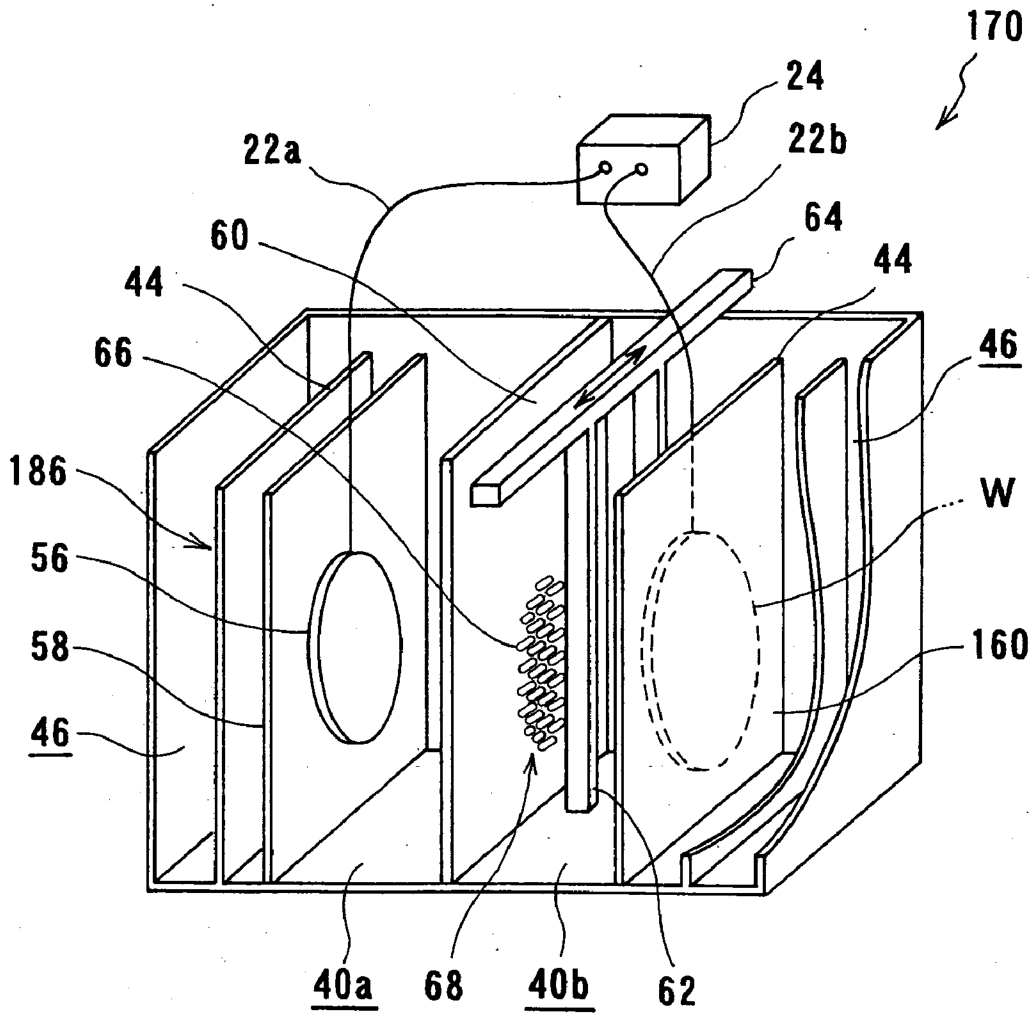
52

F I G. 4



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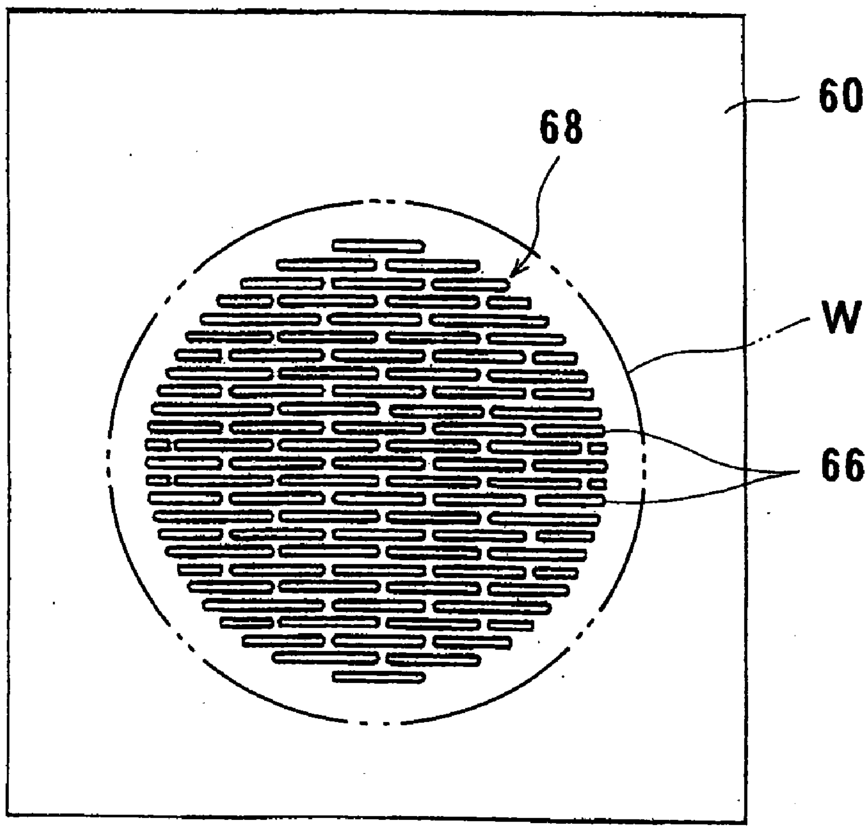


F I G. 6

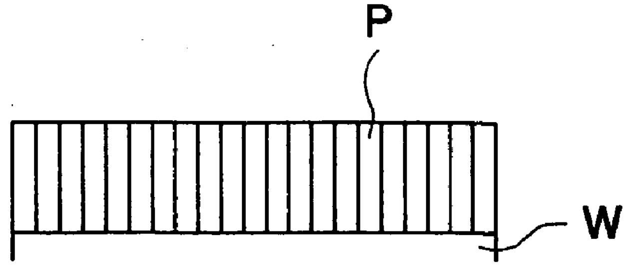


FIG. 7A

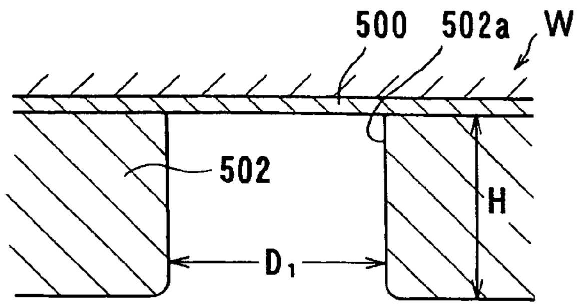


FIG. 7B

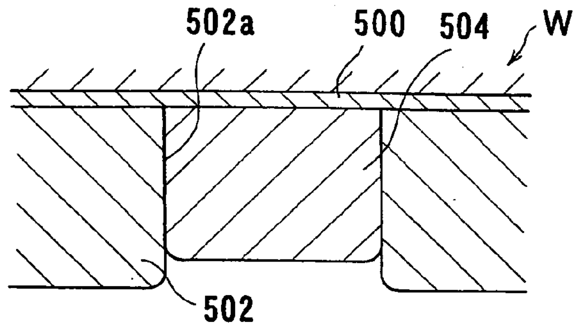


FIG. 7C

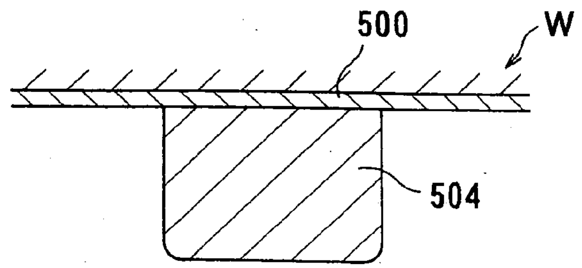


FIG. 7D

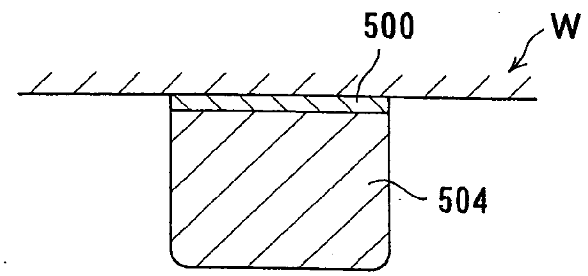


FIG. 7E

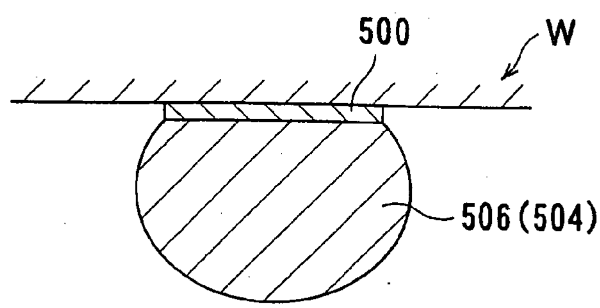


FIG. 8

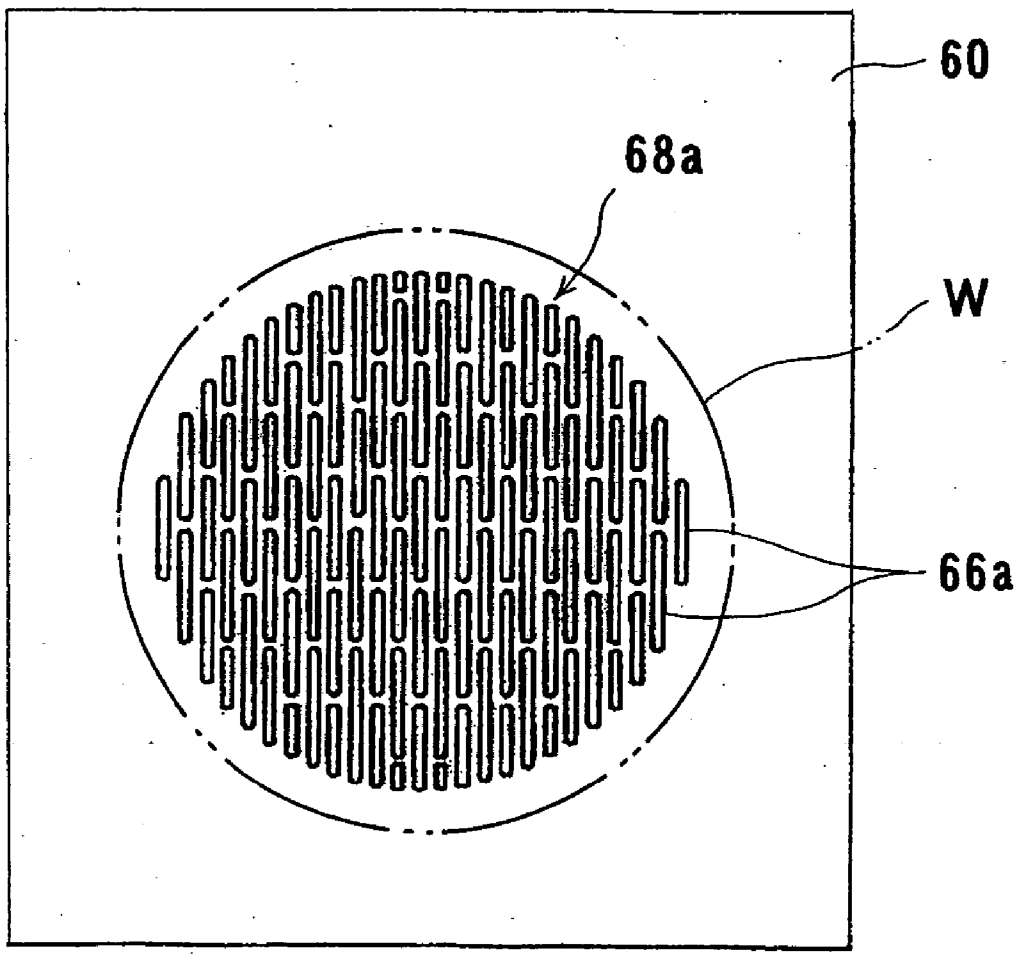


FIG. 9

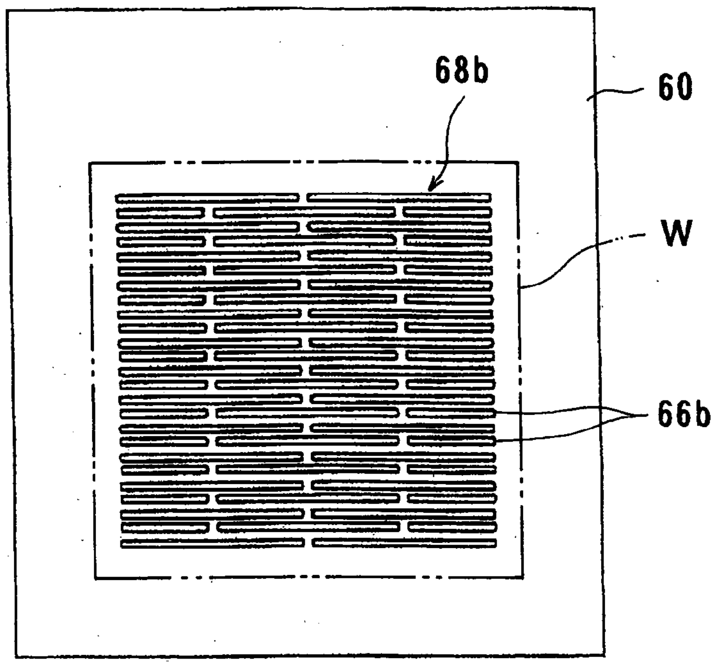
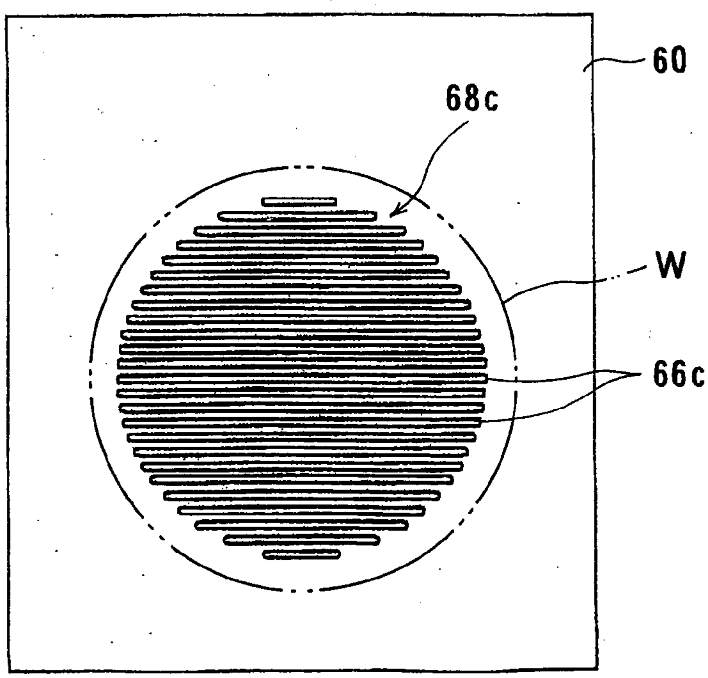
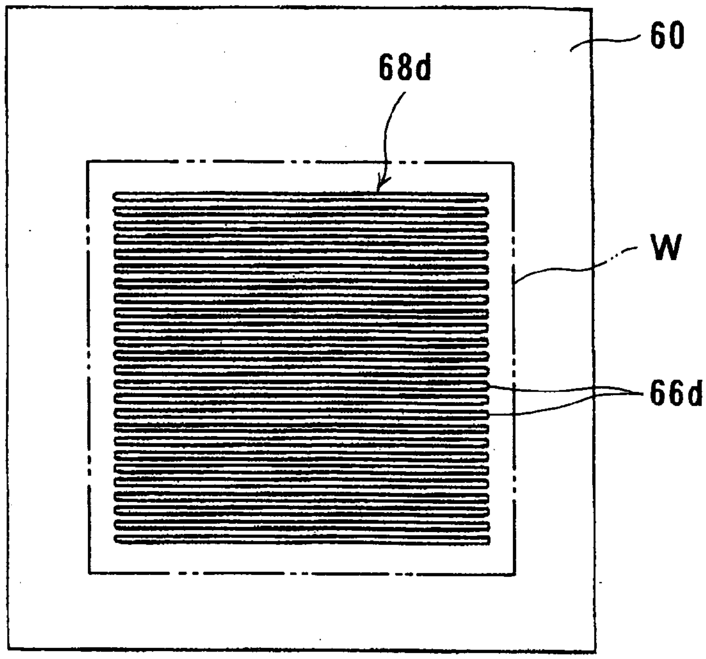


