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(54) ELECTROLYTIC PROCESSING DEVICE AND SUBSTRATE PROCESSING APPARATUS

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(52) **U.S. Cl.** **204/242**; 204/275.1

(57) **ABSTRACT**

There is provided an electrolytic processing device including: a processing electrode brought into contact with or close to a workpiece; a feeding electrode for supplying electricity to the workpiece; an ion exchanger disposed in at least one of the spaces between the workpiece and the processing electrode, and between the workpiece and the feeding electrode; a power source for applying a voltage between the processing electrode and the feeding electrode; and a liquid supply section or supplying a liquid to the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which the ion exchanger is present. A substrate processing apparatus having the electrolytic processing device is also provided.

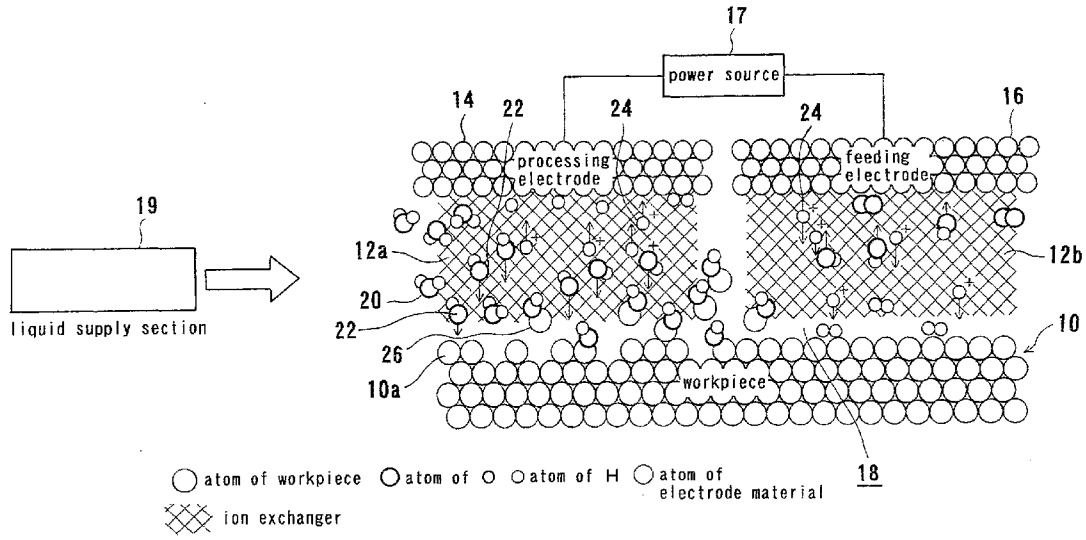


FIG. 1

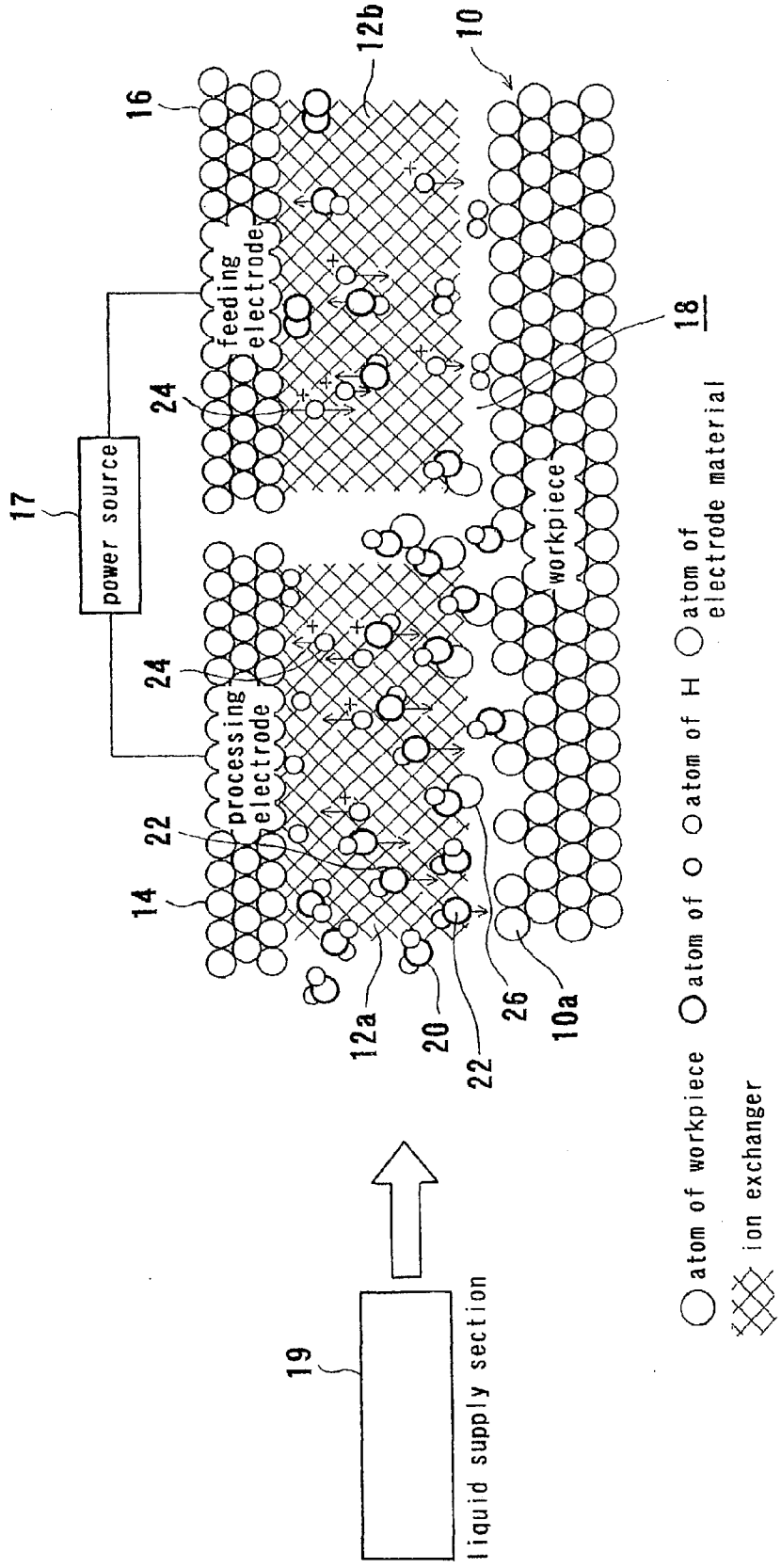

16
12b
10
feeding electrode
18
24
17
power source
workpiece
24
processing electrode
22
14
12a
20
22
26
10a
19
liquid supply section
atom of workpiece
atom of O
atom of H
atom of electrode material
ion exchanger

FIG. 2

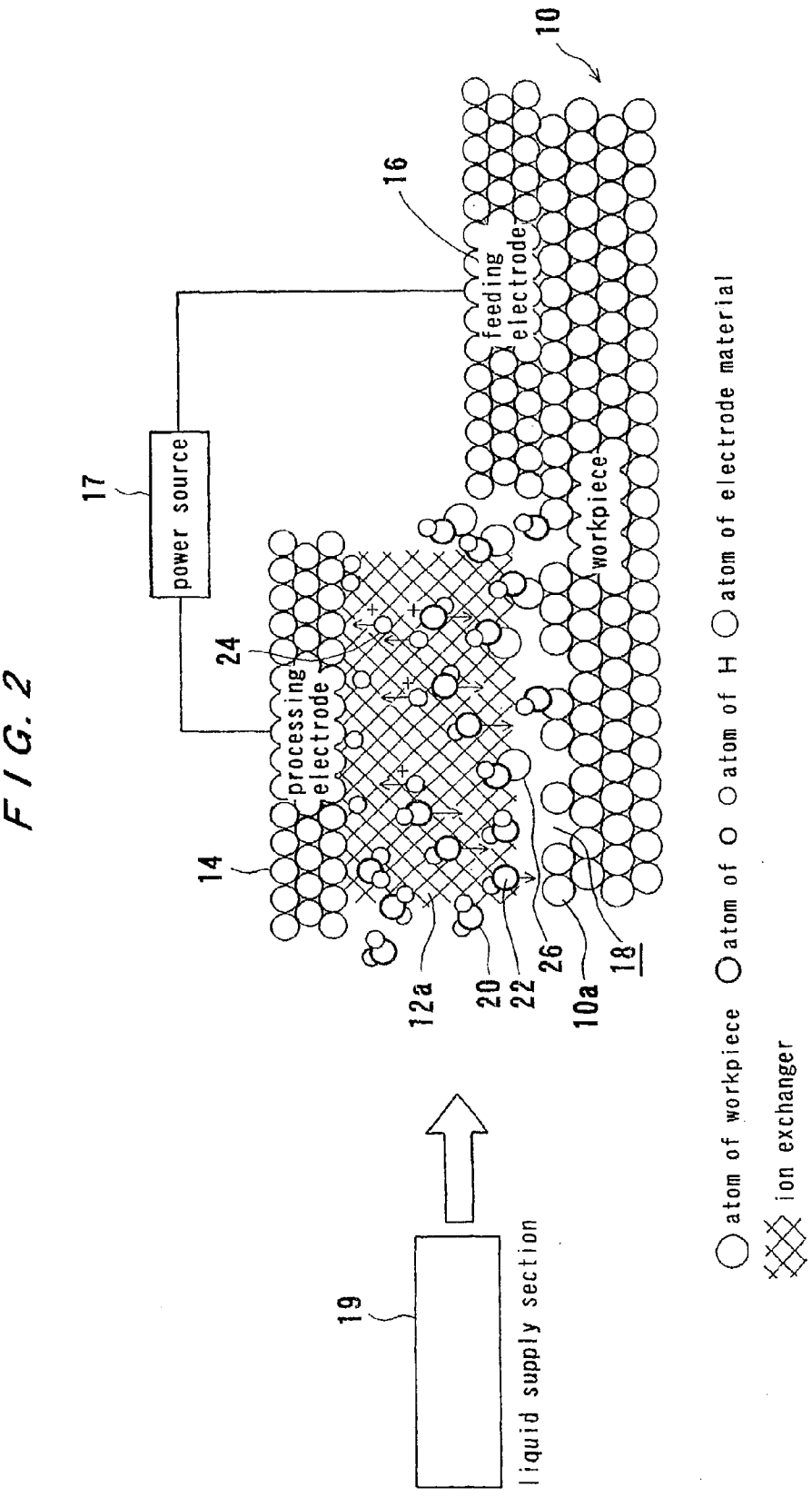

10
16
feeding electrode
17
power source
24
processing electrode
workpiece
14
12a
20
22
26
10a
18
19
liquid supply section
atom of workpiece
atom of O
atom of H
atom of electrode material
ion exchanger

FIG. 3

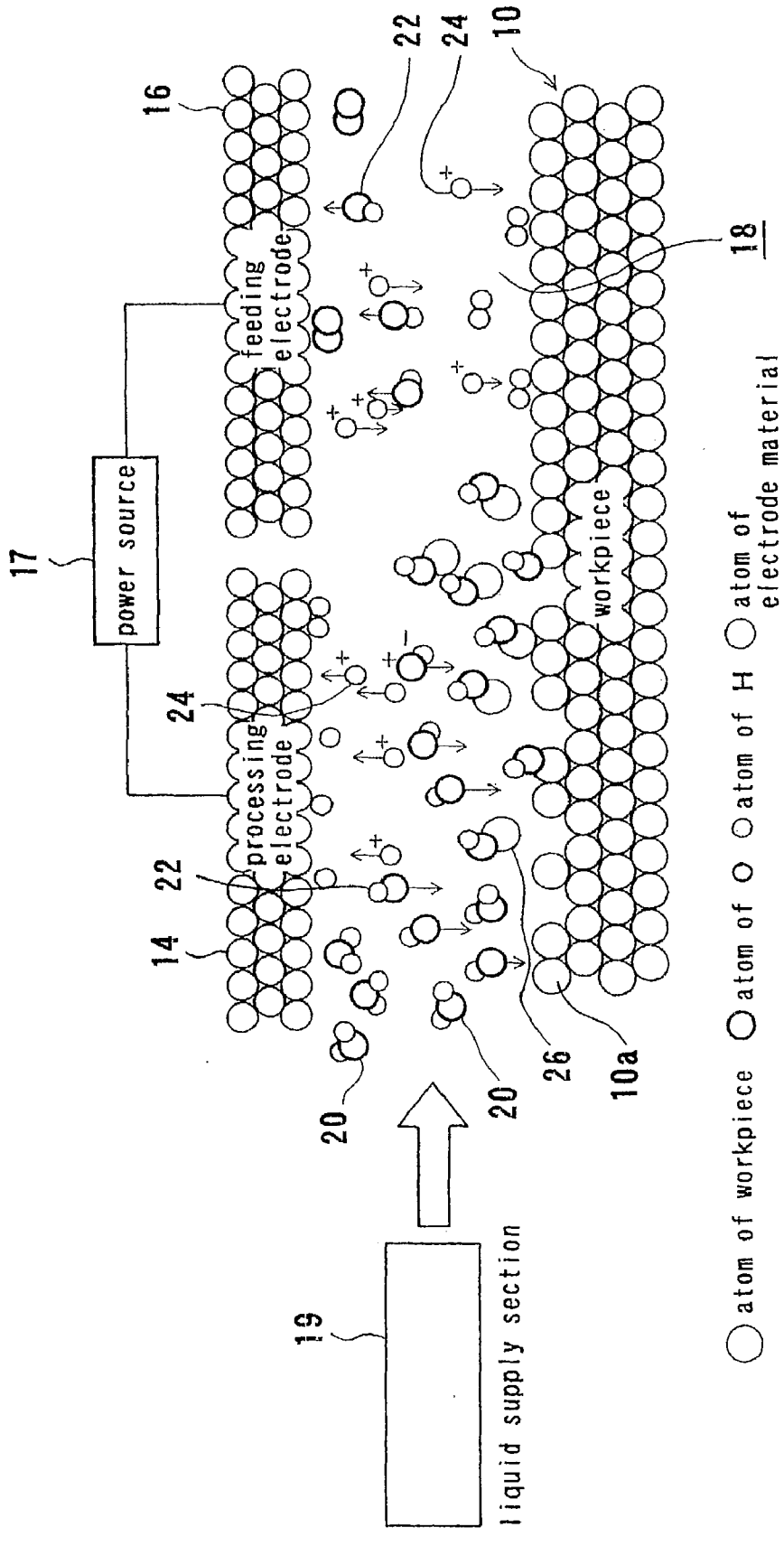

16
feeding electrode
22
24
10
18
17
power source
24
processing electrode
workpiece
14
22
20
20
26
10a
19
liquid supply section
atom of workpiece
atom of O
atom of H
atom of electrode material