FIG. 10



F I G. 1 1



F I G. 1 2

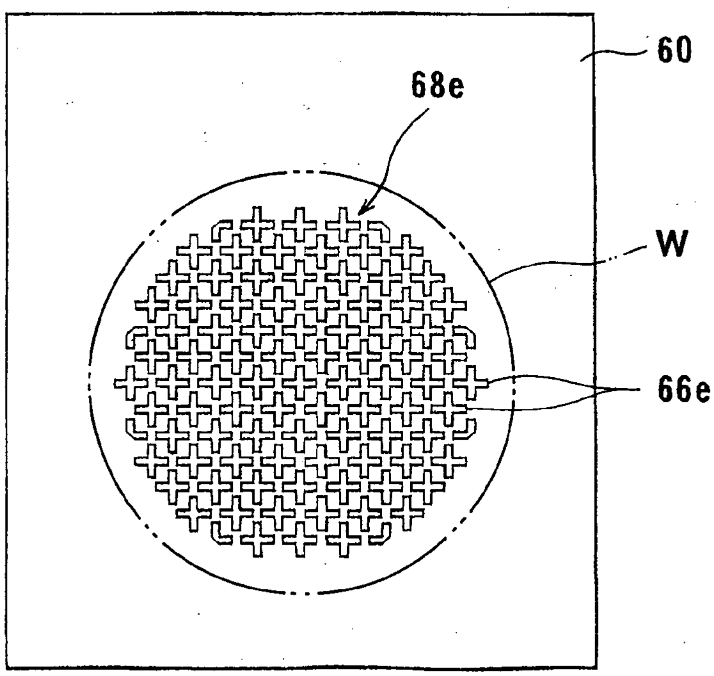


FIG. 13

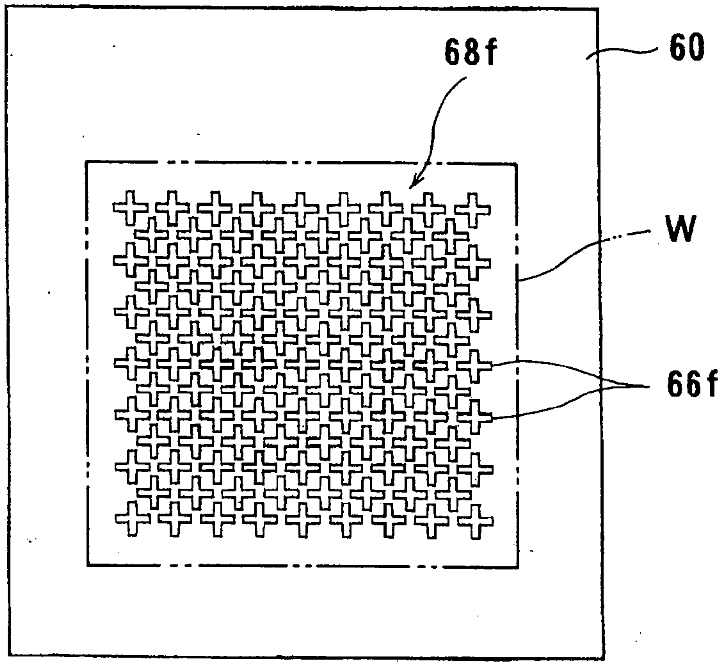


FIG. 14

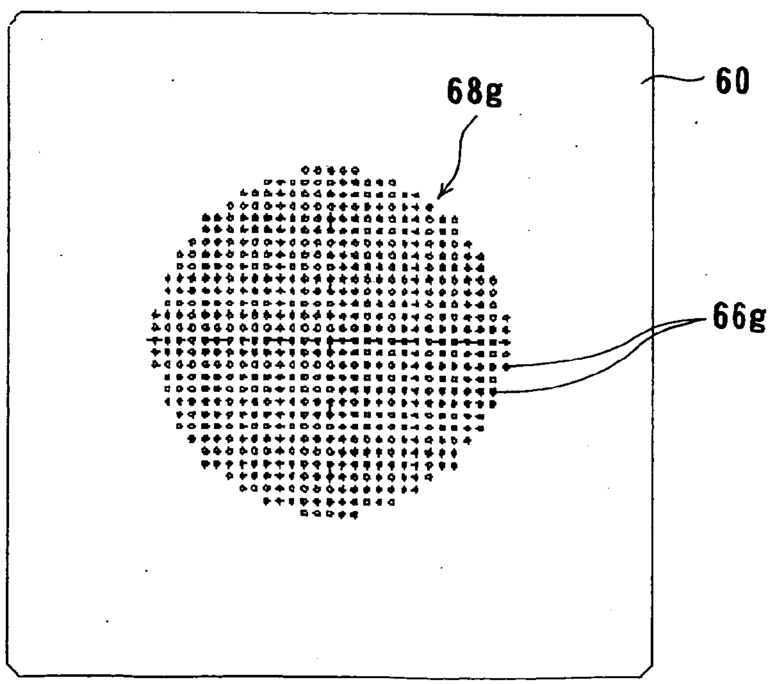


FIG. 15

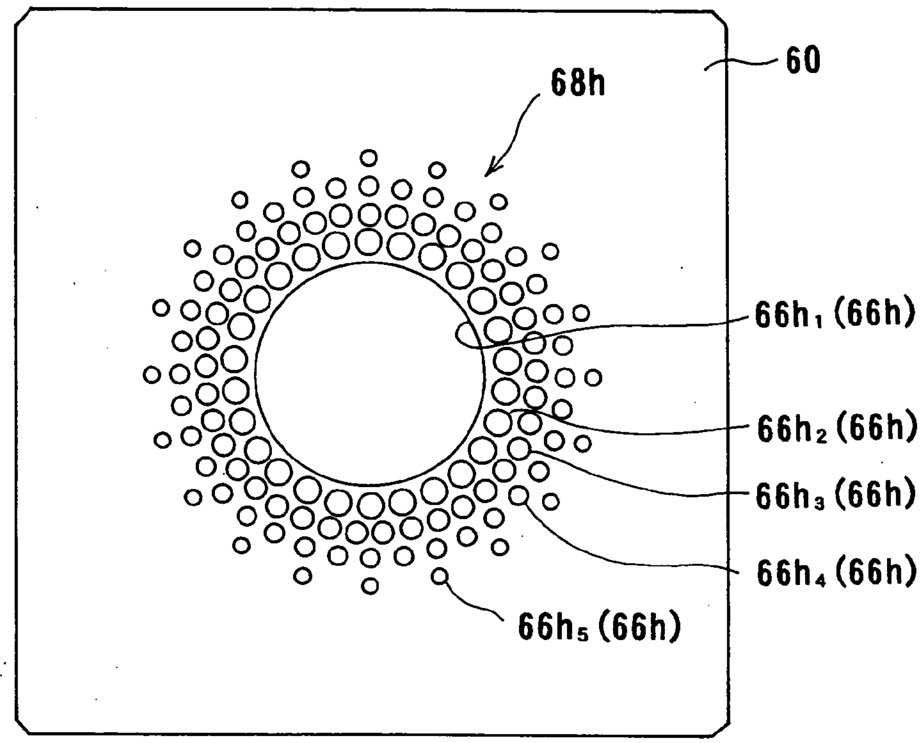

60
68h
66h1 (66h)
66h2 (66h)
66h3 (66h)
66h4 (66h)
66h5 (66h)

FIG. 16

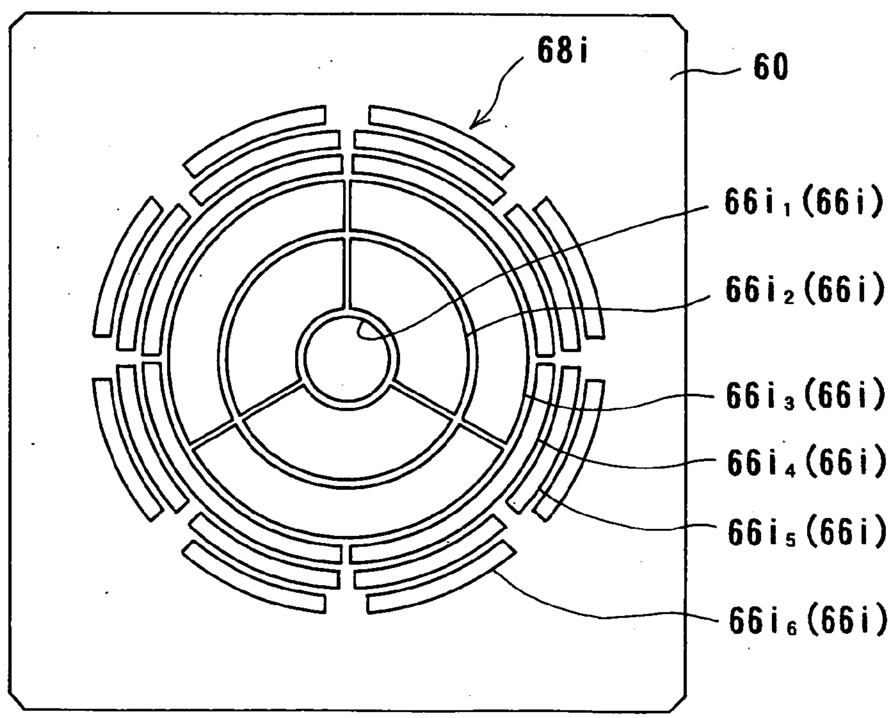

60
68i
66i1 (66i)
66i2 (66i)
66i3 (66i)
66i4 (66i)
66i5 (66i)
66i6 (66i)

FIG. 17

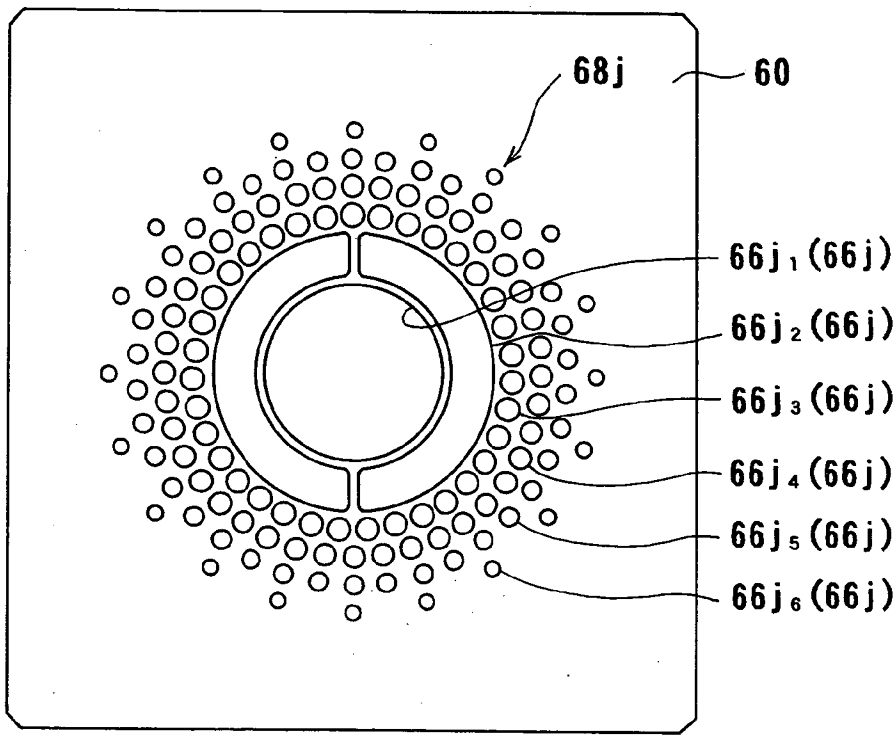
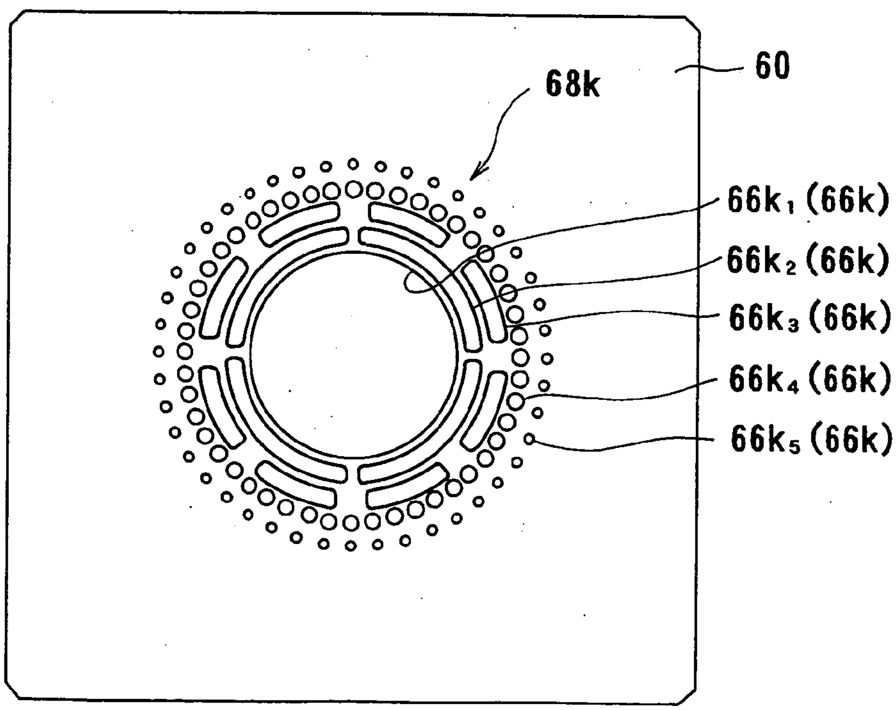
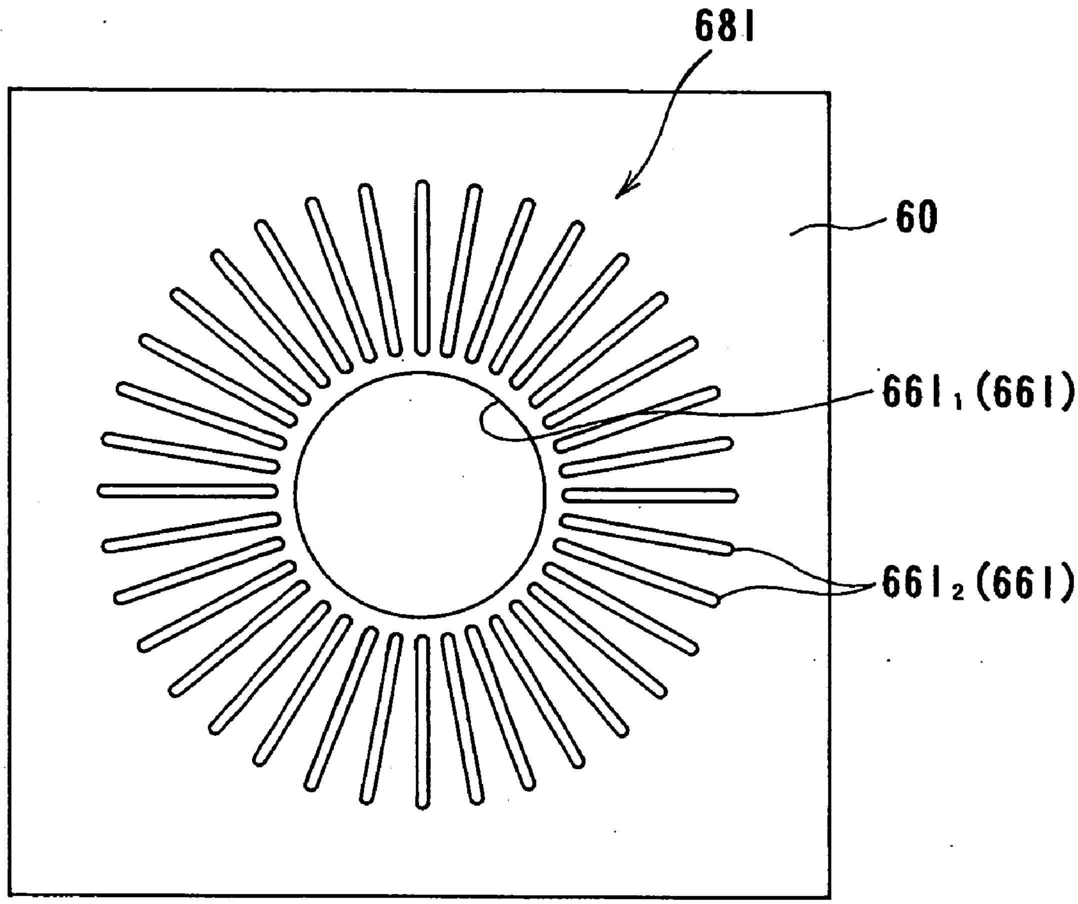

68j
60
66j1 (66j)
66j2 (66j)
66j3 (66j)
66j4 (66j)
66j5 (66j)
66j6 (66j)

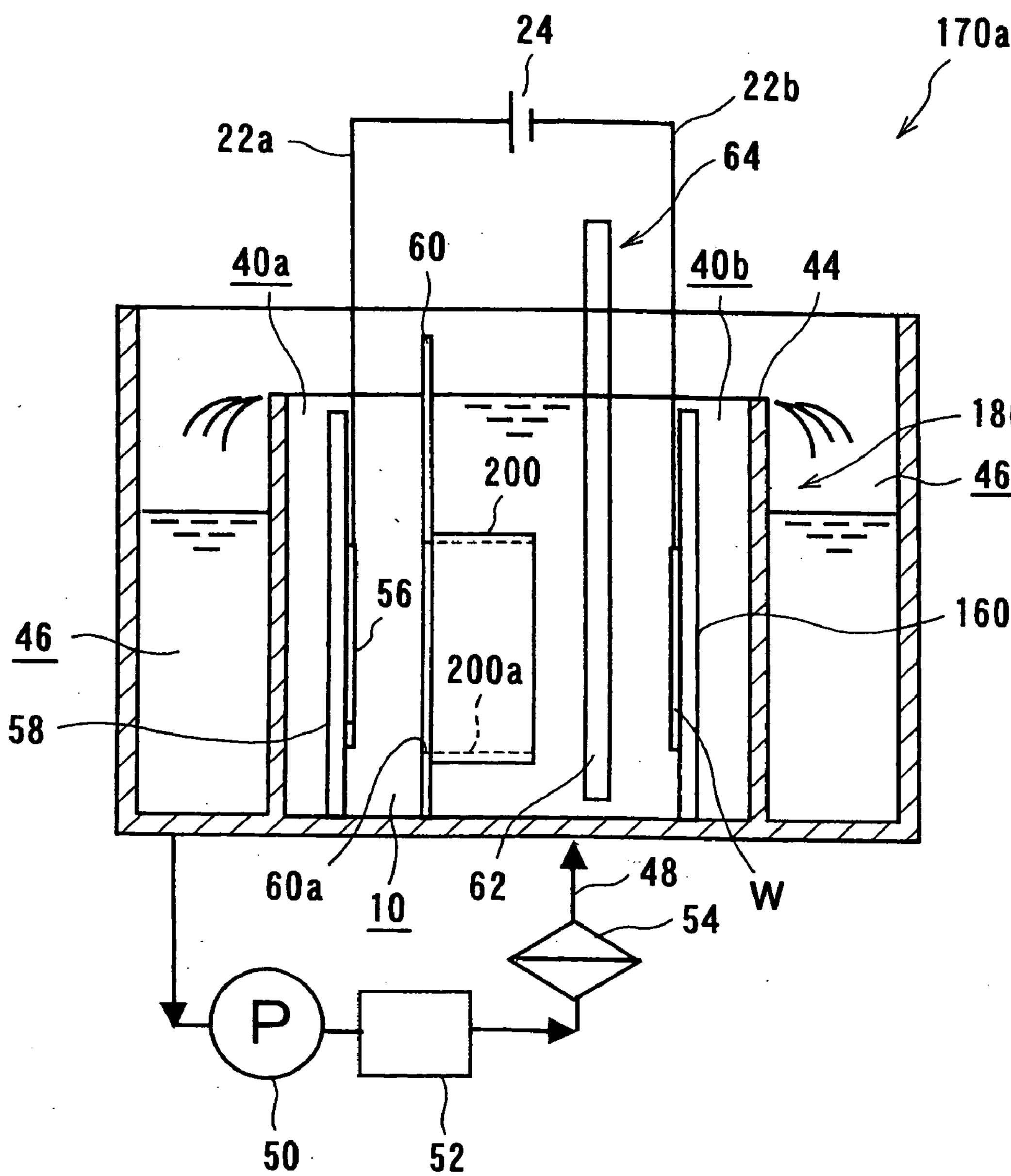
FIG. 18


68k
60
66k1 (66k)
66k2 (66k)
66k3 (66k)
66k4 (66k)
66k5 (66k)

F I G. 1 9



F I G. 2 0


24
170a
22b
22a
64
60
40a
40b
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186
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W
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50
52