FIG. 4A

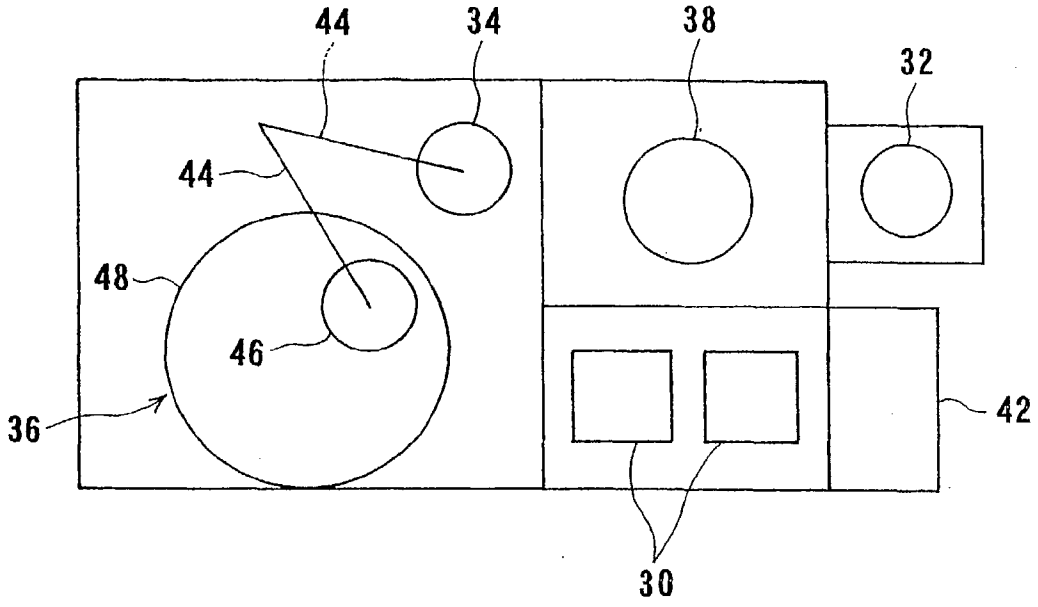


FIG. 4B

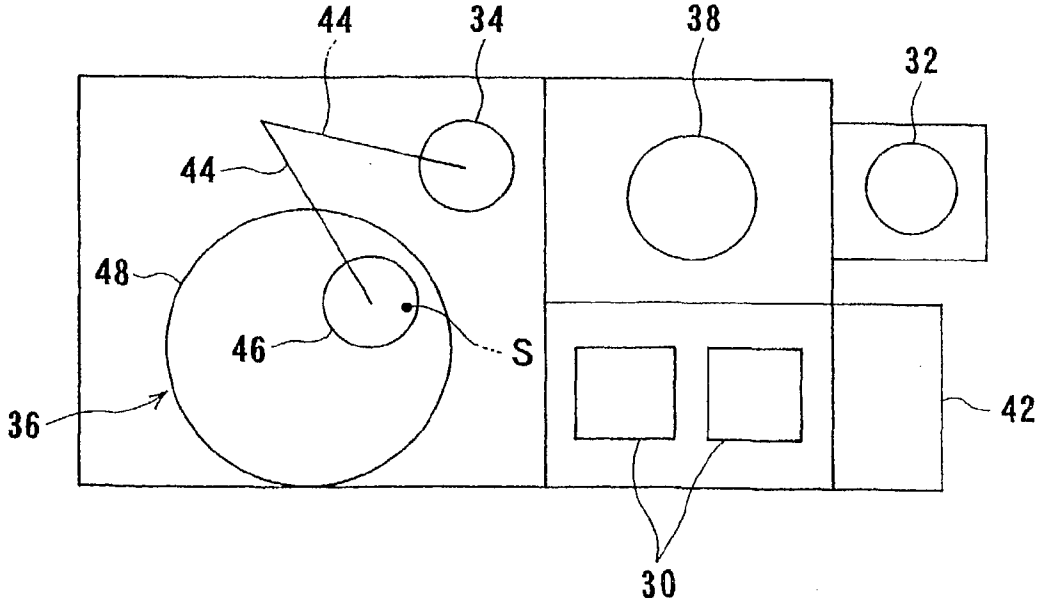


FIG. 5

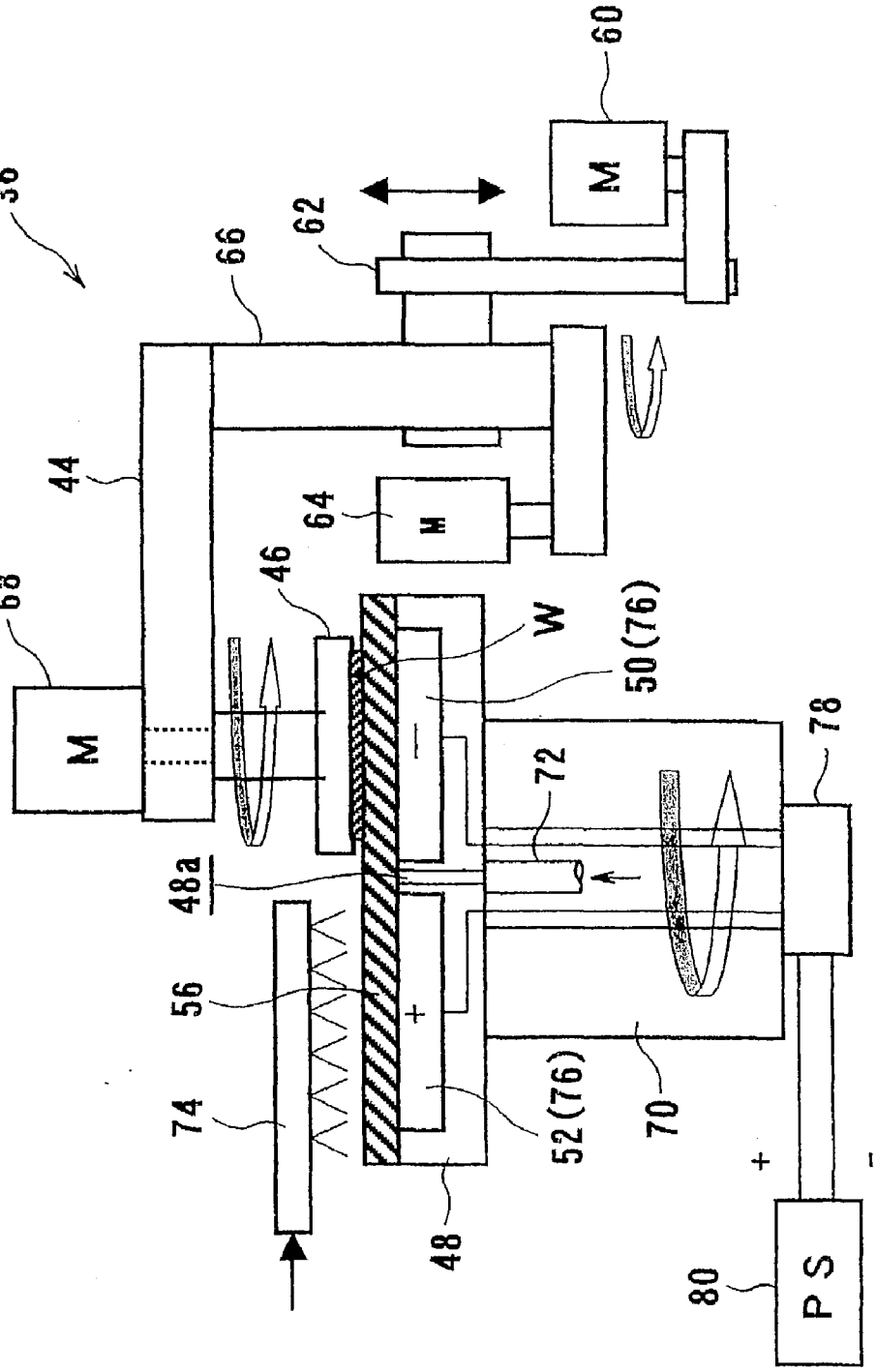


FIG. 6

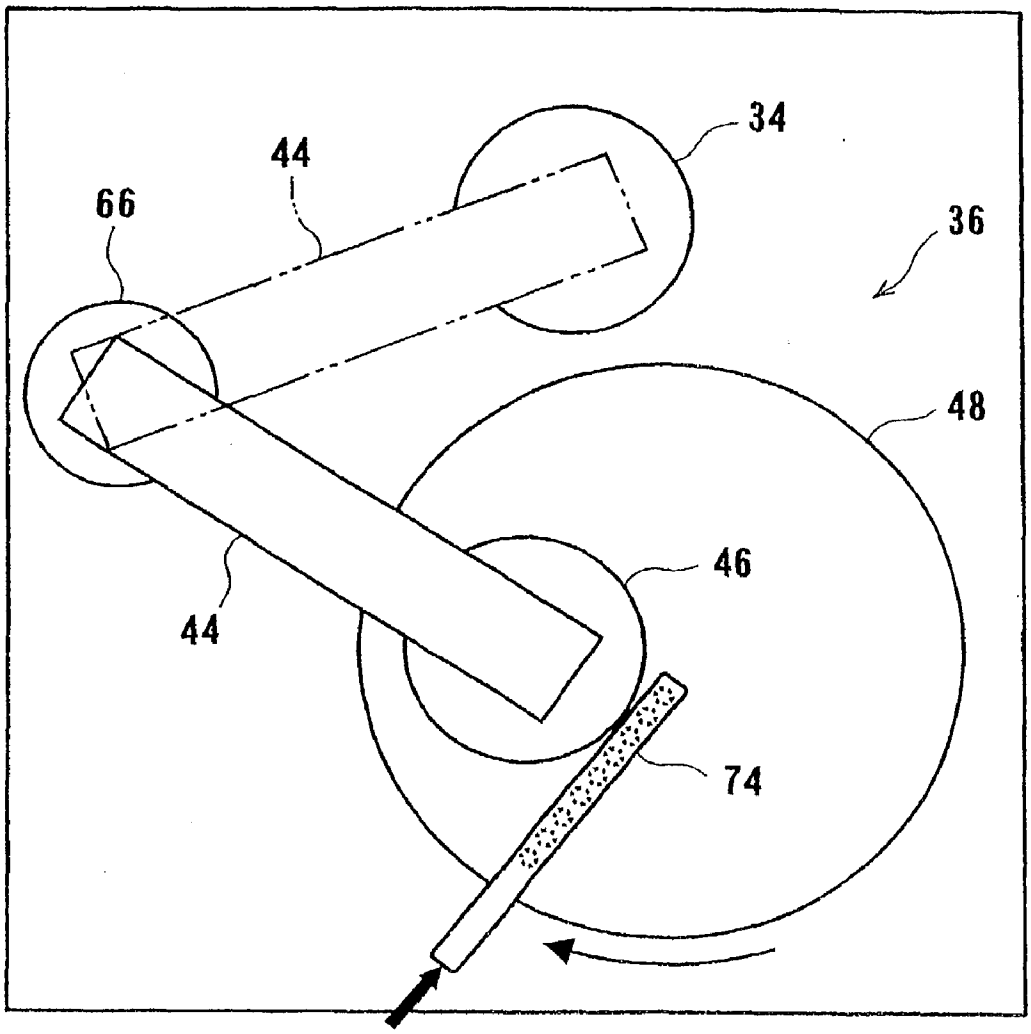


FIG. 7

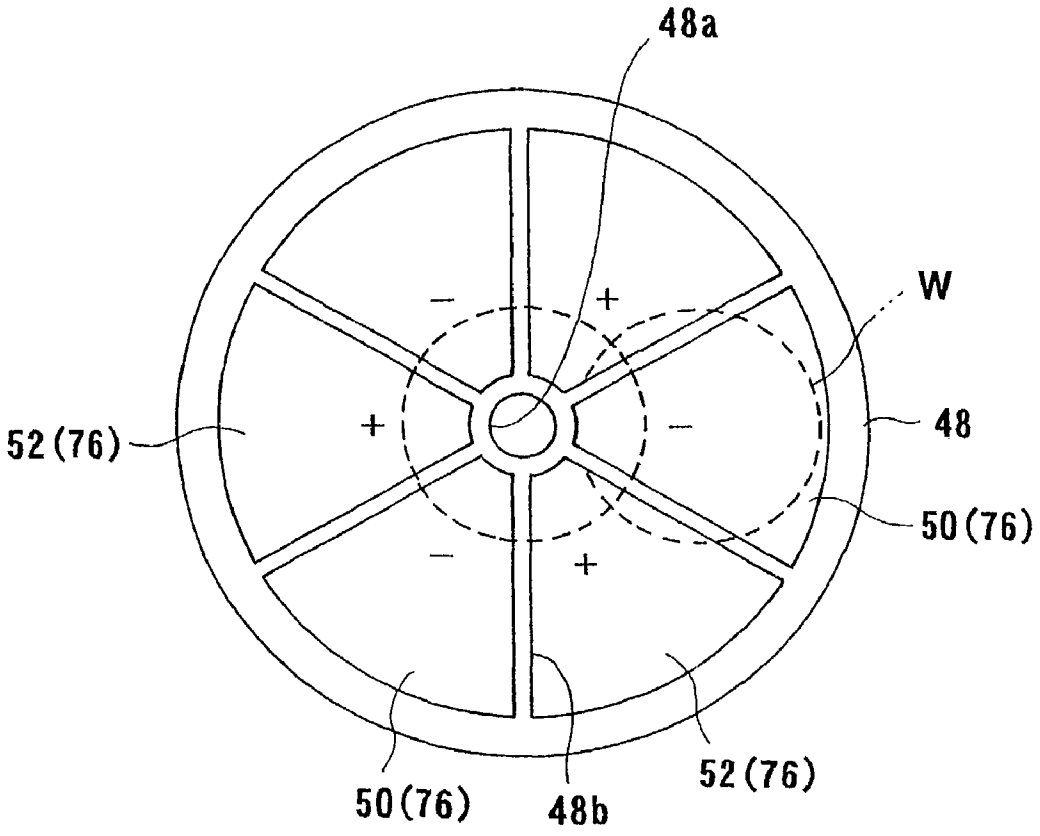


FIG. 8

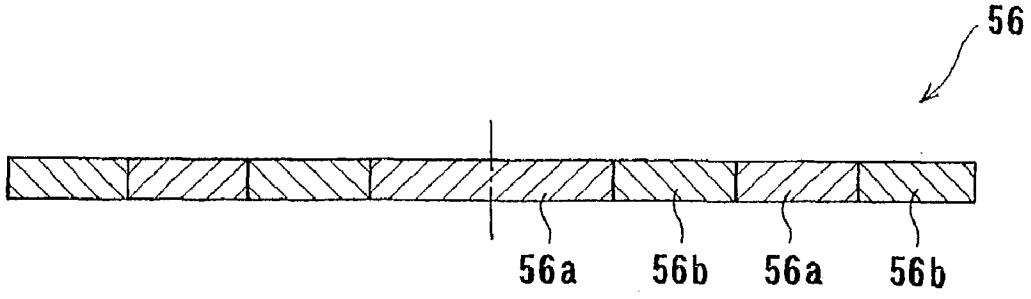


FIG. 9A

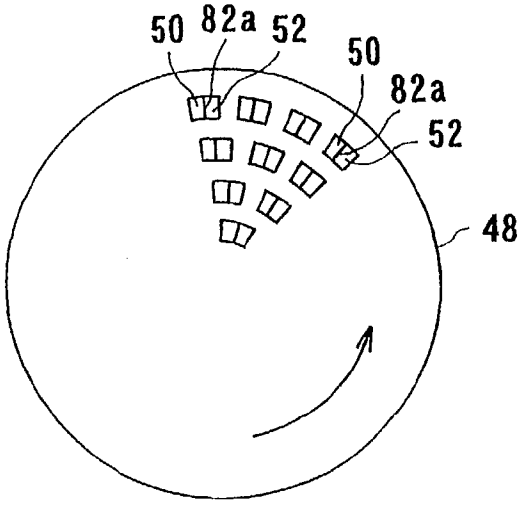


FIG. 9B

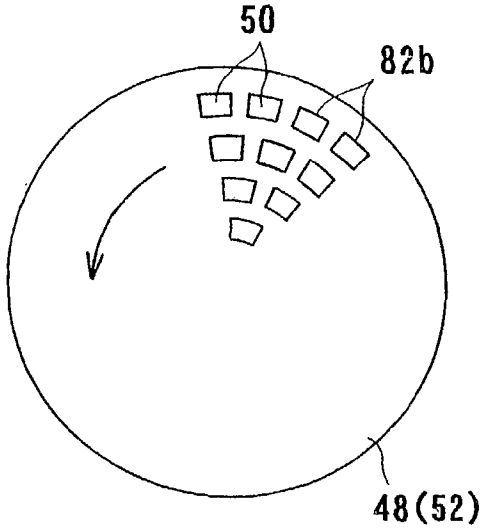


FIG. 10A

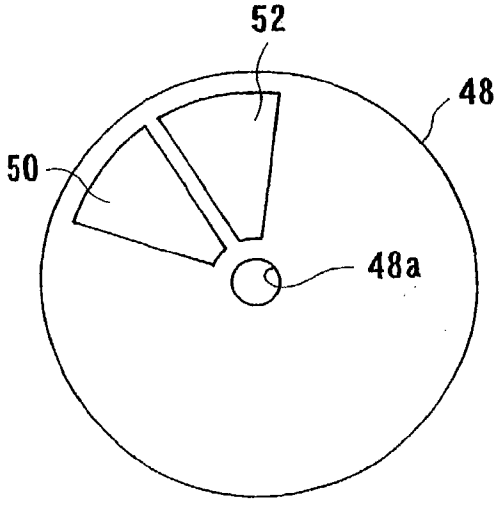


FIG. 10B

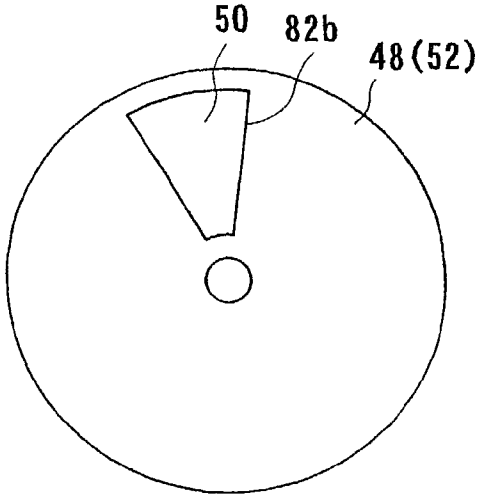


FIG. 11A

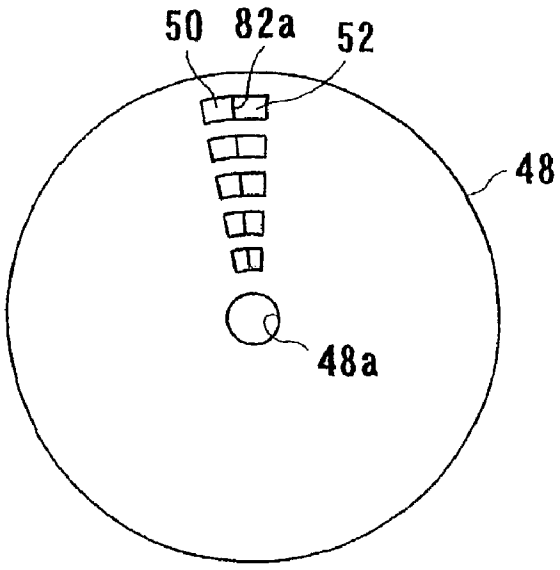


FIG. 11B

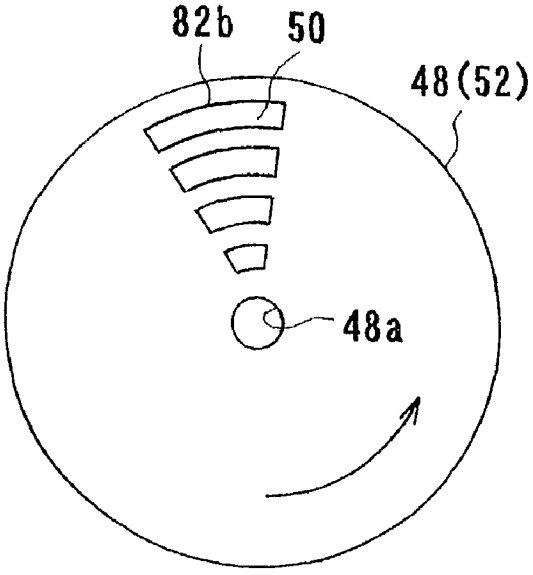


FIG. 12

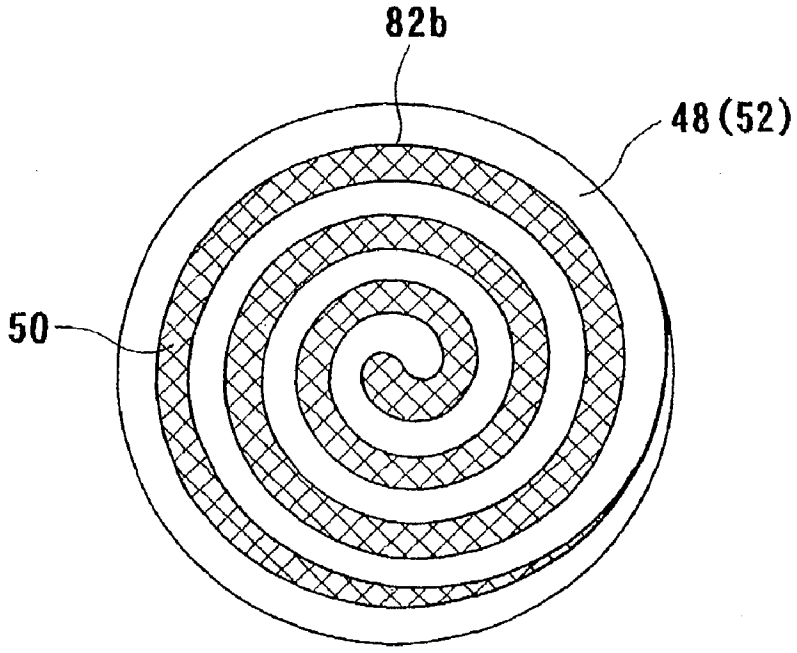


FIG. 13

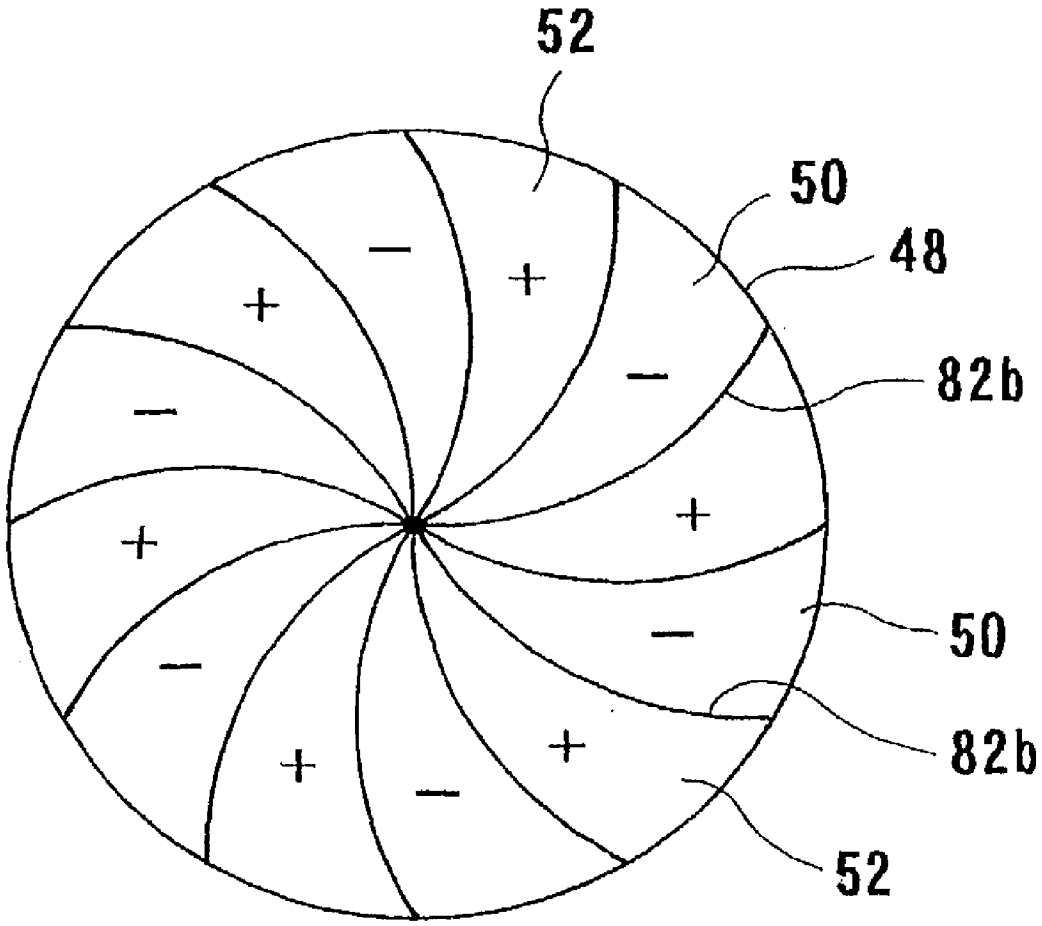


FIG. 14A

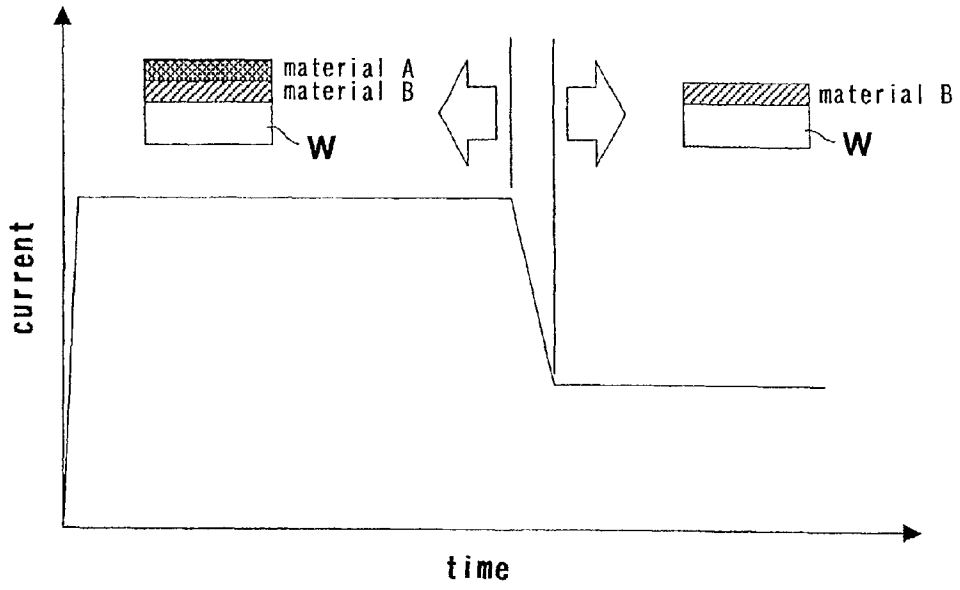


FIG. 14B

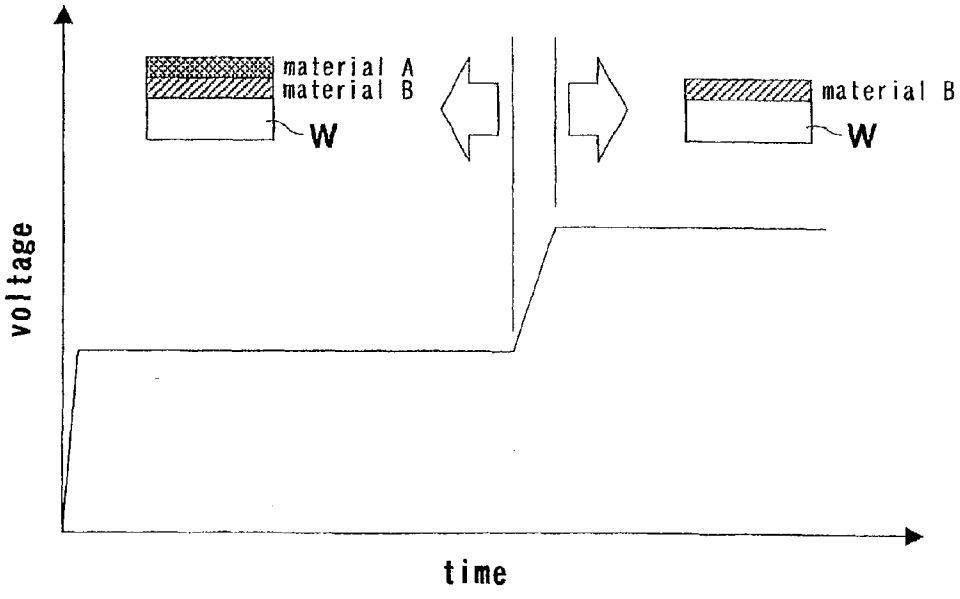


FIG. 15

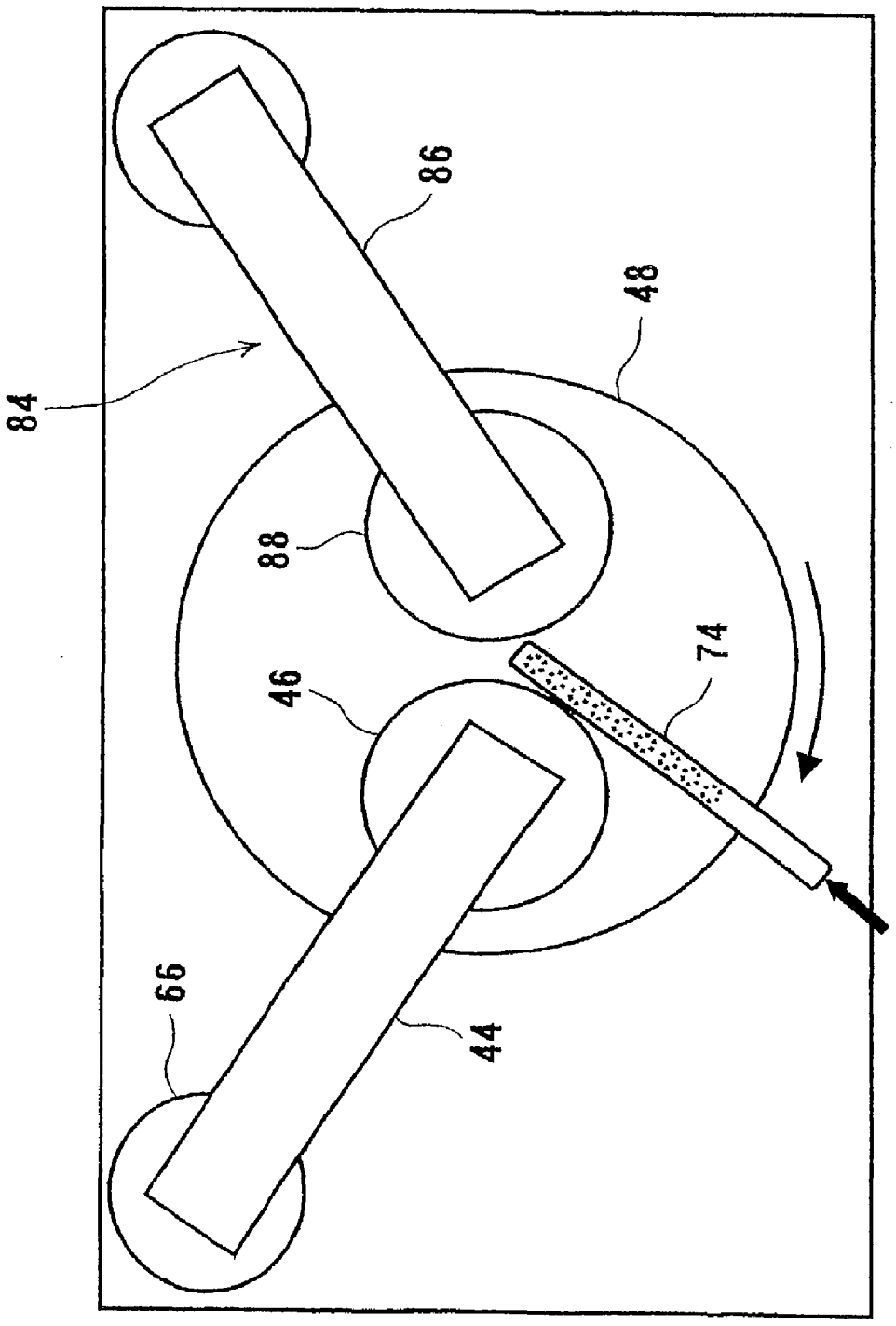


FIG. 16

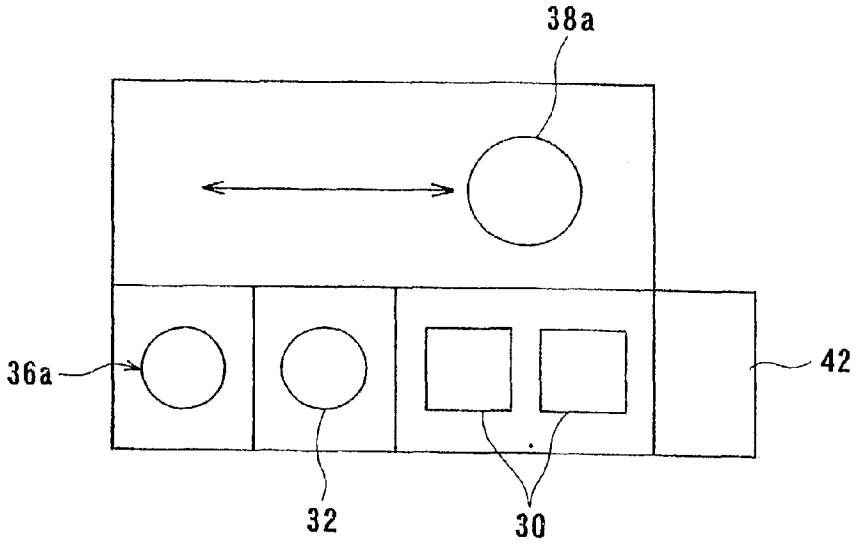

38a
36a
42
32
30

FIG. 17

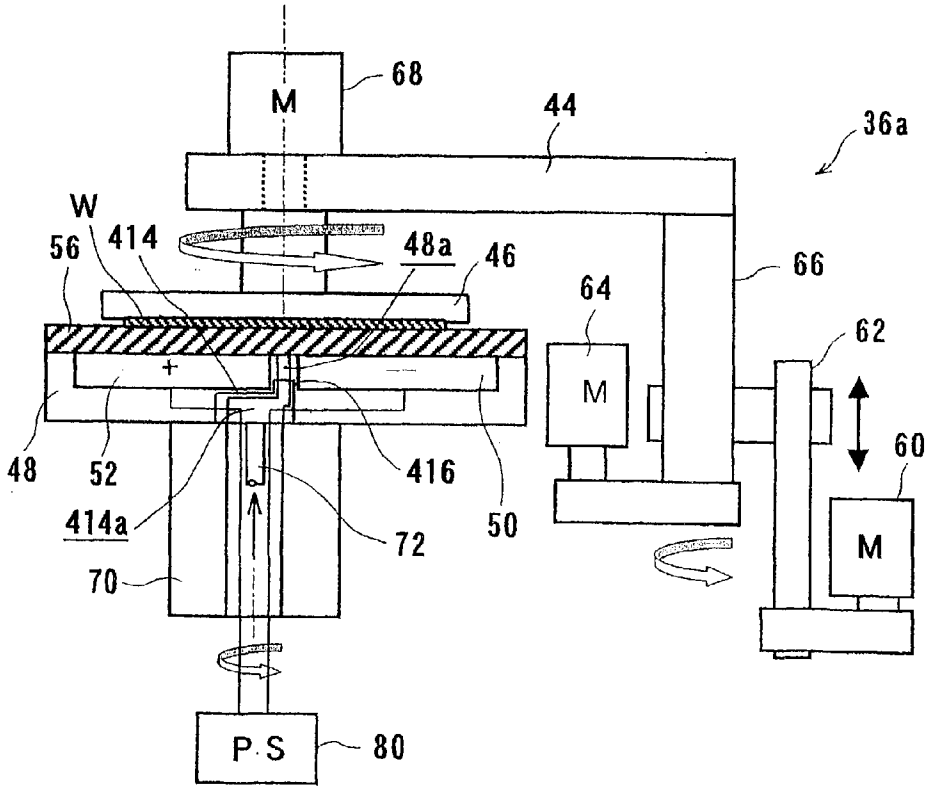

M
68
44
36a
W
56
414
48a
46
66
64
62
M
48
52
416
50
414a
72
60
70
M
P·S
80

FIG. 18

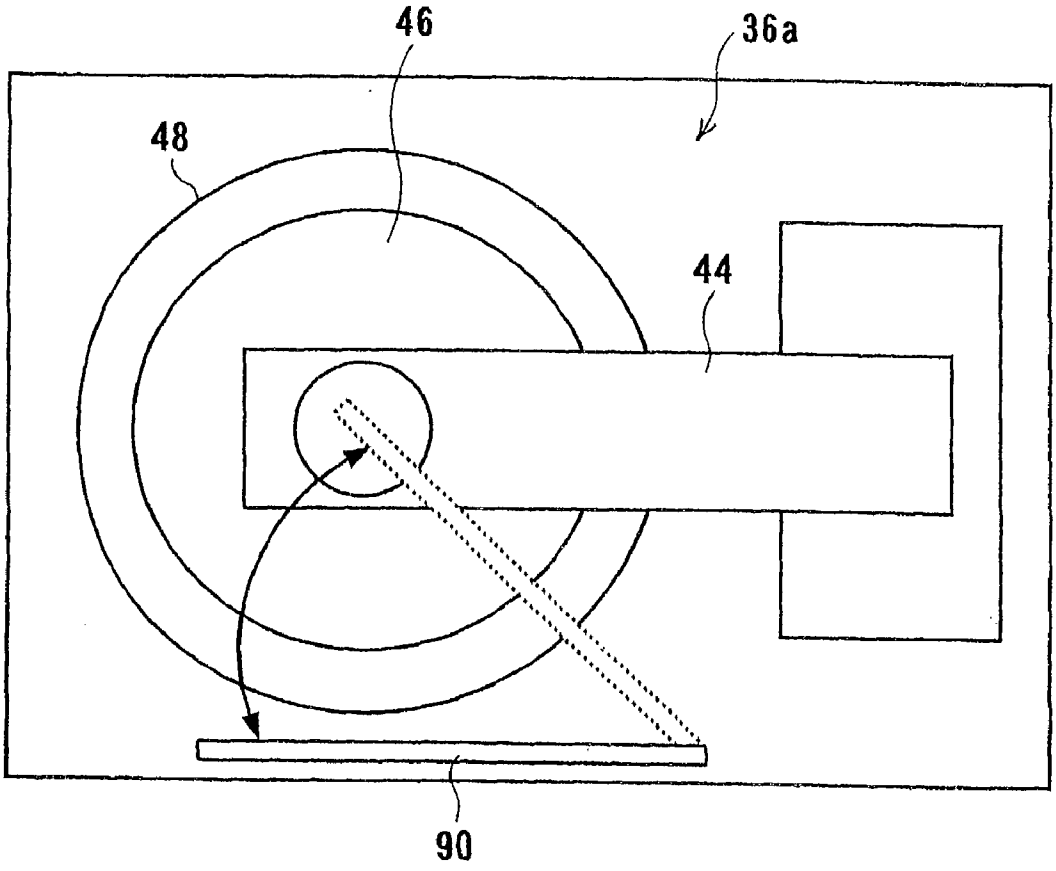


FIG. 19A

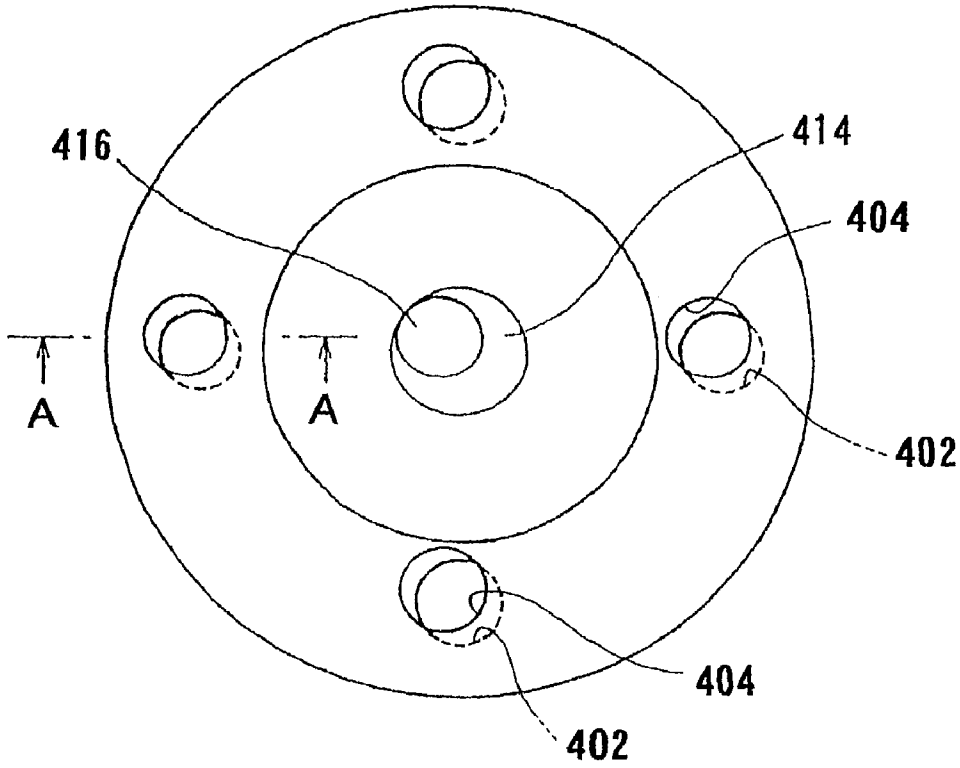


FIG. 19B

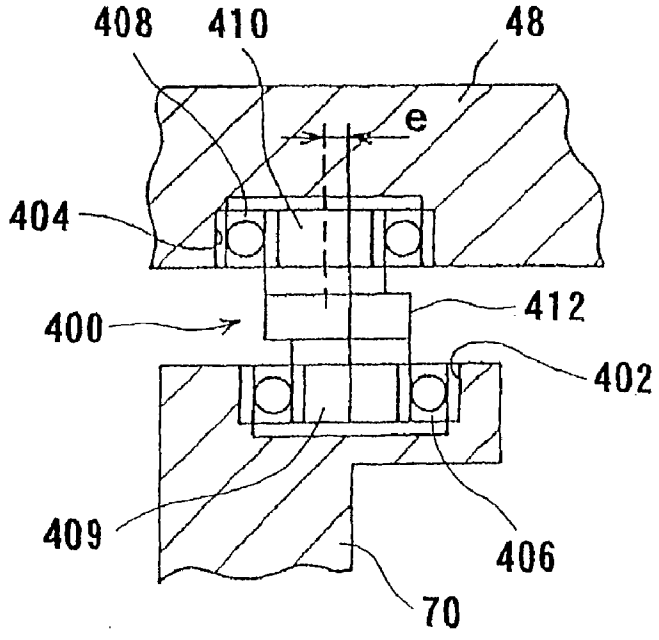


FIG. 20

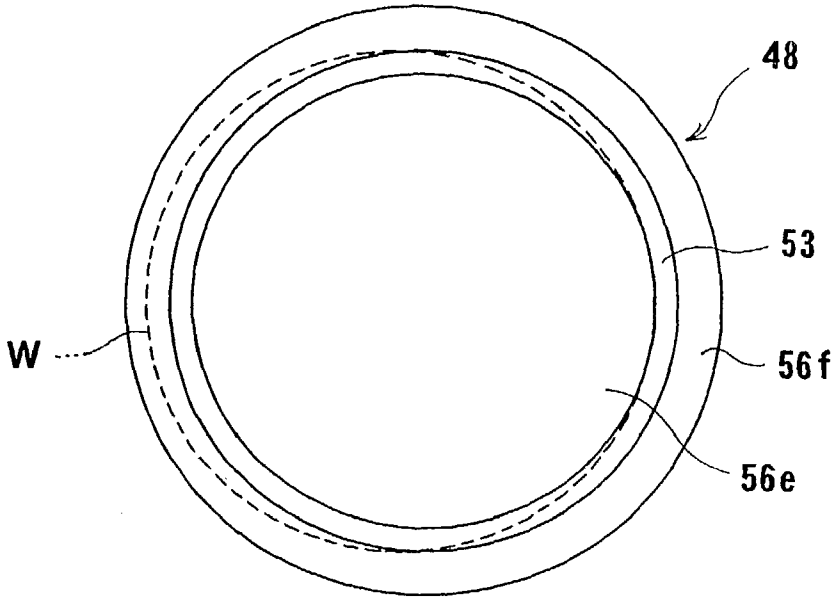


FIG. 21

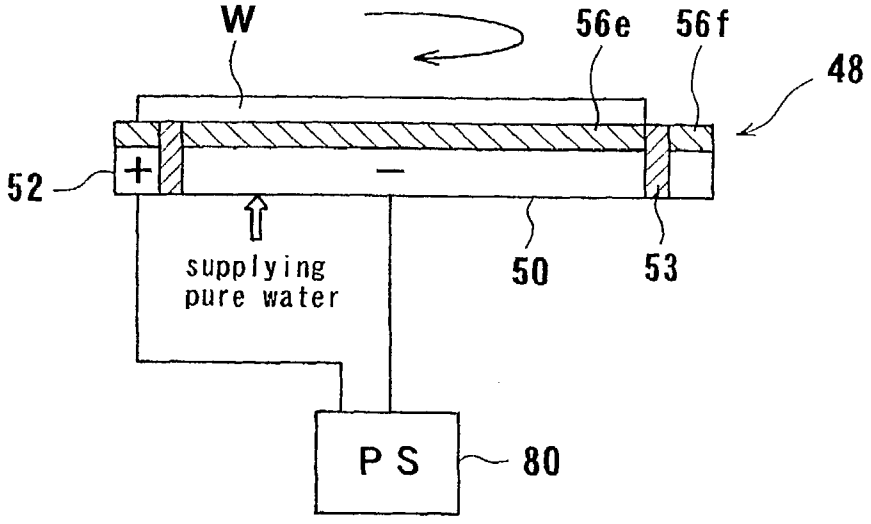


FIG. 22

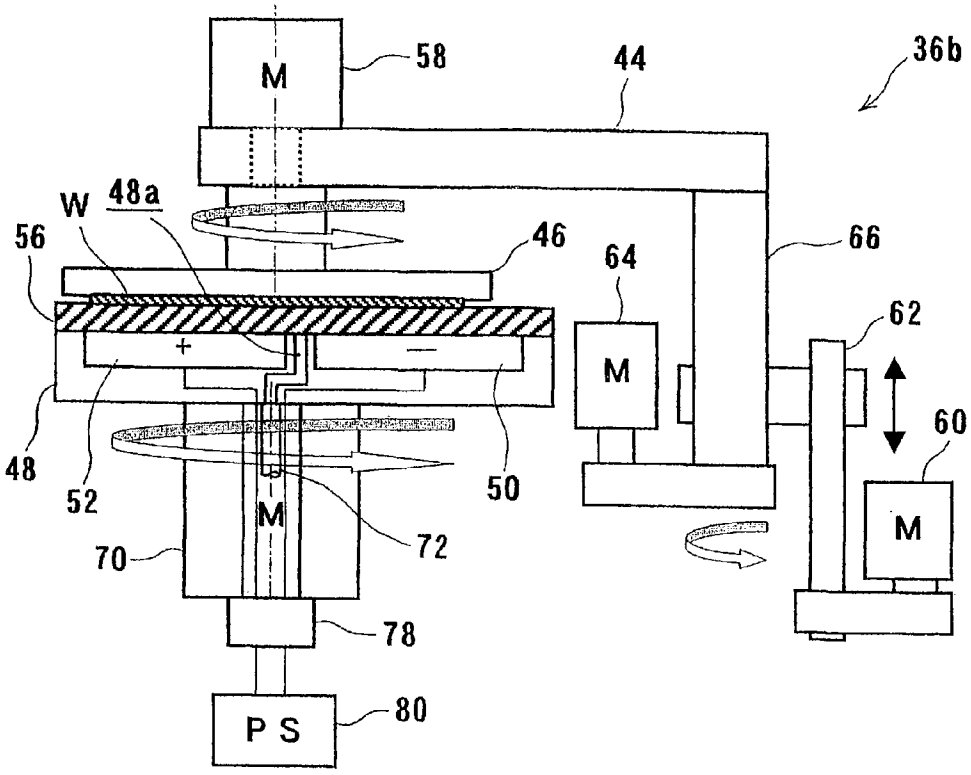


FIG. 23

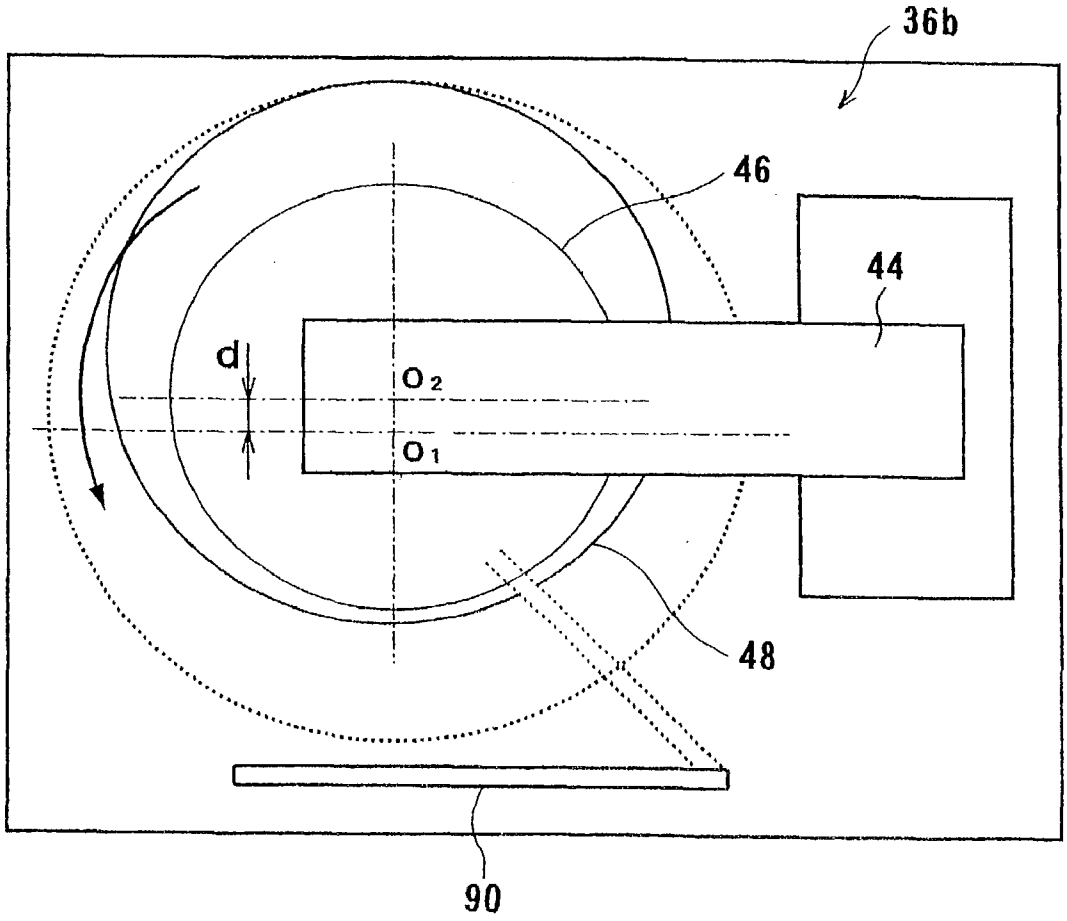


FIG. 24

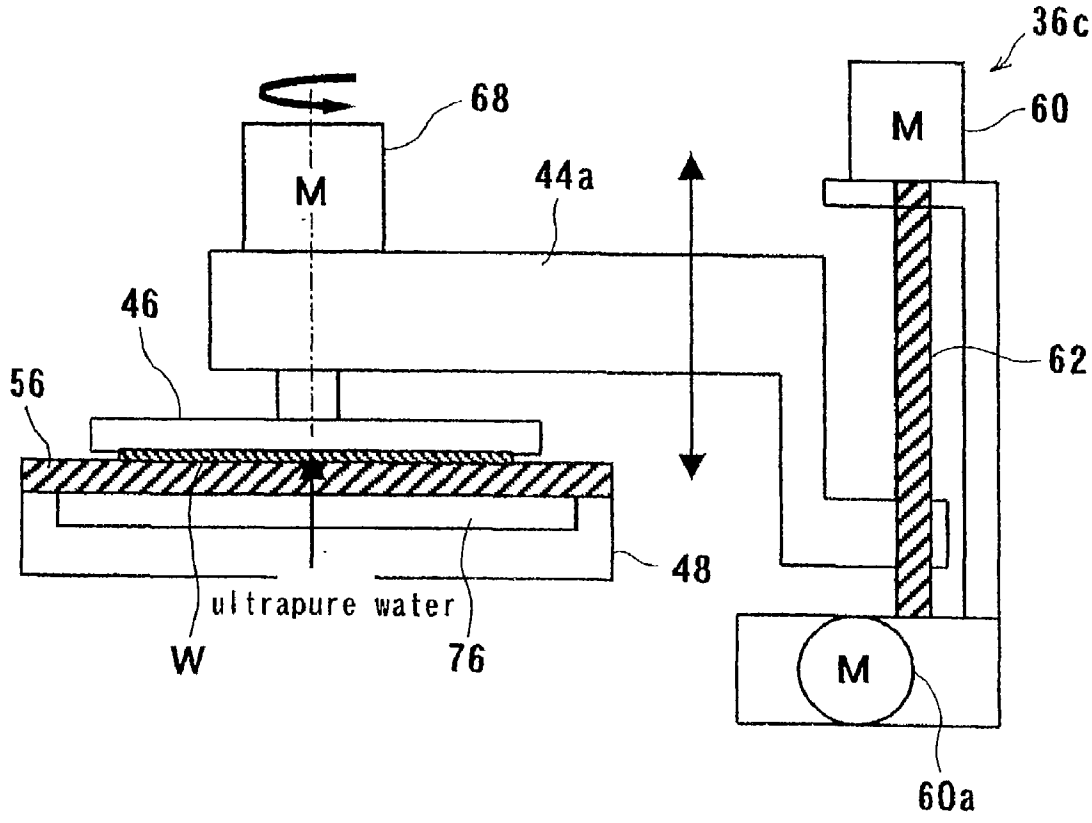


FIG. 25

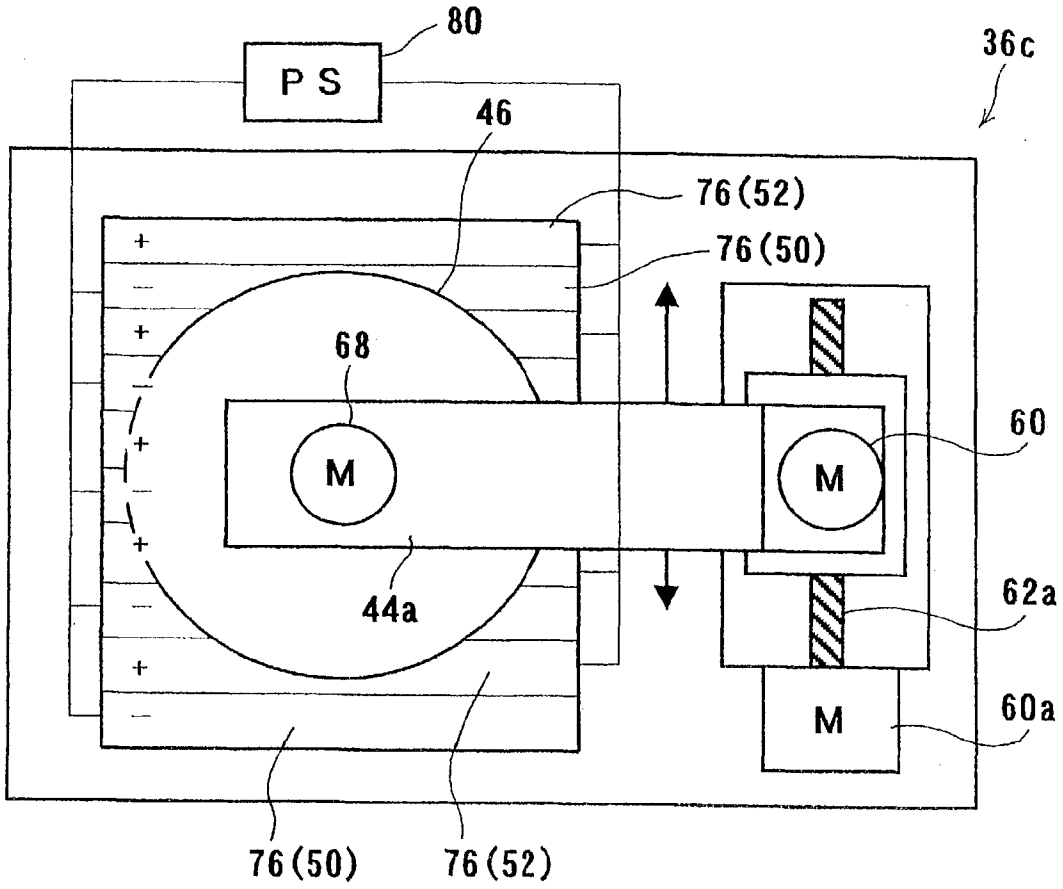


FIG. 26