FIG. 21A

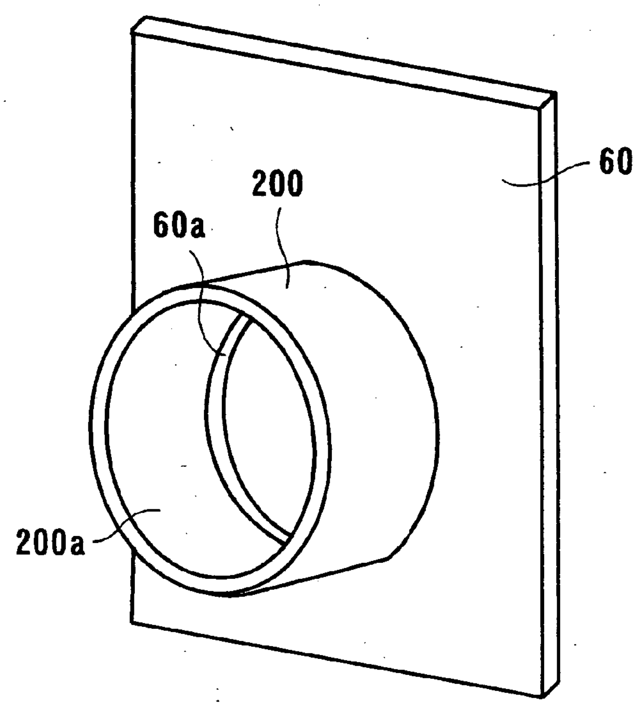


FIG. 21B

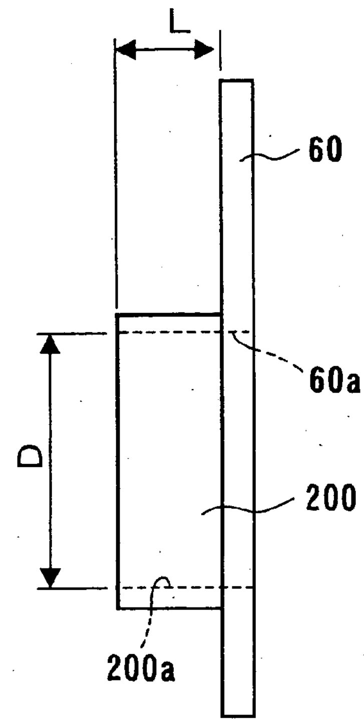


FIG. 22

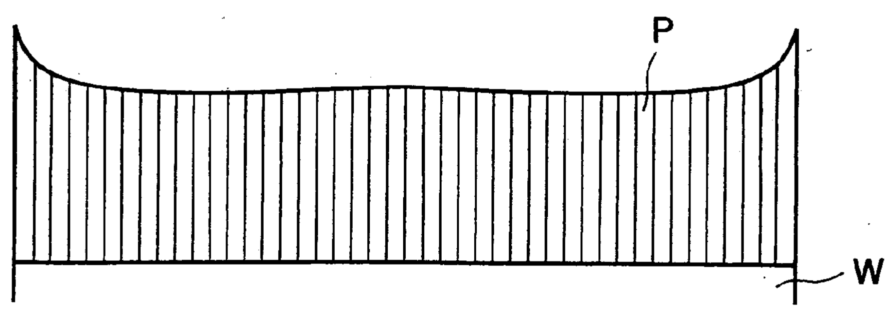
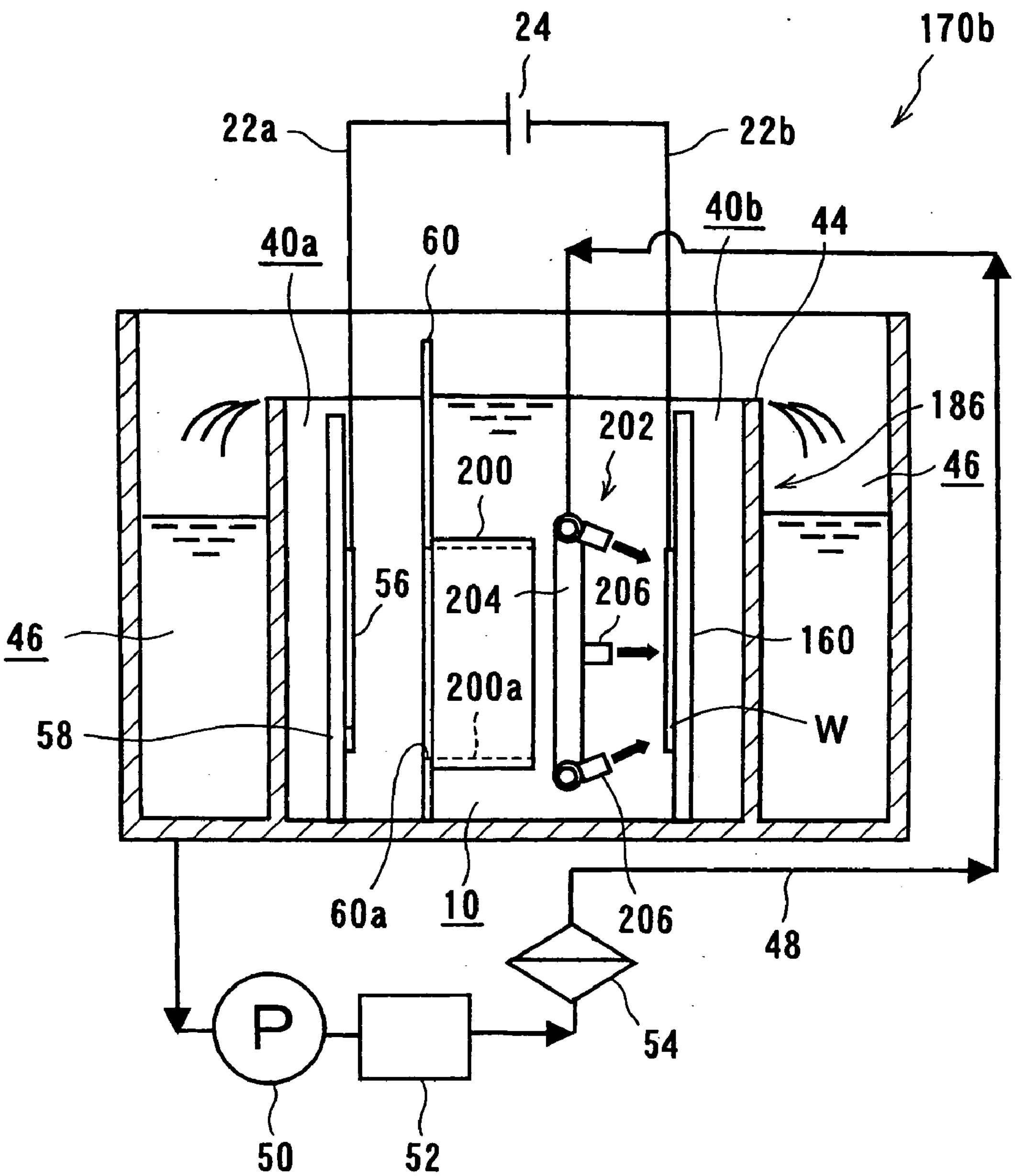


FIG. 23


24
170b
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40a
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40b
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W
60a
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206
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P
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FIG. 24A

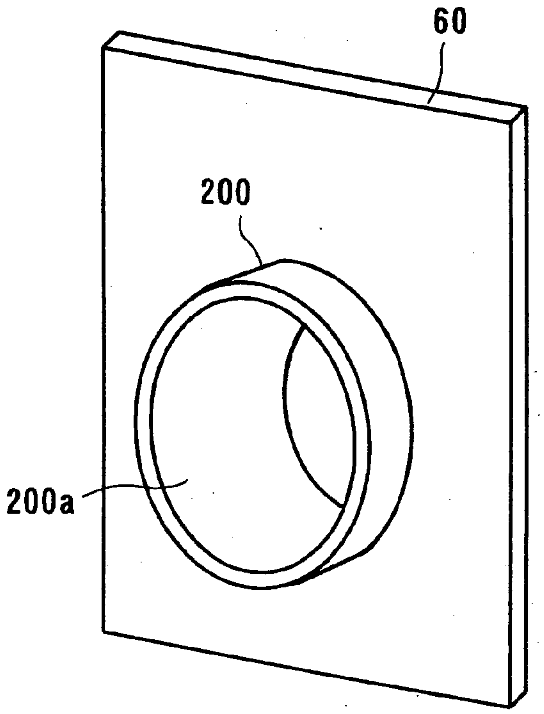


FIG. 24B

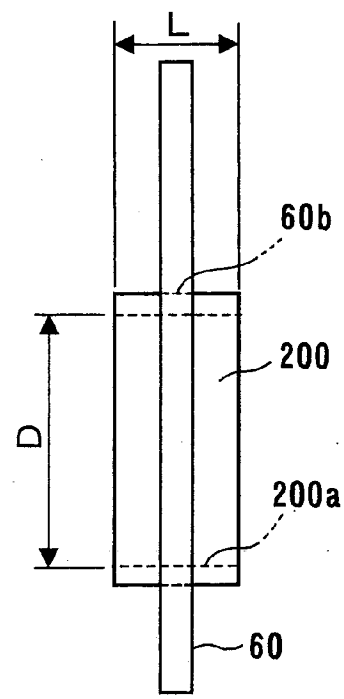


FIG. 25A

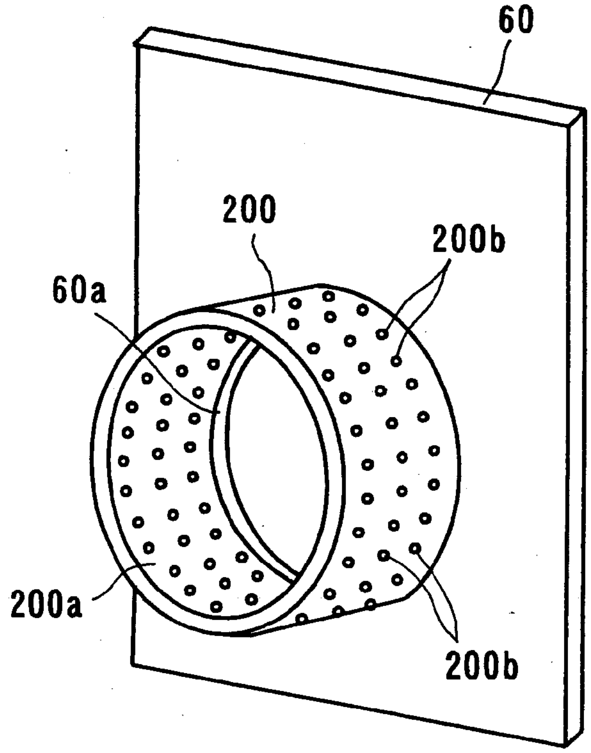


FIG. 25B

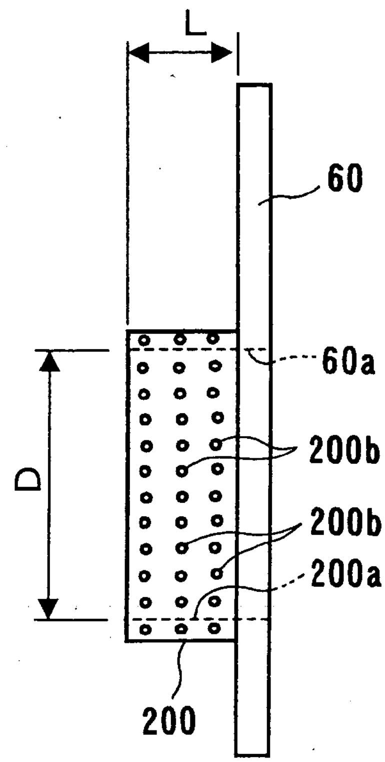


FIG. 26A

FIG. 26B

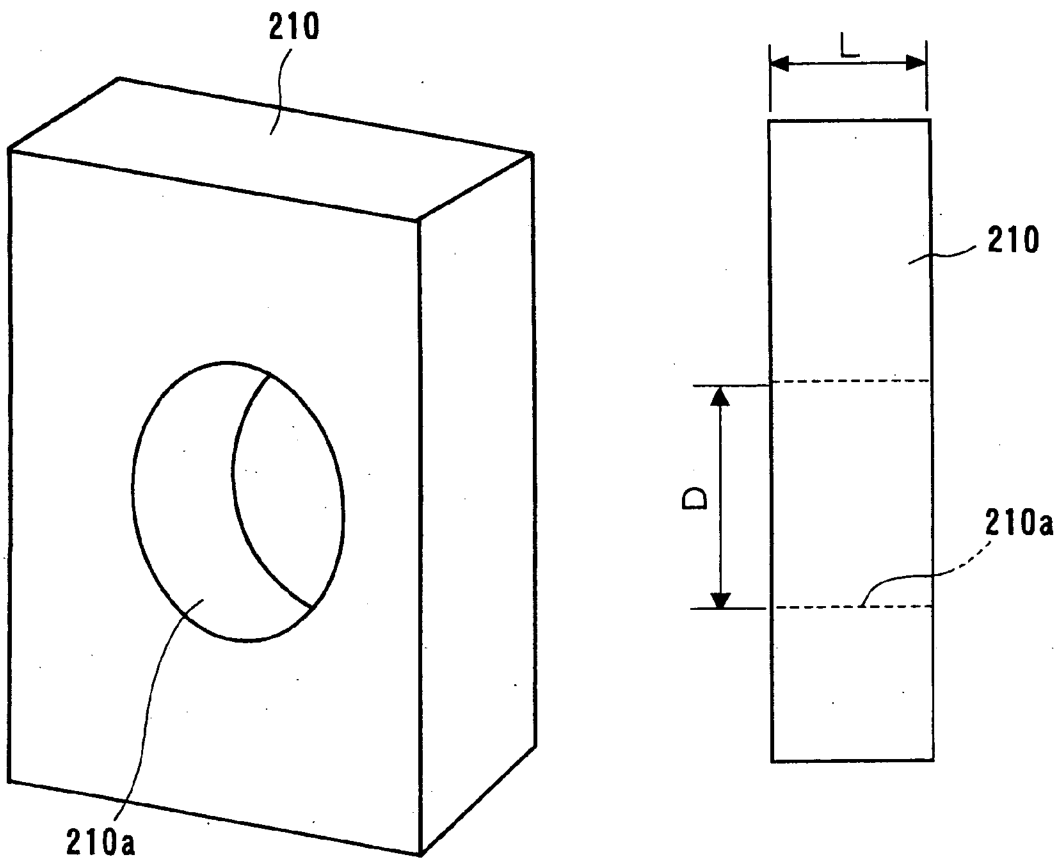


FIG. 27A

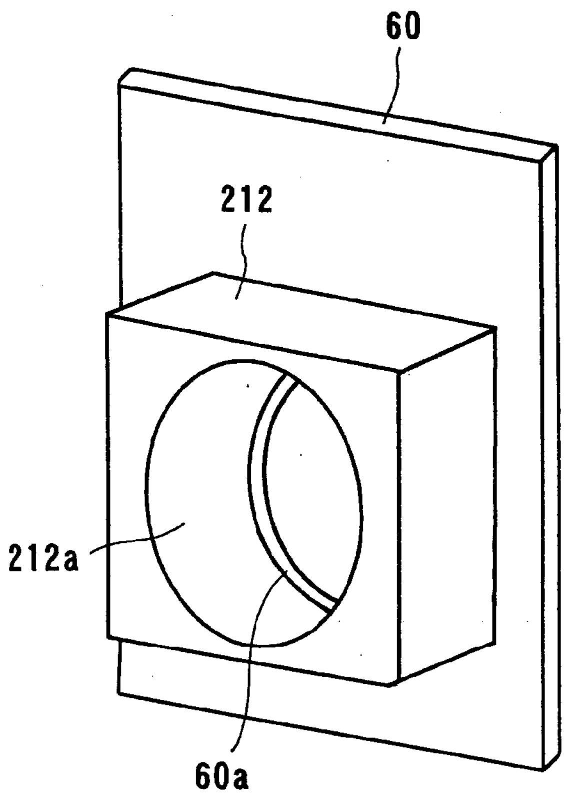
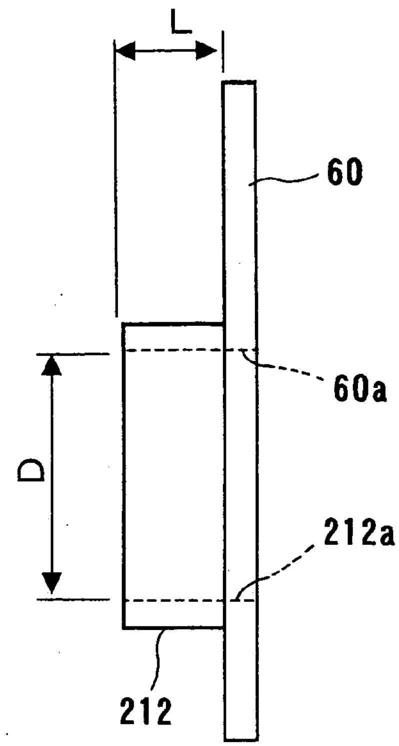
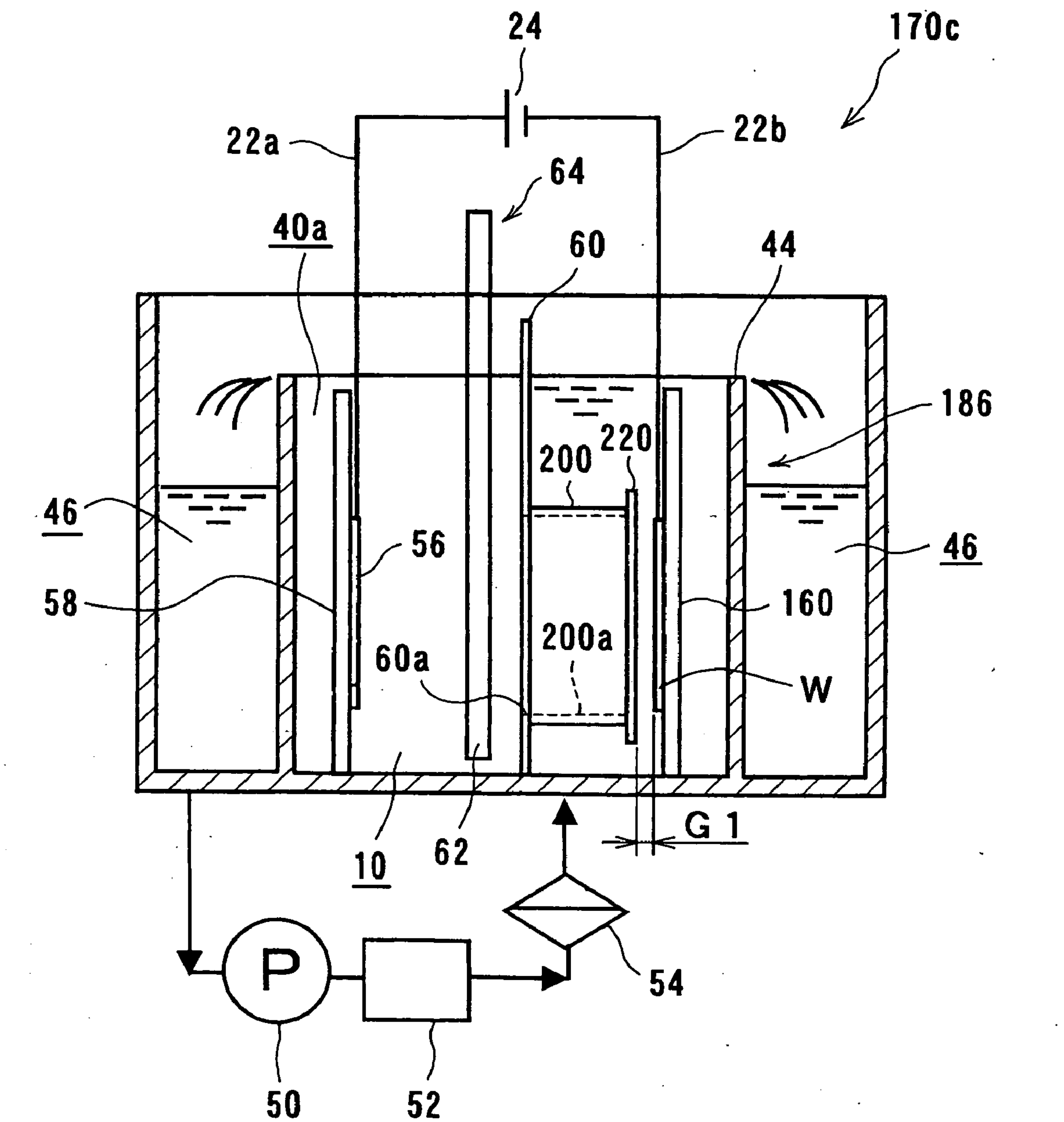