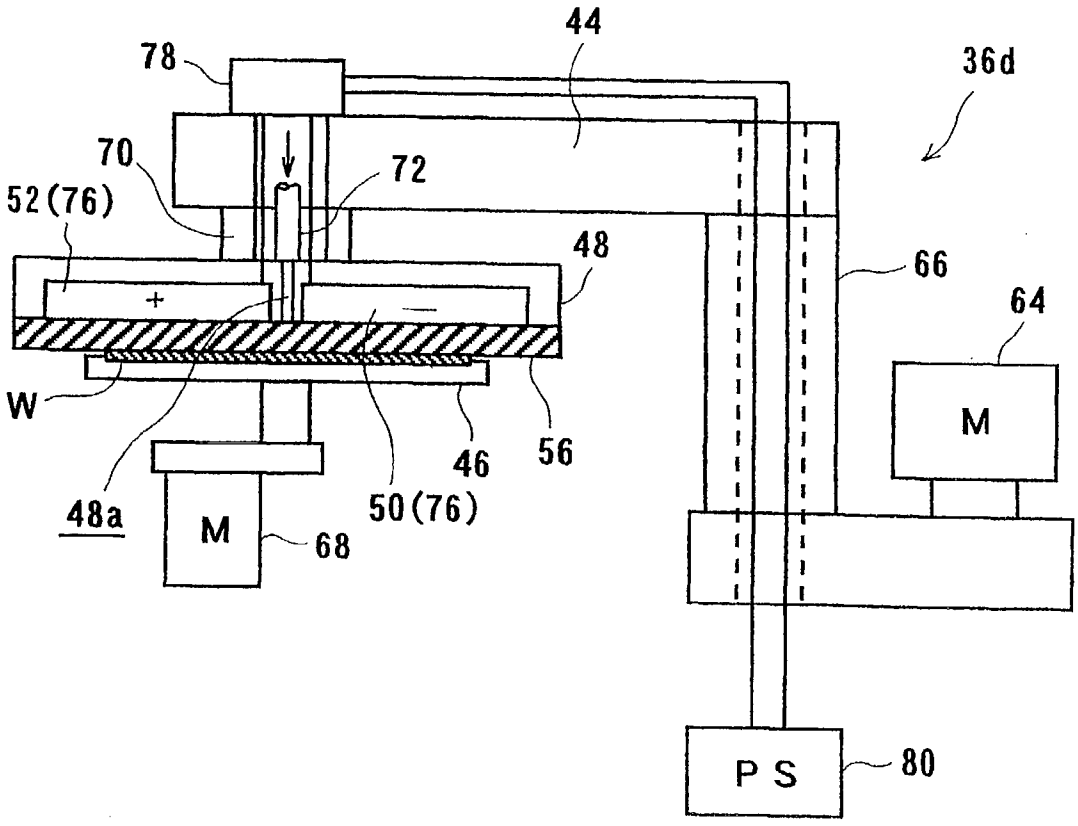


FIG. 27

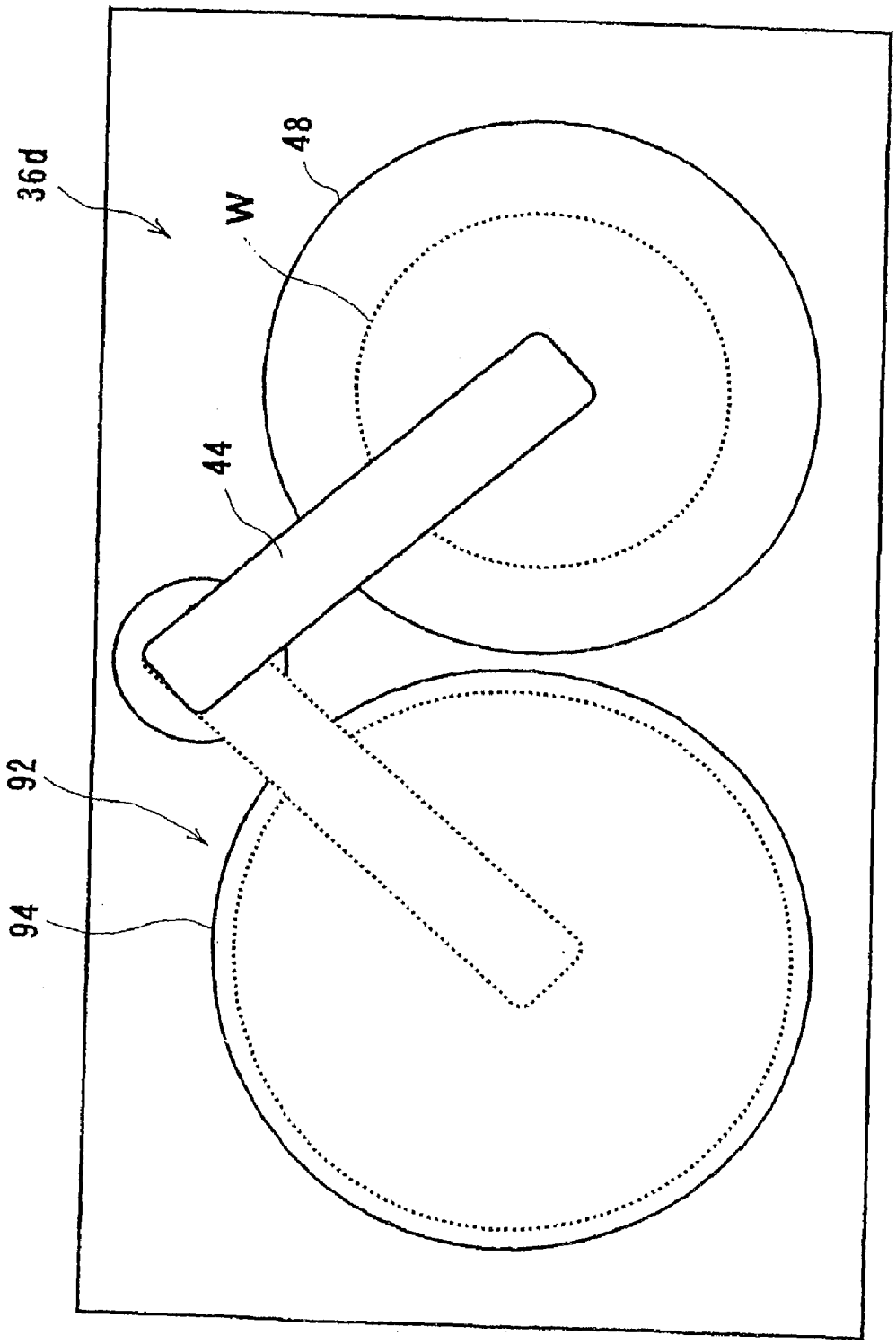


FIG. 28

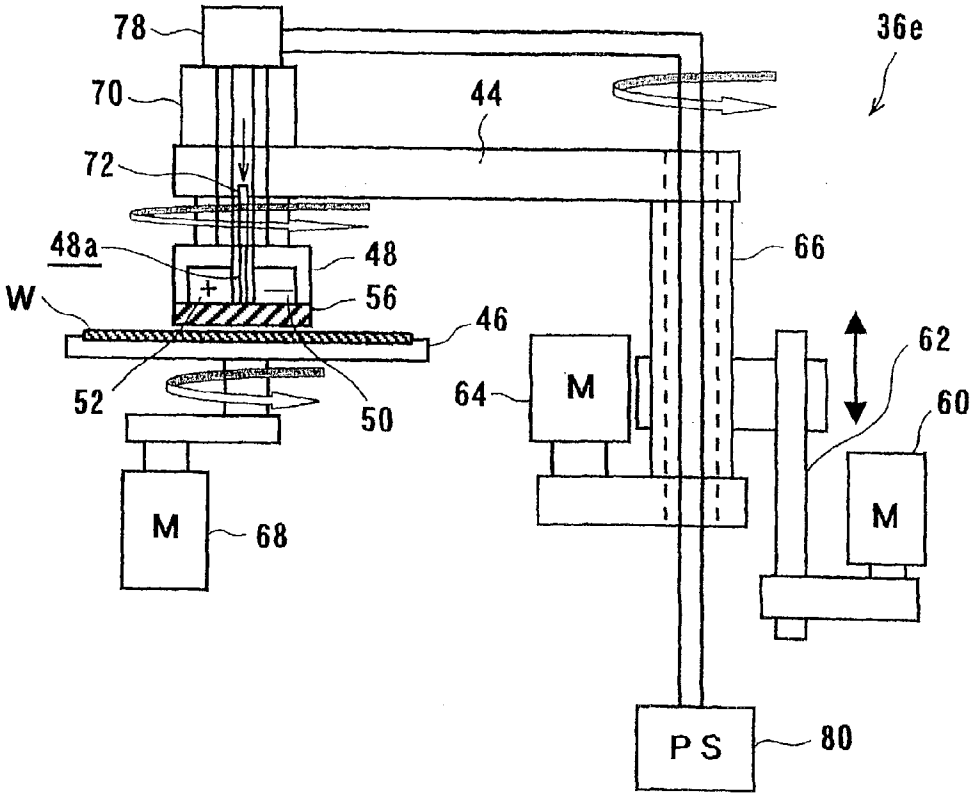

78
70
72
48a
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W
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52
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M
68
44
36e
66
62
64
M
60
M
PS
80

FIG. 29

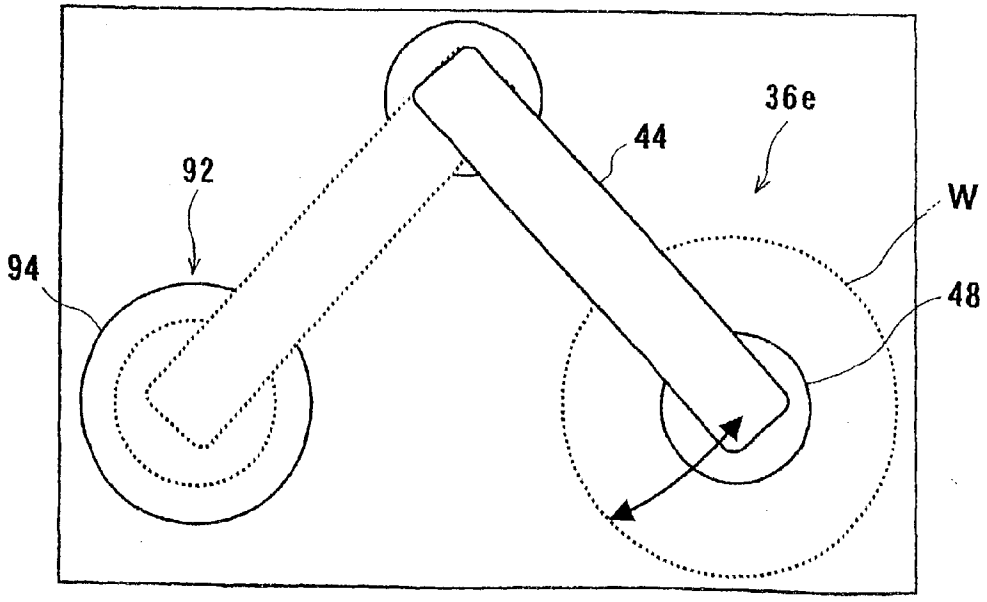

36e
44
92
W
94
48

FIG. 30

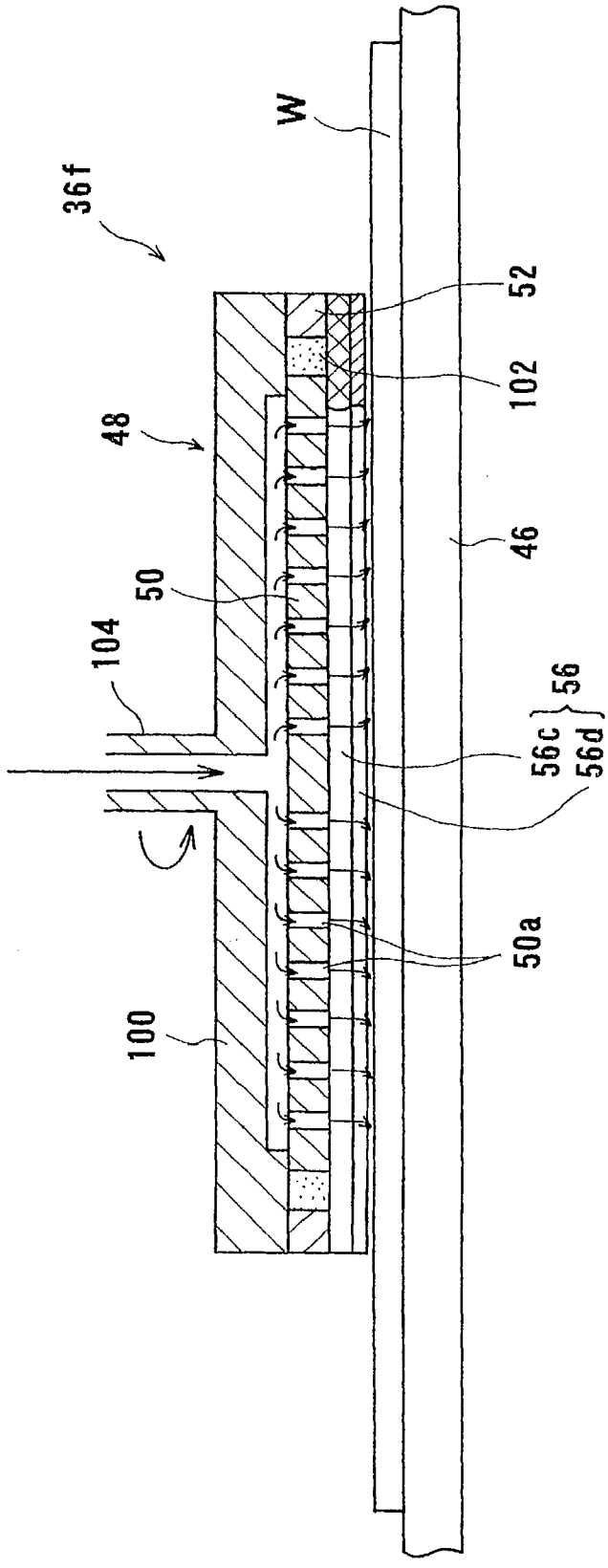


FIG. 31

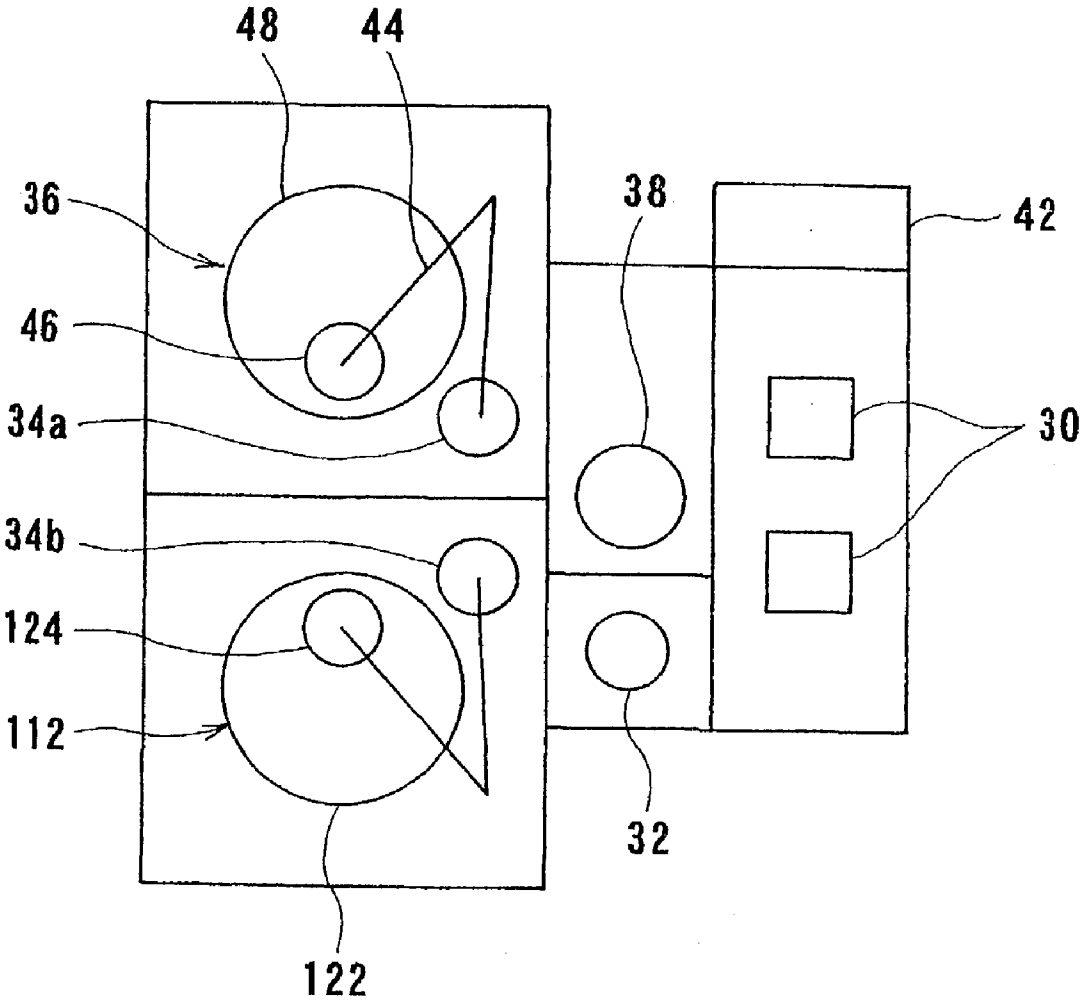


FIG. 32

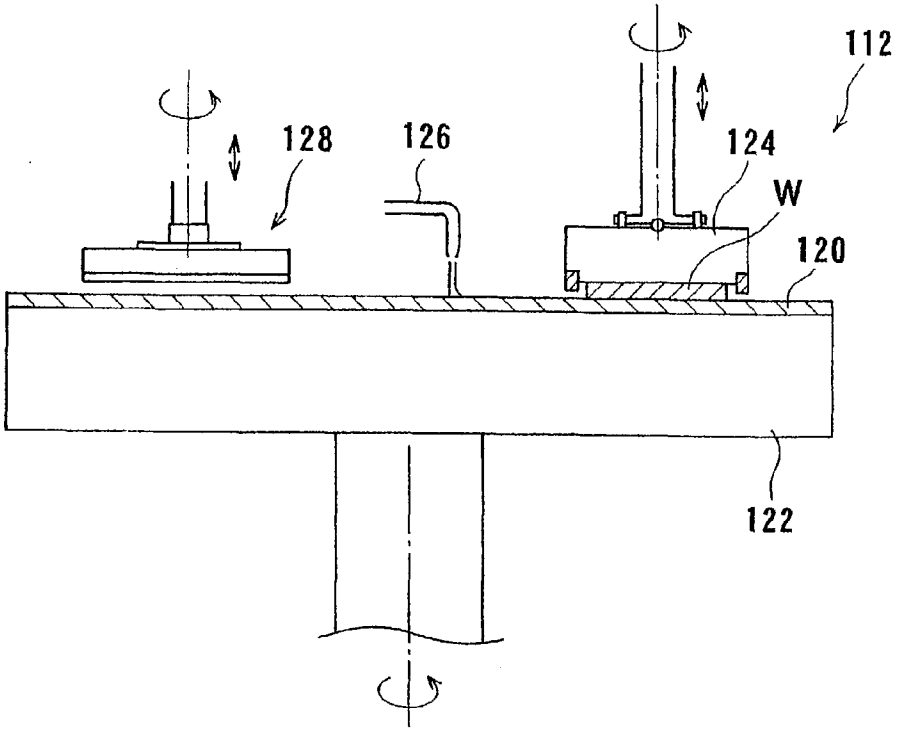


FIG. 33

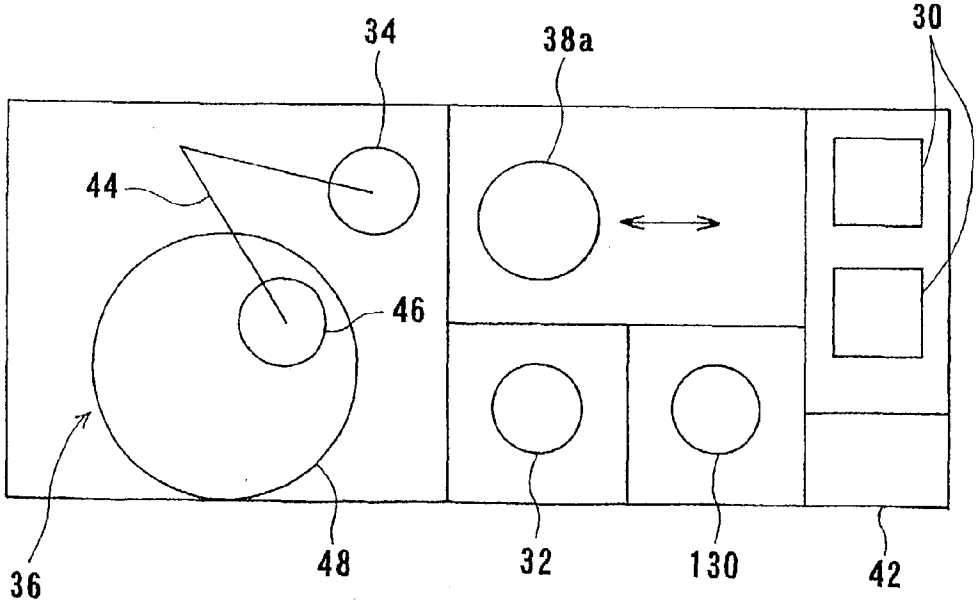


FIG. 34

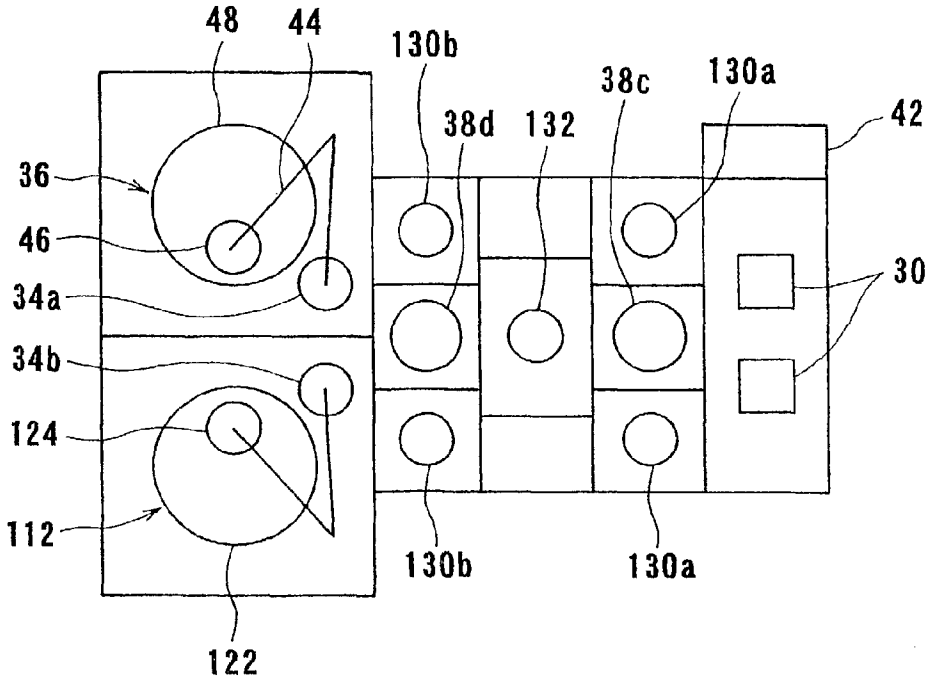

48
44
130b
38c
130a
38d
132
42
36
46
34a
30
34b
124
112
130b
130a
122

FIG. 35

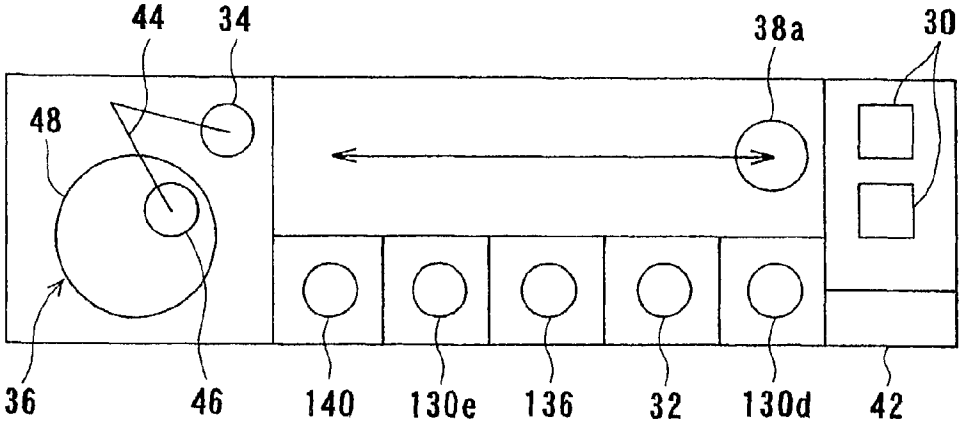

44
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38a
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130e
136
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130d
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FIG. 36

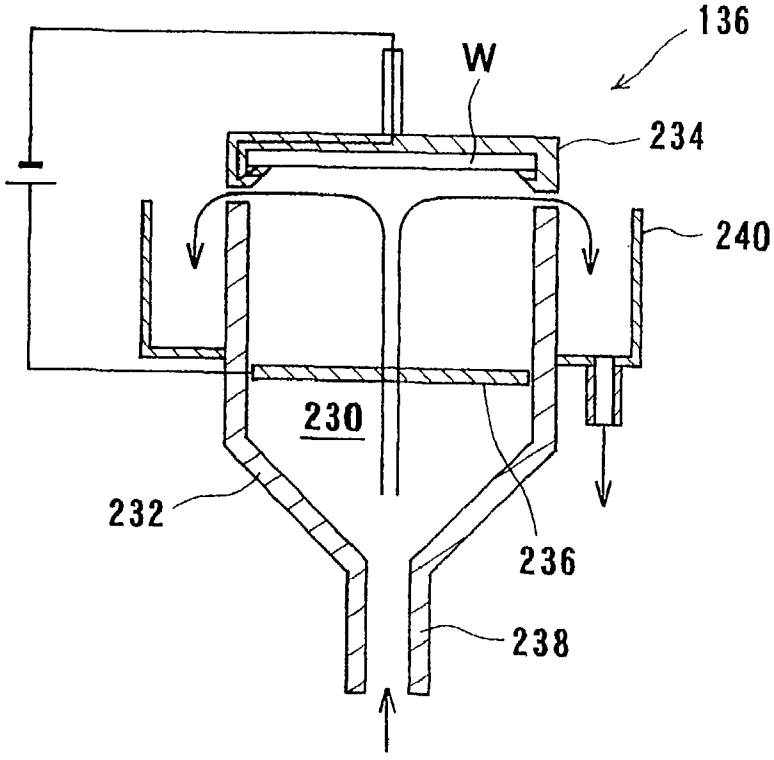

136
W
234
240
230
232
236
238

FIG. 37

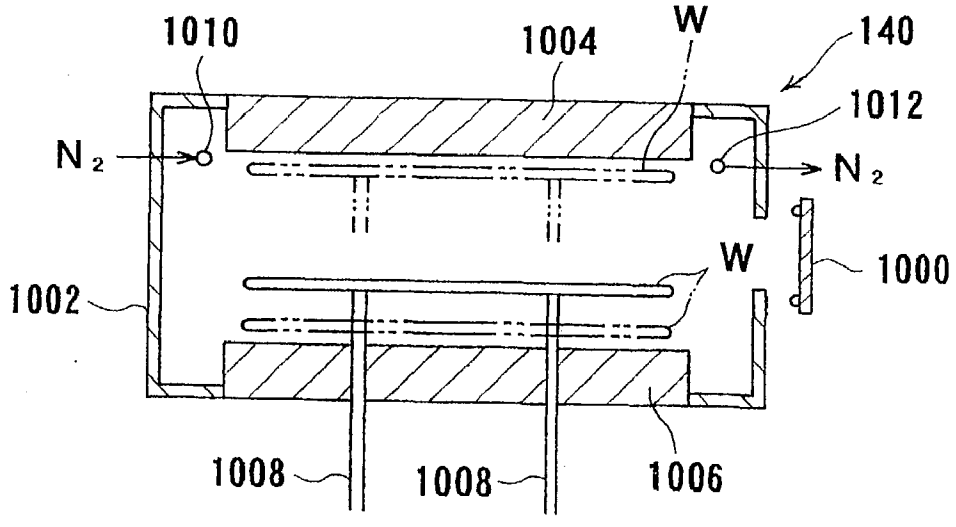

1010
1004
W
140
1012
N2
N2
W
1000
1002
1008
1008
1006

FIG. 38

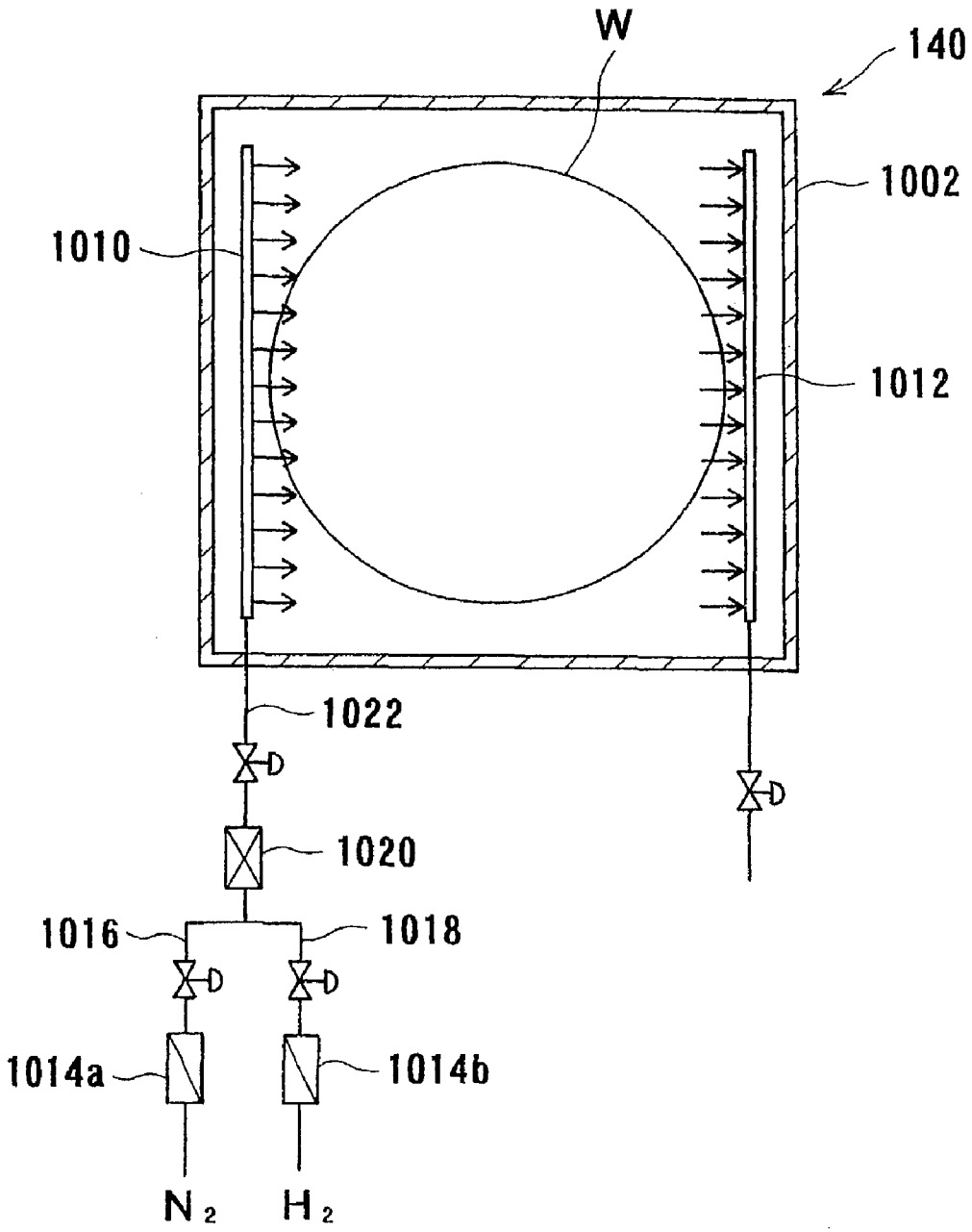


FIG. 39

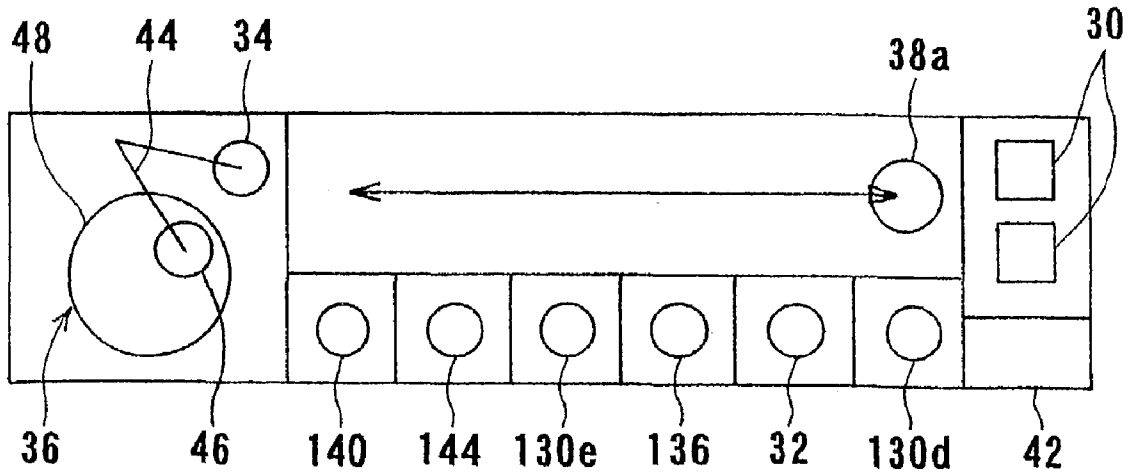

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38a
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130e
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130d
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FIG. 40

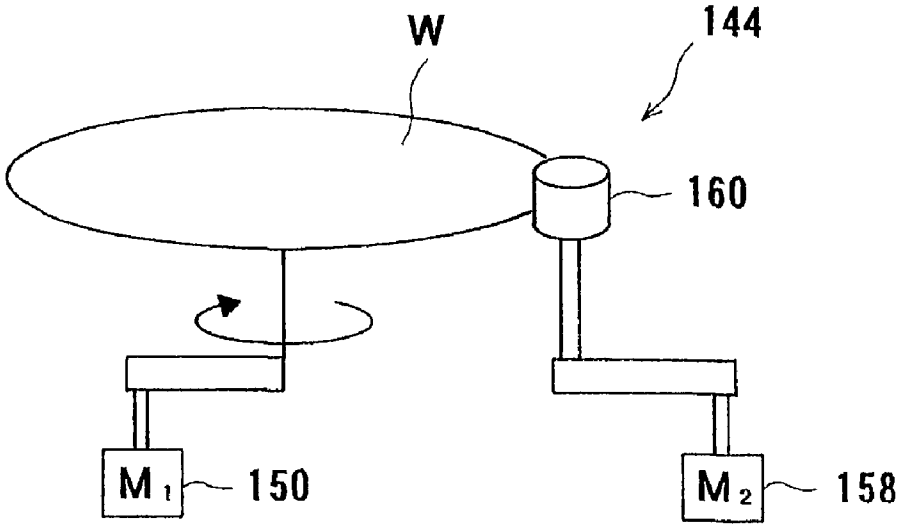

W
144
160
M1
150
M2
158

FIG. 41

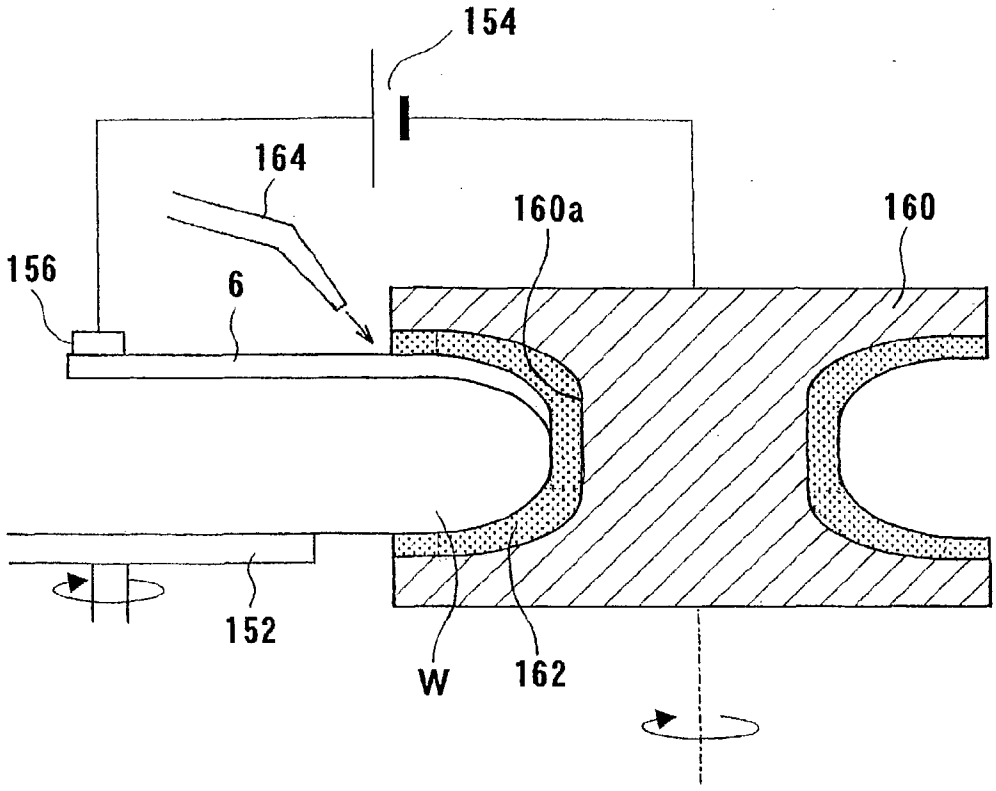

154
164
160a
160
156
6
152
W
162

FIG. 42

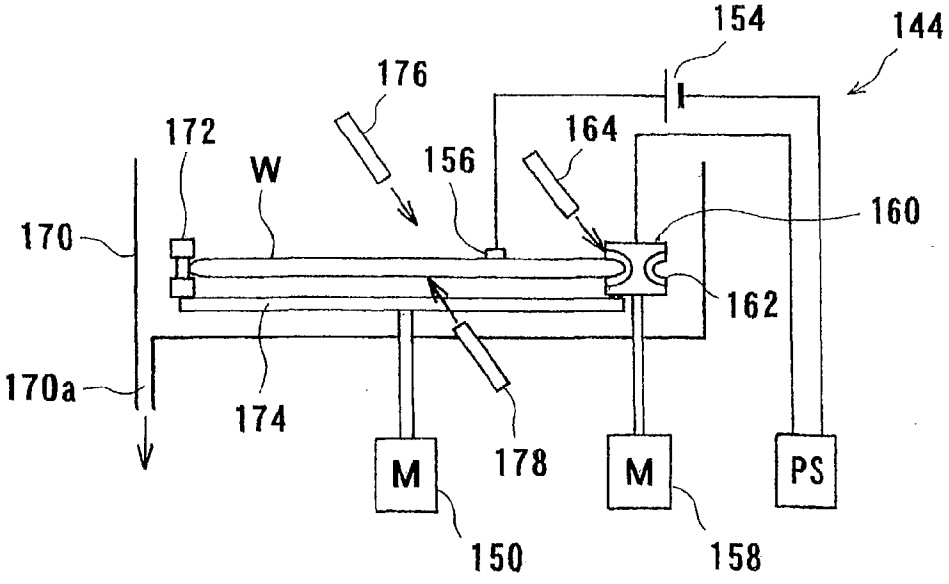

154
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164
W
156
160
170
162
170a
174
178
M
M
PS
150
158