FIG. 27B



F I G. 28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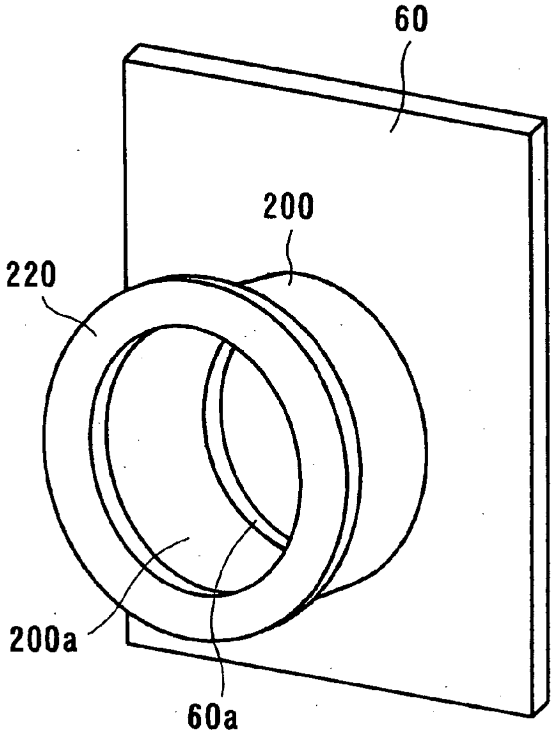
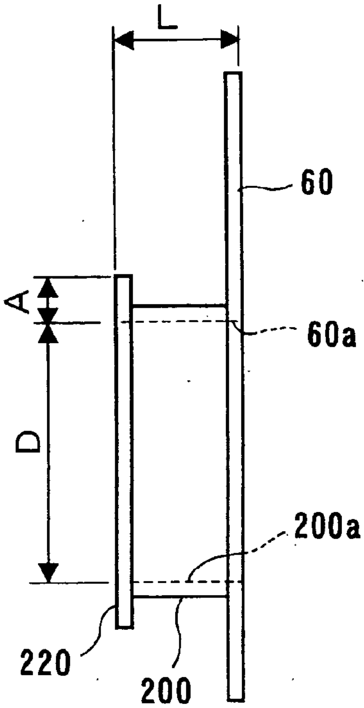
W
10
62
G 1
P
54
50
52

F I G. 2 9 A



F I G. 2 9 B



F I G. 3 0

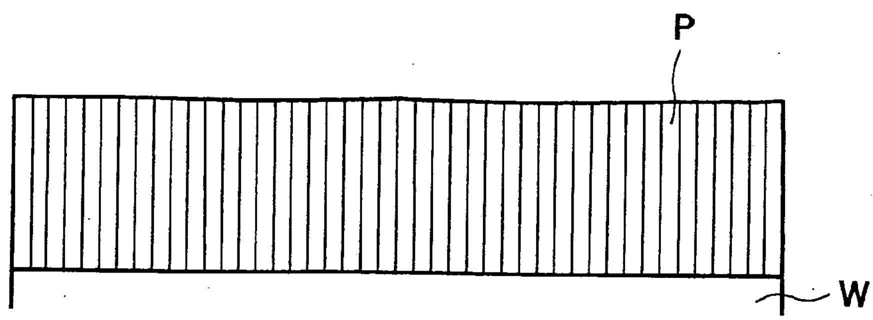
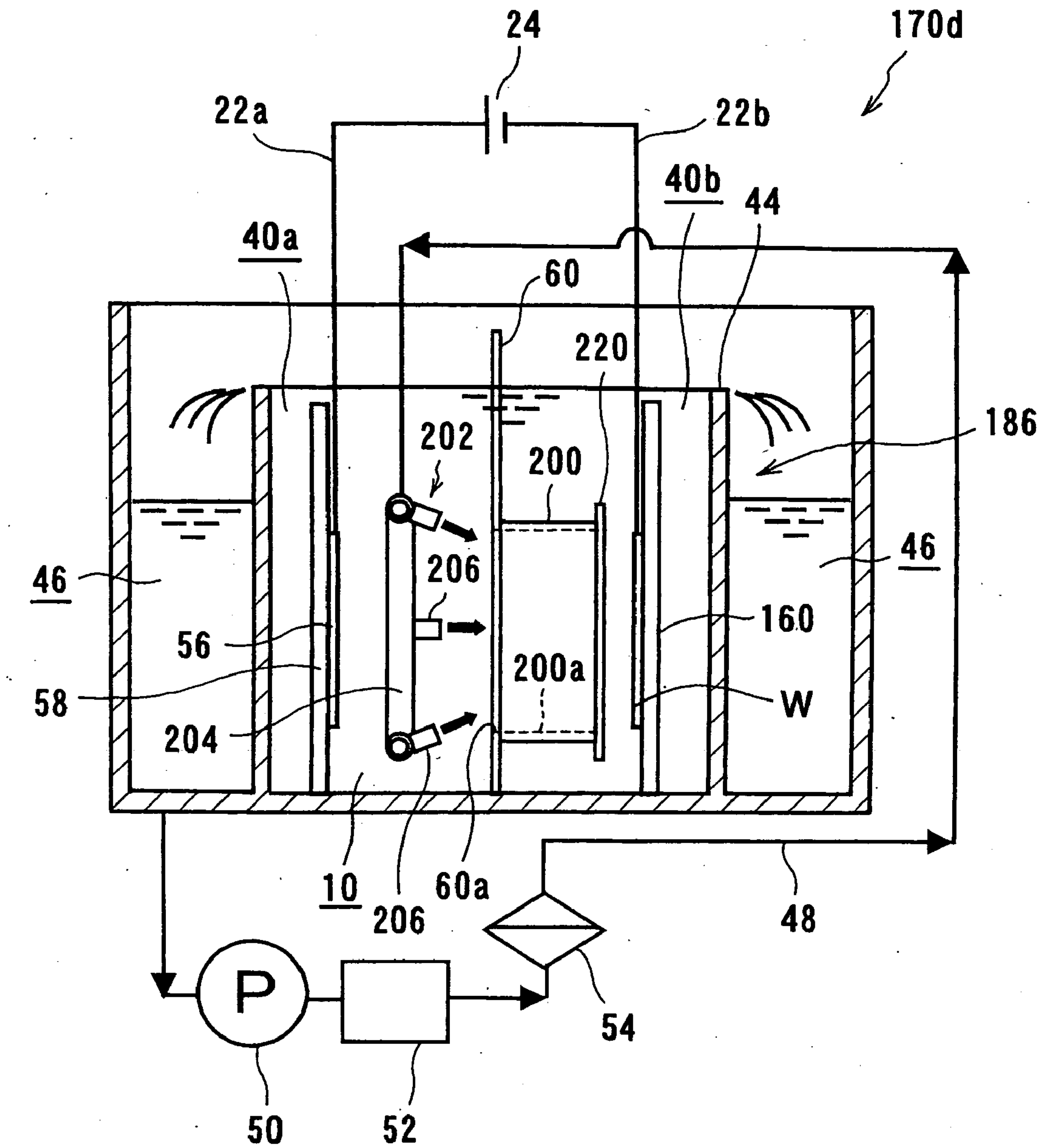


FIG. 31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40a
60
220
186
202
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W
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60a
48
P
54
50
52

FIG. 32A

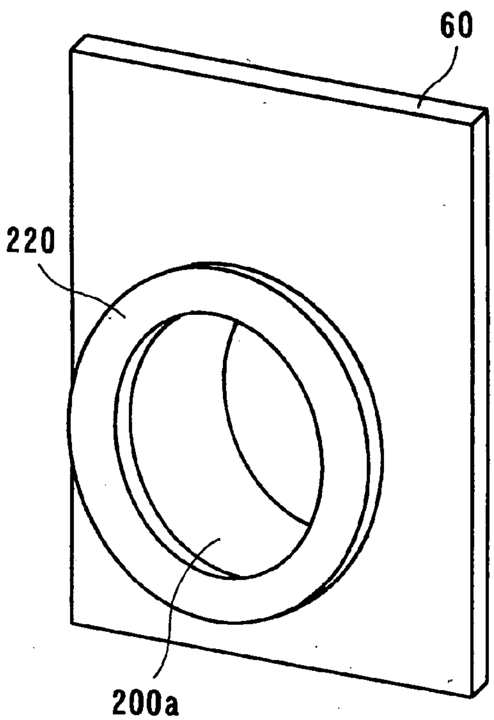


FIG. 32B

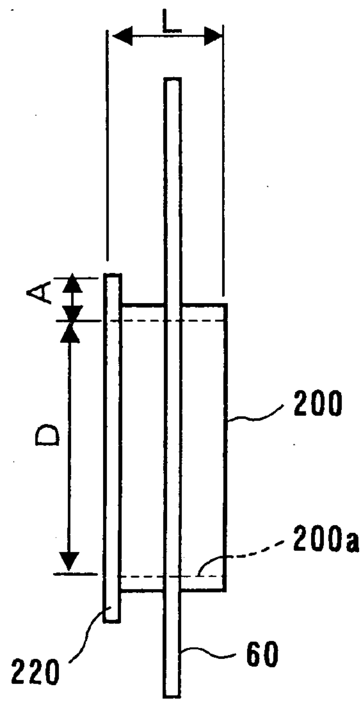


FIG. 33A

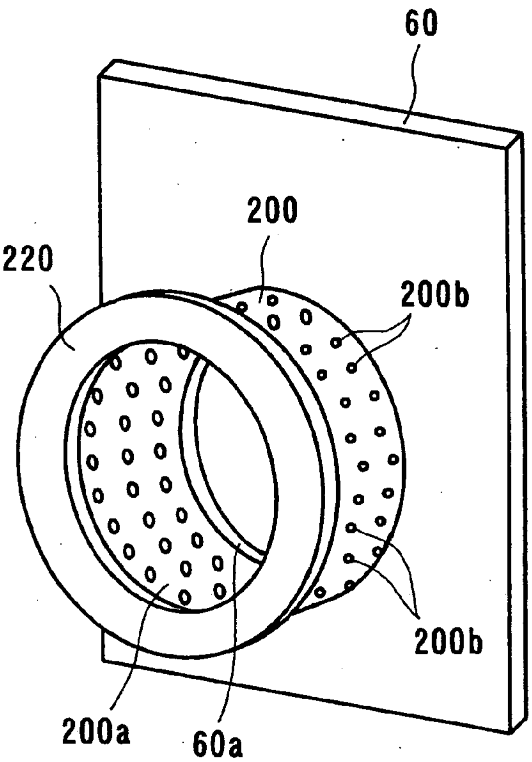


FIG. 33B

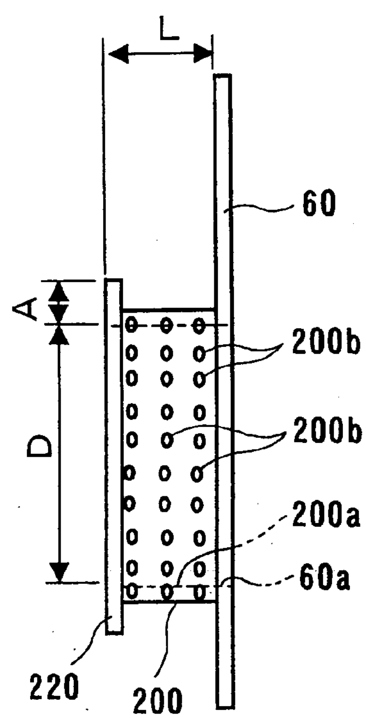


FIG. 34A

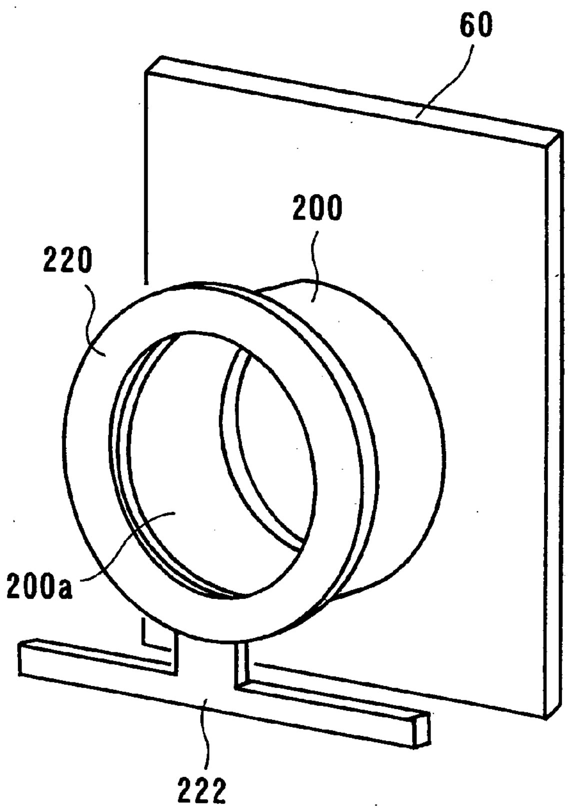


FIG. 34B

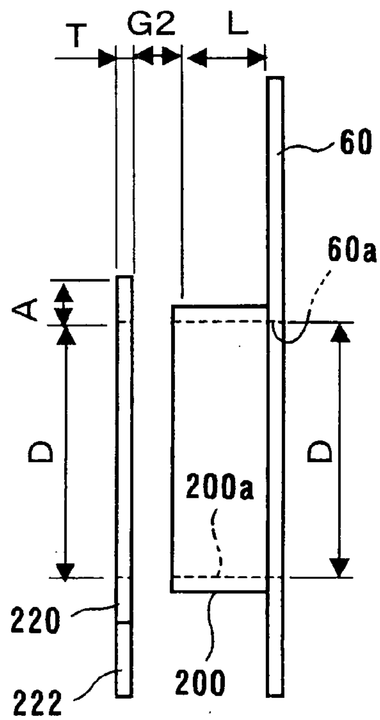


FIG. 35A

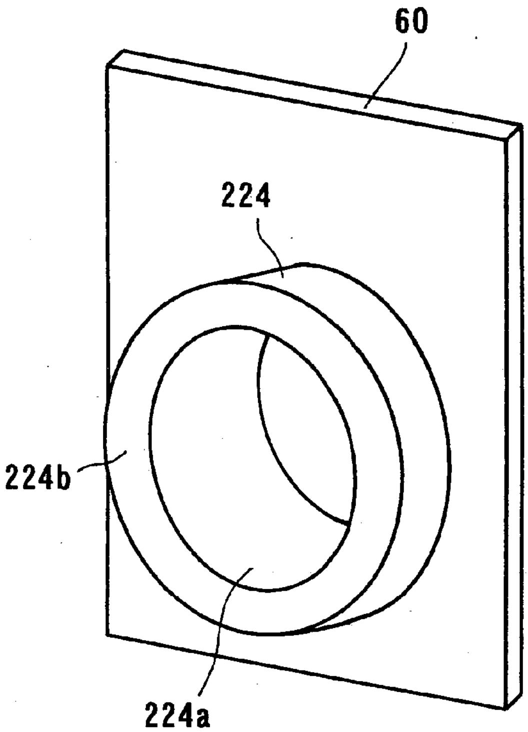


FIG. 35B

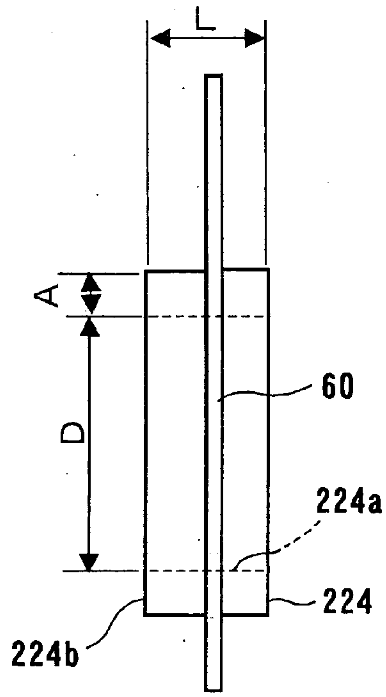


FIG. 36

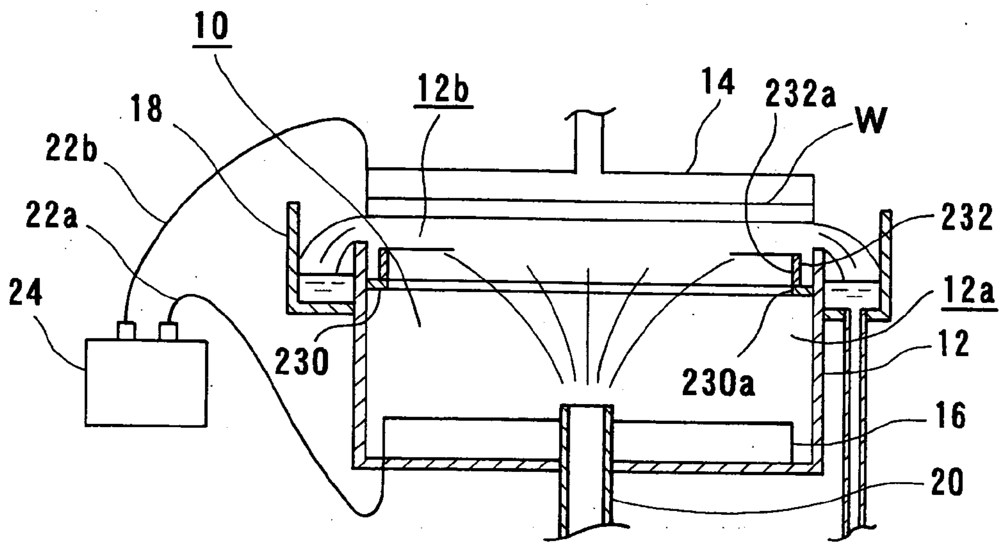


FIG. 37

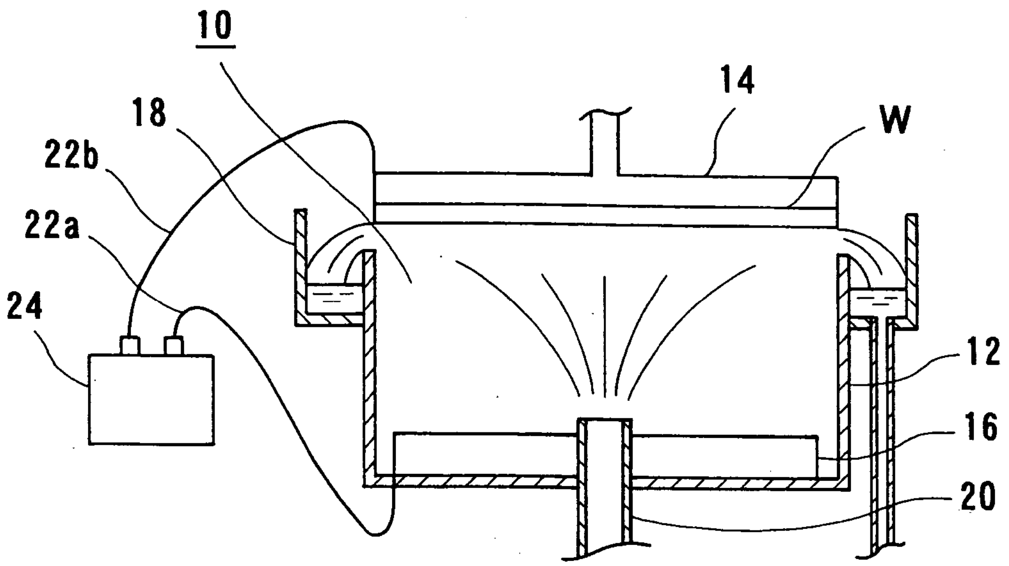


FIG. 38

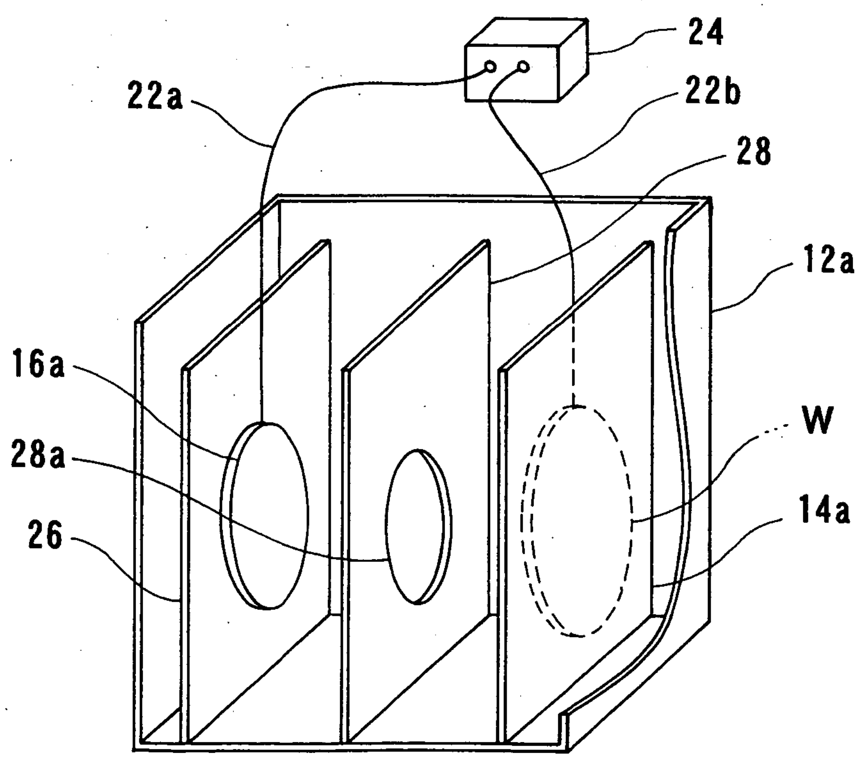


FIG. 39

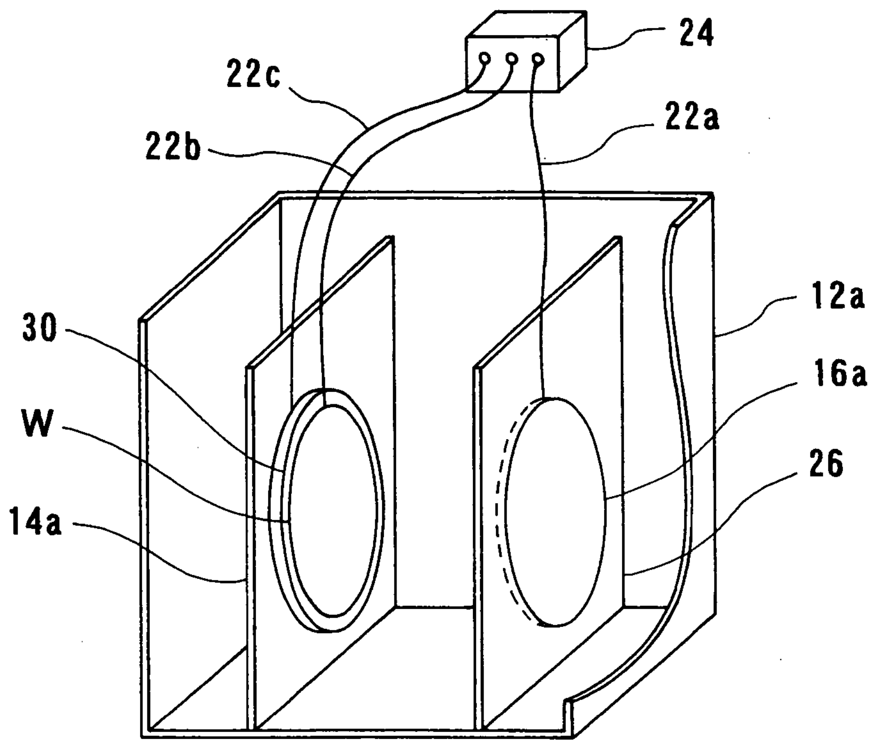
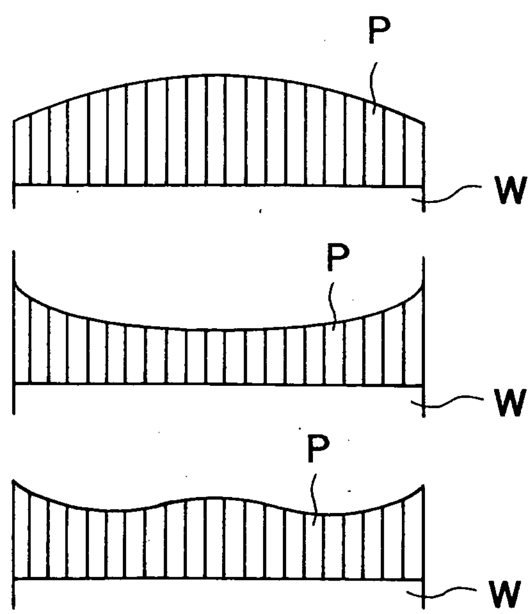


FIG. 40A

FIG. 40B

FIG. 40C



PLATING DEVICE

TECHNICAL FIELD

[0001] The present invention relates to a plating apparatus for carrying out plating of a surface of a plating workpiece to be plated, such as a substrate, and more particularly to a plating apparatus for forming a plated film in fine interconnect trenches or holes, via holes, through-holes, or resist openings formed in a surface of a semiconductor wafer or the like, or for forming a bump (protruding electrode), which provides electrical connection with an electrode of a package or the like, on a surface of a semiconductor wafer.

BACKGROUND ART

[0002] In TAB (Tape Automated Bonding) or FC (Flip Chip), for example, it has widely been practiced to form protruding connecting electrodes (bumps) of gold, copper, solder, lead-free solder, or nickel, or a multi-layer laminate of these metals at predetermined portions (electrodes) on a surface of a semiconductor chip having interconnects formed therein, and to electrically connect the interconnects via the bumps with electrodes of a package or with TAB electrodes. Methods of forming bumps include various methods, such as electroplating, vapor deposition, printing, and ball bumping. With a recent increase in the number of I/O in a semiconductor chip and a trend toward finer pitches, electroplating has more frequently been employed because it can cope with fine processing and has relatively stable performance.

[0003] With an electroplating method, a metal film (plated film) having a high purity can readily be obtained. Further, an electroplating method has a relatively high deposition rate of a metal film, and control of thickness of the metal film can be performed relatively easily.

[0004] **FIG. 37** shows an example of a conventional plating apparatus which employs a so-called face-down method. The plating apparatus has an upwardly opened plating tank **12** for holding a plating solution **10** therein and a vertically movable substrate holder **14** for detachably holding a substrate W in a state such that a front face (surface to be plated) of the substrate W faces downward (face-down). An anode **16** is disposed horizontally at a bottom of the plating tank **12**. Overflow tanks **18** are provided around an upper portion of the plating tank **12**. Further, a plating solution supply nozzle **20** is connected to the bottom of the plating tank **12**.

[0005] In operation, a substrate W held horizontally by the substrate holder **14** is located at a position such as to close an opening at an upper end of the plating tank **12**. In this state, the plating solution **10** is supplied from the plating solution supply nozzle **20** into the plating solution tank **12** and allowed to overflow the upper portion of the plating tank **12**, thereby bringing the plating solution **10** into contact with a surface of the substrate W held by the substrate holder **14**. Simultaneously, the anode **16** is connected via a conductor **22*a*** to an anode of a plating power supply **24**, and the substrate W is connected via a conductor **22*b*** to a cathode of the plating power supply **24**. Thus, due to a potential difference between the substrate W and the anode **16**, metal ions in the plating solution **10** receive electrons from the surface of the substrate W, so that metal is deposited on the surface of the substrate W so as to form a metal film.

[0006] According to the plating apparatus, uniformity of the thickness of the metal film formed on the surface of the substrate W can be adjusted to a certain extent by adjusting the size of the anode **16**, an interpolar distance and potential difference between the anode **16** and the substrate W, a supply rate of the plating solution **10** supplied from the plating solution supply nozzle **20**, and the like.

[0007] **FIG. 38** shows an example of a conventional plating apparatus which employs a so-called dipping method. The plating apparatus has a plating tank **12*a*** for holding a plating solution **12*a*** therein and a vertically movable substrate holder **14*a*** for detachably holding a substrate W in a state such that a front face (surface to be plated) is exposed while a peripheral portion of the substrate W is water-tightly sealed. An anode **16*a*** is held by an anode holder **26** and disposed vertically within the plating tank **12**. Further, a regulation plate **28** made of a dielectric material having a central hole **28*a*** is disposed in the plating tank **12** so as to be positioned between the anode **16*a*** and the substrate W when the substrate W held by the substrate holder **14*a*** is disposed at a position facing the anode **16*a***.

[0008] In operation, the anode **16*a***, the substrate W, and the regulation plate **28** are immersed in the plating solution in the plating tank **12*a***. Simultaneously, the anode **16*a*** is connected via a conductor **22*a*** to an anode of a plating power supply **24**, and the substrate W is connected via a conductor **22*b*** to a cathode of the plating power supply **24**. Accordingly, metal is deposited onto the surface of the substrate W so as to form a metal film in the same manner as described above.

[0009] According to the plating apparatus, distribution of thickness of the metal film formed on the surface of the substrate W can be adjusted to a certain extent by disposing the regulation plate **28** having the central hole **28*a*** between the anode **16*a*** and the substrate W disposed at a position facing the anode **16*a***, and adjusting a potential distribution on the plating bath **12*a*** with the regulation plate **28**.

[0010] **FIG. 39** shows another example of a conventional plating apparatus which employs a so-called dipping method. The plating apparatus differs from the apparatus shown in **FIG. 38** in that a ring-shaped dummy cathode (dummy electrode) **30** is provided instead of a regulation plate, that a substrate W is held by a substrate holder **14*a*** in a state such that the dummy cathode **30** is disposed around the substrate W, and that the dummy cathode **30** is connected to a cathode of a plating power supply **24** during plating.

[0011] According to the plating apparatus, uniformity of thickness of a plated film formed on the surface of the substrate W can be improved by adjusting an electric potential of the dummy cathode **30**.

[0012] On the other hand, for example, when a metal film (plated film) for interconnects or bumps is formed on a surface of a semiconductor substrate (wafer), the metal film formed is required to be uniform in surface profile and in film thickness over the entire surface of the substrate. There are increasing demands for a high degree of uniformity in recent high-density packaging technologies such as SOC and WL-CSP. However, with the above conventional plating apparatuses, it is quite difficult to form a metal film that meets a high degree of uniformity requirement.

[0013] Specifically, when a substrate is plated by the plating apparatus shown in **FIG. 37**, a metal film is formed under a strong influence of a flow of the plating solution. If the plating solution flows fast, as shown in **FIG. 40A**, the thickness of the metal film P tends to be thicker in a central portion of the substrate W, to which metal ions are sufficiently supplied, than in a peripheral portion of the substrate W. If the flow of the plating the solution is made considerably weak in order to prevent the above phenomenon, as shown in **FIG. 40B**, the thickness of the metal film P tends to be thicker in a peripheral portion of the substrate W than in a central portion. When a substrate W is plated by the plating apparatus shown in **FIG. 38**, a potential distribution can be improved by the regulation plate having the central hole, so that the uniformity of the film thickness distribution of a metal film can be improved to a certain extent over the entire surface of the substrate. However, as shown in **FIG. 40C**, the metal film P tends to have an undulate thickness distribution, in which the film thickness is thicker in a central portion and a peripheral portion of the substrate W. Further, when a substrate is plated by the plating apparatus shown in **FIG. 39**, it is difficult to adjust a voltage applied to the dummy electrode (dummy cathode). In addition, it becomes necessary to remove a metal film attached to a surface of the dummy electrode, and the removal necessitates a troublesome operation.

[0014] In the conventional plating apparatuses, there is a general tendency that due to a surface potential distribution produced over a surface of a substrate, the film thickness of a plated film is larger in a peripheral portion of the substrate, which serves as an electrically receiving portion, causing a U-shaped film thickness distribution over the substrate surface (see **FIG. 40B**). This is one of the main factors that impair the uniformity of film thickness. In order to suppress this phenomenon, a regulation plate or a dummy electrode is employed in a method of regulating supply of metal ions to a surface of a substrate, i.e. regulating a flow of a plating solution, and a method of controlling or regulating a potential distribution on a surface of a substrate and an electric field in a plating tank.

[0015] The regulating method of a flow of a plating solution and the regulating method using a regulation plate are intended to concentrate metal ions or an electric field to a central portion of a substrate to raise a plated film at the central portion of the substrate, thereby adjusting a film thickness distribution of the plated film over the entire substrate surface so as to be a W-shaped distribution and minimizing a film thickness variation from an average film thickness (see **FIG. 40C**). Accordingly, the uniformity of the film thickness is greatly influenced by regulation of the flow of the plating solution and by selection and fine control of the position of the regulation plate and the size of the central hole. Thus, the uniformity of the film thickness is greatly influenced by the degree of adjustment (tuning).

[0016] On the other hand, the method using a dummy electrode is intended to broaden a range of a potential distribution from a substrate surface to a region including the dummy electrode around the substrate, thereby shifting the raised portion of the plated film in the electrically receiving portion to the dummy electrode and obtaining an extremely uniform film thickness on the substrate surface. As an equivalent method to the method employing a dummy electrode, there has also been known a method which uses a pattern in a peripheral portion of a substrate as a "discarded chip" so as to serve as a dummy electrode. In such methods that employ a dummy electrode, the uniformity of the film thickness is influenced by adjustment of a voltage. Further, it is necessary to periodically remove a metal film (plated film) attached to the dummy electrode, which necessitates a troublesome operation. When a pattern in a peripheral portion of a substrate is used as a "discarded chip" so as to serve as a dummy electrode, the number of effective chips per substrate is inevitably reduced to thereby cause a lowered productivity.

[0017] All of the above-described methods eventually adjust a film thickness distribution to obtain a uniform film thickness distribution. Thus, none of the above-described methods are intended to positively control or regulate an electric field in a plating tank, which is produced between an anode and a plating workpiece as a cathode, so as to control and improve a potential distribution on a surface of the plating workpiece, thereby equalizing and improving the film thickness distribution of the plated film which would otherwise become a U-shaped distribution.

DISCLOSURE OF INVENTION

[0018] The present invention has been made in view of the above drawback. It is, therefore, an object of the present invention to provide a plating apparatus which can form a metal film (plated film) having a uniform thickness over an entire plating workpiece with a relatively simple arrangement and without needs for a complicated operation and setting.

[0019] In order to achieve the above object, the present invention provides a plating apparatus characterized by comprising a plating tank for holding a plating solution; an anode disposed so as to be immersed in the plating solution in the plating tank; a regulation plate disposed between the anode and a plating workpiece disposed so as to face the anode; and a plating power supply for supply a current between the anode and the plating workpiece to carry out plating, wherein the regulation plate is disposed so as to separate the plating solution held in the plating tank into a plating solution on the anode side and a plating solution on the plating workpiece side, and a through-hole group having a large number of through-holes is formed in the regulation plate.

[0020] According to the present invention, an electric field leaks through a large number of through-holes formed in the regulation plate disposed in the plating tank, and the leaked electric field spreads uniformly. Accordingly, a potential distribution can be made more uniform over an entire surface of the plating workpiece, and a within wafer uniformity of a metal film formed on the surface of the plating workpiece can be enhanced. Further, the plating solution is prevented from passing through a large number of through-holes formed in the regulation plate provided in the plating tank. Accordingly, non-uniform film thickness is prevented from being caused to a metal film formed on the surface of the plating workpiece due to influence of a flow of the plating solution.

[0021] According to a preferred aspect of the present invention, the through-hole group is formed by a plurality of slit-like elongated holes extending linearly in one direction or extending in an arc. The use of slit-like elongated holes as the through-holes can promote leakage of electric field while preventing the plating solution from passing through the through-holes. For example, the widths of the elongated holes are set to be about 0.5 to 20 mm, preferably about 1 to 15 mm. The lengths of the elongated holes are determined depending upon the shape of the plating workpiece.

[0022] According to a preferred aspect of the present invention, the through-hole group is formed by a plurality of cross holes extending crosswise in vertical and horizontal directions.

[0023] According to a preferred aspect of the present invention, the through-hole group is formed by a combination of a plurality of fine holes, a plurality of holes having different diameters, and slit-like elongated holes. The use of a combination of a plurality of fine holes, a plurality of holes having different diameters, and slit-like elongated holes as the through-hole group can increase the productivity. For example, the diameters of the fine holes or small holes (peripheral holes) are set to be about 1 to 20 mm, preferably about 2 to 10 mm. For example, the diameters of large holes (central holes) are set to be about 50 to 300 mm, preferably about 30 to 100 mm.