FIG. 43

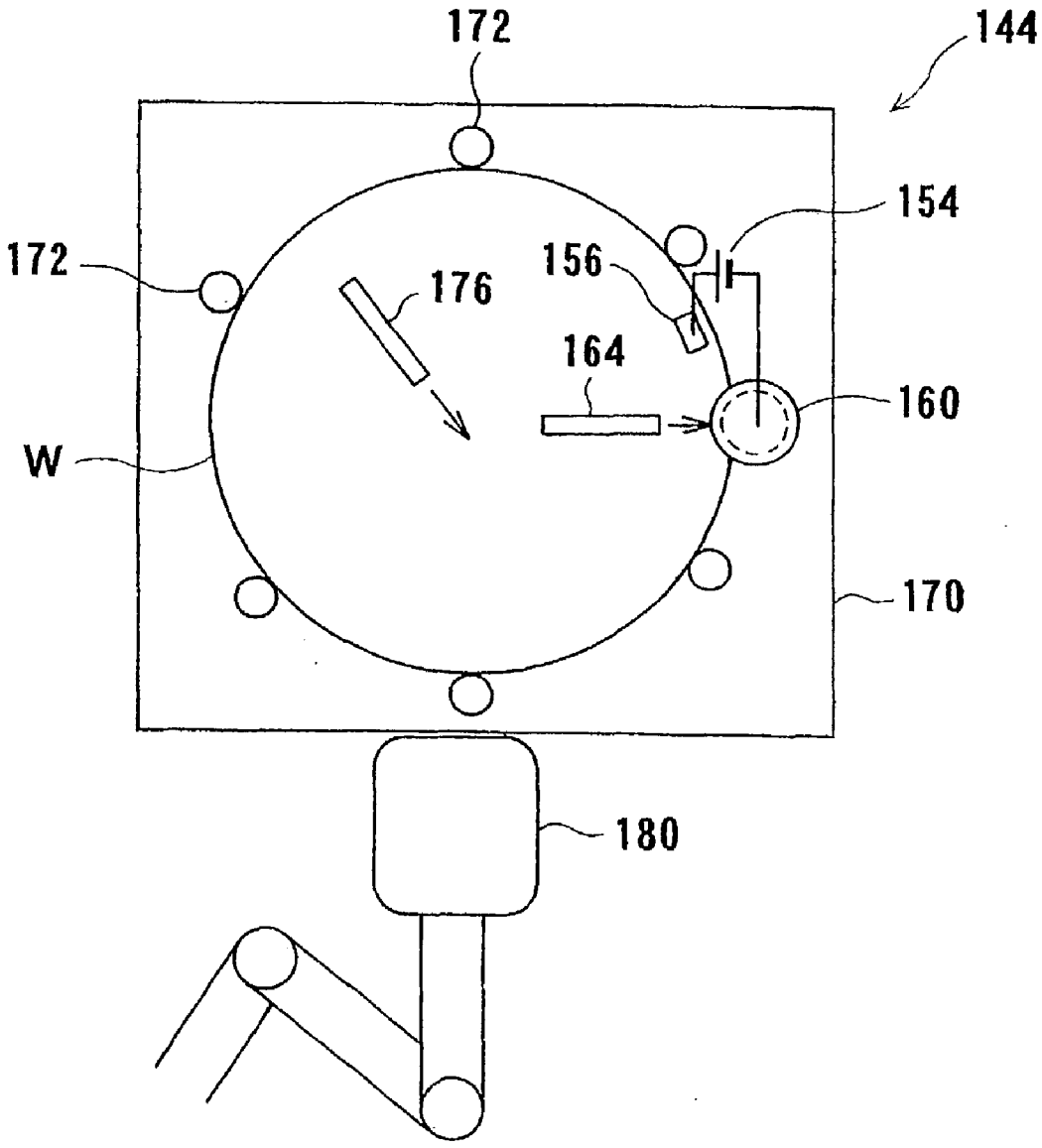


FIG. 44

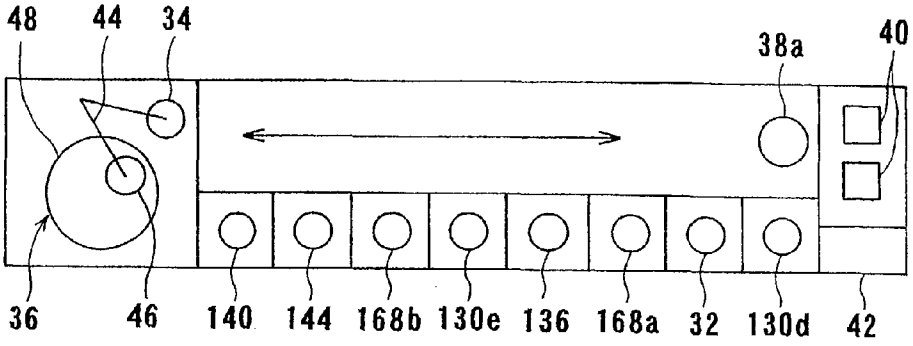

48
44
34
38a
40
36
46
140
144
168b
130e
136
168a
32
130d
42

FIG. 45

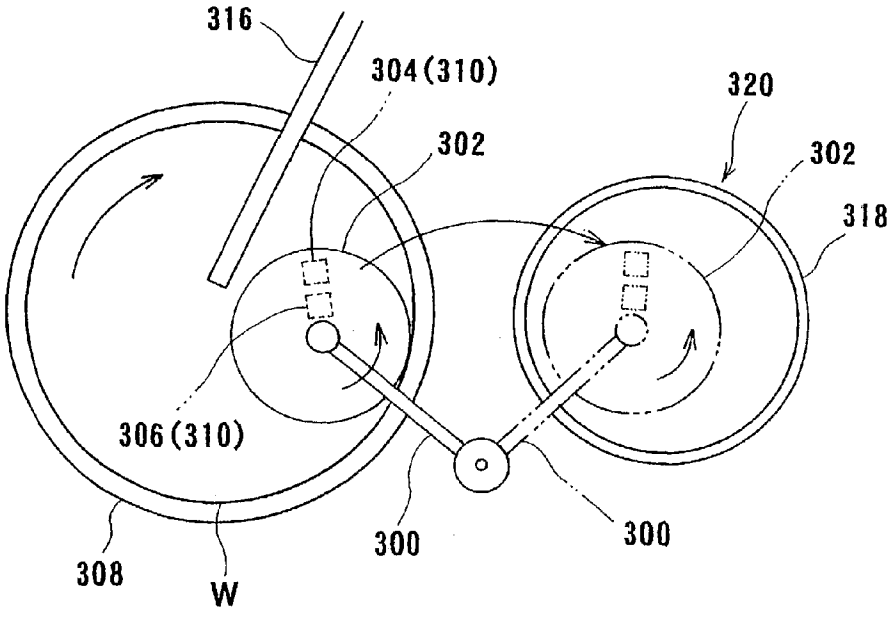

316
304(310)
302
320
302
318
306(310)
308
W
300
300

FIG. 46

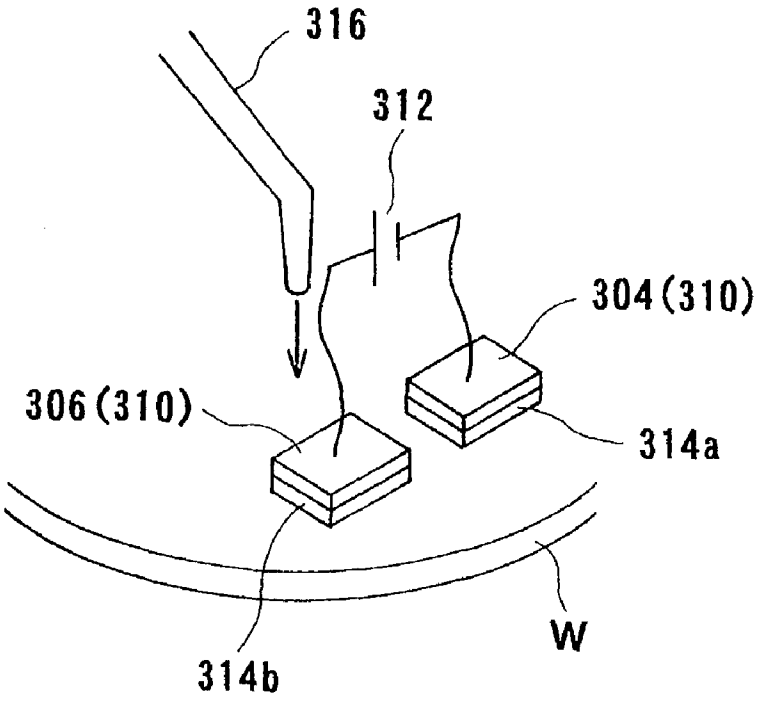

316
312
304(310)
306(310)
314a
314b
W

FIG. 47

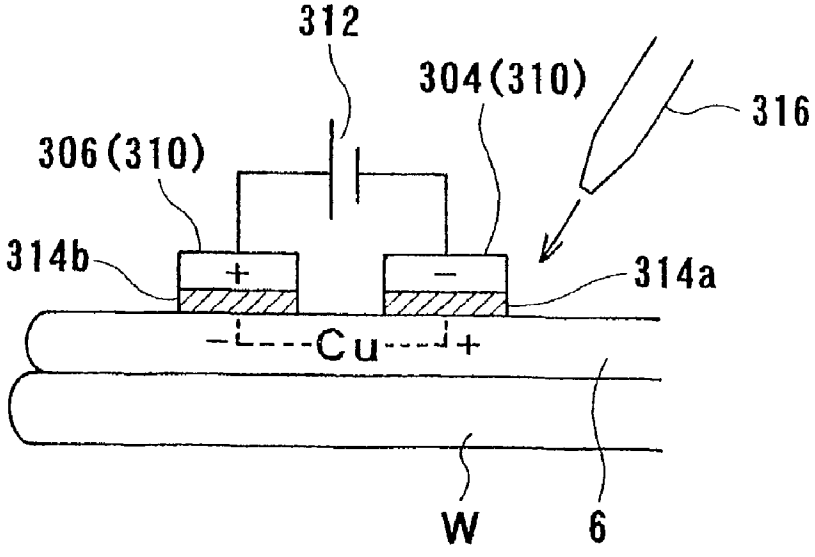

312
304(310)
316
306(310)
314b
+
−
314a
−Cu+
W
6

FIG. 48A

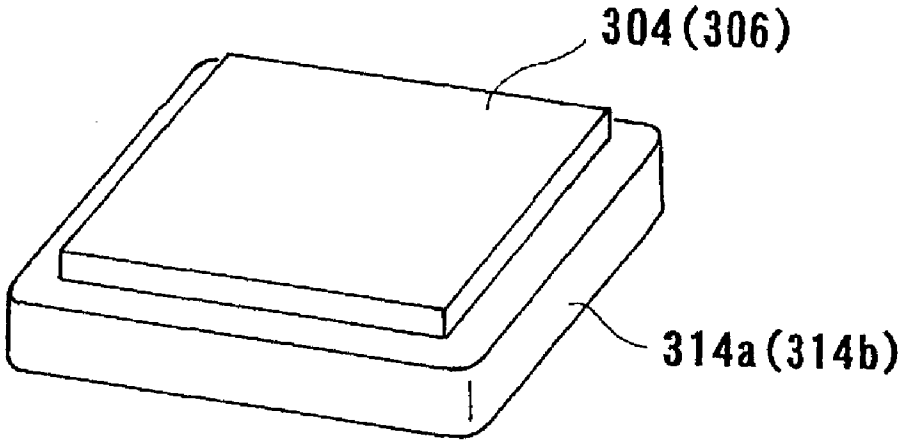


FIG. 48B

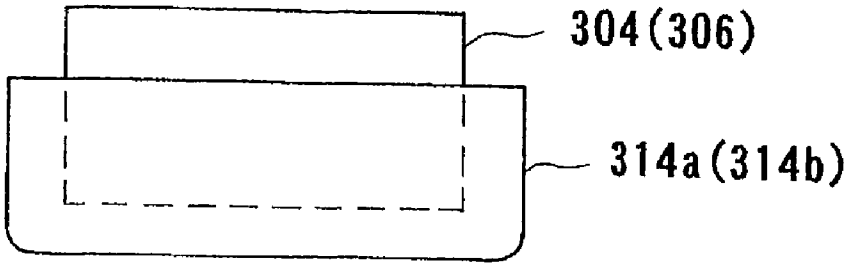


FIG. 49A

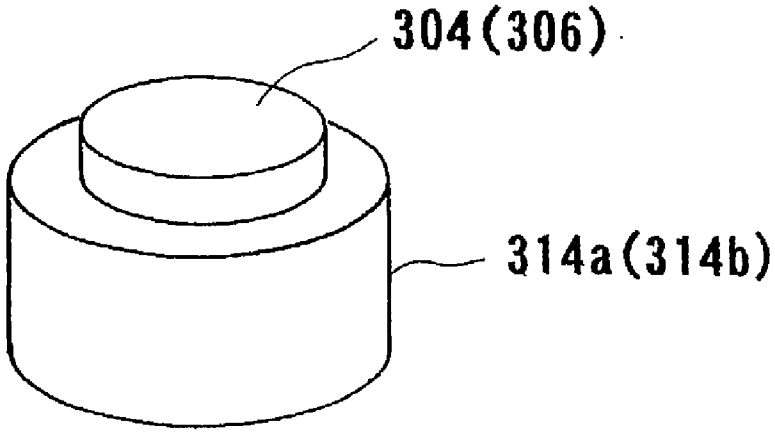


FIG. 49B

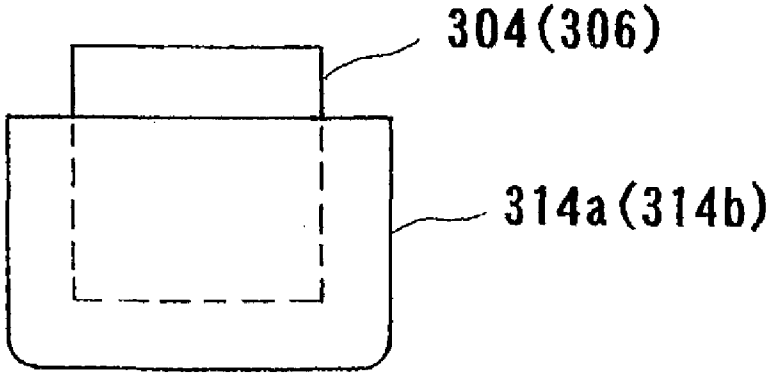


FIG. 50

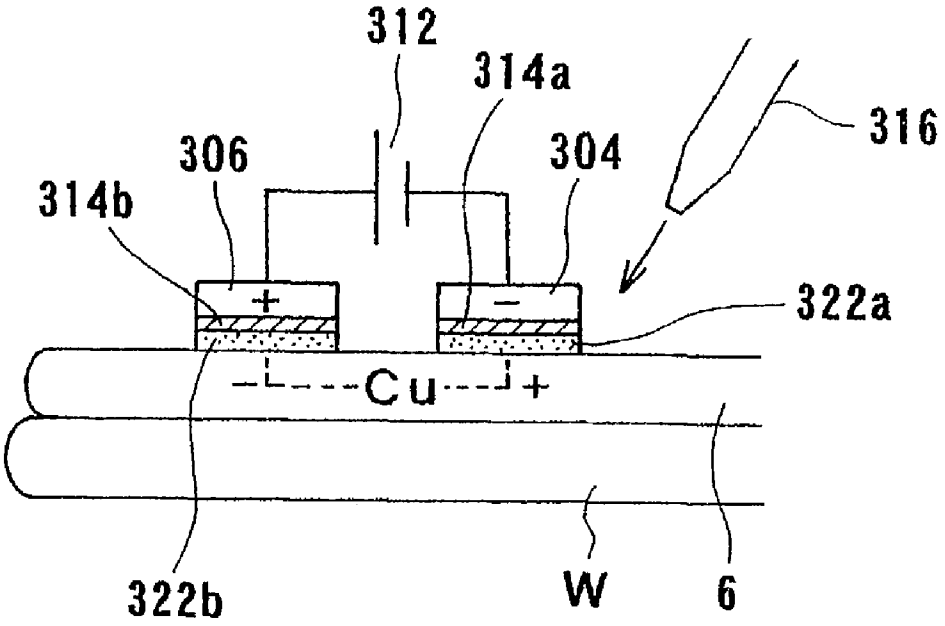


FIG. 51

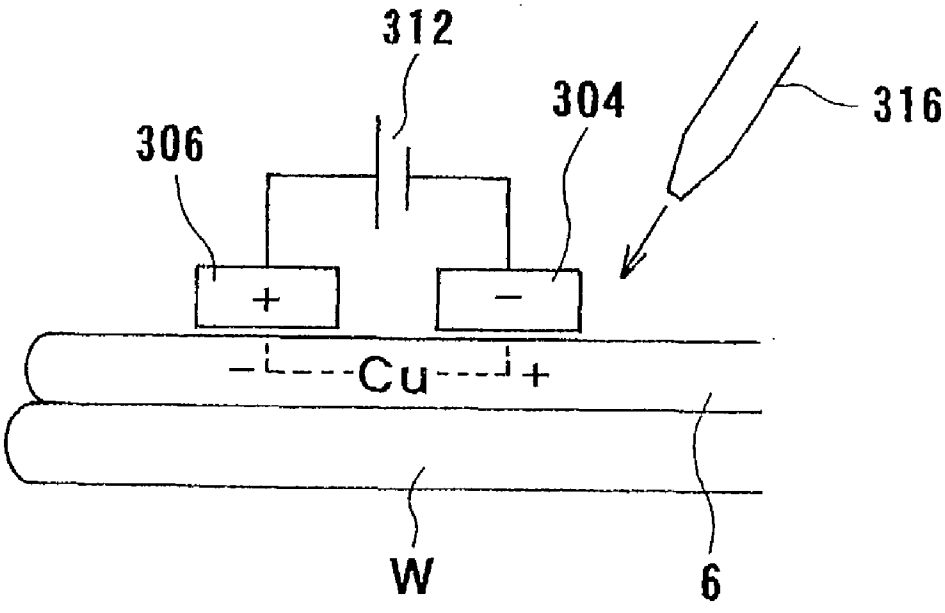


FIG. 52

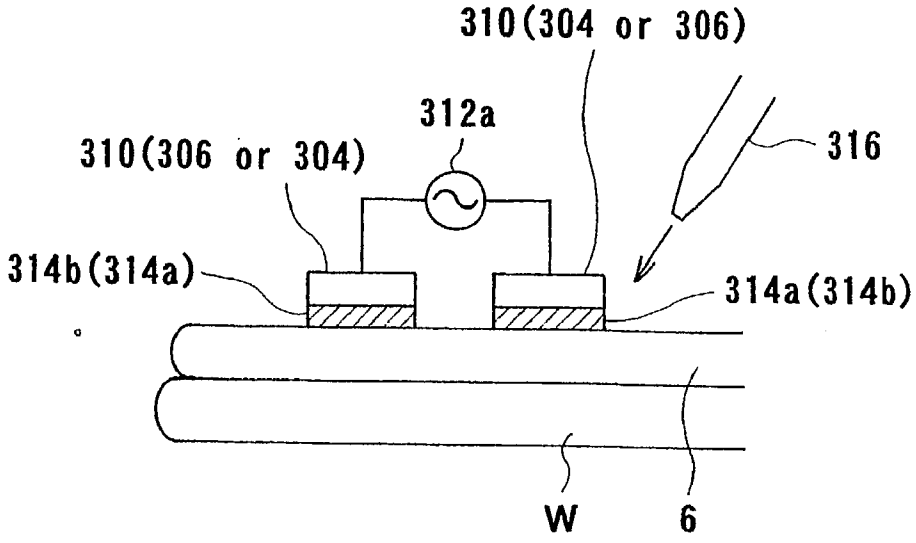

310(304 or 306)
312a
316
310(306 or 304)
314b(314a)
314a(314b)
W
6

FIG. 53

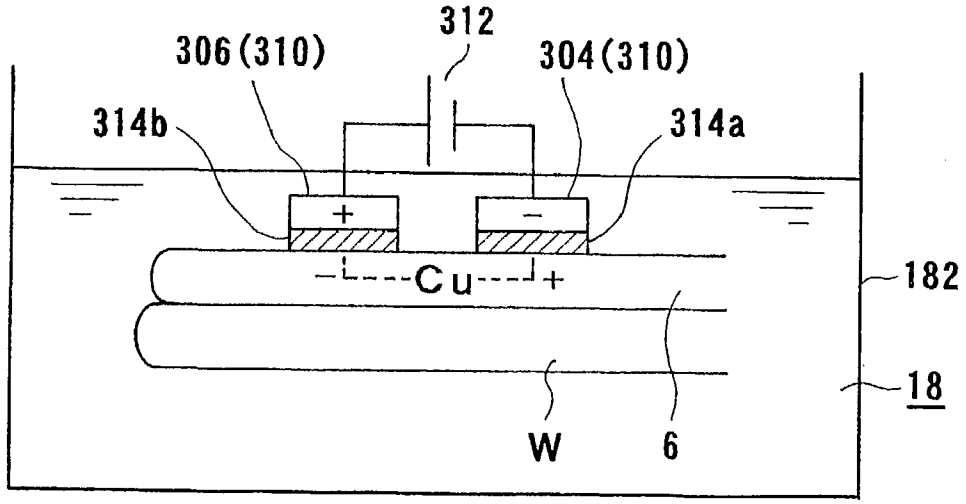

312
306(310)
304(310)
314b
314a
+
−
Cu
182
18
W
6

FIG. 54A

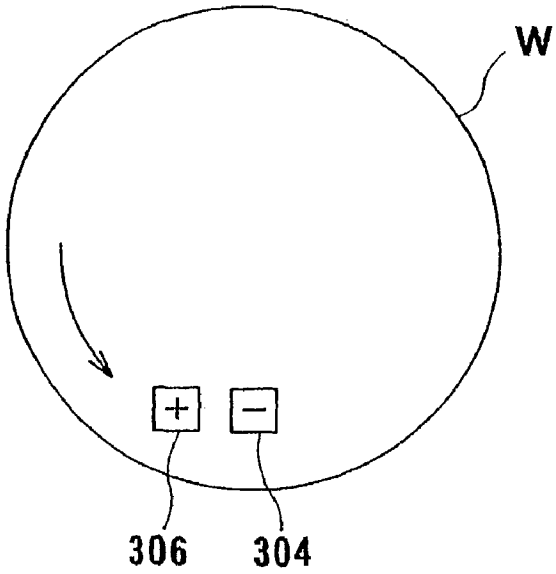


FIG. 54B

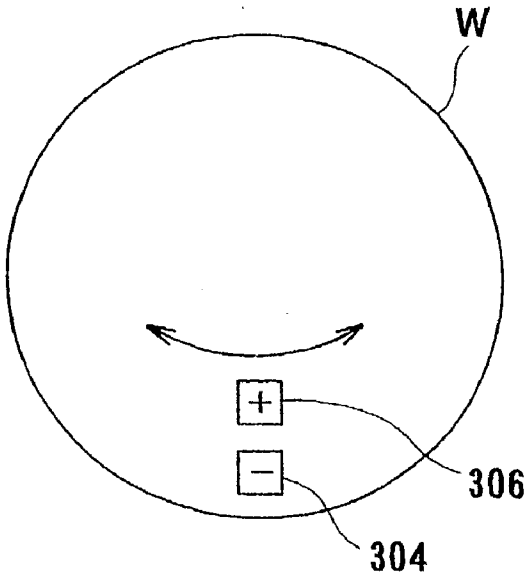


FIG. 55

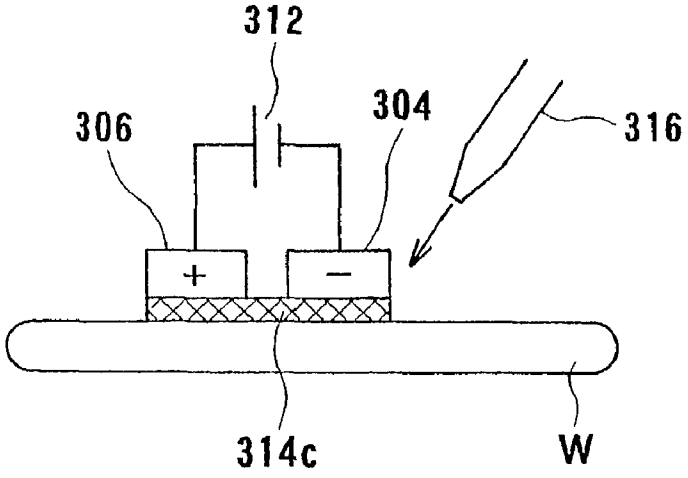


FIG. 56

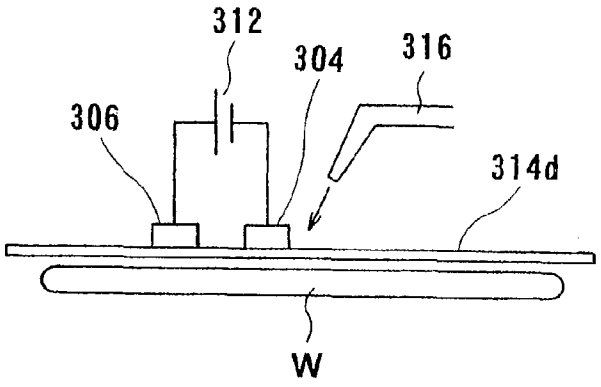

312
304
316
306
314d
W

FIG. 57

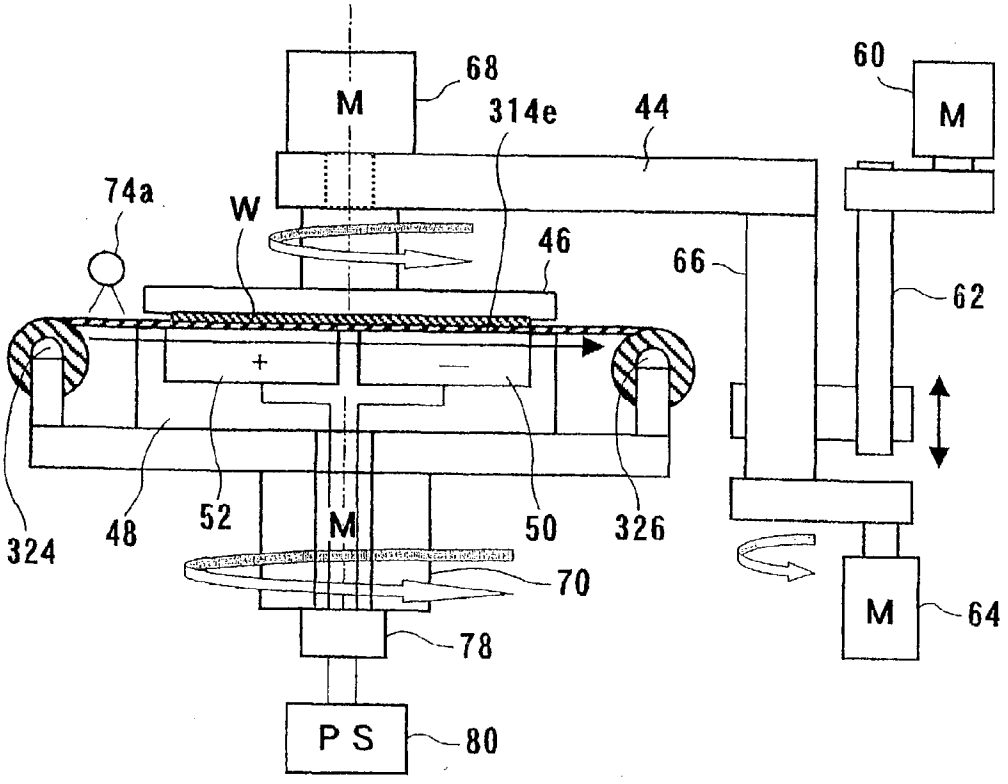

M
68
314e
44
60
M
74a
W
46
66
62
+
−
324
48
52
M
50
326
70
M
64
78
PS
80

FIG. 58

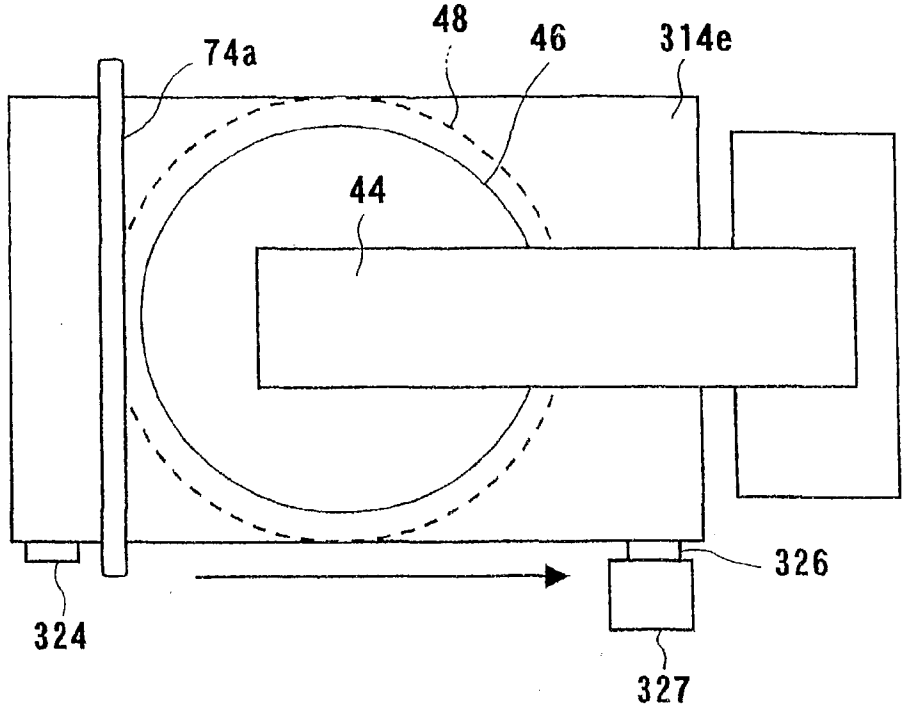


FIG. 59

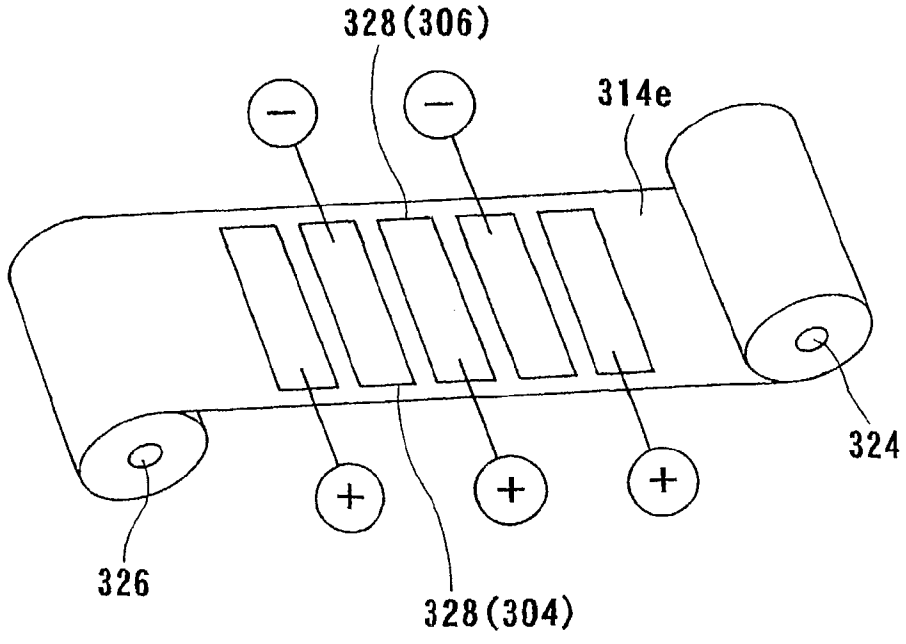


FIG. 60

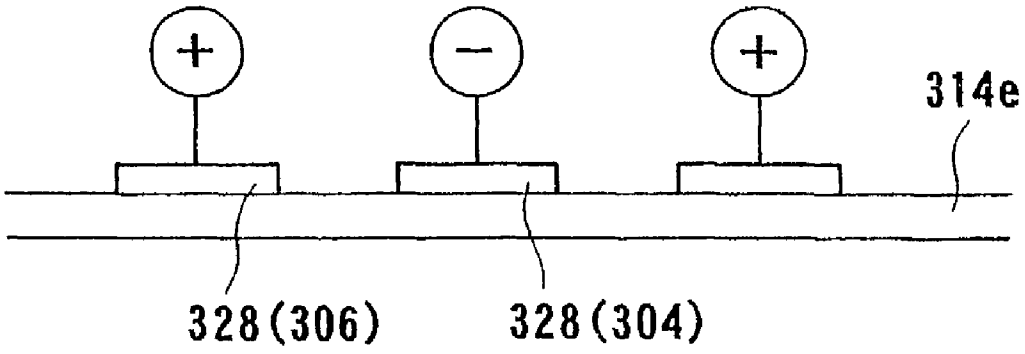


FIG. 61A

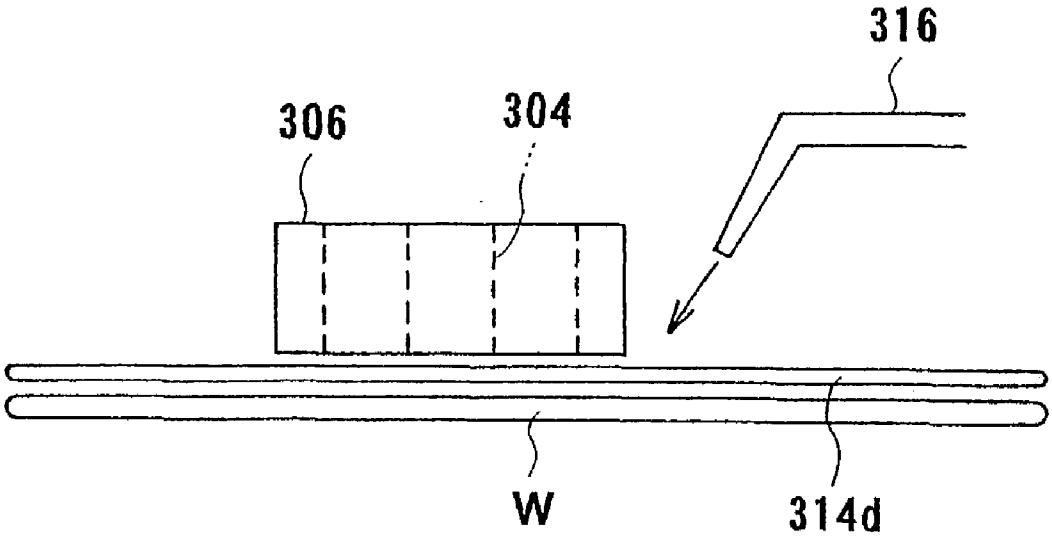


FIG. 61B

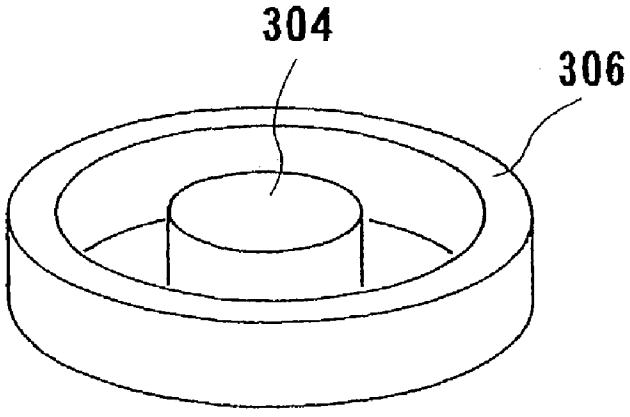


FIG. 62

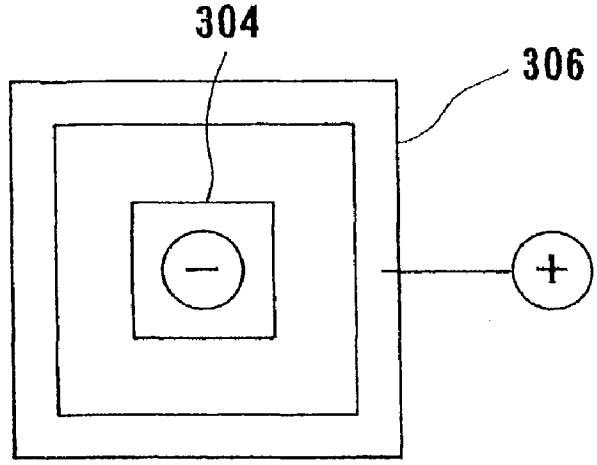


FIG. 63

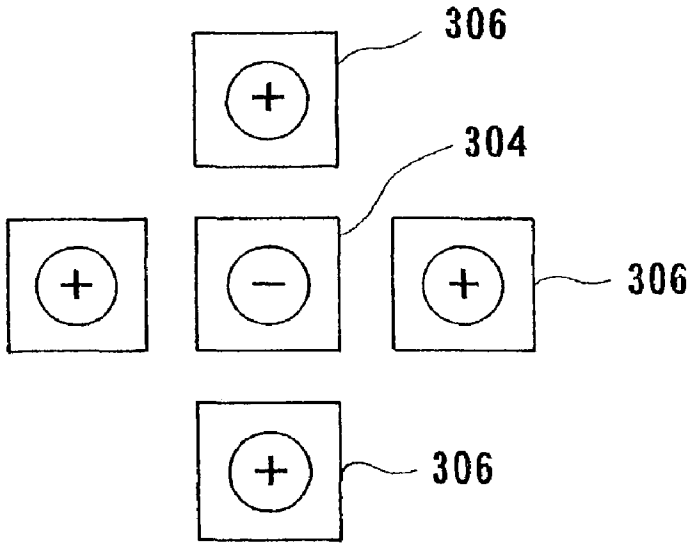


FIG. 64

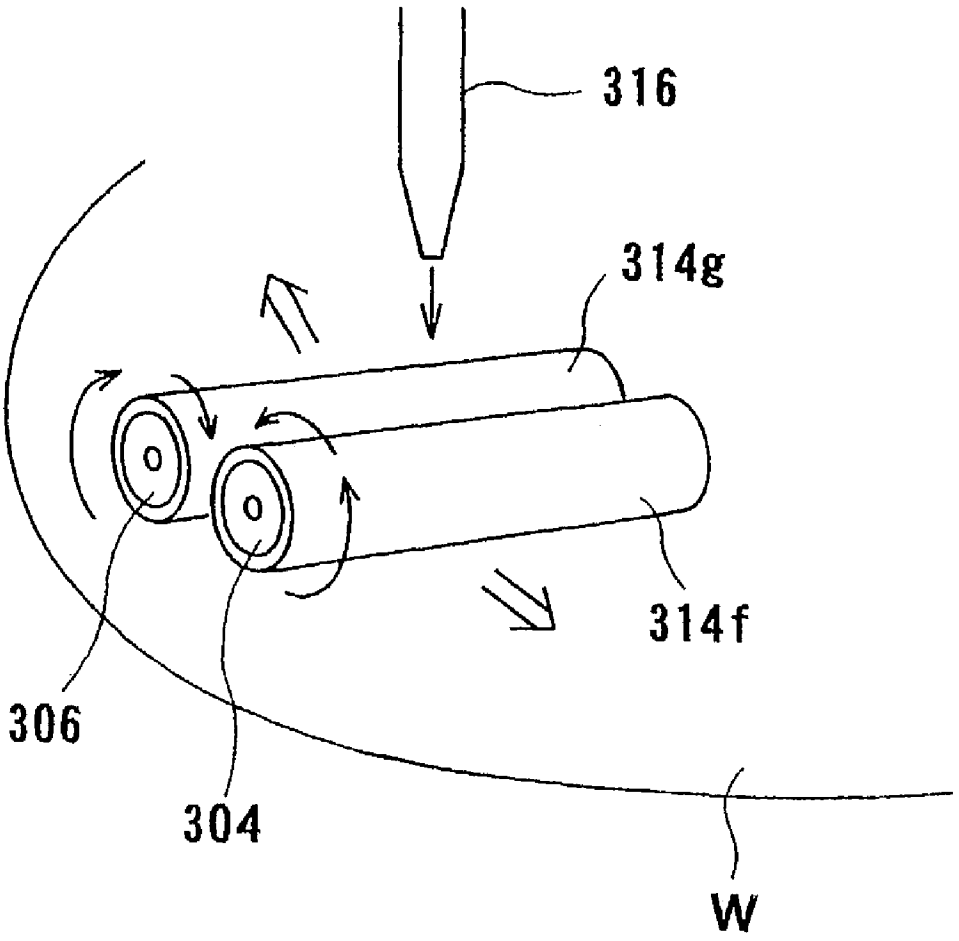


FIG. 65

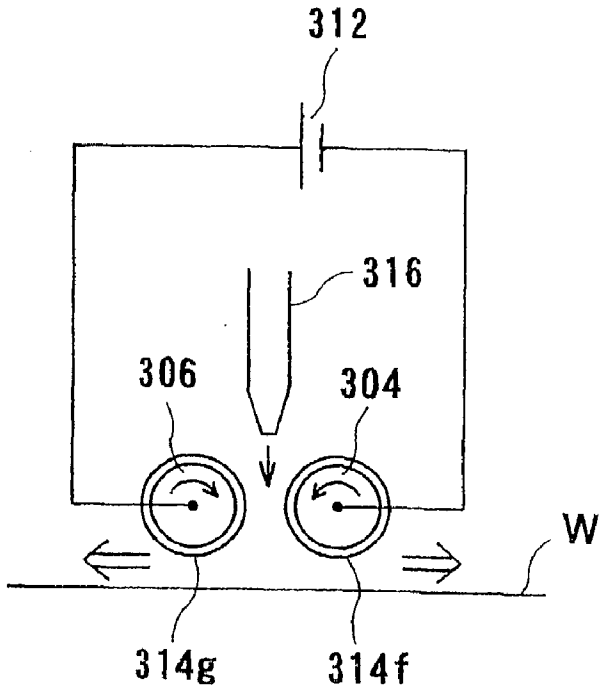

312
316
306
304
W
314g
314f

FIG. 66

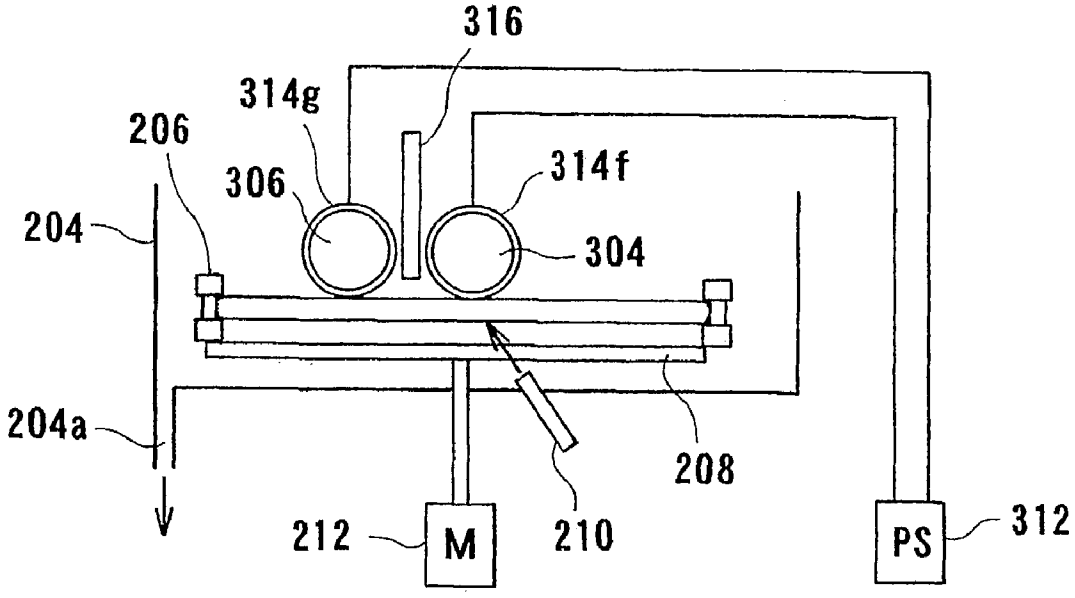

316
314g
206
306
314f
204
304
204a
208
212
M
210
PS
312

FIG. 67

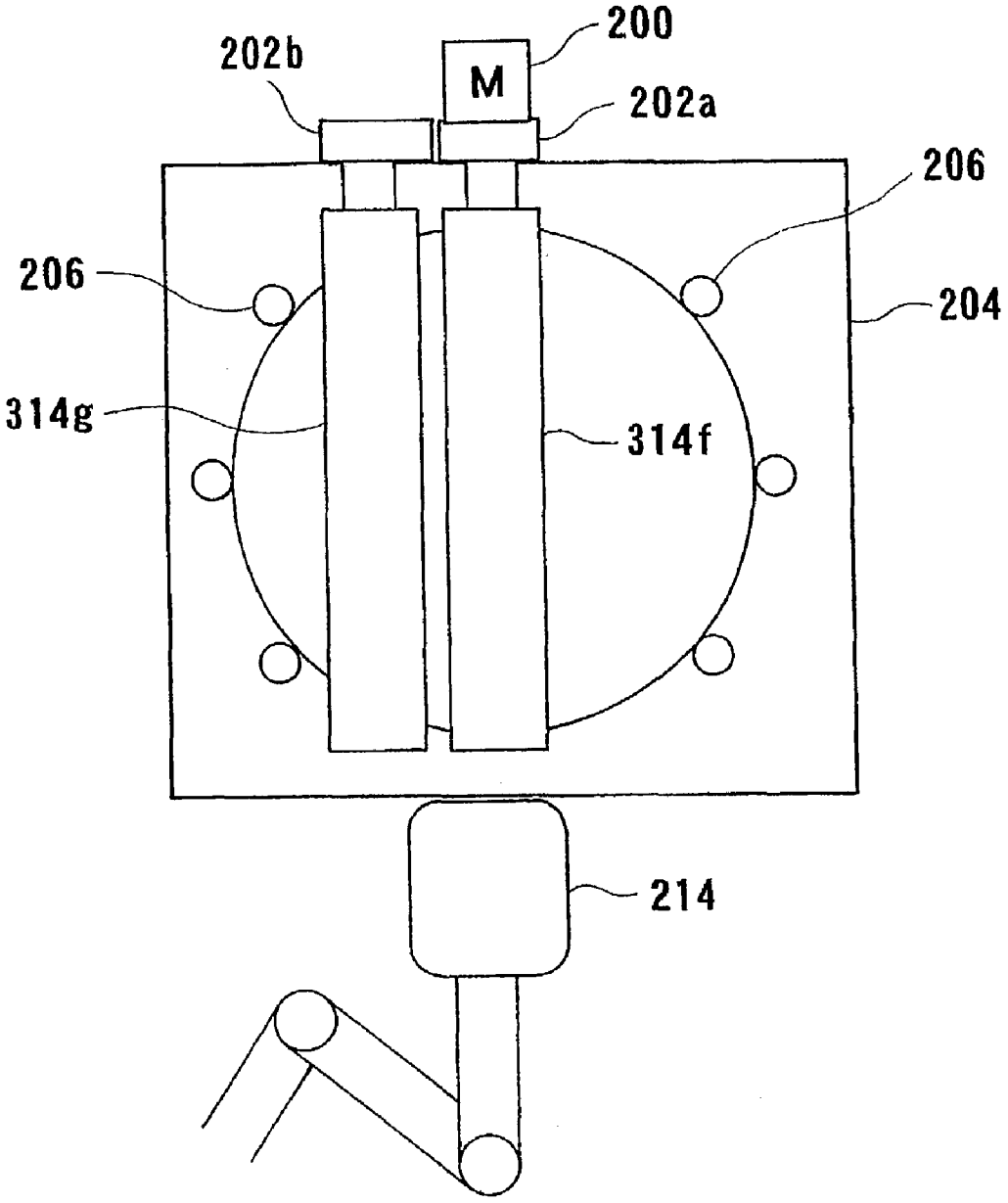


FIG. 68

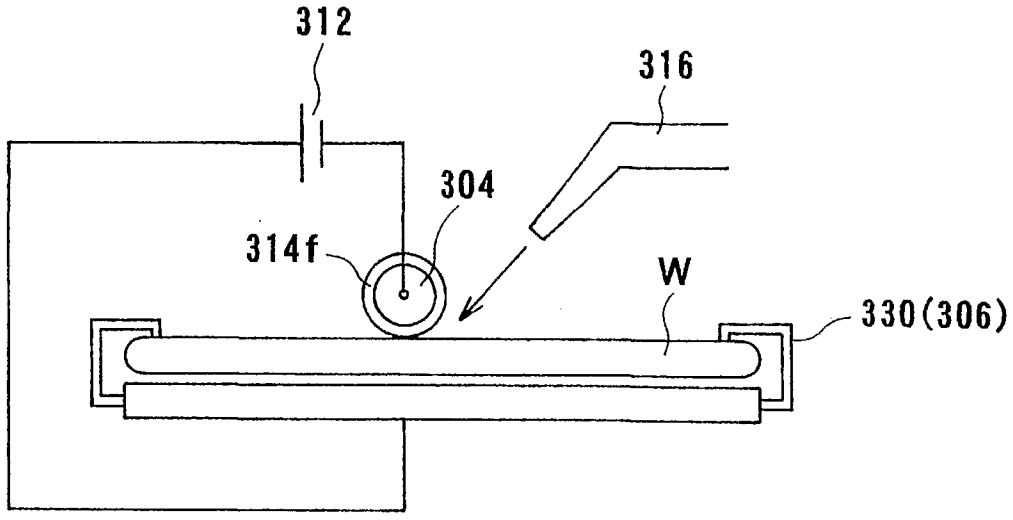


FIG. 69

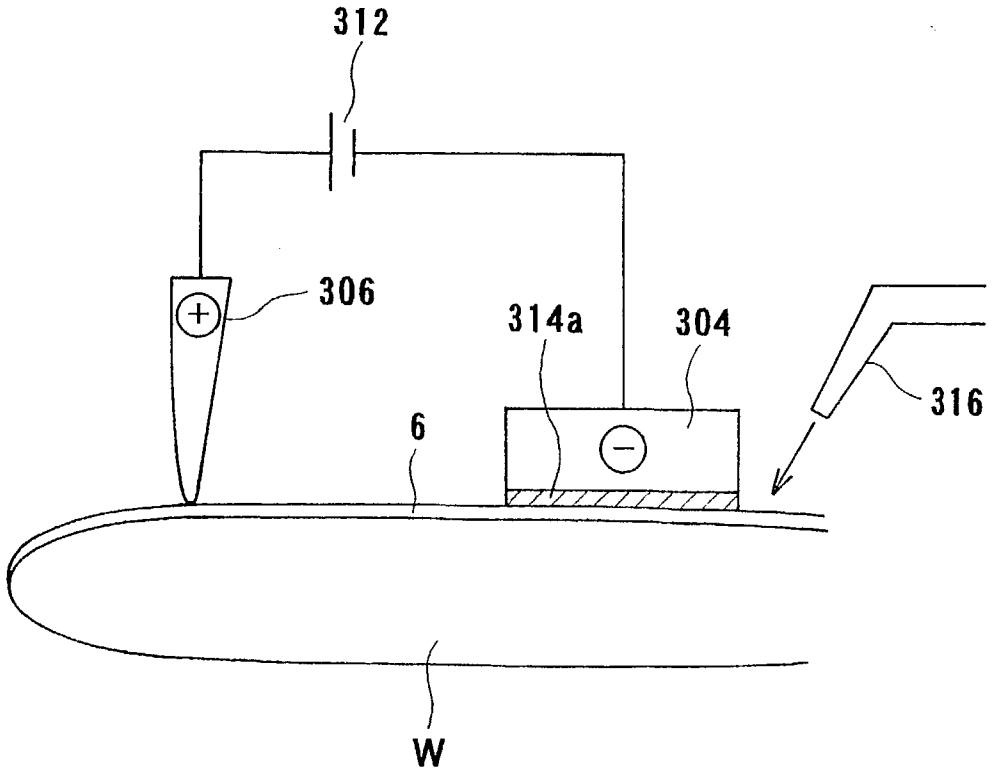


FIG. 70

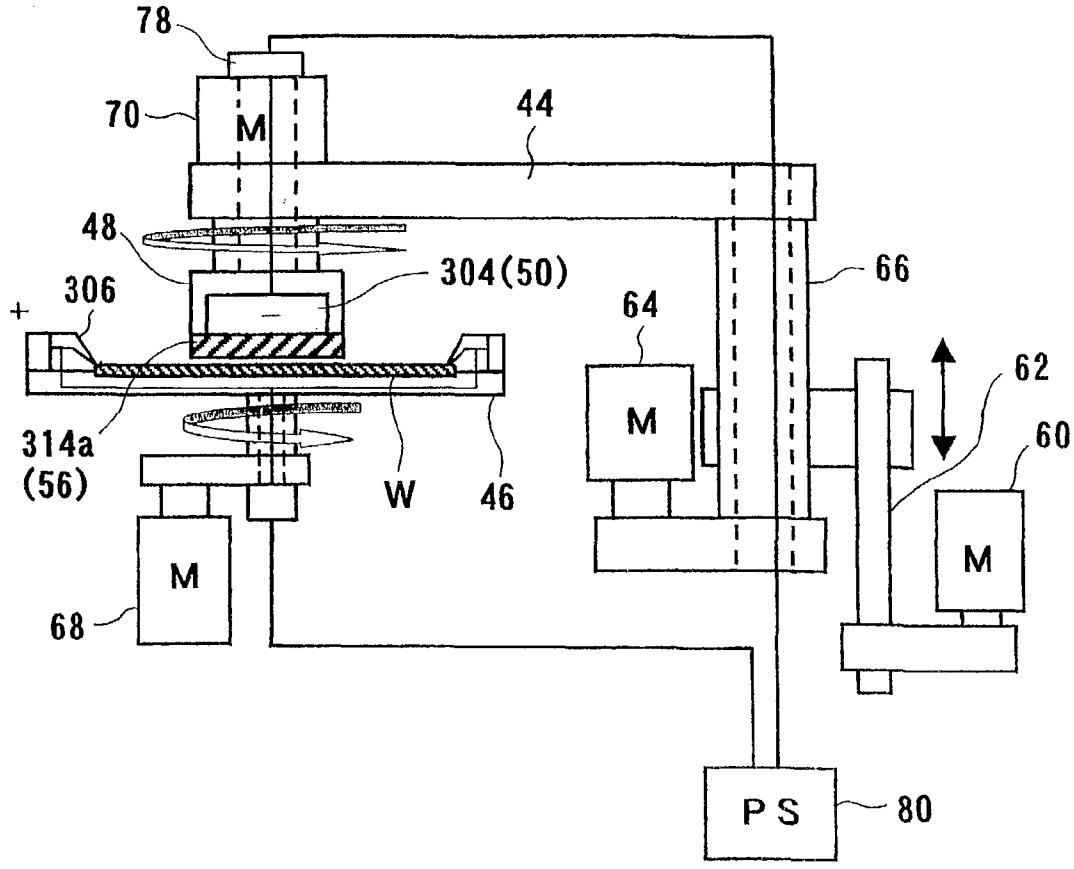


FIG. 71

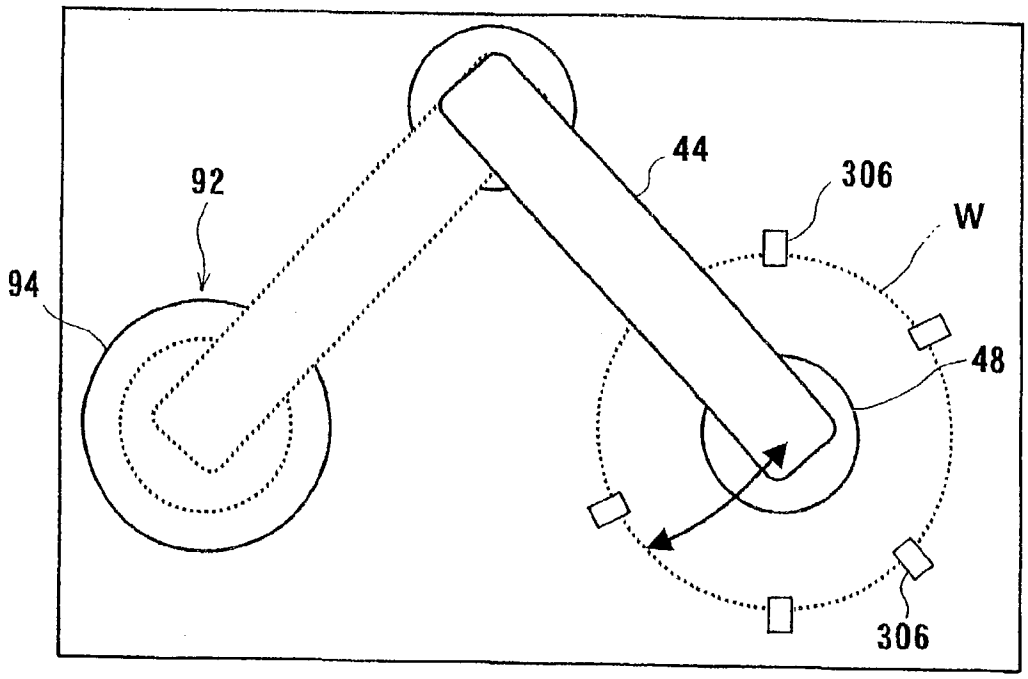


FIG. 72

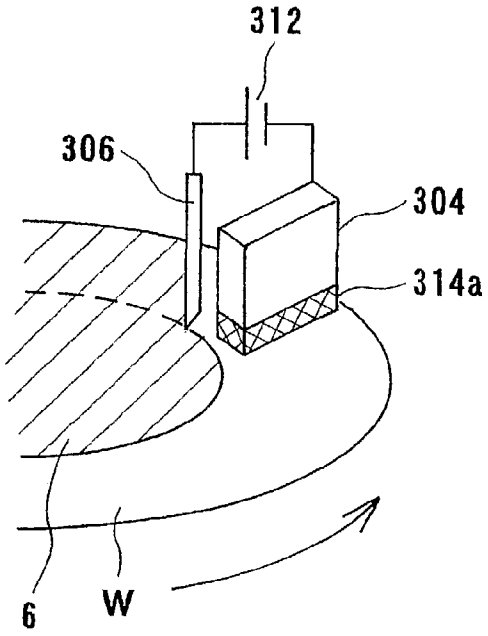


FIG. 73

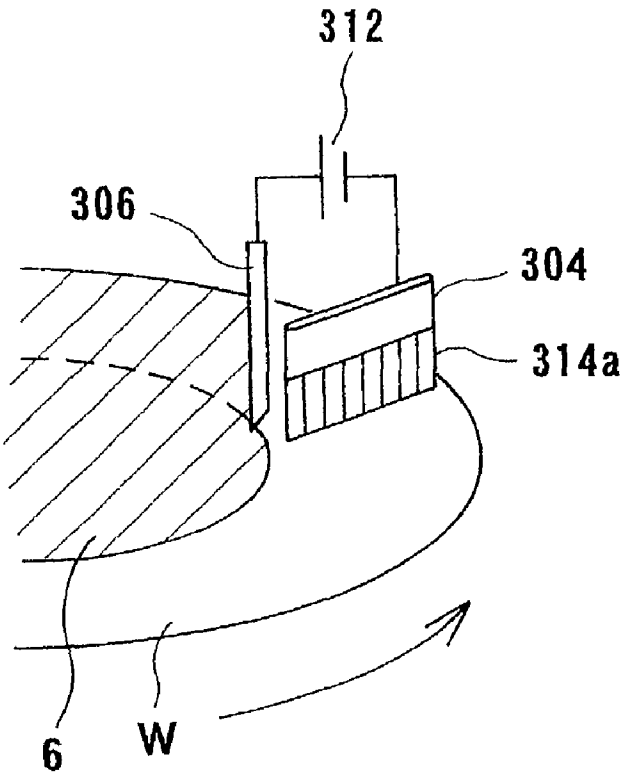


FIG. 74

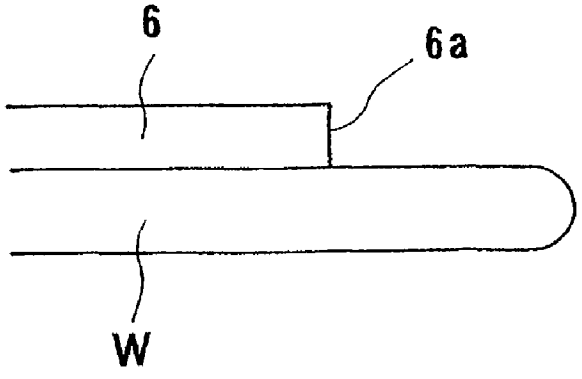


FIG. 75

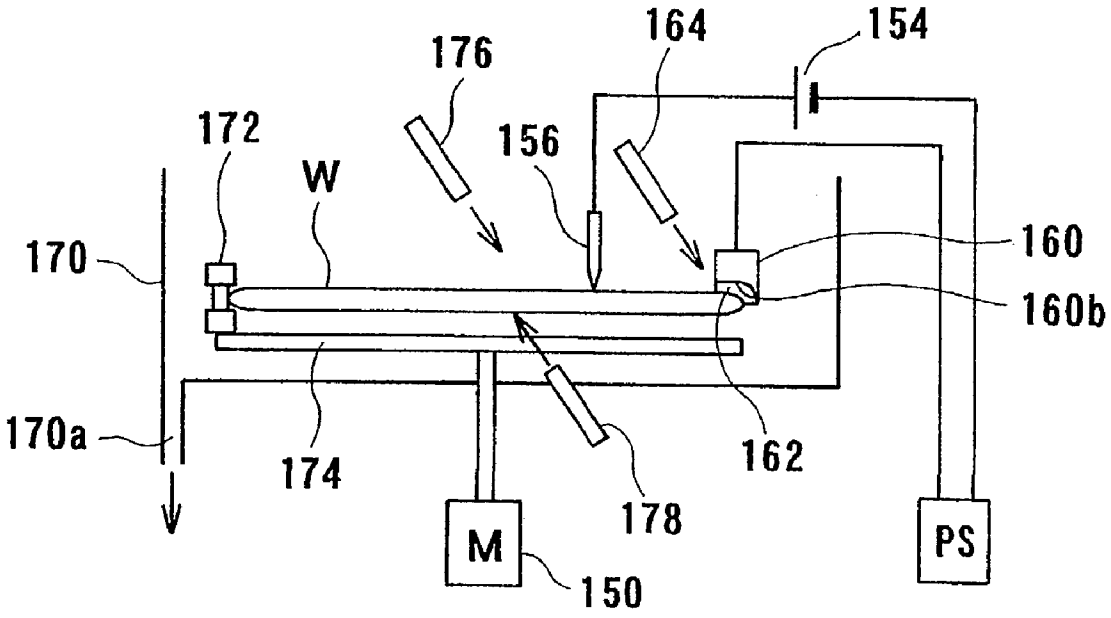


FIG. 76

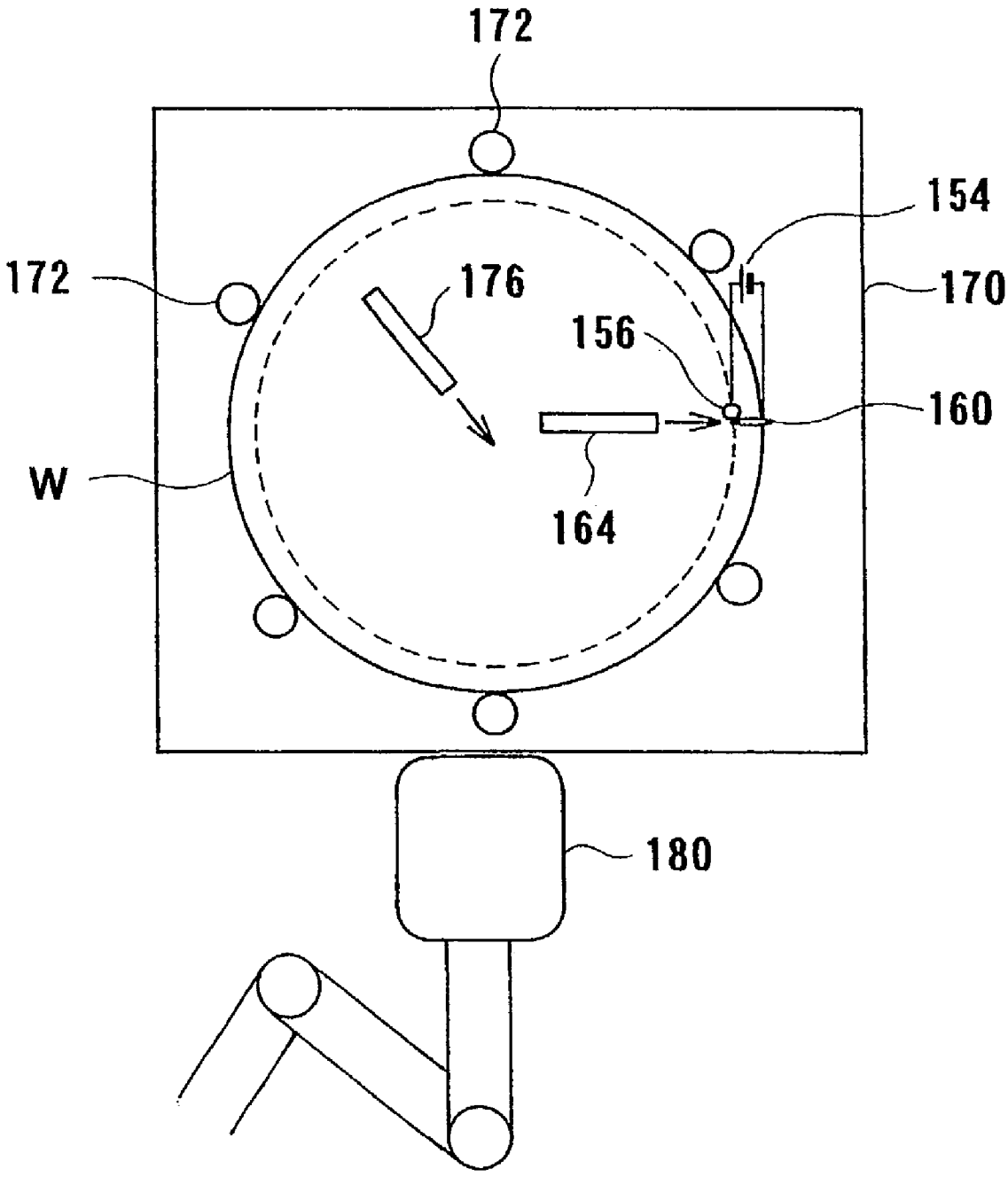


FIG. 77

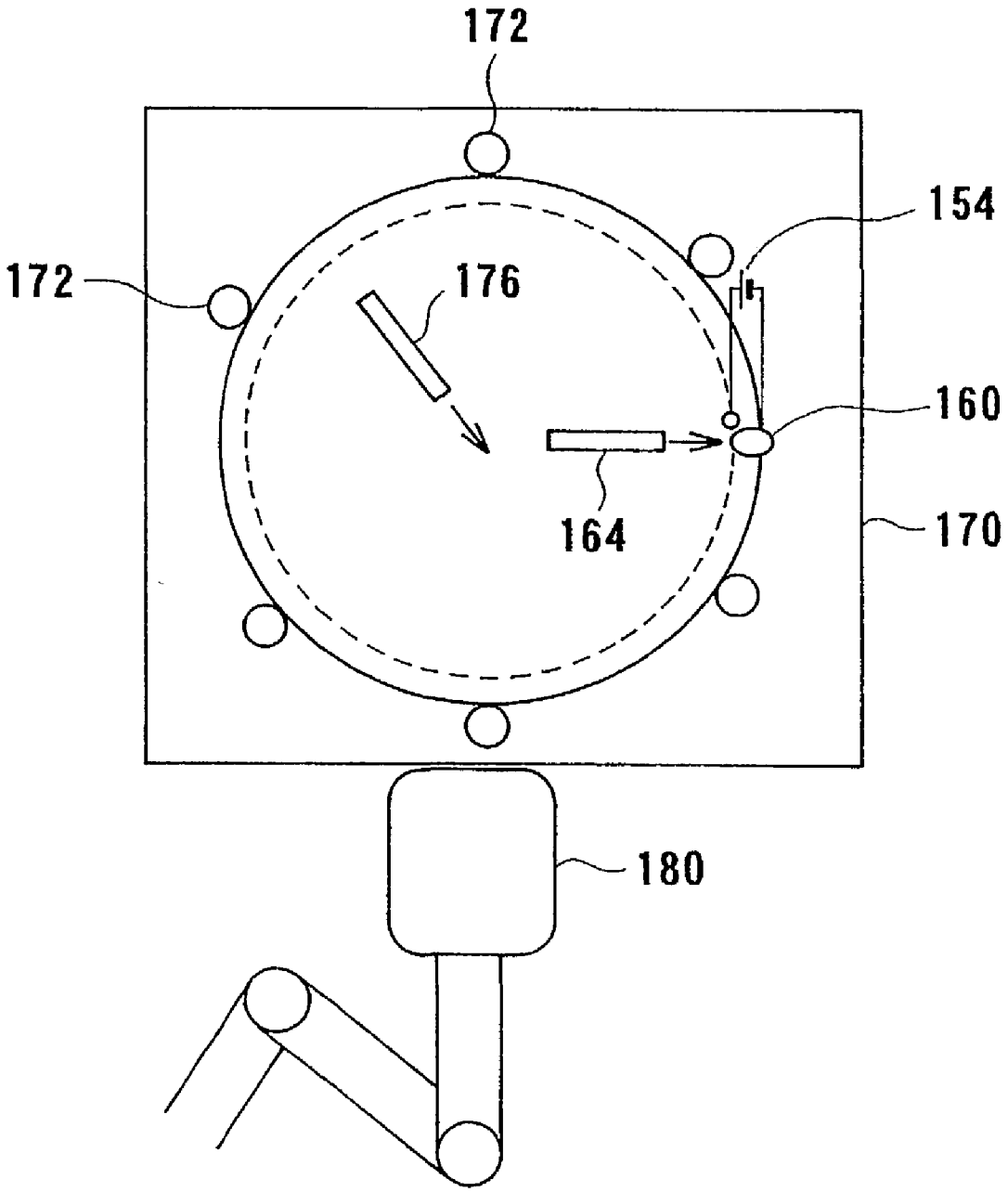


FIG. 78

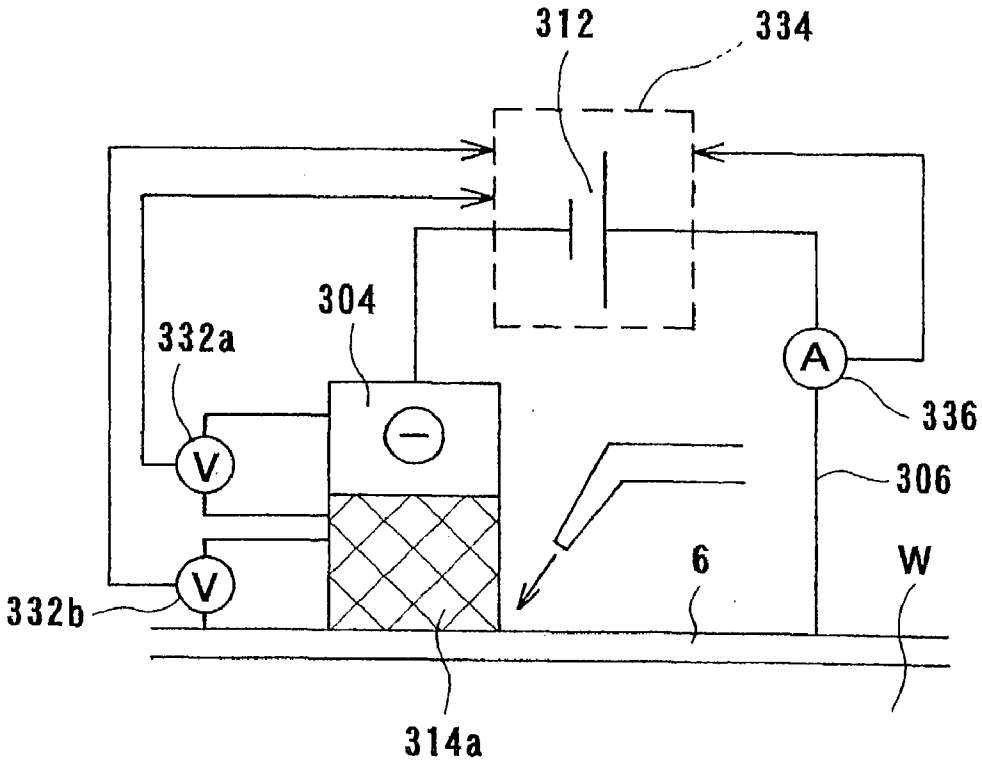

312
334
304
332a
A
336
V
306
V
6
W
332b
314a

FIG. 79

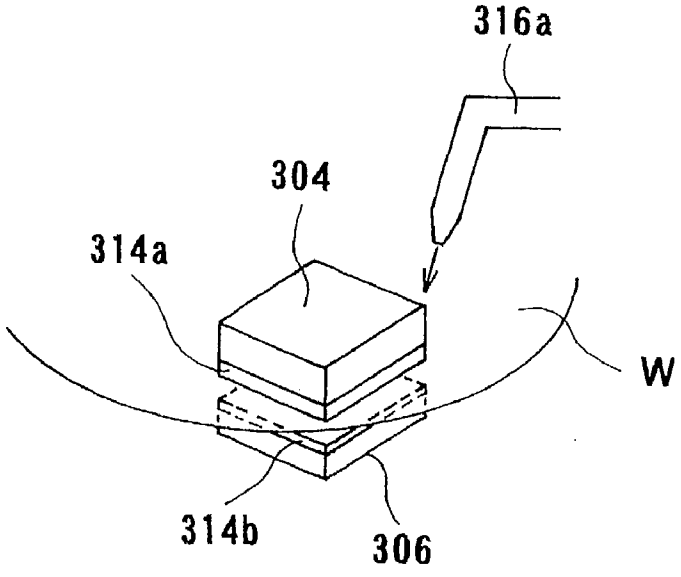

316a
304
314a
W
314b
306

FIG. 80

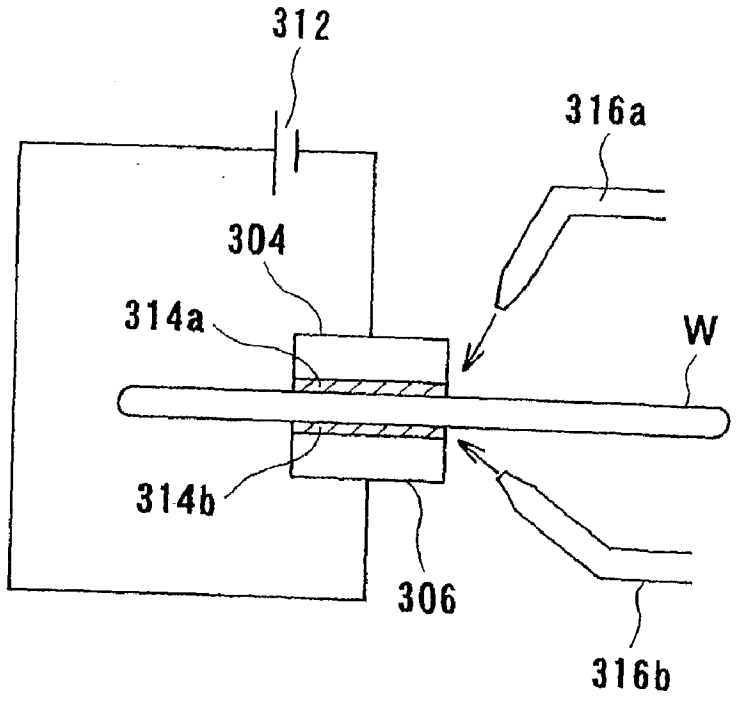


FIG. 81

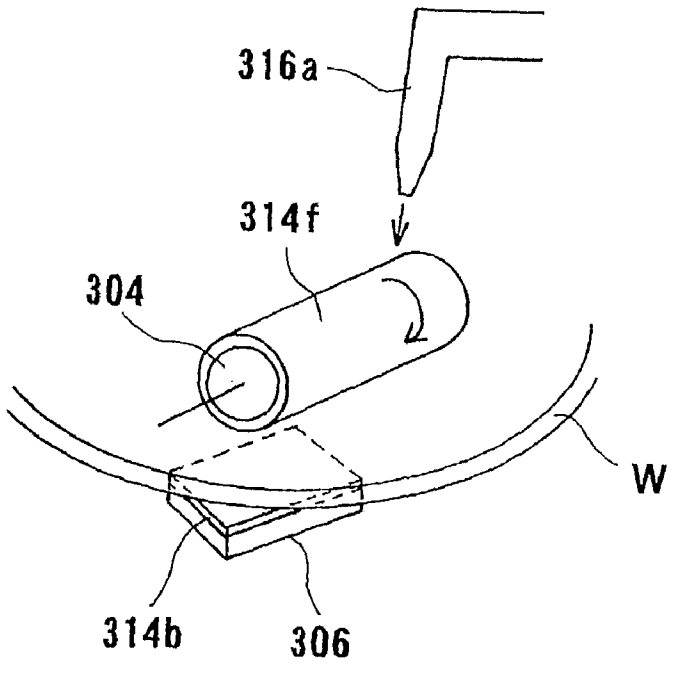


FIG. 82

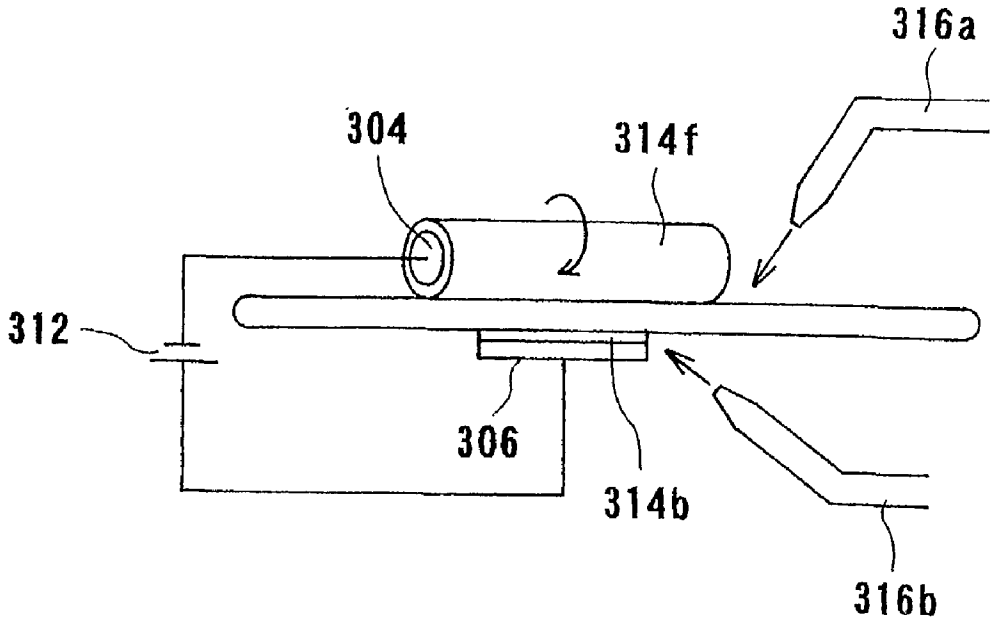


FIG. 83

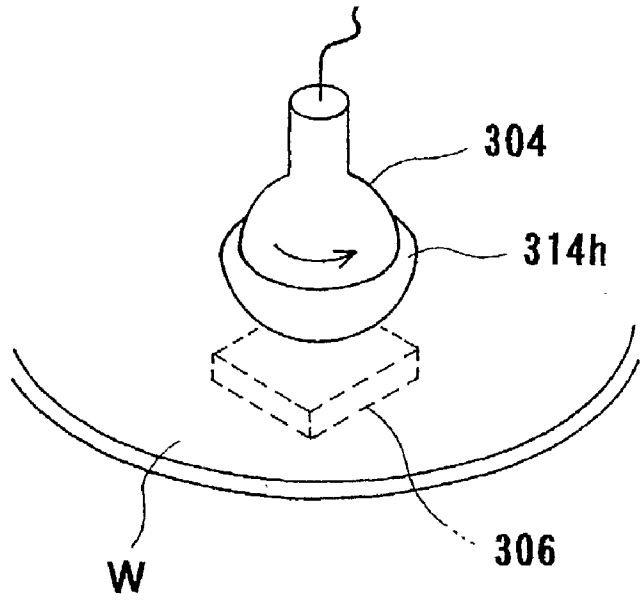


FIG. 84

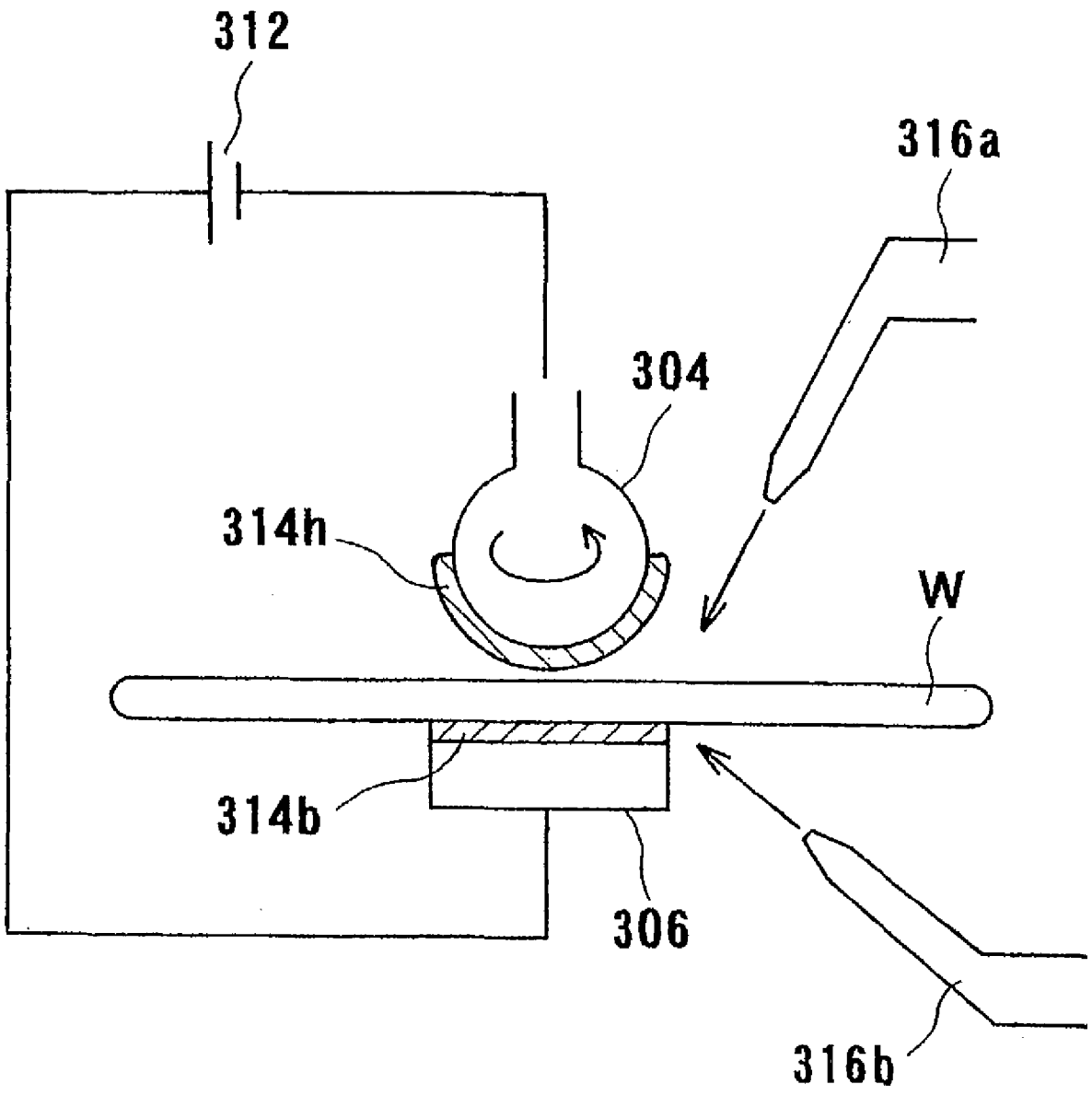


FIG. 85A

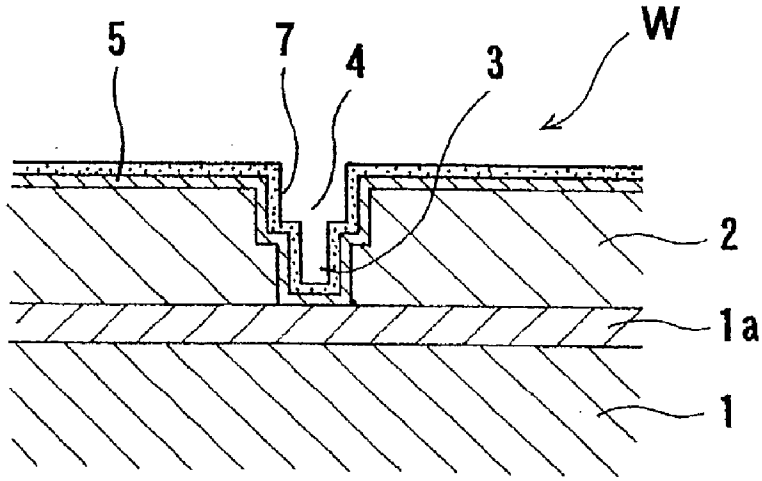


FIG. 85B

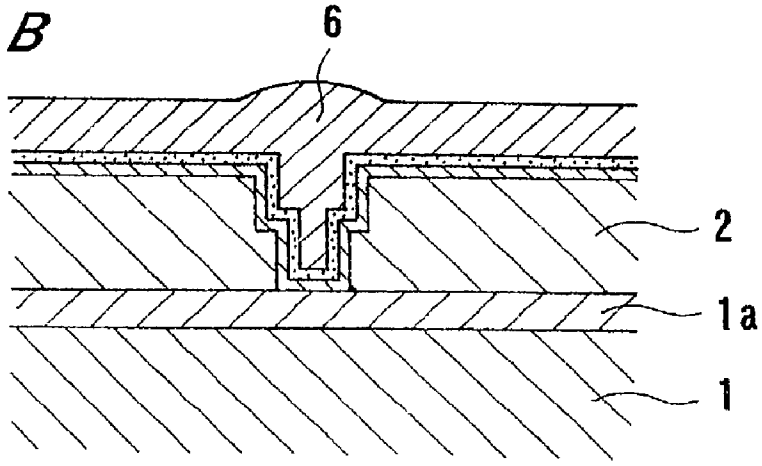
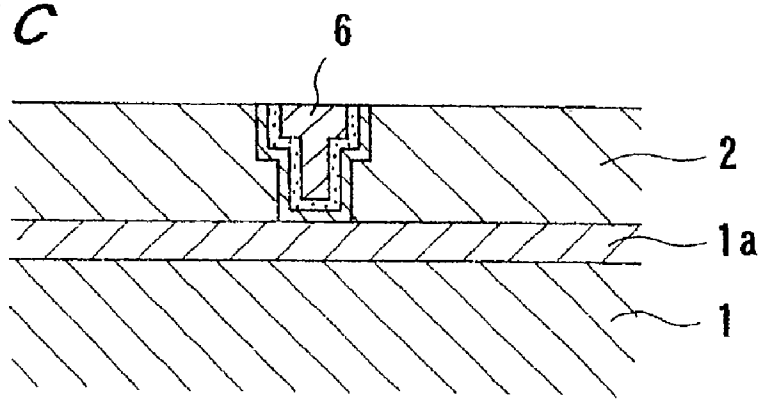


FIG. 85C



ELECTROLYTIC PROCESSING DEVICE AND SUBSTRATE PROCESSING APPARATUS

TECHNICAL FIELD

[0001] This invention relates to an electrolytic processing device and a substrate processing apparatus provided with the electrolytic processing device, and more particularly to an electrolytic processing device useful for processing a conductive material present in the surface of a substrate, especially a semiconductor wafer, or for removing impurities adhering to the surface of a substrate, and a substrate processing apparatus provided with the electrolytic processing device.

BACKGROUND ART

[0002] In recent years, instead of using aluminum or aluminum alloys as a material for forming interconnection circuits on a substrate such as a semiconductor wafer, there is an eminent movement towards using copper (Cu) which has a low electric resistance and high electromigration resistance. Copper interconnects are generally formed by filling copper into fine recesses formed in the surface of a substrate. There are known various techniques for forming such copper interconnects, including CVD, sputtering, and plating. According to any such technique, a copper film is formed in the substantially entire surface of a substrate, followed by removal of unnecessary copper by chemical mechanical polishing (CMP).

[0003] **FIGS. 85A through 85C** illustrate, in sequence of process steps, an example of forming such a substrate W having copper interconnects. As shown in **FIG. 85**A, an insulating film **2**, such as a silicon oxide film/a film of silicon oxide (SiO_2) or a film of low-k material, is deposited on a conductive layer **1***a* in which electronic devices are formed, which is formed on a semiconductor base **1**. A contact hole **3** and a trench **4** for interconnects are formed in the insulating film **2** by the lithography and etching technique. Thereafter, a barrier layer **5** of TaN or the like is formed on the entire surface, and a seed layer **7** as an electric supply layer for electroplating is formed on the barrier layer **5**.

[0004] Then, as shown in **FIG. 85**B, copper plating is performed onto the surface of the substrate W to fill the contact hole **3** and the trench **4** with copper and, at the same time, deposit a copper film **6** on the insulating film **2**. Thereafter, the copper film **6** on the insulating film **2** is removed by chemical mechanical polishing (CMP) so as to make the surface of the copper film **6** filled in the contact hole **3** and the trench **4** for interconnects and the surface of the insulating film **2** lie substantially on the same plane. An interconnection composed of the copper film **6** as shown in **FIG. 85C** is thus formed.

[0005] Components in various types of equipments have recently become finer and have required higher accuracy. As sub-micro manufacturing technology has commonly been used, the properties of materials are largely influenced by the processing method. Under these circumstances, in such a conventional machining method that a desired portion in a workpiece is physically destroyed and removed from the surface thereof by a tool, a large number of defects may be produced to deteriorate the properties of the workpiece. Therefore, it becomes important to perform processing without deteriorating the properties of the materials.

[0006] Some processing methods, such as chemical polishing, electrolytic processing, and electrolytic polishing, have been developed in order to solve this problem. In contrast with the conventional physical processing, these methods perform removal processing or the like through chemical dissolution reaction. Therefore, these methods do not suffer from defects, such as formation of an altered layer and dislocation, due to plastic deformation, so that processing can be performed without deteriorating the properties of the materials.

[0007] Chemical mechanical polishing (CMP), for example, generally necessitates a complicated operation and control, and needs a considerably long processing time. In addition, a sufficient cleaning of a substrate must be conducted after the polishing treatment. This also imposes a considerable load on the slurry or cleaning liquid waste disposal. Accordingly, there is a strong demand for omitting CMP entirely or reducing a load upon CMP. Also in this connection, it is to be pointed out that though a low-k material, which has a low dielectric constant, is expected to be predominantly used in the future as a material for the insulating film of a semiconductor substrate, the low-k material has a low mechanical strength and therefore is hard to endure the stress applied during CMP processing. Thus, also from this standpoint, there is a demand for a technique that enables the flattering of a substrate without giving any stress thereto.

[0008] Further, a method has been reported which performs CMP processing simultaneously with plating, viz. chemical mechanical electrolytic polishing. According to this method, the mechanical processing is carried out to the growing surface of a plating film, causing the problem of denaturing of the resulting film.

[0009] In the case of the above-mentioned electrolytic processing or electrolytic polishing, the process proceeds through an electrochemical interaction between a workpiece and an electrolytic solution (aqueous solution of NaCl, $NaNO_3$, HF, HCl, HNO_3, NaOH, etc.). Since an electrolytic solution containing such an electrolyte must be used, contamination of a workpiece with the electrolyte cannot be avoided.

DISCLOSURE OF INVENTION

[0010] The present invention has been made in view of the above situation in the related art. It is therefore an object of the present invention to provide an electrolytic processing device which, while omitting a CMP treatment entirely or reducing a load upon a CMP treatment to the least possible extent, can process a conductive material formed in the surface of a substrate to flatten the material, or can remove (clean) extraneous matter adhering to the surface of a workpiece such as a substrate, and also to provide a substrate processing apparatus in which the electrolytic processing device is incorporated.

[0011] In order to achieve the above object, the present invention provides an electrolytic processing device, comprising: a processing electrode brought into contact with or close to a workpiece; a feeding electrode for supplying electricity to the workpiece; an ion exchanger disposed in at least one of the spaces between the workpiece and the processing electrode, and between the workpiece and the feeding electrode; a power source for applying a voltage

between the processing electrode and the feeding electrode; and a liquid supply section for supplying a liquid to the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which the ion exchanger is present.