[0024] It is desirable that the through-hole group be formed in the regulation plate substantially over an entire area facing the plating workpiece, and formed in an area substantially similar to a shape of the plating workpiece. With such a through-hole group, it is possible to form a metal film having a good film thickness uniformity in all directions on the plating workpiece.

[0025] Preferably, the plating apparatus comprises an agitating mechanism provided between the plating workpiece and the regulation plate for stirring the plating solution held in the plating tank. By agitating the plating solution between the plating workpiece and the regulation plate by the agitating mechanism during plating, sufficient ions can be supplied more uniformly to the plating workpiece. Therefore, a metal film having a more uniform thickness can be formed more rapidly.

[0026] Preferably, the agitating mechanism should comprise a paddle-type agitating mechanism having a paddle which reciprocates parallel to the plating workpiece. By reciprocating a paddle parallel to the plating workpiece during plating to agitate the plating solution by the paddle, the directionality of the flow of the plating solution can be eliminated, and simultaneously sufficient ions can be supplied more uniformly to the surface of the plating workpiece.

[0027] According to a preferred aspect of the present invention, the anode and the regulation plate are provided in a vertical direction. This arrangement provides a plating apparatus with a small installation space and having excellent maintainability.

[0028] The present invention also provides another plating apparatus characterized by comprising a plating tank for holding a plating solution; an anode disposed so as to be immersed in the plating solution in the plating tank; a regulation plate disposed between the anode and a plating workpiece disposed so as to face the anode; and a plating power supply for supply a current between the anode and the plating workpiece to carry out plating, wherein the regulation plate is disposed so as to separate the plating solution held in the plating tank into a plating solution on the anode side and a plating solution on the plating workpiece side, and a plating solution passage is formed in the regulation plate for allowing an electric field to uniformly pass therethrough and allowing the plating solution to pass therethrough.

[0029] By thus allowing the electric field produced between the anode and the plating workpiece in the plating tank to pass uniformly through the plating solution passage without leaking out of the plating solution passage, distortion or deviation of the electric field can be adjusted and corrected so as to equalize a potential distribution over an entire surface of the plating workpiece, thereby enhancing a within wafer uniformity of a metal film formed on the plating workpiece.

[0030] The length of the plating solution passage is properly determined depending upon the shape of the plating tank, the distance between the anode and the plating workpiece, and the like. However, the length is generally 10 to 90 mm, preferably 20 to 75 mm, more preferably 30 to 60 mm.

[0031] Preferably, the plating solution passage is defined by an inner circumferential surface of a cylindrical member or a rectangular block. This arrangement can simplify the structure.

[0032] It is desirable that a large number of through-holes having a size such as to prevent leakage of an electric field be formed in a circumferential wall of the cylindrical member. With this arrangement, the plating solution is allowed to pass through the through-holes formed in the circumferential wall of the cylindrical member while preventing leakage of the electric field. Accordingly, the concentration of the plating solution is prevented from being different between the inside and outside of the cylindrical member. With respect to the shape of the through-holes, for example, fine holes, slit-like elongated holes, cross holes extending vertically and horizontally, and a combination thereof may be exemplified.

[0033] According to a preferred aspect of the present invention, the plating apparatus comprises an agitating mechanism provided in at least one of a space between the plating workpiece and the regulation plate and a space between the anode and the regulation plate for agitating the plating solution held in the plating tank. By agitating the plating solution during plating, the concentration of the plating solution containing metal ions and various additives can be made uniform in the plating tank, and the plating solution having a uniform concentration can be supplied to the plating workpiece. Accordingly, a metal film having a more uniform thickness can be formed more rapidly.

[0034] The agitating mechanism is preferably a paddle-type agitating mechanism having a paddle which reciprocates parallel to the plating workpiece.

[0035] The agitating mechanism may comprise a plating solution injection type agitating mechanism having a plurality of plating solution injection nozzles for ejecting the plating solution toward the plating workpiece. By injecting the plating solution from the plurality of plating solution injection nozzles toward the plating workpiece, the plating solution in the plating tank can be agitated so as to uniformize the plating solution concentration and, simultaneously, to sufficiently supply components of the plating solution to the plating workpiece. Thus, a metal film having a more uniform thickness can be formed more rapidly.

[0036] The plating solution passage may be formed in the regulation plate integrally with the regulation plate. A thick regulation plate may be used, and a through-hole may be formed in the regulation plate so as to serve as a plating solution passage.

[0037] The present invention provides yet another plating apparatus comprising a plating tank for holding a plating solution; an anode disposed so as to be immersed in the plating solution in the plating tank; a regulation plate disposed between the anode and a plating workpiece disposed so as to face the anode for separating the plating solution held in the plating tank into a plating solution on the anode side and a plating solution on the plating workpiece side, the regulation plate having a plating solution passage for allowing an electric field to uniformly pass therethrough and allowing the plating solution to pass therethrough; a plating power supply for supply a current between the anode and the plating workpiece to carry out plating; and an electric field adjustment ring disposed at an end of the plating solution passage on the plating workpiece side for adjusting an electric field at a peripheral portion of the plating workpiece.

[0038] By adjusting an electric field at a peripheral portion of the plating workpiece by the electric field adjustment ring, an electric field produced between the anode and the plating workpiece can be uniformized over an entire surface of the plating workpiece, including an edge portion of the plating workpiece, which serves as an electrically receiving portion. Therefore, a within wafer uniformity of a metal film formed on the plating workpiece can be further enhanced.

[0039] The shape of the electric field adjustment ring may be properly determined depending upon the shape of the plating tank, the shape of the plating workpiece, the distance between the anode and the plating workpiece, and the like. The width of the ring is generally set to be in a range of 1 to 20 mm, preferably 3 to 17 mm, more preferably 5 to 15 mm.

[0040] A gap between the electric field adjustment ring and the plating workpiece is generally set to be in a range of 0.5 to 30 mm, preferably 1 to 15 mm, more preferably 1.5 to 6 mm.

[0041] According to a preferred aspect of the present invention, the plating solution passage is defined by an inner circumferential surface of a cylindrical member, and the electric field adjustment ring is connected to an end of the cylindrical member on the plating workpiece side.

[0042] Alternatively, the plating solution passage may be defined by an inner circumferential surface of a cylindrical member, and the electric field adjustment ring may be disposed at an end of the cylindrical member on the plating workpiece side so as to be separated from the cylindrical member. With such a separated plating solution passage, the cylindrical member and the electric field adjustment ring can be separated so as to offer a broader choice.

[0043] Alternatively, the plating solution passage may be defined by an inner circumferential surface of a cylindrical member, and the electric field adjustment ring may be formed on an end surface of the plating workpiece side. With this arrangement, the number of parts can be reduced.

BRIEF DESCRIPTION OF DRAWINGS

[0044] **FIG. 1** is an overall layout of a plating facility having a plating apparatus according to an embodiment of the present invention;

[0045] **FIG. 2** is a schematic view of a transfer robot provided in a plating space of a plating processing apparatus shown in **FIG. 1**;

[0046] **FIG. 3** is a schematic cross-sectional view of a plating apparatus provided in the plating processing apparatus shown in **FIG. 1**;

[0047] **FIG. 4** is a schematic perspective view of a main portion of the plating apparatus shown in **FIG. 3**;

[0048] **FIG. 5** is a plan view of a regulation plate provided in the plating apparatus shown in **FIG. 3**;

[0049] **FIG. 6** is a schematic diagram illustrating a state of a metal film (plated film) formed by the plating apparatus shown in **FIG. 3**;

[0050] **FIGS. 7A through 7E** are cross-sectional diagrams sequentially illustrating a process of forming a bump (protruding electrode) on a substrate;

[0051] **FIG. 8** is a plan view showing another example of a regulation plate;

[0052] **FIG. 9** is a plan view showing still another example of a regulation plate;

[0053] **FIG. 10** is a plan view showing yet another example of a regulation plate;

[0054] **FIG. 11** is a plan view showing yet another example of a regulation plate;

[0055] **FIG. 12** is a plan view showing yet another example of a regulation plate;

[0056] **FIG. 13** is a plan view showing yet another example of a regulation plate;

[0057] **FIG. 14** is a plan view showing yet another example of a regulation plate;

[0058] **FIG. 15** is a plan view showing yet another example of a regulation plate;

[0059] **FIG. 16** is a plan view showing yet another example of a regulation plate;

[0060] **FIG. 17** is a plan view showing yet another example of a regulation plate;

[0061] **FIG. 18** is a plan view showing yet another example of a regulation plate;

[0062] **FIG. 19** is a plan view showing yet another example of a regulation plate;

[0063] **FIG. 20** is a schematic cross-sectional view showing a plating apparatus according to another embodiment of the present invention;

[0064] **FIG. 21A** is a perspective view showing a regulation plate and a cylindrical member provided in the plating apparatus shown in **FIG. 20**;

[0065] **FIG. 21B** is a front view of **FIG. 21A**;

[0066] **FIG. 22** is a schematic diagram illustrating a state of a metal film (plated film) formed by the plating apparatus shown in **FIG. 20**;

[0067] **FIG. 23** is a schematic cross-sectional view showing a plating apparatus according to still another embodiment of the present invention;

[0068] **FIG. 24A** is a perspective view showing another example of a regulation plate and a cylindrical member;

[0069] **FIG. 24B** is a front view of **FIG. 24A**;

[0070] **FIG. 25A** is a perspective view showing still another example of a regulation plate and a cylindrical member;

[0071] **FIG. 25B** is a front view of **FIG. 25A**;

[0072] **FIG. 26A** is a perspective view showing yet another example of a regulation plate and a cylindrical member;

[0073] **FIG. 26B** is a front view of **FIG. 26A**;

[0074] **FIG. 27A** is a perspective view showing yet another example of a regulation plate and a cylindrical member;

[0075] **FIG. 27B** is a front view of **FIG. 27A**;

[0076] **FIG. 28** is a schematic cross-sectional view showing a plating apparatus according to yet another embodiment of the present invention;

[0077] **FIG. 29A** is a perspective view showing a regulation plate, a cylindrical member, and an electric field adjustment ring provided in the plating apparatus shown in **FIG. 28**;

[0078] **FIG. 29B** is a front view of **FIG. 29A**;

[0079] **FIG. 30** is a schematic diagram illustrating a metal film (plated film) formed by the plating apparatus shown in **FIG. 28**;

[0080] **FIG. 31** is a schematic cross-sectional view showing a plating apparatus according to yet another embodiment of the present invention;

[0081] **FIG. 32A** is a perspective view showing another example of a regulation plate, a cylindrical member, and an electric field adjustment ring;

[0082] **FIG. 32B** is a front view of **FIG. 32A**;

[0083] **FIG. 33A** is a perspective view showing still another example of a regulation plate, a cylindrical member, and an electric field adjustment ring;

[0084] **FIG. 33B** is a front view of **FIG. 33A**;

[0085] **FIG. 34A** is a perspective view showing yet another example of a regulation plate, a cylindrical member, and an electric field adjustment ring;

[0086] **FIG. 34B** is a front view of **FIG. 34A**;

[0087] **FIG. 35A** is a perspective view showing yet another example of a regulation plate, a cylindrical member, and an electric field adjustment ring;

[0088] **FIG. 35B** is a front view of **FIG. 35A**;

[0089] **FIG. 36** is a schematic cross-sectional view showing a plating apparatus according to yet another embodiment of the present invention;

[0090] **FIG. 37** is a schematic cross-sectional view showing an example of a conventional plating apparatus;

[0091] **FIG. 38** is a schematic perspective view showing another example of a conventional plating apparatus;

[0092] **FIG. 39** is a schematic perspective view showing still another example of a conventional plating apparatus; and

[0093] **FIGS. 40A through 40C** are schematic diagrams illustrating various states of metal films (plated films) formed by conventional plating apparatuses.

BEST MODE FOR CARRYING OUT THE INVENTION

[0094] Embodiments of the present invention will be described below with reference to the drawings. The following embodiments show examples in which a substrate such as a semiconductor wafer is used as a plating workpiece.

[0095] **FIG. 1** shows an overall layout of a plating facility having a plating apparatus according to an embodiment of the present invention. The plating facility is designed so as to automatically perform all the plating processes including pretreatment of a substrate, plating, and posttreatment of the plating, in a successive manner. The interior of an apparatus frame **110** having an armored panel attached thereto is divided by a partition plate **112** into a plating space **116** for performing a plating process of a substrate and treatments of the substrate to which a plating solution is attached, and a clean space **114** for performing other processes, i.e. processes not directly involving a plating solution. Two substrate holders **160** (see **FIG. 2**) are arranged in parallel, and substrate attachment/detachment stages **162** to attach a substrate to and detach a substrate from each substrate holder **160** are provided as a substrate delivery section on a partition portion partitioned by the partition plate **112**, which divides the plating space **116** from the clean space **114**. Loading/unloading ports **120**, on which substrate cassettes storing substrates are mounted, are connected to the clean space **114**. Further, the apparatus frame **110** has a console panel **121** provided thereon.

[0096] In the clean space **114**, there are disposed at four corners an aligner **122** for aligning an orientation flat or a notch of a substrate with a predetermined direction, two cleaning/drying devices **124** for cleaning a plated substrate and rotating the substrate at a high speed to spin-dry the substrate, and a pretreatment device **126** for carrying out a pretreatment of a substrate, e.g., according to the present embodiment, a rinsing pretreatment including injecting pure water toward a front face (surface to be plated) of a substrate to thereby clean the substrate surface with pure water and, at the same time, wet the substrate surface with pure water so as to enhance a hydrophilicity of the substrate surface. Further, a first transfer robot **128** is disposed substantially at the center of these processing devices, i.e. the aligner **122**, the cleaning/drying devices **124**, and the pretreatment device **126**, to thereby transfer and deliver a substrate between the processing devices **122**, **124**, and **126**, the substrate attachment/detachment stages **162**, and the substrate cassettes mounted on the loading/unloading ports **120**.

[0097] The aligner **122**, the cleaning/drying devices **124**, and the pretreatment device **126** disposed in the clean space **114** are designed so as to hold and process a substrate in a horizontal state in which a front face of the substrate faces upward. The transfer robot **128** is designed so as to transfer and deliver a substrate in a horizontal state in which a front face of the substrate faces upward.

[0098] In the plating space **116**, in the order from the partition plate **112**, there are disposed a stocker **164** for storing or temporarily storing the substrate holders **160**, an activation treatment device **166** for etching, for example, an oxide film, having a large electric resistance, on a seed layer formed on a surface of a substrate with a chemical liquid such as sulfuric acid or hydrochloric acid to remove the oxide film, a first rinsing device **168***a* for rinsing the surface of the substrate with pure water, a plating apparatus **170** for carrying out plating, a second rinsing device **168***b*, and a blowing device **172** for dewatering the plated substrate. Two second transfer robots **174***a* and **174***b* are disposed beside these devices so as to be movable along a rail **176**. One of the second transfer robots **174***a* transfers the substrate holders **160** between the substrate attachment/detachment stages **162** and the stocker **164**. The other of the second transfer robots **174***b* transfers the substrate holders **160** between the stocker **164**, the activation treatment device **166**, the first rinsing device **168***a*, the plating apparatus **170**, the second rinsing device **168***b*, and the blowing device **172**.

[0099] As shown in **FIG. 2**, each of the second transfer robots **174***a* and **174***b* has a body **178** extending in a vertical direction and an arm **180** which is vertically movable along the body **178** and rotatable about its axis. The arm **180** has two substrate holder retaining portions **182** provided in parallel for detachably retaining the substrate holders **160**. The substrate holder **160** is designed so as to hold a substrate W in a state in which a front face of the substrate is exposed while a peripheral portion of the substrate is sealed, and to be capable of attaching the substrate W to the substrate holder **160** and detaching the substrate W from the substrate holder **160**.

[0100] The stocker **164**, the activation treatment device **166**, the rinsing devices **168***a*, **168***b*, and the plating apparatus **170** are designed so as to engage with outwardly projecting portions **160***a* provided at both ends of each substrate holder **160** to thus support the substrate holders **160** in a state such that the substrate holders **160** are suspended in a vertical direction. The activation treatment device **166** has two activation treatment tanks **183** for holding a chemical liquid therein. As shown in **FIG. 2**, the arm **180** of the second transfer robot **174***b* holding the substrate holders **160**, which are loaded with the substrates W, in a vertical state is lowered so as to engage the substrate holders **160** with upper ends of the activation treatment tanks **183** to support the substrate holders **160** in a suspended manner as needed. Thus, the activation treatment device **166** is designed so that the substrate holders **160** are immersed together with the substrates W in the chemical liquid in the activation treatment tanks **183** to carry out an activation treatment.

[0101] Similarly, the rinsing devices **168***a* and **168***b* have two rinsing tanks **184***a* and two rinsing tanks **184***b* which hold pure water therein, respectively, and the plating apparatus **170** has a plurality of plating tanks **186** which hold a plating solution therein. The rinsing devices **168***a*, **168***b* and the plating apparatus **170** are designed so that the substrate holders **160** are immersed together with the substrates W in the pure water in the rinsing tanks **184***a*, **184***b* or the plating solution in the plating tanks **186** to carry out rinsing treatment or plating in the same manner as described above. The arm **180** of the second transfer robot **174***b* holding the substrate holders **160** with substrates W in a vertical state is lowered, and air or inert gas is injected toward the substrates W mounted on the substrate holders **160** to blow away a liquid attached to the substrate holders **160** and the substrates W and to dewater the substrates W. Thus, the blowing device **172** is designed so as to carry out blowing treatment.

[0102] As shown in **FIGS. 3 and 4**, each plating tank **186** in the plating apparatus **170** is designed so as to hold a plating solution **10** therein. Thus, the substrates W, which are held in a state such that the front faces (surfaces to be plated) are exposed while peripheral portions of the substrate holders **160** are water-tightly sealed, are immersed in the plating solution **10**.

[0103] Overflow tanks **46** are provided at both sides of the plating tank **186** for receiving a plating solution **10** overflowing upper ends of overflow weirs **44** of the plating tank **186**. The overflow tanks **46** and the plating tank **186** are connected through a circulation pipe **48**. The circulation pipe **48** has a circulating pump **50**, a thermostatic unit **52**, and a filter **54** provided in the circulation pipe **48**. A plating solution **10** supplied into the plating tank **186** by operation of the circulating pump **50** fills the plating tank **186**, then overflows the overflow weirs **44**, flows into the overflow tanks **46**, and returns to the circulating pump **50**. Thus, the plating solution **10** is circulated.

[0104] An anode **56** having a circular shape corresponding to the shape of the substrate W is held by an anode holder **58** and provided vertically in the plating tank **186**. Thus, when the plating solution **10** is filled in the plating tank **186**, the anode **56** is immersed in the plating solution **10**. Further, a regulation plate **60** is provided between the anode **56** and the substrate holder **160** to partition the interior of the plating tank **186** into an anode side chamber **40***a* and a substrate side chamber **40***b* and to separate the plating solution **10** held in the plating tank **186** into an anode side plating solution and a substrate side plating solution.

[0105] A paddle-type agitating mechanism **64** having a plurality of paddles **62** extending vertically downward is disposed between the substrate holder **160** and the regulation plate **60**. The paddles **62** are reciprocated within the plating solution in the substrate side chamber **40***b* in parallel to the substrate W held by the substrate holder **160**, thereby stirring the plating solution in the substrate side chamber **40***b*.

[0106] The regulation plate **60** has a thickness of, for example, about 0.5 to 10 mm and is made of a dielectric material including PVC, PP, PEEK, PES, HT-PVC, PFA, PTFE, and other resin materials. A through-hole group **68** including a large number of through-holes **66** is provided in a predetermined area of the regulation plate **60**, which is substantially the entire area facing the surface of the substrate W when the substrate W is held by the substrate holder **160** and located at a predetermined plating position in the plating tank **186**, and which is a circular area similar to the shape of the substrate W.

[0107] According to the present embodiment, as particularly shown in **FIG. 5**, the through-holes **66** are formed by slit-like elongated holes extending linearly in a horizontal direction. The through-holes (elongated holes) **66** are lineally arranged in parallel within a circular area corresponding to the shape of the substrate W so as to form the through-hole group **68**. The through-holes (elongated holes) **66** generally have a width of about 0.5 to 20 mm, preferably about 1 to 15 mm. The length of the through-hole **66** is determined depending upon the size (diameter) of the substrate W.

[**0108**] Thus, the through-hole group **68** including a large number of through-holes **66** is provided in the regulation plate **60** so that an electric field leaks through the respective through-holes **66** at the time of plating, and that the leaked electric field spreads uniformly. Accordingly, a potential distribution can be made more uniform over the entire surface (surface to be plated) of the substrate W, and a within wafer uniformity of a metal film formed on the surface of the substrate W can be enhanced. Further, the plating solution **10** is prevented from passing through a large number of through-holes **66** formed in the regulation plate **60** provided in the plating tank **186**. Accordingly, non-uniform film thickness is prevented from being caused to a metal film formed on the surface of the substrate W due to influence of a flow of the plating solution **10** (return flow of the plating solution).

[**0109**] Particularly, the use of slit-like elongated holes as the through-holes **66** can prevent the plating solution **10** from passing through the through-holes (elongated holes) **66** and simultaneously promote leakage of the electric field. Further, by forming the through-hole group **68**, including a large number of through-holes **66**, substantially in the entire area facing the surface of the substrate W which is a circular area similar to the shape of the substrate W, a metal film having a good film thickness uniformity can be formed in all directions on the surface of the substrate W.

[**0110**] With the plating apparatus **170**, a plating solution **10** is first filled in the plating tank **186** and circulated as described above. In this state, the substrate holder **160** holding the substrate W is lowered to locate the substrate W at a predetermined position within the plating tank **186** at which the substrate W is immersed in the plating solution **10**. The anode **56** is connected via a conductor **22***a* to an anode of a plating power supply **24**, and the substrate W is connected via a conductor **22***b* to a cathode of the plating power supply **24**. At the same time, the paddle-type agitating mechanism **64** is operated so as to reciprocate the paddles **62** along the surface of the substrate W to thereby agitate the plating solution **10** in the substrate side chamber **40***b*. As a result, a metal is deposited on the surface of the substrate W so as to form a metal film on the surface of the substrate W.

[**0111**] At that time, as described above, an electric field leaks through a large number of through-holes **66** formed in the regulation plate **60**, and the leaked electric field spreads uniformly. Accordingly, a potential distribution can be made more uniform over the entire front face (surface to be plated) of the substrate W, and a metal film P having an enhanced within wafer uniformity can be formed on the surface of the substrate W as shown in **FIG. 6**. Further, by agitating the plating solution **10** between the substrate W and the regulation plate **60** with the paddles **62** during plating, the directionality of the flow of the plating solution can be eliminated, and simultaneously sufficient ions can be supplied more uniformly to the surface of the substrate W. Therefore, a metal film having a more uniform thickness can be formed more rapidly.

[**0112**] After completion of the plating, the plating power supply **24** is disconnected from the substrate W and the anode **56**, and the substrate holder **160** is pulled up together with the substrate W. After necessary treatments such as water-cleaning and rinsing of the substrate W, the plated substrate W is transferred to a subsequent process.

[**0113**] A series of bump plating processes in the plating facility thus constructed will be described below with reference to **FIGS. 7A through 7E**. First, as shown in **FIG. 7A**, a seed layer **500** is deposited as a feeding layer on a surface of a substrate W, and a resist **502** having a height H of, for example, about 20 to 120 μm is applied onto the entire surface of the seed layer **500**. Thereafter, an opening **502***a* having a diameter D_1 of, for example, about 20 to 200 μm is formed at a predetermined position of the resist **502**. Substrates W thus prepared are housed in a substrate cassette in a state such that front faces (surfaces to be plated) of the substrates face upward. The substrate cassette is mounted on the loading/unloading port **120**.

[**0114**] One of the substrates W is taken out of the substrate cassette mounted on the loading/unloading port **120** by the first transfer robot **128** and placed on the aligner **122** to align an orientation flat or a notch of the substrate with a predetermined direction. The substrate W thus aligned is transferred to the pretreatment device **126** by the first transfer robot **128**. In the pretreatment device **126**, a pretreatment (rinsing pretreatment) using pure water as a pretreatment liquid is carried out. On the other hand, two substrate holders **160** which have been stored in a vertical state in the stocker **164** are taken out by the second transfer robot **174***a*, rotated through 90° so that the substrate holders **160** are brought into a horizontal state, and then placed in parallel on the substrate attachment/detachment stages **162**.

[**0115**] Then, the substrates W which have been subjected to the aforementioned pretreatment (rinsing pretreatment) are loaded into the substrate holders **160** placed on the substrate attachment/detachment stages **162** in a state such that peripheral portions of the substrates are sealed. The two substrate holders **160** which have been loaded with the substrates W are simultaneously retained, lifted, and then transferred to the stocker **164** by the second transfer robot **174***a*. The substrate holders **160** are rotated through 90° into a vertical state and lowered so that the two substrate holders **160** are held (temporarily stored) in the stocker **164** in a suspended manner. The above operation is carried out repeatedly in a sequential manner, so that substrates are sequentially loaded into the substrate holders **160**, which are stored in the stocker **164**, and are sequentially held (temporarily stored) in the stocker **164** at predetermined positions in a suspended manner.

[**0116**] On the other hand, the two substrate holders **160** which have been loaded with the substrates and temporarily stored in the stocker **164** are simultaneously retained, lifted, and then transferred to the activation treatment device **166** by the second transfer robot **174***b*. Each substrate is immersed in a chemical liquid such as sulfuric acid or hydrochloric acid held in the activation treatment tank **183** to thereby etch an oxide film, having a large electric resistance, formed on the surface of the seed layer so as to expose a clean metal surface. The substrate holders **160** which have been loaded with the substrates are transferred to the first rinsing device **168***a* in the same manner as described above to rinse the surfaces of the substrates with pure water held in the rinsing tanks **184***a*.

[**0117**] The substrate holders **160** which have been loaded with the rinsed substrates are transferred to the plating apparatus **170** in the same manner as described above. Each substrate W is supported in a suspended manner by the plating tank **186** in a state such that the substrate W is immersed in the plating solution **10** in the plating tank **186** to thus carry out plating on the surface of the substrate W. After a predetermined period of time has elapsed, the substrate holders **160** which have been loaded with the substrates are retained again and pulled up from the plating tank **186** by the second transfer robot **174***b*. Thus, the plating process is completed.

[**0118**] Thereafter, the substrate holders **160** are transferred to the second rinsing device **168***b* in the same manner as described above. The substrate holders **160** are immersed in pure water in the rinsing tanks **184***b* to clean the surfaces of the substrates with pure water. Then, the substrate holders **160** which have been loaded with the substrates are transferred to the blowing device **172** in the same manner as described above. In the blowing device **172**, inert gas or air is injected toward the substrates to blow away a plating solution and water droplets attached to the substrate holders **160**. Thereafter, the substrate holders **160** which have been loaded with the substrates are returned to predetermined positions in the stocker **164** and held in a suspended state in the same manner as described above.

[**0119**] The second transfer robot **174***b* sequentially performs the above operation repeatedly so that the substrate holders **160** which have been loaded with the plated substrates are sequentially returned to predetermined positions in the stocker **164** and held in a suspended manner.

[**0120**] On the other hand, the two substrate holders **160** which have been loaded with the plated substrates are simultaneously retained and placed on the substrate attachment/detachment stages **162** by the second transfer robot **174***a* in the same manner as described above.

[**0121**] The first transfer robot **128** disposed in the clean space **114** takes the substrate out of the substrate holders **160** placed on the substrate attachment/detachment stages **162** and transfers the substrate to either one of the cleaning/drying devices **124**. In the cleaning/drying device **124**, the substrate held in a horizontal state such that the front face of the substrate faces upward is cleaned with pure water or the like and rotated at a high speed to spin-dry the substrate. Thereafter, the substrate is then returned to the substrate cassette mounted on the loading/unloading port **120** by the first transfer robot **128**. Thus, a series of plating processes is completed. As a result, as shown in **FIG. 7B**, a substrate W having a plated film **504** grown in the opening **502***a* formed in the resist **502** can be obtained.

[**0122**] The spin-dried substrate W as described above is immersed in a solvent such as acetone at a temperature of, for example, 50 to 60° C. to remove the resist **502** from the substrate W as shown in **FIG. 7C**. Further, as shown in **FIG. 7D**, an unnecessary seed layer **502**, which is exposed after plating, is removed. Next, the plated film **504** formed on the substrate W is reflowed to form a bump **506** having a round shape due to surface tension. The substrate W is then annealed at a temperature of, for example, 100° C. or more to remove residual stress in the bump **506**.

[**0123**] According to this embodiment, delivery of substrates in the plating space **116** is performed by the second transfer robots **174***a* and **174***b* disposed in the plating space **116**, whereas delivery of substrates in the clean space **114** is performed by the first transfer robot **128** disposed in the clean space **114**. Accordingly, it is possible to improve the cleanliness around a substrate in the plating processing apparatus which performs all the plating processes including pretreatment of a substrate, plating, and posttreatment of the plating, in a successive manner, and to increase a throughput of the plating processing apparatus. Further, it is possible to reduce loads on facilities associated with the plating processing apparatus and to achieve downsizing of the plating processing apparatus.

[**0124**] According to the present embodiment, a plating tank **186** having a small footprint is used in the plating apparatus **170** for carrying out plating. Accordingly, it is possible to achieve further downsizing of the plating apparatus having a large number of plating tanks **186** and reduce loads on associated facilities in a plant. In **FIG. 1**, one of the two cleaning/drying devices **124** may be replaced with a pretreatment device.

[**0125**] **FIGS. 8 through 19** show various examples of a through-hole group including a large number of through-holes in a regulation plate **60**. Specifically, **FIG. 8** shows an example in which through-holes **66***a* are formed by slit-like elongated holes extending linearly in a vertical direction, and the through-holes (elongated holes) **66***a* are arranged linearly in parallel in a circular area corresponding to the shape of a substrate W so as to form a through-hole group **68***a*. **FIG. 9** shows an example in which through-holes (elongated holes) **66***b* are arranged linearly in parallel in a rectangular area corresponding to the shape of a substrate W so as to form a through-hole group **68***b*, which is suitable for a rectangular substrate W.

[**0126**] **FIG. 10** shows an example in which a through-hole group **68***c* is formed by a plurality of through-holes (elongated holes) **66***c* which are slit-like elongated holes extending linearly substantially across the entire width of an area of a regulation plate **60** facing a surface of a substrate W. In this case, when a rectangular substrate W is used, as shown in **FIG. 11**, through-holes (elongated holes) **66***d* may be arranged in parallel in a rectangular area corresponding to the shape of the substrate W so as to form a through-hole group **68***d*. Further, the through-holes **66***d* may be arranged so as to extend linearly in a vertical direction, which is not shown.

[**0127**] **FIG. 12** shows an example in which through-holes (cross holes) **66***e* which are cross holes extending crosswise in vertical and horizontal directions are arranged uniformly in a circular area so as to form a through-hole group **68***e*. In this case, when a rectangular substrate W is used, as shown in **FIG. 13**, through-holes (cross holes) **66***f* may be arranged uniformly in a rectangular area corresponding to the shape of the substrate W so as to form a through-hole group **68***f*.

[**0128**] **FIG. 14** shows an example in which a plurality of through-holes (fine holes) **66***g* which are fine holes is distributed uniformly in a circular area so as to form a through-hole group **68***g*. In this illustrated example, the diameter of each through-hole (fine hole) **66***g* is set to be 2 mm, and **633** holes are provided in total. Although the diameters of the through-holes **66***g* as well as small holes (peripheral holes) **66**h_2 through **66**h_5 described below may be set arbitrarily within a range of, for example, 1 to 20 mm, they should preferably be in a range of about 2 to 10 mm.

When the through-hole group **68***g* is formed by the through-holes (fine holes) **66***g*, productivity of the regulation plate **60** can be increased.

[0129] **FIG. 15** shows an example in which a through-hole group **68***h* is formed by a plurality of through-holes **66***h* having different diameters, i.e. a large hole (central hole) **66***h*$_1$ having a large diameter and located at a central portion, and small holes (peripheral holes) **66***h*$_2$ through **66***h*$_5$ arranged outside of the large hole **66***h*$_1$ along a circumferential direction in a plurality of arrays (four arrays in **FIG. 15**) having diameters gradually reduced in a radial direction. The diameter of the large hole (central hole) **66***h*$_1$ is set to be 84 mm in this example. Although the diameter of the large hole may be set arbitrarily within a range of, for example, 50 to 300 mm, it should preferably be in a range of about 30 to 100 mm. The diameters of the small holes (peripheral holes) **66***h*$_2$ through **66***h*$_5$ are set to be 10 mm, 8 mm, 7 mm, and 6 mm, respectively.

[0130] **FIG. 16** shows an example in which a through-hole group **68***i* is formed by a plurality of through-holes **66***i* including a central hole **66***i*$_1$ located at a central portion, and elongated holes **66***i*$_2$ through **66***i*$_6$ arranged outside of the central hole **66***i*$_1$ along a circumferential direction in a plurality of arrays (five arrays in **FIG. 16**). In this example, the diameter of the central hole **66***i*$_1$ is set to be 34 mm, and the widths of the elongated holes **66***i*$_2$ through **66***i*$_6$ are set to be 27 mm, 18.5 mm, 7 mm, 7 mm, and 7 mm, respectively.

[0131] **FIG. 17** shows an example in which a through-hole group **68***j* is formed by a plurality of through-holes **66***j* including a large hole (central hole) **66***j*$_1$ having a large diameter and located at a central portion, elongated holes **66***j*$_2$ arranged outside of the central hole **66***j*$_1$ along a circumferential direction, and small holes (peripheral holes) **66***j*$_3$ through **66***j*$_6$ arranged outside of the elongated holes **66***j*$_2$ in a plurality of arrays (four arrays in **FIG. 17**) having diameters gradually reduced in a radial direction. In this example, the diameter of the large hole (central hole) **66***j*, is set to be 67 mm, the width of the elongated hole **66***j*$_2$ is set to be 17 mm, and the diameters of the small holes (peripheral holes) **66***j*$_3$ through **66***j*$_6$ are set to be 9 mm, 8 mm, 7 mm, and 6 mm, respectively.

[0132] **FIG. 18** shows an example in which a through-hole group **68***k* is formed by a plurality of through-holes **66***k* including a large hole (central hole) **66***k*, having a large diameter and located at a central portion, elongated holes **66***k*$_2$, **66***k*$_3$ arranged outside of the central hole **66***k*$_1$ along a circumferential direction in a plurality of arrays (two arrays in **FIG. 18**), and small holes (peripheral holes) **66***k*$_4$, **66***k*$_5$ arranged outside of the elongated holes **66***k*$_3$ in a plurality of arrays (two arrays in **FIG. 18**) having diameters gradually reduced in a radial direction. In this example, the diameter of the large hole (central hole) **66***k*$_1$ is set to be 80 mm, the widths of the elongated holes **66***k*$_2$, **66***k*$_3$ are set to be 7 mm, and the diameters of the small holes (peripheral holes) **66***k*$_4$, **66***k*$_5$ are set to be 6 mm and 4 mm, respectively.

[0133] **FIG. 19** shows an example in which a through-hole group **68***l* is formed by a plurality of through-holes **66***l* including a large hole (central hole) **66***l*$_1$ having a large diameter and located at a central portion, and a plurality of slit-like elongated holes **66***l*$_2$ arranged outside of the central hole **66***l*$_1$ at a predetermined pitch along a circumferential direction and extending linearly in a radial direction. The widths of the elongated holes **66***l*$_2$ are generally in a range of about 0.5 to 20 mm, preferably about 1 to 15 mm. The lengths of the elongated holes **66***l*$_2$ are set arbitrarily according to the shape of a plating workpiece.

[0134] Thus, a through-hole group is formed by combination of a plurality of through-holes having desired shapes, such as a plurality of fine holes, a plurality of holes having different diameters, and slit-like elongated holes. Accordingly, a through-hole group can meet various requirements regarding plating sites, plating conditions, and the like.

[0135] In the examples shown in **FIGS. 14 through 19**, through-holes are arranged in a circular area so as to form a through-hole group. However, as described above, when a rectangular substrate is used, through-holes may be arranged, as a matter of course, in a rectangular area corresponding to the shape of the substrate so as to form a through-hole group.

[0136] As described above, according to the present invention, an electric field leaks through a large number of through-holes formed in a regulation plate provided in the plating tank, and the leaked electric field spreads uniformly. Accordingly, a potential distribution can be made more uniform over the entire surface of a plating workpiece, and a within wafer uniformity of a metal film formed on the surface of the plating workpiece can be enhanced. Further, a plating solution is prevented from passing through a large number of through-holes formed in the regulation plate provided in the plating tank **186**. Accordingly, non-uniform film thickness is prevented from being caused to a metal film formed on the surface of the plating workpiece due to influence of a flow of the plating solution.

[0137] **FIG. 20** shows a plating apparatus **170***a* according to another embodiment of the present invention, and **FIGS. 21A and 21B** show a regulation plate and a cylindrical member forming a plating solution passage which are used in the plating apparatus **170***a*. The plating apparatus **170***a* differs from the apparatus shown in **FIGS. 3 through 5** in that the plating apparatus **170***a* employs a regulation plate **60** having a thickness of, for example, about 0.5 to 10 mm and having a central hole **60***a* at the center thereof which faces a substrate W held by a substrate holder **160** and has an inside diameter D corresponding to the outside diameter of the substrate W, and that a cylindrical member **200** having an inside diameter equal to the inside diameter D of the central hole **60***a* is concentrically connected to a surface of the regulation plate **60** on the substrate holder **160** side continuously with the central hole **60***a* so as to define a plating solution passage **200***a* inside an inner circumferential surface of the cylindrical member **200** for allowing an electric field to pass uniformly therethrough and allowing a plating solution **10** to pass therethrough. As with the regulation plate **60**, the cylindrical member **200** is made of a dielectric material including PVC, PP, PEEK, PES, HT-PVC, PFA, PTFE, and other resin materials. Other constructions are the same as those shown in **FIGS. 3 through 5**.