[0012] **FIGS. 1 and 2** illustrate the principle of electrolytic processing effected in the above electrolytic processing device. **FIG. 1** shows the ionic state in the electrolytic processing device when a ion exchanger **12***a* mounted on a processing electrode **14** and a ion exchanger **12***b* mounted on a feeding electrode **16** are brought into contact with or close to a surface of a workpiece **10**, while a voltage is applied via a power source **17** between the processing electrode **14** and the feeding electrode **16**, and a liquid **18**, e.g. ultrapure water, is supplied from a liquid supply section. **19** between the processing electrode **14**, the feeding electrode **16** and the workpiece **10**. **FIG. 2** shows the ionic state in the electrolytic processing device when the ion exchanger **12***a* mounted on the processing electrode **14** is brought into contact with or close to the surface of the workpiece **10** and the feeding electrode **16** is directly contacted with the workpiece **10**, while a voltage is applied via the power source **17** between the processing electrode **14** and the feeding electrode **16**, and the liquid **18**, such as ultrapure water, is supplied from the liquid supply section **19** between the processing electrode **14** and the workpiece **10**.

[0013] When a liquid like ultrapure water that in itself has a large resistivity is used, it is preferred to bring the ion exchanger **12***a* into contact with the surface of the workpiece **10**. This can lower the electric resistance, lower the requisite voltage and reduce the power consumption. The "contact" in the present electrolytic processing does not imply "press" for giving a physical energy (stress) to a workpiece as in CMP.

[0014] Water molecules **20** in the liquid **18** such as ultrapure water are dissociated by the ion exchangers **12***a*, **12***b* into hydroxide ions **22** and hydrogen ions **24**. The hydroxide ions **22** thus produced, for example, are carried, by the electric field between the workpiece **10** and the processing electrode **14** and by the flow of the liquid **18**, to the surface of the workpiece **10** opposite to the processing electrode **14** whereby the density of the hydroxide ions **22** in the vicinity of the workpiece **10** is enhanced, and the hydroxide ions **22** are reacted with the atoms **10***a* of the workpiece **10**. The reaction product **26** produced by this reaction is dissolved in the liquid **18**, and removed from the workpiece **10** by the flow of the liquid **18** along the surface of the workpiece **10**. Removal processing of the surface of the workpiece **10** is thus effected.

[0015] As will be appreciated from the above, the removal processing according to the present invention is effected purely by the electrochemical interaction between the reactant ions and the workpiece. The present electrolytic processing thus clearly differs in the processing principle from CMP according to which processing is effected by the combination of the physical interaction between an abrasive and a workpiece, and the chemical interaction between a chemical species in a polishing liquid and the workpiece.

[0016] According to the above-described method, the portion of the workpiece **10** facing the processing electrode **14** is processed. Therefore, by moving the processing electrode **14**, the workpiece **10** can be processed into a desired surface configuration.

[0017] As described above, the removal processing in the electrolytic processing device of the present invention is effected solely by the dissolution reaction due to the electrochemical interaction, and is clearly distinct in the processing principle from CMP in which processing is effected by the combination of the physical interaction between an abrasive and a workpiece, and the chemical interaction between a chemical species in a polishing liquid and the workpiece. Accordingly, the electrolytic processing device of the present invention can conduct removal processing of the surface of a workpiece without impairing the properties of the material of the workpiece. Even when the material of a workpiece is of a low mechanical strength, such as the above-described low-k material, removal processing of the surface of the workpiece can be effected without any physical damage to the workpiece. Further, as compared to conventional electrolytic processing devices, the electrolytic processing device of the present invention, due to the use of a processing liquid having an electric conductivity of not more than 500 μS/cm, preferably pure water, more preferably ultrapure water, can remarkably reduce contamination of the surface of a workpiece with impurities and can facilitate disposal of waste liquid after the processing.

[0018] The liquid may be pure water, a liquid having an electric conductivity (referring herein to that at 25° C., 1 atm) of not more than 500 μS/cm, or an electrolytic solution.

[0019] Pure water may be a water having an electric conductivity of not more than 10 μS/cm. The use of pure water in electrolytic processing enables a clean processing without leaving impurities on the processed surface of a workpiece, whereby a cleaning step after the electrolytic processing can be simplified. Specifically, one or two-stages of cleaning may suffice after the electrolytic processing.

[0020] It is also possible to use a liquid obtained by adding an additive, such as a surfactant, to pure water or ultrapure water, and having an electric conductivity of not more than 500 μS/cm, preferably not more than 50 μS/cm, more preferably not more than 0.1 μS/cm (resistivity of not less than 10 MΩ·cm). Such a liquid can form a layer, which functions to inhibit ion migration evenly, at the interface between a workpiece (e.g. substrate) and an ion exchanger, thereby moderating concentration of ion exchange (metal dissolution) to enhance the flatness of the processed surface.

[0021] The additive plays a role to prevent local concentration of ions (e.g. hydroxide ions (OH-)). It is noted in this regard that "an equal processing (removal) rate at various points over the entire processing surface" is an important factor for providing a flat processed surface. When a single electrochemical removal reaction is in progress, a local difference in the processing removal rate may be produced by a local concentration of reactant ions. The local concentration of reactant ions may be caused mainly by a deviation in the electric field intensity between the processing electrode and the feeding electrode, and a deviation in the distribution of reactant ions in the vicinity of the surface of a workpiece. The local concentration of reactant ions can be prevented by allowing the additive, which plays a role to prevent local concentration of ions (e.g. hydroxide ions), to exist between a workpiece and an ion exchanger.

[0022] An aqueous solution of a neutral salt such as NaCl or Na_2SO_4, an acid such as HCl or H_2SO_4, or an alkali such as ammonia may be used as the electrolytic solution, and

may be properly selected according to the properties of a workpiece. When using electrolytic solution, it is better to use the low concentration electrolytic solution which electric conductivity is not more than 500 μS/cm, to avoid much contamination.

[0023] In one embodiment of the electrolytic processing device of the present invention, the ion exchanger is disposed separately in the space between the processing electrode and a workpiece, and in the space between the feeding electrode and a workpiece. This prevents the occurrence of "the so-called short circuit" between the processing electrode and the feeding electrode, and ensures a high processing efficiency.

[0024] According to another embodiment, the ion exchanger is disposed, as an integrated structure, in both of the spaces between the processing electrode and a workpiece, and between the feeding electrode and a workpiece. This facilitates the production of the processing electrode and the feeding electrode, and can further lower the electric resistance.

[0025] According to still another embodiment, the ion exchanger covers the surface, to be processed, of a workpiece, and is disposed in both of the spaces between the processing electrode and the workpiece, and between the feeding electrode and the workpiece. This makes it possible to easily and quickly change the ion exchanger covering the processing surface of a workpiece when, for example, the ion exchanger is stained.

[0026] In the above embodiments, the ion exchanger may be stretched between a supply shaft and a rewind shaft, and taken up sequentially. This makes it possible to change the ion exchanger by taking it up by a one-time use length when, for example, the ion exchanger is stained, whereby the change operation can be conducted in a successive manner.

[0027] In the case of the ion exchanger of this embodiment, the processing electrode and the feeding electrode may be mounted alternately on the ion exchanger at a given pitch along the length of the ion exchanger. This eliminates the need to provide electrode sections for supplying electricity separately, and thus can simplify the device.

[0028] The ion exchanger may have water-absorbing properties. This allows a liquid such as ultrapure water to flow within the ion exchanger.

[0029] The ion exchanger may have one or both of an anion-exchange ability and a cation-exchange ability. An ion exchanger having an anion-exchange ability and an ion exchanger having a cation-exchange ability can be used selectively according to a workpiece. The use of an ion-exchanger having both of anion-and cation-exchange abilities can broaden the range of processible materials and, in addition, can prevent the formation of impurities due to the polarity.

[0030] The ion exchanger may be covered with a porous body. This can provide a workpiece with a flatter processed surface. In this case, the ion exchanger itself may be composed of a porous body.