[0138] The inside diameters D of the central hole of the regulation plate **60** and the cylindrical member **200** are generally set to be approximately in a range of ±10 mm of an outside diameter (plated surface outside diameter) of a surface of a substrate W to be plated, preferably in a range of ±5 mm of an outside diameter of a surface to be plated, more preferably in a range of ±1 mm of an outside diameter of a surface to be plated. The length L of the cylindrical member **200** may properly be set depending upon the shape of the plating tank **186**, the distance between the anode **56** and the substrate W, and the like. However, the length L is generally set to be in a range of 10 to 90 mm, preferably 20 to 75 mm, more preferably 30 to 60 mm.

[**0139**] Thus, an electric field produced between the anode **56** and the substrate W in the plating tank **186** passes along the plating solution passage **200***a*, i.e., passes uniformly through the cylindrical member **200** without leaking out of the cylindrical member **200**. Accordingly, distortion and deviation of the electric field can be adjusted and corrected so as to equalize a potential distribution over the entire surface of the substrate W. As a result, as shown in **FIG. 22**, a metal film P having an enhanced within wafer uniformity can be formed on the surface of the substrate W although it has a slightly thicker film at an edge portion of the substrate W.

[**0140**] Specifically, a regulation plate **60** generally is as thin as about 0.5 to 10 mm. Therefore, with a regulation plate **60** having only a central hole **60***a* formed therein, an electric field produced between the anode **56** and a substrate W in the plating tank **186** is not sufficiently regulated, and distortion or deviation of an electric field is caused. Accordingly, the substrate tends to be thicker at an edge portion, which serves as an electrically receiving portion. According to the present example, passing of an electric field is regulated over the length L of the cylindrical member **200**, so that the above drawback is solved. Thus, a within wafer uniformity of a metal film can be enhanced.

[**0141**] In this example, as in the examples shown in **FIGS. 3 through 5**, a paddle-type agitating mechanism **64** having a plurality of paddles **62** extending vertically downward is disposed between the cylindrical member **200** and the substrate W held by the substrate holder **160**. The paddle-type agitating mechanism **64** is operated during plating so as to reciprocate the paddles **62** along the surface of the substrate W, thereby agitating the plating solution **10** in a substrate side chamber **40***b*. Accordingly, the directionality of the flow of the plating solution can be eliminated, and simultaneously sufficient ions can be supplied more uniformly to the surface of the substrate W. Therefore, a metal film having a more uniform thickness can be formed more rapidly.

[**0142**] **FIG. 23** shows a plating apparatus **170***b* according to still another embodiment of the present invention. The plating apparatus **170***b* differs from the apparatus shown in **FIGS. 21 and 22** in that a plating solution injection type agitating mechanism **202** is disposed between the cylindrical member **200** and a substrate W held by the substrate holder **160** instead of the paddle-type agitating mechanism **64**. Specifically, the plating solution injection type agitating mechanism **202** has a plating solution supply pipe **204**, for example, in a ring shape, communicating with a circulation pipe **48** and immersed in the plating solution **10** in the plating tank **186**, and a plurality of plating solution injection nozzles **206** attached to predetermined portions of the plating solution supply pipe **204** along a circumferential direction for ejecting the plating solution **10** toward the substrate W held by the substrate holder **160**. A plating solution **10** fed by a pump **50** is supplied to the plating solution supply pipe **204** and injected from the plating solution injection nozzles **206** toward the substrate. Thus, the plating solution **10** is introduced into the plating tank **186**, overflows upper ends of overflow weirs **44**, and is circulated.

[**0143**] Thus, the plating solution **10** is injected from a plurality of plating solution injection nozzles **206** toward the substrate W. Accordingly, the plating solution **10** in the plating tank **186** can be agitated so as to uniformize the plating solution concentration and, simultaneously, to sufficiently supply components of the plating solution **10** to the substrate W. Thus, a metal film having a more uniform thickness can be formed more rapidly.

[**0144**] In this example, the cylindrical member **200** is coupled to a surface of the regulation plate **60** on the substrate W side. However, as shown in **FIG. 24B**, an insertion hole **60***b* may be formed in the regulation plate **60**, and a cylindrical member **200** having an inside diameter D, a length L, and a plating solution passage **200***a* inside an inner circumferential surface thereof may be inserted into the insertion hole **60***b*. In this manner, the cylindrical member **200** may be held at a predetermined position along a longitudinal direction of the cylindrical member **200**. This arrangement ensures a sufficient length L as the cylindrical member **200** even if a distance between the regulation plate **60** and the paddles **62** (see **FIG. 20**) or the plating solution supply pipe **204** (see **FIG. 23**) is short.

[**0145**] Further, as shown in **FIGS. 25A and 25B**, the cylindrical member **200** may have a circumferential wall having a large number of through-holes **200***b* which have a size such as to prevent leakage of an electric field. With this arrangement, the plating solution **10** can pass through the through-holes **200***b* formed in the circumferential wall of the cylindrical member **200** while preventing leakage of the electric field. Accordingly, the concentration of the plating solution is prevented from being different between the inside and outside of the cylindrical member **200**. With respect to the shape of the through-holes, besides fine holes as in this example, slit-like elongated holes, cross holes extending vertically and horizontally, and a combination thereof may be exemplified.

[**0146**] Further, as shown in **FIGS. 26A and 26B**, a regulation plate **210** may be formed by a plate having a sufficient thickness, and a through-hole having a predetermined inside diameter may be formed at a predetermined position in the regulation plate **210** so that the through-hole serves as a plating solution passage **210***a* having a predetermined inside diameter D and a predetermined length L. In such a case, the number of parts can be reduced.

[**0147**] Furthermore, as shown in **FIGS. 27A and 27B**, a rectangular block **212** having a sufficient thickness may be prepared so that a through-hole formed in the rectangular block **212** serves as a plating solution passage **210***a* having a predetermined inside diameter D and a predetermined length L, and the rectangular block **212** may be connected to a surface of a regulation plate **60** having a center hole **60***a* on the substrate W side.

[**0148**] **FIG. 28** shows a plating apparatus **170***c* according to yet another embodiment of the present invention, and **FIGS. 29A and 29B** shows a regulation plate, a cylindrical member forming a plating solution passage, and an electric field adjustment ring which are used in the plating apparatus **170***c* shown in **FIG. 28**. The plating apparatus **170***c* differs from the apparatus shown in **FIGS. 20 and 21** in the following points: An electric field adjustment ring **220** having the same inside diameter D as an inside diameter of the cylindrical member **200** and a width A is concentrically attached to a substrate W side end surface of the cylindrical member **200** having a plating solution passage **200***a* defined inside an inner circumferential surface thereof. The electric field adjustment ring **220** is disposed close to a substrate W with a gap G**1**. Further, the paddle-type agitating mechanism **64** having a plurality of paddles **62** extending vertically downward is disposed between the anode **56** and the regulation plate **60** in the anode side chamber **40***a* so as to reciprocate the paddles **62** in parallel to the substrate W held by the substrate holder **160**, thereby agitating the plating solution. Thus, the paddle-type agitating mechanism **64** agitates the plating solution **10** in the anode side chamber **40***a*. Other constructions are the same as those shown in **FIGS. 20 and 21**.

[**0149**] As with the regulation plate **60** and the cylindrical member **200**, the electric field adjustment ring **220** is made of a dielectric material including PVC, PP, PEEK, PES, HT-PVC, PFA, PTFE, and other resin materials. Other constructions are the same as those shown in **FIGS. 3 through 5**. The shape of the electric field adjustment ring **220** may properly be set depending upon the shapes of the plating tank **186** and the substrate W, the distance between the anode **56** and the substrate W, and the like. However, the width A is generally set to be in a range of 1 to 20 mm, preferably 3 to 17 mm, more preferably 5 to 15 mm. A gap G1 between the electric field adjustment ring **220** and the substrate W is generally set to be in a range of 0.5 to 30 mm, preferably 1 to 15 mm, more preferably 1.5 to 6 mm.

[**0150**] The electric field adjustment ring **220** serves to adjust an electric field at a peripheral portion of the substrate W by covering a location near a peripheral portion of a substrate W over a predetermined width. Thus, an electric field is adjusted at a peripheral portion of the substrate W. Accordingly, an electric field produced between the anode **56** and the substrate W can be uniformized over the entire surface of the substrate W, including an edge portion of the substrate W, which serves as an electrically receiving portion. Therefore, as shown in **FIG. 30**, a metal film P having an enhanced within wafer uniformity can be formed on the surface of the substrate W, including the edge portion of the substrate.

[**0151**] **FIG. 31** shows a plating apparatus **170***d* according to yet another embodiment of the present invention. The plating apparatus **170***d* has a plating solution injection type aditating mechanism **202**, which is shown in **FIG. 23**, disposed between the anode **56** and the regulation plate **60** in the anode side chamber **40***a*, instead of the paddle-type agitating mechanism **64** used in the plating apparatus shown in **FIGS. 28 and 29**. Specifically, in this example, a plating solution **10** fed by a pump **50** is supplied to the plating solution supply pipe **204** and injected from the plating solution injection nozzles **206** toward a plating solution passage **200***a* of the cylindrical member **200**. Thus, the plating solution **10** is introduced into the plating tank **186**, overflows upper ends of overflow weirs **44**, and is circulated. Other constructions are the same as those shown in **FIGS. 28 and 29**.

[**0152**] Thus, the plating solution injection type agitating mechanism **202** is disposed in the anode side chamber **40***a*, and the plating solution is injected from the plating solution injection nozzles **206** toward the plating solution passage **200***a* of the cylindrical member **200**. The plating solution can be supplied through the plating solution passage **200***a* to the substrate W held by the substrate holder **160** even if a gap G1 between an electric field adjustment ring **220** and the substrate W held by the substrate **160** is narrow.

[**0153**] As shown in **FIGS. 32A and 32B**, an insertion hole **60***b* may be formed in the regulation plate **60**, and a cylindrical member **200** having an inside diameter D, a length L, a plating solution passage **200***a* inside an inner circumferential surface thereof, and an electric field adjustment ring **220** attached to an end surface thereof may be inserted into the insertion hole **60***b* substantially in the same manner as shown in **FIGS. 24A and 24B**. Thus, the cylindrical member **200** may be held at a predetermined position along a longitudinal direction of the cylindrical member **200**.

[**0154**] As shown in **FIGS. 33A and 33B**, a large number of through-holes **200***b* having a size such as to prevent leakage of an electric field may be formed in a circumferential wall of a cylindrical member **200** having an electric field adjustment ring **220** attached to an end surface thereof substantially in the same manner as shown in **FIGS. 25A and 25B**. Thus, the plating solution **10** can pass through the through-holes **200***b* formed in the circumferential wall of the cylindrical member **200** while preventing leakage of the electric field.

[**0155**] Further, as shown in **FIGS. 34A and 34B**, the electric field adjustment ring **220** may not be fixed to the end surface of the cylindrical member **200**, but may be supported by a support **222** so as to have a gap G2 between the front of the substrate W side end surface of the cylindrical member **200** and the substrate W. As with the gap G1 between the electric field adjustment ring **220** and the substrate W, the gap G2 is generally set to be in a range of 0.5 to 30 mm, preferably 1 to 15 mm, more preferably 1.5 to 6 mm. With the plating solution passage **200***a* thus formed, the cylindrical member **200** and the electric field adjustment ring **220** can be separated so as to offer a broader choice.

[**0156**] As shown in **FIGS. 35A and 35B**, a plating solution passage **224***a* having a predetermined inside diameter D and a length L may be defined by an inner circumferential surface of a thick ring **224** having a sufficient thickness, and an electric field adjustment ring **224***b* having a predetermined width A may be formed by a substrate side end surface of the thick ring **224**. In this case, the number of parts can be reduced.

[**0157**] Although the aforementioned examples show that the present invention is applied to a so-called dipping type plating apparatus, the present invention is also applicable to a face-down type plating apparatus or a face-up type plating apparatus.

[**0158**] **FIG. 36** shows an example in which the present invention is applied to a face-down type plating apparatus. In this example, the following structures are added to a conventional plating apparatus shown in **FIG. 37**. Specifically, a regulation plate **230** having a central hole **230***a* formed therein is disposed at an upper position of the plating tank **12** so as to separate the interior of the plating tank **12** into an anode side chamber **12***a* and a substrate side chamber **12***b*. Further, a cylindrical member **232** having an inside diameter equal to the diameter of the central hole **230***a* and an inner circumferential surface forming a plating solution passage **232***a* is concentrically attached to an upper surface of the regulation plate **230** in a manner so as to project upward. With this arrangement, an electric field produced between the anode **16** and a substrate W in the plating tank **12** can pass along the plating solution passage **232***a*, i.e. uniformly through the cylindrical member **232** without leaking out of the cylindrical member **232**. Accordingly, distortion and deviation of the electric field can be adjusted and corrected so as to equalize a potential distribution over the entire surface of the substrate W.

[**0159**] An electric field adjustment ring having an inside diameter equal to an inside diameter of the cylindrical member and a predetermined width may concentrically be attached to an upper end surface of the cylindrical member so as to cover a location near a peripheral portion of the substrate W over a predetermined width. Thus, an electric field can be adjusted at the peripheral portion of the substrate W. Accordingly, an electric field produced between the anode **56** and the substrate can be uniformized over the entire surface of the substrate, including an edge portion of the substrate, which serves as an electrically receiving portion. Therefore, a metal film having an enhanced within wafer uniformity can be formed on the surface of the substrate, including the edge portion of the substrate.

1. A plating apparatus characterized by comprising:

a plating tank for holding a plating solution;

an anode disposed so as to be immersed in the plating solution in said plating tank;

a regulation plate disposed between said anode and a plating workpiece disposed so as to face said anode; and

a plating power supply for supply a current between said anode and the plating workpiece to carry out plating,

wherein said regulation plate is disposed so as to separate the plating solution held in said plating tank into a plating solution on said anode side and a plating solution on the plating workpiece side, and a through-hole group having a large number of through-holes is formed in said regulation plate.

2. The plating apparatus according to claim 1, characterized in that said through-hole group is formed by a plurality of slit-like elongated holes extending linearly in one direction or extending in an arc.

3. The plating apparatus according to claim 1, characterized in that said through-hole group is formed by a plurality of cross holes extending crosswise in vertical and horizontal directions.

4. The plating apparatus according to claim 1, characterized in that said through-hole group is formed by a combination of a plurality of fine holes, a plurality of holes having different diameters, and slit-like elongated holes.

5. The plating apparatus according to claim 1, characterized in that said through-hole group is formed in said regulation plate substantially over an entire area facing the plating workpiece, and formed in an area substantially similar to a shape of the plating workpiece.

6. The plating apparatus according to claim 1, characterized by comprising an agitating mechanism provided between the plating workpiece and said regulation plate for agitating the plating solution held in said plating tank.

7. The plating apparatus according to claim 6, characterized in that said agitating mechanism comprises a paddle-type agitating mechanism having a paddle which reciprocates parallel to the plating workpiece.

8. The plating apparatus according to claim 1, characterized in that said anode and said regulation plate are provided in a vertical direction.

9. A plating apparatus characterized by comprising:

a plating tank for holding a plating solution;

an anode disposed so as to be immersed in the plating solution in said plating tank;

a regulation plate disposed between said anode and a plating workpiece disposed so as to face said anode; and

a plating power supply for supply a current between said anode and the plating workpiece to carry out plating,

wherein said regulation plate is disposed so as to separate the plating solution held in said plating tank into a plating solution on said anode side and a plating solution on the plating workpiece side, and a plating solution passage is formed in said regulation plate for allowing an electric field to uniformly pass therethrough and allowing the plating solution to pass therethrough.

10. The plating apparatus according to claim 9, characterized in that a length of said plating solution passage is set to be in a range of 10 to 90 mm.

11. The plating apparatus according to claim 9, characterized in that said plating solution passage is defined by an inner circumferential surface of a cylindrical member or a rectangular block.

12. The plating apparatus according to claim 11, characterized in that a large number of through-holes having a size such as to prevent leakage of an electric field are formed in a circumferential wall of said cylindrical member.

13. The plating apparatus according to claim 9, characterized by comprising an agitating mechanism provided in at least one of a space between the plating workpiece and said regulation plate and a space between said anode and said regulation plate for agitating the plating solution held in said plating tank.

14. The plating apparatus according to claim 13, characterized in that said agitating mechanism comprises a paddle-type agitating mechanism having a paddle which reciprocates parallel to the plating workpiece.

15. The plating apparatus according to claim 13, characterized in that said agitating mechanism comprises a plating solution injection type agitating mechanism having a plurality of plating solution injection nozzles for injecting the plating solution toward the plating workpiece.

16. The plating apparatus according to claim 13, characterized in that said plating solution passage is formed in said regulation plate integrally with said regulation plate.

17. A plating apparatus characterized by comprising:

a plating tank for holding a plating solution;

an anode disposed so as to be immersed in the plating solution in said plating tank;

a regulation plate disposed between said anode and a plating workpiece disposed so as to face said anode for separating the plating solution held in said plating tank into a plating solution on said anode side and a plating solution on the plating workpiece side, said regulation plate having a plating solution passage for allowing an electric field to uniformly pass therethrough and allowing the plating solution to pass therethrough;

a plating power supply for supply a current between said anode and the plating workpiece to carry out plating; and

an electric field adjustment ring disposed at an end of said plating solution passage on the plating workpiece side for adjusting an electric field at a peripheral portion of the plating workpiece.

18. The plating apparatus according to claim 17, characterized in that a width of said electric field adjustment ring is set to be in a range of 1 to 20 mm.

19. The plating apparatus according to claim 17, characterized in that a gap between said electric field adjustment ring and the plating workpiece is set to be in a range of 0.5 to 30 mm.

20. The plating apparatus according to claim 17, characterized in that said plating solution passage is defined by an inner circumferential surface of a cylindrical member, and said electric field adjustment ring is connected to an end of said cylindrical member on the plating workpiece side.

21. The plating apparatus according to claim 20, characterized in that a large number of through-holes having a size such as to prevent leakage of an electric field are formed in a circumferential wall of said cylindrical member.

22. The plating apparatus according to claim 17, characterized in that said plating solution passage is defined by an inner circumferential surface of a cylindrical member, and said electric field adjustment ring is disposed at an end of said cylindrical member on the plating workpiece side so as to be separated from said cylindrical member.

23. The plating apparatus according to claim 17, characterized in that said plating solution passage is defined by an inner circumferential surface of a cylindrical member, and said electric field adjustment ring is formed on an end surface of the plating workpiece side.

24. The plating apparatus according to claim 17, characterized by comprising an agitating mechanism provided in at least one of a space between the plating workpiece and said regulation plate and a space between said anode and said regulation plate for agitating the plating solution held in said plating tank.

25. The plating apparatus according to claim 24, characterized in that said agitating mechanism comprises a paddle-type agitating mechanism having a paddle which reciprocates parallel to the plating workpiece.

26. The plating apparatus according to claim 24, characterized in that said agitating mechanism comprises a plating solution injection type agitating mechanism having a plurality of plating solution injection nozzles for injecting the plating solution toward the plating workpiece.

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