[0031] According to a preferred embodiment, the electrolytic processing device further comprises a regeneration section for regenerating the ion exchanger. By regenerating the ion exchanger during processing or in an interval of processing to remove extraneous matter, such as copper, from the ion exchanger, contamination of a new workpiece with the matter coming from the ion exchanger can be prevented, and furthermore, lowering of the processing efficiency and accuracy can be avoided.

[0032] The present invention also provides an electrolytic processing device comprising: a processing electrode brought into contact with or close to a workpiece; a feeding electrode for supplying electricity to the workpiece; a power source for applying a voltage between the processing electrode and the feeding electrode; and a liquid supply section for supplying pure water or a liquid having an electric conductivity of not more than 500 μS/cm between the workpiece and the processing electrode.

[0033] **FIG. 3** illustrates the principle of electrolytic processing effected in this electrolytic processing device. **FIG. 3** shows the ionic state in the electrolytic processing device when a processing electrode **14** and a feeding electrode **16** are brought close to a surface of a workpiece **10**, while a voltage is applied via a power supply source **17** between the processing electrode **14** and the feeding electrode **16**, and the liquid **18**, such as ultrapure water, is supplied from a liquid supply section **19** between the processing electrode **14**, the feeding electrode **16** and the workpiece **10**.

[0034] Water molecules **20** in the liquid **18** such as ultrapure water are dissociated into hydroxide ions **22** and hydrogen ions **24**. The hydroxide ions **22** thus produced are carried, by the electric field between the workpiece **10** and the processing electrode **14** and by the flow of the liquid **18**, to the surface of the workpiece **10** opposite to the processing electrode **14** whereby the density of the hydroxide ions **22** in the vicinity of the workpiece **10** is enhanced, and the hydroxide ions **22** are reacted with the atoms **10***a* of the workpiece **10**. The reaction product **26** is dissolved in the liquid **18**, and removed from the workpiece **10** by the flow of the liquid **18** along the surface of the workpiece **10**. Removal processing of the surface of the workpiece **10** is thus effected.

[0035] Ultrapure water is preferably used as the liquid. By "ultrapure water" is herein meant a water having an electric conductivity of not more than 0.1 μS/cm. The use of ultrapure water enables a cleaner processing without leaving impurities on the processed surface of a workpiece.

[0036] In the above-described electrolytic processing devices, according to one embodiment of the present invention, at least one of the processing electrode and the feeding electrode is in the shape of a flat rectangular plate.

[0037] According to another embodiment, at least one of the processing electrode and the feeding electrode is in the shape of a column, and is disposed such that the central axis thereof is parallel to the surface, to be processed, of a workpiece. This allows that at least one of the processing electrode and the feeding electrode to linearly contact or get close to a workpiece, thereby enhancing the flatness of the processed surface of the workpiece.

[0038] According to still another embodiment, at least one of the processing electrode and the feeding electrode is in a spherical or oval spherical shape. This enables processing at a point and processing of a curved surface.

[0039] According to yet another embodiment, at least one of the processing electrode and the feeding electrode has a

depressed portion or a raised portion conforming to the configuration of a workpiece, and processing of the workpiece is conducted by allowing the workpiece to face the depressed or raised portion. For example, the processing electrode may have a depressed portion conforming to the configuration of a peripheral portion of a substrate. Processing of the substrate can be conducted by allowing the peripheral portion of the substrate to be positioned in the depressed portion, thereby removing a material, to be processed, formed on or adhering to the peripheral portion (bevel portion or edge portion). Thus, in this case, the electrolytic processing device is utilized as a bevel-etching device for the substrate.

[0040] The above-described electrolytic processing devices of the present invention may be constructed so that at least one of between the processing electrodes and the workpiece, and between the feeding electrodes and the workpiece can make a relative movement. This can produce a flow of the liquid, such as ultrapure water, between a workpiece and at least one of the processing and feeding electrodes, thereby effectively expelling unnecessary products, whereby the flatness of the processed surface of the workpiece can be enhanced.

[0041] The relative movement may be rotation, reciprocation, eccentric rotation or scroll movement, or a combination thereof.

[0042] Further according to the present invention, the processing electrode and the feeding electrode may be disposed such that one of the electrodes surrounds the other. This allows all of the electric currents to flow from the feeding electrode to the processing electrode through the shortest routes, thereby enhancing the electric current efficiency and reducing the electric power consumption.

[0043] According to another embodiment, at least one of the processing electrode and the feeding electrode is in the shape of a fan. This allows the processing electrode to face a workpiece for a constant time in the radial direction, whereby the electrolytic processing rate can be made constant.

[0044] According to yet another embodiment, at least one of the processing electrode and the feeding electrode is disposed linearly or in a circle.

[0045] The present invention provides a substrate processing apparatus, comprising: a substrate carry-in and carry-out section for carrying in and carrying out a substrate; an electrolytic processing device; and a transport device for transporting the substrate between the substrate carry-in and carry-out section and the electrolytic processing device; wherein the electrolytic processing device comprises a processing electrode brought into contact with or close to a workpiece, a feeding electrode for supplying electricity to the workpiece, an ion exchanger disposed in at least one of a spaces between the workpiece and the processing electrode, and between the workpiece and the feeding electrode, a power source for applying a voltage between the processing electrode and the feeding electrode, and a liquid supply section for supplying a liquid to the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which the ion exchanger is present.

[0046] The present invention also provides a substrate processing apparatus, comprising: a substrate carry-in and carry-out section for carrying in and carrying out a substrate; an electrolytic processing device; and a transport device for transporting the substrate between the substrate carry-in and carry-out section and the electrolytic processing device; wherein the electrolytic processing device comprises a processing electrode brought into contact with or close to a workpiece, a feeding electrode for supplying electricity to the workpiece, a power source for applying a voltage between the processing electrode and the feeding electrode, and a liquid supply section for supplying pure water or a liquid having an electric conductivity of not more than 500 μS/cm between the workpiece and the processing electrode.

[0047] In a preferred embodiment, the substrate processing apparatus further comprises a cleaning device for cleaning the processed substrate by the electrolytic processing device.

[0048] In another embodiment, the substrate processing apparatus further comprises a CMP device for chemical mechanical polishing the surface of a substrate. In this case, the substrate processing apparatus may further comprise a cleaning device for cleaning the polished substrate by the CMP device.

[0049] In still another embodiment, the substrate processing apparatus further comprises a film-forming device for forming a film as a portion to be processed in the surface of a substrate. In this case, the substrate processing apparatus may further comprise at least one of a cleaning device for cleaning the portion to be processed having been formed in the film-forming device and an annealing device for annealing the portion to be processed.

[0050] Also in this case, the substrate processing apparatus may further comprise a bevel-etching device for etching the portion to be processed formed in or adhering to a peripheral portion of the substrate. In the bevel-etching device, the etching of the portion to be processed may be effected by electrolytic processing.

[0051] The substrate processing apparatus may further comprise a film thickness-measuring section for measuring the film thickness of the portion to be processed during or after the polishing in the CMP device. Moreover, the substrate processing apparatus may further comprise a film thickness-measuring section for measuring the film thickness of the portion to be processed during or after the film formation in the film-forming device.

[0052] The film formation in the film-forming device may be conducted by plating.

[0053] In yet another embodiment, the substrate processing apparatus further comprises a monitor for monitoring at least one of electrolytic current and electrolytic voltage when the voltage is applied between the feeding electrode and the processing electrode.

[0054] According to yet another embodiment, the substrate processing apparatus further comprises a drying device for finally drying the processed substrate. This can realize the so-called "dry-in, dry-out".

[0055] According to yet another embodiment, the substrate processing apparatus monitors a change in the state of the substrate being processed and detects the end point of processing. By the "end point of processing" is herein meant a point at which a desired processing amount is attained for

a specified region in a surface to be processed, or a point at which an amount corresponding to a desired processing amount is attained in terms of a parameter correlated with a processing amount for a specified region in a surface to be processed. By thus arbitrarily setting and detecting the end point of processing even in the middle of processing, it becomes possible to conduct a multi-step electrolytic processing.

[0056] According to yet another embodiment, the substrate processing apparatus further comprises a film-thickness detection section for detecting the end point of processing.

[0057] The above and other objects, features, and advantages of the present invention will be apparent from the following description when taken in conjunction with the accompanying drawings which illustrates preferred embodiments of the present invention by way of example.

BRIEF DESCRIPTION OF DRAWINGS

[0058] **FIG. 1** is a diagram illustrating the principle of electrolytic processing effected in an electrolytic processing device in accordance with the present invention when an ion exchanger is mounted on both of a processing electrode and a feeding electrode, and a liquid is supplied between the processing electrode, the feeding electrode and a substrate (workpiece);

[0059] **FIG. 2** is a diagram illustrating the principle of electrolytic processing effected in an electrolytic processing device in accordance with the present invention when an ion exchanger is mounted only on a processing electrode, and a liquid is supplied between the processing electrode and a substrate (workpiece);

[0060] **FIG. 3** is a diagram illustrating the principle of electrolytic processing effected in an electrolytic processing device in accordance with the present invention when a processing electrode and a feeding electrode are brought close to a substrate, and pure water or a liquid having an electric conductivity of not more than 500 μS/cm is supplied between the processing electrode, the feeding electrode and the substrate (workpiece);

[0061] **FIGS. 4A and 4B** are plan views showing the layout of a substrate processing apparatus according to a first embodiment of the present invention;

[0062] **FIG. 5** is a vertical sectional front view of an electrolytic processing device according to one embodiment of the present invention, which is provided in the substrate processing apparatus of **FIG. 4**;

[0063] **FIG. 6** is a plan view of the electrolytic processing device of **FIG. 5**;

[0064] **FIG. 7** is a plan view of an electrode plate provided in the electrolytic processing device of **FIG. 4**;

[0065] **FIG. 8** is a cross-sectional view of another ion exchanger;

[0066] **FIGS. 9A and 9B** are plan views of other electrode plates;

[0067] **FIGS. 10A and 10B** are plan views of still other electrode plates;

[0068] **FIGS. 11A and 11B** are plan views of yet other electrode plates;

[0069] **FIG. 12** is a plan view of yet another electrode plate;

[0070] **FIG. 13** is a plan view of yet another electrode plate;

[0071] **FIGS. 14A and 14B** are graphs showing the relationship between the electric current and time, and the relationship between the voltage applied and time, respectively, in electrolytic processing conducted to the surface of a substrate in which a laminated film of two different materials is formed;

[0072] **FIG. 15** is a plan view showing a variation of the electrolytic processing device of **FIG. 5**;

[0073] **FIG. 16** is a plan view showing the layout of a substrate processing apparatus according to another embodiment of the present invention;

[0074] **FIG. 17** is a cross-sectional view of an electrolytic processing device according to another embodiment of the present invention, which is provided in the substrate processing apparatus of **FIG. 16**;

[0075] **FIG. 18** is a plan view of the electrolytic processing device of **FIG. 17**;

[0076] **FIG. 19A** is a plan view showing the relationship between the substrate holder and the electrode section of the electrolytic processing device of **FIG. 17**, and **FIG. 19B** is a cross-sectional view taken along the line A-A of **FIG. 19A**;

[0077] **FIG. 20** is a plan view of an electrode plate used in a variation of the electrolytic processing device of **FIG. 17**;

[0078] **FIG. 21** is a vertical sectional front view of the electrode plate of **FIG. 20**;

[0079] **FIG. 22** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0080] **FIG. 23** is a plan view of the electrolytic processing device of **FIG. 22**;

[0081] **FIG. 24** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0082] **FIG. 25** is a plan view of the electrolytic processing device of **FIG. 24**;

[0083] **FIG. 26** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0084] **FIG. 27** is a plan view of the electrolytic processing device of **FIG. 26**;

[0085] **FIG. 28** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0086] **FIG. 29** is a plan view of the electrolytic processing device of **FIG. 28**;

[0087] **FIG. 30** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0088] **FIG. 31** is a plan view showing the layout of a substrate processing apparatus according to yet another embodiment of the present invention;

[0089] **FIG. 32** is a schematic sectional view of a CMP device;

[0090] **FIG. 33** is a plan view showing the layout of a substrate processing apparatus according to yet another embodiment of the present invention;

[0091] **FIG. 34** is a plan view showing the layout of a substrate processing apparatus according to yet another embodiment of the present invention;

[0092] **FIG. 35** is a plan view showing the layout of a substrate processing apparatus according to yet another embodiment of the present invention;

[0093] **FIG. 36** is a schematic sectional view of a plating device;

[0094] **FIG. 37** is a vertical sectional view of an annealing device;

[0095] **FIG. 38** is a horizontal sectional view of the annealing device;

[0096] **FIG. 39** is a plan view showing the layout of a substrate processing apparatus according to yet another embodiment of the present invention in which a bevel-etching device is incorporated;

[0097] **FIG. 40** is a schematic view of an electrolytic processing device according to yet another embodiment of the present invention, which is utilized as a bevel-etching device;

[0098] **FIG. 41** is an enlarged sectional view of the main portion of an electrolytic processing device according to yet another embodiment of the present invention, which is utilized as a bevel-etching device;

[0099] **FIG. 42** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention, which is utilized as a bevel-etching device;

[0100] **FIG. 43** is a plan view of the bevel-etching device of **FIG. 42**;

[0101] **FIG. 44** is a plan view showing the layout of a substrate processing apparatus according to yet another embodiment of the present invention;

[0102] **FIG. 45** is a schematic plan view of an electrolytic processing device according to yet another embodiment of the present invention;

[0103] **FIG. 46** is a schematic perspective view showing the processing electrode and the feeding electrode of the electrolytic processing device of **FIG. 45**;

[0104] **FIG. 47** is a schematic front view showing the processing electrode and the feeding electrode of the electrolytic processing device of **FIG. 45**;

[0105] **FIGS. 48A and 48B** are respectively perspective and front views illustrating a case of mounting an ion exchanger on a rectangular electrode;

[0106] **FIGS. 49A and 49B** are respectively perspective and front views illustrating a case of mounting an ion exchanger on a column-shaped electrode;

[0107] **FIG. 50** is a schematic front view of other processing and feeding electrodes;

[0108] **FIG. 51** is a schematic front view of yet other processing and feeding electrodes;

[0109] **FIG. 52** is a schematic front view of yet other processing and feeding electrodes;

[0110] **FIG. 53** is a schematic front view of yet other processing and feeding electrodes;

[0111] **FIGS. 54A and 54B** are diagrams illustrating different arrangements of processing and feeding electrodes relative to a substrate;

[0112] **FIG. 55** is a schematic front view of other processing electrode, feeding electrode and ion exchanger;

[0113] **FIG. 56** is a schematic front view of yet other processing electrode, feeding electrode and ion exchanger;

[0114] **FIG. 57** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0115] **FIG. 58** is a plan view of the electrolytic processing device of **FIG. 57**;

[0116] **FIG. 59** is a perspective view of yet another ion exchanger;

[0117] **FIG. 60** is a front view of the ion exchanger of **FIG. 59**;

[0118] **FIGS. 61A and 61B** are respectively front and perspective views showing yet another arrangement of processing and feeding electrodes;

[0119] **FIG. 62** is a plan view showing yet another arrangement of processing and feeding electrodes;

[0120] **FIG. 63** is a plan view showing yet another arrangement of processing and feeding electrodes;

[0121] **FIG. 64** is a schematic perspective view of an electrolytic processing device according to yet another embodiment of the present invention;

[0122] **FIG. 65** is a schematic side view of the electrolytic processing device of **FIG. 64**;

[0123] **FIG. 66** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0124] **FIG. 67** is a plan view of the electrolytic processing device of **FIG. 66**;

[0125] **FIG. 68** is a schematic front view of an electrolytic processing device according to yet another embodiment of the present invention;

[0126] **FIG. 69** is a schematic front view of an electrolytic processing device according to yet another embodiment of the present invention;

[0127] **FIG. 70** is a vertical sectional view of an electrolytic processing device according to yet another embodiment of the present invention;

[0128] **FIG. 71** is a plan view of the electrolytic processing device of **FIG. 70**;

[0129] **FIG. 72** is a schematic perspective view of an electrolytic processing device according to yet another embodiment of the present invention, which is utilized as a bevel-etching device;

[0130] **FIG. 73** is a schematic perspective view of an electrolytic processing device according to yet another embodiment of the present invention, which is utilized as a bevel-etching device;

[0131] **FIG. 74** is a diagram illustrating the state of a substrate after undergoing electrolytic processing in the electrolytic processing device (bevel-etching device) of **FIG. 72** or of **FIG. 73**;

[0132] **FIG. 75** is a cross-sectional view of an electrolytic processing device according to yet another embodiment of the present invention, which is utilized as a bevel-etching device;

[0133] **FIG. 76** is a plan view of the electrolytic processing device of **FIG. 75**;

[0134] **FIG. 77** is a plan view showing a variation of the electrolytic processing device of **FIG. 75**;

[0135] **FIG. 78** is a schematic front view of an electrolytic processing device according to yet another embodiment of the present invention;

[0136] **FIG. 79** is a schematic perspective view of an electrolytic processing device according to yet another embodiment of the present invention;

[0137] **FIG. 80** is a schematic front view of the electrolytic processing device of **FIG. 79**;

[0138] **FIG. 81** is a schematic front view of an electrolytic processing device according to yet another embodiment of the present invention;

[0139] **FIG. 82** is a schematic front view of the electrolytic processing device of **FIG. 81**;

[0140] **FIG. 83** is a schematic front view of an electrolytic processing device according to yet another embodiment of the present invention;

[0141] **FIG. 84** is a schematic front view of the electrolytic processing device of **FIG. 83**; and

[0142] **FIGS. 85A through 85C** are diagrams illustrating, in sequence of process steps, for forming of copper interconnects.

BEST MODE FOR CARRYING OUT THE INVENTION

[0143] Preferred embodiments of the present invention will now be described with reference to the drawings.

[0144] **FIG. 4A** shows a plan view of a substrate processing apparatus according to a first embodiment of the present invention. **FIGS. 5 through 7** show an electrolytic processing device according to a first embodiment of the present invention which is used in the substrate processing apparatus. Though this embodiment uses a substrate as a workpiece to be processed by the electrolytic processing device, a workpiece other than a substrate can, of course, also be employed.

[0145] As shown in **FIG. 4A**, the substrate processing apparatus comprises a pair of loading/unloading units **30** as a carry-in and carry-out section for carrying in and carrying out a cassette housing a substrate W, e.g. a substrate W as shown in **FIG. 85B**, which has in its surface a copper film **6** as a conductor film (portion to be processed), a reversing machine **32** for reversing the substrate W, a pusher **34** for transferring the substrate W, and an electrolytic processing device **36**. A fixed-type transport robot **38** is provided in between the loading/unloading units **30**, the reversing machine **32** and the pusher **34** as a transport device for transporting the substrate W therebetween. The substrate processing apparatus is also provided with a monitor **42** for monitoring a voltage applied between the below-described processing electrodes **50** and feeding electrodes **52** upon electrolytic processing in the electrolytic processing device **36**, or an electric current flowing therebetween.

[0146] As shown in **FIG. 5**, the electrolytic processing device **36** includes a substrate holder **46**, supported at the free end of a swingable arm **44** that can swing horizontally, for attracting and holding the substrate W with its front surface downward (so-called "face down" manner), and, positioned beneath the substrate holder **46**, a disc-shaped electrode section **48** made of an insulating material. As shown in **FIG. 7**, the electrode section **48** has, embedded therein, fan-shaped processing electrodes **50** and feeding electrodes **52** that are disposed alternately with their surfaces (upper faces) exposed. A film-like ion exchanger **56** is mounted on the upper surface of the electrode section **48** so as to cover the surfaces of the processing electrodes **50** and the feeding electrodes **52**.

[0147] This embodiment uses, merely as an example of the electrode section **48** having the processing electrodes **50** and the feeding electrodes **52**, such one that has a diameter more than twice that of the substrate W so that the entire surface of the substrate W may undergo electrolytic processing.

[0148] The ion exchanger **56** may be a nonwoven fabric which has an anion-exchange ability or a cation-exchange ability. A cation exchanger preferably carries a strongly acidic cation-exchange group (sulfonic acid group); however, a cation exchanger carrying a weakly acidic cation-exchange group (carboxyl group) may also be used. Though an anion exchanger preferably carries a strongly basic anion-exchange group (quaternary ammonium group), an anion exchanger carrying a weakly basic anion-exchange group (tertiary or lower amino group) may also be used.

[0149] The nonwoven fabric carrying a strongly basic anion-exchange group can be prepared by, for example, the following method: A polyolefin nonwoven fabric having a fiber diameter of 20-50 μm and a porosity of about 90% is subjected to the so-called radiation graft polymerization, comprising γ-ray irradiation onto the nonwoven fabric and the subsequent graft polymerization, thereby introducing graft chains; and the graft chains thus introduced are then aminated to introduce quaternary ammonium groups thereinto. The capacity of the ion-exchange groups introduced can be determined by the amount of the graft chains introduced. The graft polymerization may be conducted by the

use of a monomer such as acrylic acid, styrene, glicidyl methacrylate, sodium styrenesulfonate or chloromethylstyrene. The amount of the graft chains can be controlled by adjusting the monomer concentration, the reaction temperature and the reaction time. Thus, the degree of grafting, i.e. the ratio of the weight of the nonwoven fabric after graft polymerization to the weight of the nonwoven fabric before graft polymerization, can be made 500% at its maximum. Consequently, the capacity of the ion-exchange groups introduced after graft polymerization can be made 5 meq/g at its maximum.

[0150] The nonwoven fabric carrying a strongly acidic cation-exchange group can be prepared by the following method: As in the case of the nonwoven fabric carrying a strongly basic anion-exchange group, a polyolefin nonwoven fabric having a fiber diameter of 20-50 μm and a porosity of about 90% is subjected to the so-called radiation graft polymerization comprising y-ray irradiation onto the nonwoven fabric and the subsequent graft polymerization, thereby introducing graft chains; and the graft chains thus introduced are then treated with a heated sulfuric acid to introduce sulfonic acid groups thereinto. If the graft chains are treated with a heated phosphoric acid, phosphate groups can be introduced. The degree of grafting can reach 500% at its maximum, and the capacity of the ion-exchange groups thus introduced after graft polymerization can reach 5 meq/g at its maximum.

[0151] The base material of the ion-exchanger **56** may be a polyolefin such as polyethylene or polypropylene, or any other organic polymer. Further, besides the form of a nonwoven fabric, the ion-exchanger may be in the form of a woven fabric, a sheet, a porous material, short fibers, etc.

[0152] When polyethylene or polypropylene is used as the base material, graft polymerization can be effected by first irradiating radioactive rays (γ-rays or electron beam) onto the base material (pre-irradiation) to thereby generate a radical, and then reacting the radical with a monomer, whereby uniform graft chains with few impurities can be obtained. When an organic polymer other than polyolefin is used as the base material, on the other hand, radical polymerization can be effected by impregnating the base material with a monomer and irradiating radioactive rays (γ-rays, electron beam or UV-rays) onto the base material (simultaneous irradiation). Though this method fails to provide uniform graft chains, it is applicable to a wide variety of base materials.

[0153] By using as the ion exchanger **56** a nonwoven fabric having an anion-exchange ability or a cation-exchange ability, it becomes possible that pure water or ultrapure water, or a liquid such as an electrolytic solution can freely move within the nonwoven fabric and easily arrive at the active points in the nonwoven fabric having a catalytic activity for water dissociation, so that many water molecules are dissociated into hydrogen ions and hydroxide ions. Further, by the movement of pure water or ultrapure water, or a liquid such as an electrolytic solution, the hydroxide ions produced by the water dissociation can be efficiently carried to the surface of the processing electrode **50**, whereby a high electric current can be obtained even with a low voltage applied.

[0154] When the ion exchanger **56** has only one of anion-exchange ability and cation-exchange ability, a limitation is imposed on electrolytically processible materials and, in addition, impurities are likely to form due to the polarity. In order to solve this problem, the ion exchanger **56** may have such a structure as shown in **FIG. 8** wherein anion-exchangers **56***a* having an anion-exchange ability and cation-exchangers **56***b* having a cation-exchange ability are concentrically disposed to constitute an integral structure. The anion exchangers and the cation exchangers may be superimposed on the surface, to be processed, of a substrate. It may also be possible to make the anion-exchangers and the cation-exchangers each in the shape of a fan, and dispose them alternately. Alternatively, the above problem can be solved by using, as the ion exchanger **56**, an ion-exchanger which in itself carries both of an anion-exchange group and a cation-exchange group. Such an ion exchanger may include an amphoteric ion exchanger in which anion-exchange groups and cation-exchange groups are distributed randomly, a bipolar ion exchanger in which anion-exchange groups and cation-exchange groups are present in layers, and a mosaic ion exchanger in which portions containing anion-exchange groups and portions containing cation-exchange groups are present in parallel in the thickness direction. Incidentally, it is of course possible to selectively use, as the ion exchange **56**, one having an anion-exchange ability or one having a cation-exchange ability according to the material to be processed.

[0155] As shown in **FIG. 5**, the swingable arm **44**, which moves up and down via a ball screw **62** by the actuation of a motor **60** for vertical movement, is connected to the upper end of a shaft **66** that rotates by the actuation of a motor **64** for swinging. The substrate holder **46** is connected to a motor **68** for rotation that is mounted on the free end of the swingable arm **44**, and is allowed to rotate by the actuation of the motor **68** for rotation.

[0156] The electrode section **48** is connected directly to a hollow motor **70**, and is allowed to rotate by the actuation of the hollow motor **70**. A through-hole **48***a* as a pure water supply section for supplying pure water, preferably ultrapure water, is formed in the central portion of the electrode section **48**. The through-hole **48***a* is connected to a pure water supply pipe **72** that vertically extends inside the hollow motor **70**. Pure water or ultrapure water is supplied through the through-hole **48***a*, and via the ion exchanger **56**, is supplied to the entire processing surface of the substrate W. A plurality of through-holes **48***a*, each communicating with the pure water supply pipe **72**, may be provided to facilitate the processing liquid reaching over the entire processing surface of the substrate W.

[0157] Further, a pure water nozzle **74** as a pure water supply section for supplying pure water or ultrapure water, extending in the radial direction of the electrode section **48** and having a plurality of supply ports, is disposed above the electrode section **48**. Pure water or ultrapure water is thus supplied to the surface of the substrate W from above and beneath the substrate W. Pure water herein refers to a water having an electric conductivity of not more than 10 μS/cm, and ultrapure water refers to a water having an electric conductivity of not more than 0.1 μS/cm. Instead of pure water, a liquid having an electric conductivity of not more than 500 μS/cm or any electrolytic solution may be used. By supplying such a processing liquid during processing, the instability factors of processing, such as process products

and dissolved gases, can be removed, and processing can be effected uniformly with good reproducibility.

[0158] According to this embodiment, as shown in **FIG. 5** and **FIG. 7**, fan-shaped electrode plates **76** are disposed in the electrode section **48**, and the cathode and anode of a power source **80** are alternately connected, via a slip ring **78**, to the electrode plates **76**. The electrode plates **76** connected to the cathode of the power source **80** become the processing electrodes **50** and the electrode plates **76** connected to the anode become the feeding electrodes **52**. This applies to processing of e.g. copper, because electrolytic processing of copper proceeds on the cathode side. Depending upon a material to be processed, the cathode side can be a feeding electrode and the anode side can be a processing electrode. More specifically, when the material to be processed is copper, molybdenum, iron or the like, electrolytic processing proceeds on the cathode side, and therefore the electrode plates **76** connected to the cathode of the power source **80** should be the processing electrodes **50** and the electrode plates **76** connected to the anode should be the feeding electrodes **52**. In the case of aluminum, silicon or the like, on the other hand, electrolytic processing proceeds on the anode side. Accordingly, the electrode plates connected to the anode of the power source should be the processing electrodes and the electrode plates connected to the cathode should be the feeding electrodes.

[0159] Though this embodiment shows a case in which fan-shaped electrode plates **76** are separated from one another by the ribs **48***b* of the electrode section **48** which is composed of an insulating material. The ribs **48***b* may also be formed as a separate body of another insulating material so that pure water or the like can be supplied through interspaces between the insulating materials.

[0160] By thus disposing the processing electrodes **50** and the feeding electrodes **52** separately and alternately in the circumferential direction of the electrode section **48**, fixed feeding portions to supply electricity to a conductive film (portion to be processed) of the substrate is not needed, and processing can be effected to the entire surface of the substrate. Further, be changing the positive and negative in a pulse manner, an electrolysis product can be dissolved and the flatness of the processed surface can be enhanced by the multiplex repetition of processing.

[0161] With respect to the processing electrode **50** and the feeding electrode **52**, oxidation or dissolution thereof due to an electrolytic reaction is generally a problem. In view of this, it is preferred to use, as a base material of the feeding electrode **52**, carbon, a noble metal that is relatively inactive, a conductive oxide or a conductive ceramics, rather than a metal or metal compound widely used for electrodes. A noble metal-based electrode may, for example, be one obtained by plating or coating platinum or iridium onto a titanium electrode, and then sintering the coated electrode at a high temperature to stabilize and strengthen the electrode. Ceramics products are generally obtained by heat-treating inorganic raw materials, and ceramics products having various properties are produced from various raw materials including oxides, carbides and nitrides of metals and non-metals. Among them there are ceramics having an electric conductivity. When an electrode is oxidized, the value of the electric resistance generally increases to cause an increase of applied voltage. However, by protecting the surface of an electrode with a non-oxidative material such as platinum or with a conductive oxide such as an iridium oxide, the decrease of electric conductivity due to oxidation of the base material of an electrode can be prevented.

[0162] The processing electrodes **50** and the feeding electrodes **52** may be disposed as shown in **FIG. 9**A: Pairs of the processing electrodes **50** and the feeding electrodes **52**, each pair sandwiching an insulator **82***a*, are disposed, within the electrode section **48**, in a fan-shaped region ranging from the center to the periphery of the electrode section **48** so that the number of the pairs gradually increases from the center to the periphery of the electrode section **48**. With this arrangement, the electrode section **48** and the substrate W are rotated, an electric current per unit area, i.e. current density, becomes even between a central portion of the electrode section **48** where the relative speed to the substrate W is low and a peripheral portion of the electrode section **48** where the relative speed to the substrate W is high, whereby the electrolytic processing rate can be made constant over the entire surface of the substrate W. This arrangement is adapted not only to this embodiment in which the substrate W is positioned on one side across the center of the electrode section **48**, but also to a case in which the electrode portion **48**, which is slightly larger than the substrate, is allowed to rotate about the center of the substrate W (see **FIG. 17** and **FIG. 18**).

[0163] As a modification of the above electrode arrangement, as shown in **FIG. 9**B, it is possible to make the electrode section **48** of a conductive material so that the electrode section **48** itself can function as the feeding electrode **52** (or the processing electrode **50**), and embed the processing electrodes **50** (or the feeding electrodes **52**), which are separated by the insulator **82***b*, in the inside of the electrode section **48**. This can reduce the number of wires.

[0164] Alternatively, as shown in **FIG. 10**A, one processing electrode **50** and one feeding electrode **52**, adjacent to each other and each in the shape of a fan extending from the center towards the periphery of the electrode section **48**, may be disposed in the inside of the electrode section **48**. Also in this case, as shown in **FIG. 10**B, it is possible to make the electrode section **48** of a conductive material so that the electrode section **48** itself can function as the feeding electrode **52** (or the processing electrode **50**), and embed the processing electrode **50** (or the feeding electrode **52**), which is separated by the insulator **82***b*, in the inside of the electrode section **48**.

[0165] Alternatively, as shown in **FIG. 11**A, pairs of the processing electrodes **50** and the feeding electrodes **52**, each pair sandwiching the insulator **82***a*, may be disposed in the inside of the electrode section **48** such that the length of the processing electrode **50** and that of the feeding electrode **52** in the circumferential direction gradually increases from the center to the periphery of the electrode section **48**. Also in this case, as shown in **FIG. 11**B, it is possible to make the electrode section **48** of a conductive material so that the electrode section **48** itself can function as the feeding electrode **52** (or the processing electrode **50**), and embed the processing electrodes **50** (or the feeding electrodes **52**), which are separated by the insulator **82***b*, in the inside of the electrode section **48**.

[0166] Alternatively, as shown in **FIG. 12**, it is possible to make the electrode section **48** of a conductive material so

that the electrode section **48** itself can function as the feeding electrode **52** (or the processing electrode **50**), and embed the processing electrode **50**, which is separated by the insulator **82***b* and extends spirally continuously, in the inside of the electrode section **48**. Further, as shown in **FIG. 13**, the processing electrodes **50** and the feeding electrodes **52**, extending like a screw from the center to the periphery of the electrode section **48**, may be disposed in the inside of the electrode section **48** alternately, with the insulators **82***b* being sandwiched.

[**0167**] Furthermore, though not figured, it is of course possible to distribute or dot the processing electrodes and the feeding electrodes uniformly in the inside of the electrode section **48**.

[**0168**] Next, substrate processing (electrolytic processing) by the substrate processing apparatus will be described by referring to **FIG. 4A**.

[**0169**] First, a substrate W, e.g. a substrate W as shown in **FIG. 85B** which has in its surface a copper film **6** as a conductor film (portion to be processed), is taken by the transport robot **38** out of the cassette housing substrates and set in the loading/unloading unit **30**. If necessary, the substrate W is transported to the reversing machine **32** to reverse the substrate so that the front surface of the substrate W having the conductor film faces downward. The substrate W, its front surface faces downward, is then transported by the transport robot **38** to the pusher **34** to place the substrate W on the pusher **34**.

[**0170**] The substrate W on the pusher **34** is attracted and held by the substrate holder **46** of the electrolytic processing device **36**, and the substrate holder **46** is moved by the swingable arm **44** to a processing position right above the electrode section **48**. The substrate holder **46** is then lowered by the actuation of the motor **60** for vertical movement, so that the substrate W held by the substrate holder **46** contacts or gets close to the surface of the ion exchanger **56** mounted on the upper surface of the electrode section **48**.

[**0171**] It is to be noted here that when a liquid like ultrapure water which itself has a large resistivity is used, the electric resistance can be lowered by bringing the ion exchanger **56** into contact with the substrate W, whereby the requisite voltage can also be lowered and hence the power consumption can be reduced. The "contact" does not imply "press" forgiving a physical energy (stress) to a workpiece as in CMP. Accordingly, the electrolytic processing device of this embodiment employs the vertical-movement motor **60** for bringing the substrate W into contact with or close to the electrode section **48**, and does not have such a press mechanism as usually employed in a CMP device that presses a substrate against a polishing member. This holds also for the below-described embodiments.

[**0172**] In this regard, according to a CMP device, a substrate is pressed against a polishing surface generally at a pressure of about 20-50 kPa, whereas in the electrolytic processing device of this embodiment, the substrate W may be contacted with the ion exchanger **56** at a pressure of less than 20 kPa. Even at a pressure less than 10 kPa, a sufficient removal processing effect can be achieved.

[**0173**] Next, a given voltage is applied from the power source **80** (see **FIG. 5**) between the processing electrodes **50** and the feeding electrodes **52**, while the substrate holder **46** and the electrode section **48** are rotated. At the same time, pure water or ultrapure water is supplied, through the through-hole **48***a*, from beneath the electrode section **48** to the upper surface thereof, and simultaneously, pure water or ultrapure water is supplied, through the pure water nozzle **74**, from above the electrode section **48** to the upper surface thereof, thereby filling pure water or ultrapure water into the space between the processing and feeding electrodes **50**, **52** and the substrate W. Thereby, electrolytic processing of the conductor film (copper film **6**) formed on the substrate W is effected by hydrogen ions or hydroxide ions produced in the ion exchanger **56**. According to the above electrolytic processing device, a large amount of hydrogen ions or hydroxide ions can be produced by allowing pure water or ultrapure water to flow within the ion exchanger **56**, and the large amount of such ions can be supplied to the surface of the substrate W, whereby the electrolytic processing can be conducted efficiently.

[**0174**] More specifically, by allowing pure water or ultrapure water to flow within the ion exchanger **56**, a sufficient amount of water can be supplied to a functional group (sulfonic acid group in the case of an ion exchanger carrying a strongly acidic cation-exchange group) thereby to increase the amount of dissociated water molecules, and the process product (including a gas) formed by the reaction between the conductor film (copper film **6**) and hydroxide ions (or OH radicals) can be removed by the flow of water, whereby the processing efficiency can be enhanced. The flow of pure water or ultrapure water is thus necessary, and the flow of water should desirably be constant and uniform. The constancy and uniformity of the flow of water leads to constancy and uniformity in the supply of ions and the removal of the process product, which in turn leads to constancy and uniformity in the processing. This embodiment is not a soak type. Compared with the soak type apparatus, the not-soak type apparatus is simple in an arrangement because there isn't the necessity to control contamination of the liquid in the container.

[**0175**] The monitor **42** monitors the voltage applied between the processing electrodes **50** and the feeding electrodes **52** or the electric current flowing therebetween to detect the end point (terminal of processing). It is noted in this connection that in electrolytic processing an electric current (applied voltage) varies, depending upon the material to be processed, even with the same voltage (electric current). For example, as shown in **FIG. 14**A, when an electric current is monitored in electrolytic processing of the surface of a substrate W to which a film of material B and a film of material A are laminated in this order, a constant electric current is observed during the processing of material A, but it changes upon the shift to the processing of the different material B. Likewise, as shown in **FIG. 14**B, though a constant voltage is applied between the processing electrodes **50** and the feeding electrodes **52** during the processing of material A, the voltage applied changes upon the shift to the processing of the different material B. **FIG. 14A** illustrates, by way of example, a case in which an electric current is harder to flow in electrolytic processing of material B compared to electrolytic processing of material A, and **FIG. 14B** illustrates a case in which the applied voltage becomes higher in electrolytic processing of material B compared to electrolytic processing of material A. As

will be appreciated from the above-described example, the monitoring of changes in electric current or in voltage can surely detect the end point.

[0176] Though this embodiment shows the case where the monitor **42** monitors the voltage applied between the processing electrodes **50** and the feeding electrodes **52**, or the electric current flowing therebetween to detect the end point of processing, it is also possible to allow the monitor **42** to monitor a change in the state of the substrate being processed to detect an arbitrarily set end point of processing. In this case, the end point of processing refers to a point at which a desired processing amount is attained for a specified region in a surface to be processed, or a point at which an amount corresponding to a desired processing amount is attained in terms of a parameter correlated with a processing amount for a specified region in a surface to be processed. By thus arbitrarily setting and detecting the end point of processing even in the middle of processing, it becomes possible to conduct a multi-step electrolytic processing. This holds also for the below-described embodiments.

[0177] In this connection, as shown in **FIG. 4**B, it is possible to form a window extending through the electrode section **48** for transmitting a light therethrough and provide beneath the electrode section **48** a film-thickness sensor (film-thickness detection section) S having a light-emitting section for emitting a light and a light-receiving section for receiving a light. The film-thickness sensor S can measure the film thickness of a portion, to be processed, being processed in situ based on the detected change in the intensity of the reflected light. The end point of processing can be detected based on the results of the film-thickness measurement.

[0178] After completion of the electrolytic processing, the power source **80** is disconnected, and the rotation of the substrate holder **46** and of the electrode section **48** is stopped. Thereafter, the substrate holder **46** is raised, and is carried to the pusher **34** by the swingable arm **44** to place the substrate W on the pusher **34**. The transport robot **38** takes the substrate W from the pusher **34** and, if necessary, transports the substrate to the reversing machine **32** for reversing it, and then returns the substrate W to the cassette in the loading/unloading unit **30**.

[0179] When electrolytic processing of a workpiece is conducted without interposing an ion exchanger between the processing electrode and the workpiece, the electric resistance is proportional to "the distance between the workpiece and the processing electrode (electrode-to-electrode distance)". This is because as the distance of ion migration becomes smaller, the less energy is required for ion migration. In the presence of ultrapure water, for example, the electric resistance is 18.25 MΩ (0.54 μA at a voltage of 10 V) at the electrode-to-electrode distance of 1 cm, and 1.825 KΩ (5.4 mA at a voltage of 10 V) at the electrode-to-electrode distance of 1 μm.

[0180] In the case where an ion exchanger is interposed between the processing electrode and the workpiece, when the ion exchanger is brought close to the workpiece, but not into contract with it, the electric resistance is basically proportional to the "distance between the workpiece and the surface of the ion exchanger" as in the above case. When the ion exchanger is contacted with the workpiece, however, the electric resistance decreases to a further degree. This is ascribable to a large difference in ion concentration between the inside and outside of the ion exchanger.

[0181] More especially, in the inside of the ion exchanger, electrolytic dissociation of ultrapure water is promoted by the catalytic action whereby the concentration of ions (H^+ and OH^-) increases. Thus, the inside of the ion exchanger, due to the presence of an ion-exchange group, becomes a special field in which a high concentration of ions is (or can be) accumulated. In the outside of the ion exchanger, on the other hand, due to the absence of an ion-exchange group, the ions tend to return to the original state (H_2O) whereby the ion concentration is remarkably lower.

[0182] Accordingly, by bringing the ion exchanger into contact with the workpiece, the electric resistance can be kept at a certain low level irrespective of the distance between the workpiece and the processing electrode when the ion exchanger is in contact with the workpiece.

[0183] This embodiment shows the case of supplying pure water, preferably ultrapure water, between the electrode section **48** and the substrate W. The use of pure water or ultrapure water containing no electrolyte upon electrolytic processing can prevent impurities such as an electrolyte from adhering to and remaining on the surface of the substrate W. Further, copper ions or the like dissolved during electrolytic processing are immediately caught by the ion exchanger **56** through the ion-exchange reaction. This can prevent the dissolved copper ions or the like from re-precipitating on the other portions of the substrate W, or from being oxidized to become fine particles which contaminate the surface of the substrate W.

[0184] Ultrapure water has a high resistivity, and therefore an electric current is hard to flow therethrough. A lowering of the electric resistance is made by making the distance between the electrode and a workpiece as small as possible, or by interposing the ion exchanger between the electrode and a workpiece. Further, an electrolytic solution, when used in combination with ultrapure water, can further lower the electric resistance and reduce the power consumption. When electrolytic processing is conducted by using an electrolytic solution, the portion of a workpiece that undergoes processing ranges over a slightly wider area than the area of the processing electrode. In the case of the combined use of ultrapure water and the ion exchanger, on the other hand, since almost no electric current flows through ultrapure water, electric processing is effected only within the area of a workpiece that is equal to the area of the processing electrode and the ion exchanger.

[0185] It is possible to use, instead of pure water or ultrapure water, an electrolytic solution obtained by adding an electrolyte to pure water or ultrapure water. The use of such an electrolytic solution can further lower the electric resistance and reduce the power consumption. A solution of a neutral salt such as NaCl or Na_2SO_4, a solution of an acid such as HCl or H_2SO_4, or a solution of an alkali such as ammonia, may be used as the electrolytic solution, and these solutions may be selectively used according to the properties of the workpiece. When the electrolytic solution is used, it is preferred to provide a slight interspace between the substrate W and the ion exchanger **56** so that they are not in contact with each other. To avoid contamination of the wafer induced by an electrolytic solution, it is better to use a dilute

electrolytic solution which electric conductivity is not more than 500 μs/cm. Therefore, the cleanliness of the processed workpiece can be increased.

[0186] Further, it is also possible to use, instead of pure water or ultrapure water, a liquid obtained by adding a surfactant to pure water or ultrapure water, and having an electric conductivity of not more than 500 μS/cm, preferably not more than 50 μS/cm, more preferably not more than 0.1 μS/cm (resistivity of not less than 10 MΩ·cm). Due to the presence of a surfactant, the liquid can form a layer, which functions to inhibit ion migration evenly, at the interface between the substrate W and the ion exchanger **56**, thereby moderating concentration of ion exchange (metal dissolution) to enhance the flatness of the processed surface. The surfactant concentration is desirably not more than 100 ppm. When the value of the electric conductivity is too high, the current efficiency is lowered and the processing rate is decreased. The use of the liquid having an electric conductivity of not more than 500 μs/cm, preferably not more than 50 μS/cm, more preferably not more than 0.1 μS/cm, can attain a desired processing rate.

[0187] According to the present invention, the processing rate can be considerably enhanced by interposing the ion exchanger **56** between the substrate W and the processing and feeding electrodes **50**, **52**. In this regard, electrochemical processing using ultrapure water is effected by a chemical interaction between hydroxide ions in ultrapure water and a material to be processed. However, the amount of the hydroxide ions acting as reactant in ultrapure water is as small as 10^{-7} mol/L under normal temperature and pressure conditions, so that the removal processing efficiency can decrease due to reactions (such as an oxide film-forming reaction) other than the reaction for removal processing. It is therefore necessary to increase hydroxide ions in order to conduct removal processing efficiently. A method for increasing hydroxide ions is to promote the dissociation reaction of ultrapure water by using a catalytic material, and an ion exchanger can be effectively used as such a catalytic material. More specifically, the activation energy relating to water-molecule dissociation reaction is lowered by the interaction between functional groups in an ion exchanger and water molecules, whereby the dissociation of water is promoted to thereby enhance the processing rate.

[0188] It may be possible to omit the ion exchanger **56**, and supply pure water or ultrapure water between the substrate W and the processing and feeding electrodes **50**, **52**. Though the processing rate is lowered by the omission of the ion exchanger **56**, the electrolytic processing is effective especially for removing an extremely thin film. Moreover, this excludes the possibility that extra impurities such as an electrolyte will adhere to and remain on the surface of the substrate W.

[0189] Further, according to this embodiment, the ion exchanger **56** is brought into contact with or close to the substrate W upon electrolytic processing. When the ion exchanger **56** is positioned close to the substrate W, though depending on the distance therebetween, the electric resistance is large to some degree and, therefore, a somewhat large voltage is necessary to provide a requisite electric current density. However on the other hand, because of the non-contact relation, it is easy to form flow of pure water or ultrapure water along the surface of the substrate W, whereby the reaction product produced on the substrate surface can be efficiently removed. In the case where the ion exchanger **56** is brought into contact with the substrate W, the electric resistance becomes very small and therefore only a small voltage needs to be applied, whereby the power consumption can be reduced.

[0190] If a voltage is raised to increase the current density in order to enhance the processing rate, an electric discharge can occur when the electric resistance between the electrode and the substrate (workpiece) is large. The occurrence of electric discharge causes pitching on the surface of the workpiece, thus failing to form an even and flat processed surface. To the contrary, since the electric resistance is very small when the ion exchanger **56** is in contact with the substrate W, the occurrence of an electric discharge can be avoided.

[0191] When electrolytic processing of copper is conducted by using, as the ion exchanger **56**, an ion exchanger having a cation-exchange group, the ion-exchange group of the ion exchanger (cation exchanger) **56** is saturated with copper after the processing, whereby the processing efficiency of the next processing is lowered. When electrolytic processing of copper is conducted by using, as the ion exchanger **56**, an ion exchanger having an anion-exchange group, fine particles of a copper oxide can be produced and adhere to the surface of the ion exchanger (anion exchanger) **56**, which particles can contaminate the surface of a next substrate to be processed.

[0192] In order to obviate such drawbacks, as shown in **FIG. 15, a** regeneration section **84** for regenerating the ion exchanger **56** is provided, and the regeneration of the ion exchanger **56** can be effected during electrolytic processing. The regeneration section **84** comprises a swingable arm **86** having a structure similar to the swingable arm **44** that holds the substrate holder **46** and positioned at the opposite side to the swingable arm **44** across the electrode section **48**, and a regeneration head **88** held by the swingable arm **86** at the free end thereof. In operation, the reverse electric potential to that for processing is given to the ion exchanger **56** from the power source **80**, thereby promoting dissolution of extraneous matter such as copper adhering to the ion exchanger **56**. The regeneration of the ion exchanger **56** during processing can thus be effected. The regenerated ion exchanger **56** is rinsed by pure water or ultrapure water supplied to the upper surface of the electrode section **48**.

[0193] **FIG. 16** shows the layout of a substrate processing apparatus according to another embodiment of the present invention **FIGS. 17 through 19** show an electrolytic processing device according to another embodiment of the present invention provided with the substrate processing apparatus. In the description given below, the same members as in the above-described embodiment are given the same reference numerals, and the description thereof is partly omitted. This holds for all of the below-described embodiments.

[0194] As shown in **FIG. 16**, the substrate processing apparatus comprises a pair of the loading/unloading units **30** as a carry-in and carry-out section for carrying in and carrying out a substrate W, the reversing machine **32** for reversing the substrate W. and an electrolytic processing device **36***a*, which are disposed in series. A transport robot **38***a* as a transport device is provided which can move

parallel to these devices for transporting and transferring the substrate W therebetween. The substrate processing apparatus is also provided with the monitor **42** for monitoring a voltage applied between the processing electrode **50** and the feeding electrode **52** upon electrolytic processing in the electrolytic processing device **36***a*, or an electric current flowing therebetween.

[**0195**] In the electrolytic processing device **36***a*, the electrode section **48**, in which the processing electrodes **50** and the feeding electrodes **52** are embedded, is designed to have a slightly larger diameter than that of the substrate W to be held by the substrate holder **46**. By the actuation of the hollow motor **70**, the electrode section **48** makes a revolutionary movement with the distance between the central axis of the hollow motor **70** and the central axis of the electrode section **48** as radius, without rotation about its own axis, i.e. the so-called scroll movement (translational rotation).

[**0196**] In this regard, as shown in **FIGS. 19A and 19B**, three or more (four in **FIG. 19A**) of rotation-prevention mechanisms **400** are provided in the circumferential direction between the electrode section **48** and the hollow motor **70**. In particular, a plurality of depressions **402** and **404** are formed at equal intervals in the circumferential direction at the corresponding positions in the upper surface of the hollow motor **70** and in the lower surface of the electrode **48**. Bearings **406** and **408** are fixed in each depression **402** and depression **404**, respectively. As shown in **FIG. 19B, a** connecting member **412**, which has two shafts **409**, **410** that are eccentric to each other by eccentricity "e", is coupled to each pair of the bearings **406**, **408** by inserting the respective ends of the shafts **409**, **410** into the bearings **406**, **408**. Further, a drive end **416**, formed at the upper end portion of the main shaft **414** of the hollow motor **70** and arranged eccentrically position to the center of the main shaft, is rotatably connected, via a bearing (not shown), to a lower central portion of the electrode section **48**. The eccentricity is also "e". Accordingly, the electrode section **48** is allowed to make a translational movement along a circle with radius "e".

[**0197**] According to this embodiment, it is not possible to supply pure water or ultrapure water to the upper surface of the electrode section **48** from above the electrode section **48** during electrolytic processing. Thus, as shown in **FIG. 17**, pure water or ultrapure water is supplied to the upper surface of the electrode section **48** only through a through-hole **414***a* formed in the main shaft **414** and the through-hole **48***a* formed in the electrode section **48**. Further, since the electrode section **48** does not rotate about its own axis, the slip ring **78** is omitted. Furthermore, as shown in **FIG. 18, a** ultrapure water-spray nozzle **90** as a regeneration section is retreatably provided beside the electrode section **48**, which sprays ultrapure water onto the ion exchanger **56** after the electrolytic processing, thereby regenerating the ion exchanger **56**. The other construction is the same as the first embodiment.

[**0198**] According to the electrolytic processing device **36***a*, electrolytic processing of the surface of the substrate W is carried out by rotating, via the substrate holder **46**, the substrate W which is in contact with or close to the ion exchanger **56**, and, at the same time, allowing the electrode section **48** to make a scroll movement by the actuation of the hollow motor **70**, while supplying pure water or ultrapure water to the upper surface of the electrode section **48** and applying a given voltage between the processing electrodes **50** and the feeding electrodes **52**.

[**0199**] The flow of the substrate W in handling thereof in the substrate processing apparatus of this embodiment is the same as in the above-described embodiment shown in **FIG. 4**, except that the substrate W is transferred directly between the transport robot **38***a* and the electrolytic processing device **36***a* (i.e. not via the pusher), and therefore the description thereof is omitted here.

[**0200**] **FIGS. 20 and 21** show a variation of the electrolytic processing device **36***a*. In this electrolytic processing device **36***a*, the electrode section **48**, which makes a scroll movement, comprises a disc-shaped processing electrode **50** and a ring-shaped feeding electrode **52** that surrounds the outer periphery of the processing electrode **50**, which are separated by a ring-shaped insulator **53**. Further, the upper surface of the processing electrode **50** is covered with an ion exchanger **56***e* and the upper surface of the feeding electrode **52** is covered with an ion-exchanger **56***f*, the respective ion exchangers **56***e*, **56***f* being separated by the insulator **53**. When rotating the substrate W, which is in contact with or close to the ion exchangers **56***e*, **56***f*, and, at the same time, allowing the electrode section **48** to make a scroll movement as described above, part of the substrate W is always positioned above the feeding electrode **52**, so that the substrate W can receive electricity therefrom. The other construction is the same as in the electrolytic processing device shown in **FIGS. 16 through 19**. According to this embodiment, the current efficiency is enhanced by surrounding the processing electrode **50** with the feeding electrode **52**, and a uniform processing can be conducted over the substantially entire surface of the substrate W.

[**0201**] **FIGS. 22 and 23** show an electrolytic processing device **36***b* according to another embodiment of the present invention. In this electrolytic processing device **36***b*, the rotational center O_1 of the electrode section **48** is distant from the rotational center O_2 of the substrate holder **46** by a distance d; and the electrode section **48** rotates about the rotational center O_1 and the substrate holder **46** rotates about the rotational center O_2. Further, the processing electrodes **50** and the feeding electrodes **52** are connected to the power source **80** via the slip ring **78**. The other construction is the same as in the embodiment shown in **FIGS. 18 and 19**, and hence the description thereof is omitted here.

[**0202**] According to the electrolytic processing device **36***b*, electrolytic processing of the surface of the substrate W is carried out by rotating the substrate W via the substrate holder **46** and, at the same, rotating the electrode section **48** by the actuation of the hollow motor **70**, while supplying pure water or ultrapure water to the upper surface of the electrode section **48** and applying a given voltage between the processing electrodes **50** and the feeding electrodes **52**.

[**0203**] **FIGS. 24 and 25** show an electrolytic processing device **36***c* according to yet another embodiment of the present invention. This electrolytic processing device **36***c* employs a rectangular fixed-type electrode section **48** and a substrate holder **46** that can move up and down, does not swing, and makes a reciprocating movement in a horizontal direction. More specifically, electrode plates **76**, extending in the width direction of the rectangular electrode **48** over the entire length thereof, are disposed in parallel in the upper

surface of the electrode section **48**, and the cathode and the anode of the power source **80** are alternately connected to the electrode plates **76**, so that the electrode plates **76** connected to the cathode becomes the processing electrodes **50** or, adversely, the electrode plates **76** connected to the anode becomes the feeding electrodes **52**. The substrate holder **46**, on the other hand, is secured to the free end of a lifting arm **44***a* that moves vertically via the ball screw **62** by the actuation of the motor **60** for vertical movement, is allowed to rotate about its own axis by the actuation of the motor **68** for rotation, and is also allowed to reciprocate together with the lifting arm **44***a*, via a ball screw **62***a* by the actuation of a motor **60***a* for reciprocation, in the orthogonal direction relative to the electrode plates **76**.

[**0204**] According to the electrolytic processing device **36***c*, electrolytic processing of the surface of the substrate W is carried out by rotating, via the substrate holder **46**, the substrate W which is in contact with or close to the ion exchanger **56** and, at the same time, reciprocating the substrate holder **46** by the actuation of the motor **60***a* for reciprocation, while supplying pure water or ultrapure water to the upper surface of the electrode section **48** and applying a given voltage between the processing electrodes **50** and the feeding electrodes **52**.

[**0205**] **FIGS. 26 and 27** show an electrolytic processing device **36***d* according to yet another embodiment of the present invention. In this electrolytic processing device **36***d*, the positional relationship between the substrate holder **46** and the electrode section **48** in the preceding embodiments is reversed, and the substrate W is held with its front surface upward (so-called "face-up" manner) so that electrolytic processing is conducted to the upper surface of the substrate. Thus, the substrate holder **46** is disposed beneath the electrode section **48**, holds the substrate W with its front surface upward, and rotates about its own axis by the actuation of the motor **68** for rotation. On the other hand, the electrode section **48**, which has the processing electrodes **50** and the feeding electrodes **52** that are covered with the ion exchanger **56**, is disposed above the substrate holder **46**, is held with its front surface downward by the swingable arm **44** at the free end thereof, and rotates about its own axis by the actuation of the hollow motor **70**. Further, wires extending from the power source **80** pass through a hollow portion formed in the shaft **66** for swinging and reach the slip ring **78**, and further pass through the hollow portion of the hollow motor **70** and reach the processing electrodes **50** and the feeding electrodes **52** to apply a voltage therebetween.

[**0206**] Pure water or ultrapure water is supplied from the pure water supply pipe **72**, via the through-hole **48***a* formed in the central portion of the electrode section **48**, to the front surface (upper surface) of the substrate W.

[**0207**] A regeneration section **92** for regenerating the ion exchanger **56** mounted on the electrode section **48** is disposed beside the substrate holder **46**. The regeneration section **92** includes a regeneration tank **94** filled with e.g. a dilute acid solution. In operation, the electrode section **48** is moved by the swingable arm **44** to a position right above the regeneration tank **94**, and is then lowered so that at least the ion exchanger **56** of the electrode section **48** is immersed in the acid solution in the regeneration tank **94**. Thereafter, the reverse electric potential to that for processing is given to the electrode plates **76**, i.e. by connecting the processing electrodes **50** to the anode of the power source **80** and connecting the feeding electrodes **52** to the cathode, thereby promoting dissolution of extraneous matter such as copper adhering to the ion exchanger **56** to thereby regenerate the ion exchanger **56**. The regenerated ion exchanger **56** is rinsed by e.g. ultrapure water.

[**0208**] Further, according to this embodiment, the electrode section **48** is designed to have a sufficiently larger diameter than the substrate W held by the substrate holder **48**. Electrolytic processing of the surface of the substrate W is conducted by lowering the electrode section **48** so that the ion exchanger **56** contacts or gets close to the substrate W held by the substrate holder **46**, then rotating the substrate holder **46** and the electrode section **48** and, at the same time, swinging the swingable arm **44** to move the electrode section **48** along the upper surface of the substrate W, while supplying pure water or ultrapure water to the upper surface of the substrate and applying a given voltage between the processing electrode **50** and the feeding electrode **52**.

[**0209**] **FIGS. 28 and 29** show an electrolytic processing device **36***e* according to yet another embodiment of the present invention. This electrolytic processing device **36***e* employs, as the electrode section **48**, such one that has a sufficiently smaller diameter than that of the substrate W held by the substrate holder **46** so that the surface of the substrate may not be entirely covered with the electrode section **48**. The other construction is the same as in the embodiment shown in **FIGS. 26 and 27**. The above construction can make the electrode section small and compact, and, in addition, can prevent a generated gas from adhering to the substrate.

[**0210**] **FIG. 30** shows an electrolytic processing device **36***f* according to yet another embodiment of the present invention. In this electrolytic processing device **36***f*, the electrode section **48** is disposed above the substrate holder **46** that holds the substrate W with its front surface upward. The electrode section **48** comprises a disk-shaped base **100** composed of insulating material, a disc-shaped processing electrode **50** having through-holes **50***a* for supplying pure water or ultrapure water, and a ring-shaped feeding electrode **52**, which are separated by a ring-shaped insulator **102**. The processing electrode **50** and the feeding electrode **52** are mounted on the lower surface of the base **100** in the same plane. Further, on the lower surface of the processing electrode **50** and the feeding electrode **52** is mounted an ion exchanger **56** which is composed of e.g. fibers containing a strongly acidic cation-exchange group and promotes the dissociation reaction of pure water or ultrapure water. The base **100** is rotatable, and is connected to the lower end of a hollow rotating shaft **104**. Pure water or ultrapure water is supplied through the hollow portion of the rotating shaft **104** to the inside of the base **100**. Further in this embodiment, an ion exchanger having a two-layer structure of a soft exchanger **56***c* and a hard exchanger **56***d*, both having the same level of resistivity, is employed as the ion exchanger **56**.

[**0211**] By thus making the ion exchanger **56** a multi-layer structure consisting of laminated layers of ion-exchange materials, such as a nonwoven fabric, a woven fabric and a porous membrane, it is possible to increase the total ion exchange capacity whereby formation of an oxide, for example in removal (polishing) processing of copper, can be

restrained to thereby avoid the oxide adversely affecting the processing rate. In this regard, when the total ion exchange capacity of an ion exchanger is smaller than the amount of copper ions taken in the ion exchanger during removal processing, the oxide should inevitably be formed on the surface or in the inside of the ion exchanger, which adversely affects the processing rate. Thus, the formation of the oxide is governed by the ion exchange capacity of an ion exchanger, and copper ions exceeding the capacity should become the oxide. The formation of an oxide can thus be effectively restrained by using, as the ion exchanger **56**, a multi-layer ion exchanger composed of laminated layers of ion-exchange materials which has enhanced total ion exchange capacity. Incidentally, the formation of an oxide can also be restrained by regenerating an ion exchanger so as to suppress accumulation of copper ions within the ion exchanger.

[**0212**] Further, when an interconnect pattern, for example an interconnect pattern composed of copper film **6** as shown in **FIG. 85**, is formed by removal (polishing) processing, the copper film **6** filled into the trench is likely to be hollowed out or peeled off after the processing. This maybe influenced by the hardness and form of an outermost ion exchanger (ion-exchange material) to be contacted with the copper film **6**. It is then considered that the above defects may be obviated by making the ion exchanger **56** a multi-layer structure, as in this embodiment, and using the ion exchanger (ion-exchange material) which meets the requirements of ① good surface smoothness, ② hard material and ③ water-permeable, such as a porous membrane or a woven fabric, as the outermost ion exchanger.

[**0213**] According to this embodiment, pure water or ultrapure water fed through a feed line into the rotating shaft **104** is allowed to flow, under centrifugal force due to rotation of the base **100**, through the through-holes **50***a* formed in the processing electrode **50** and supplied to the ion exchanger **56**. The pure water or ultrapure water supplied dissociates by the catalytic action of the ion exchanger **56** to produce hydroxide ions. Since the processing electrode **50** and the feeding electrode **52** are separated by the insulator **102**, migration of the hydroxide ions is intercepted by the insulator **102**. Further, when the substrate W is in an electrically insulated state, the portion of the substrate W facing the processing electrode (e.g. cathode) **50** functions as an anode, and the portion of the substrate W facing the feeding electrode (e.g. anode) **52** functions as a cathode. Accordingly, electrochemical dissolution occurs in the anode portion of the substrate W facing the processing electrode **50**.

[**0214**] In the case where an ion exchanger is contacted with the substrate W, the ion exchanger can deteriorate due to the sliding movement. Such deterioration can, however, be avoided by making the ion exchanger a two-layer structure in which the outer layer to be contacted with the substrate W is composed of e.g. a woven fabric or a porous membrane, as described above, or by using such material as a pad having an ion-exchange ability to enhance the mechanical strength.

[**0215**] **FIG. 31** shows a substrate processing apparatus according to yet another embodiment of the present invention provided with the electrolytic processing device **36**. This substrate processing apparatus comprises a pair of the loading/unloading units **30** as a carry-in and carry-out section for carrying in and carrying out a cassette housing a substrate W, the reversing machine **32**, pushers **34***a*, **34***b* for transferring the substrate W, the electrolytic processing device **36**, and a CMP device **112**. The fixed-type transport robot **38** is provided in between the loading/unloading units **30**, the reversing machine **32** and the pushers **34***a*, **34***b* as a transport device for transporting and transferring the substrate W therebetween. The substrate processing apparatus is also provided with the monitor **42** for monitoring a voltage applied between the processing electrode **50** and the feeding electrode **52** upon electrolytic processing in the electrolytic processing device **36**, or an electric current flowing therebetween.

[**0216**] **FIG. 32** shows an example of the CMP device **112**. The CMP device **112** comprises a polishing table **122** having a polishing surface composed of a polishing cloth (polishing pad) which is attached to the upper surface of the polishing table **122**, and a top ring **124** for holding a substrate W with its surface to be polished facing the polishing table **122**. Polishing of the surface of the substrate W is carried out by rotating the polishing table **122** and the top ring **124** respectively, and supplying an abrasive liquid from an abrasive liquid nozzle **126** disposed above the polishing table **122**, while pressing the substrate W against the polishing cloth **120** of the polishing table **122** at a given pressure by the top ring **124**. As the abrasive liquid supplied from the abrasive liquid nozzle **126**, a suspension of abrasive particles, such as fine particles of silica, in an alkali solution may be used. By the combination of chemical polishing by an alkali and mechanical polishing by abrasive particles, i.e. chemical mechanical polishing, the substrate W can be polished into a flat mirror surface.

[**0217**] The polishing power of the polishing surface of the polishing cloth **120** decreases with a continuous polishing operation. In order to restore the polishing power, a dresser **128** is provided to conduct dressing of the polishing cloth **120**, for example at the time of changing the substrate W. In the dressing treatment, while rotating the dresser **128** and the polishing table **122** respectively, the dressing surface (dressing member) of the dresser **128** is pressed against the polishing cloth **120** of the polishing table **122**, thereby removing the abrasive liquid and chips adhering to the polishing surface and, at the same time, flattening and dressing the polishing surface, whereby the polishing surface is regenerated.

[**0218**] According to this substrate processing apparatus, a substrate W is taken by the transport robot **38** out of the cassette set in the loading/unloading unit **30**. The substrate W is transported to the reversing machine **32**, according to necessity, to reverse the substrate W, and is then transported by the transport robot **38** to the pusher **34***a* beside the electrolytic processing device **36**. The substrate W is transferred from the pusher **34***a* to the substrate holder **46** of the electrolytic processing device **36**. Rough cutting (etching) by electrolytic processing of the surface of the substrate W is conducted in the electrolytic processing device **36**. After completion of the processing, the substrate W is returned to the pusher **34***a*. Thereafter, the substrate W on the pusher **34***a* is transported by the transport robot **38** to the pusher **34***b* beside the CMP device **112**, and is then transferred to the top ring **124** of the CMP device **112**. Finishing by CMP polishing of the substrate W is conducted in the CMP device **112**. After completion of the CMP polishing, the substrate W is

returned to the pusher **34***b*. Thereafter, the transport robot **38** takes the substrate W from the pusher **34***b* and, after transporting the substrate W to the reversing machine **32**, according to necessity, to reverse the substrate, returns the substrate W to the cassette in the loading/unloading unit **30**.

[**0219**] Though in this embodiment rough cutting of the substrate W is conducted by electrolytic processing in the electrolytic processing device **36** and finishing of the substrate W is conducted by CMP polishing in the CMP device **112**, it is possible to conduct rough cutting of the substrate W by CMP polishing in the CMP device **112** and conduct finishing of the substrate W by electrolytic processing in the electrolytic processing device **36**. A load upon CMP processing can thus be reduced.

[**0220**] **FIG. 33** shows a substrate processing apparatus according to yet another embodiment of the present invention provided with the electrolytic processing device **36**. This substrate processing apparatus comprises a pair of the loading/unloading units **30** as a carry-in and carry-out section for carrying in and carrying out a cassette housing a substrate W, the reversing machine **32**, the pusher **34** for transferring the substrate W, the electrolytic processing device **36**, and a cleaning device **130** for cleaning and drying the processed substrate W. A movable transport robot **38***a* is provided in a region between the loading/unloading units **30**, the reversing machine **32** and the pusher **34** as a transport device for transporting and transferring the substrate W therebetween. The substrate processing apparatus is also provided with the monitor **42** for monitoring a voltage applied between the processing electrode **50** and the feeding electrode **52** upon electrolytic processing in the electrolytic processing device **36**, or an electric current flowing therebetween.

[**0221**] According to this substrate processing apparatus, the substrate W having been carried in a dry state and undergone electrolytic processing in the electrolytic processing device **36** is reversed, according to necessity, and transported to the cleaning device **130** where the substrate is cleaned and dried, and the substrate can then be returned, in a dry state, to the cassette in the loading/unloading unit **30** (dry-in/dry-out).

[**0222**] **FIG. 34** shows a substrate processing apparatus according to yet another embodiment of the present invention provided with the electrolytic processing device **36**. This substrate processing apparatus comprises, as the same in the above-described embodiment shown in **FIG. 31, a** pair of the loading/unloading units **30** as a carry-in and carry-out section for carrying in and carrying out a cassette housing a substrate W, the pushers **34***a* and **34***b*, the electrolytic processing device **36** and the CMP device **112**, and further comprises a couple of first cleaning devices **130***a* and a couple of second cleaning devices **130***b*. Further, a temporary storage table **132** that has a function of traversing a substrate is provided between the first cleaning devices **130***a* and the second cleaning devices **130***b*. A first transport robot **38***c* is provided at a certain place between the loading/unloading units **30**, the first cleaning devices **130***a* and the temporary storage table **132** as a transport device for transporting and transferring the substrate W therebetween; and a second transport robot **38***d* is provided at a certain place between the temporary storage table **132**, the second cleaning devices **130***b* and the pushers **34***a*, **34***b* as a transport device for transporting and transferring the substrate W therebetween. The substrate processing apparatus is also provided with the monitor **42** for monitoring a voltage applied between the processing electrodes **50** and the feeding electrodes **52** upon electrolytic processing in the electrolytic processing device **36**.

[**0223**] According to this substrate processing apparatus, the substrate W which has undergone rough cutting, for example, by electrolytic processing in the electrolytic processing device **36** and finishing by CMP polishing in the CMP device **112**, as in the above-described embodiment shown in **FIG. 31**, is transported to the second cleaning device **130***b* for rough cleaning and is then temporarily stored on the temporary storage table **132** where the substrate is reversed, if necessary. Thereafter, the substrate W is transported to the first cleaning device **130***a* for finish cleaning and drying, and then can be returned, in a dry state, to the cassette in the loading/unloading section **30**.

[**0224**] **FIG. 35** shows a substrate processing apparatus according to yet another embodiment of the present invention provided with the electrolytic processing device **36**. This substrate processing apparatus comprises a pair of the loading/unloading units **30** as a carry-in and carry-out section for carrying in and carrying out a cassette housing a substrate W, the pusher **34**, and the electrolytic processing device **36**. The substrate processing apparatus also comprises a cleaning device **130***d* for cleaning the processed substrate, the reversing machine **32**, a plating device **136** for plating the surface of the substrate W, a cleaning device **130***e* for cleaning the plated substrate, and an annealing device **140** for annealing the plated substrate, which are disposed in series. A transport robot **38***a* as a transport device is provided which can move parallel to these devices for transporting and transferring the substrate W therebetween. The substrate processing apparatus is also provided the monitor **42** for monitoring a voltage applied between the processing electrodes **50** and the feeding electrodes **52** upon electrolytic processing in the electrolytic processing device **36**.

[**0225**] **FIG. 36** shows an example of the plating device **136**. The plating device **136** includes a top-opened cylindrical plating tank **232** for containing a plating liquid **230**, and a substrate holder **234** for detachably holding the substrate W with its front surface downward in such a position that the substrate W covers the top opening of the plating tank **232**. In the inside of the plating tank **232**, an anode plate **236** in a flat plate shape, which becomes an anode electrode when immersed in the plating liquid **230** with the substrate as a cathode, is disposed horizontally. The center portion of the bottom of the plating tank **232** communicates with a plating liquid ejecting pipe **238** for forming an ejecting flow of the plating liquid upwardly. Further, a plating liquid receiver **240** is provided around the upper outer periphery of the plating tank **232**.

[**0226**] In operation, the substrate W held with its front surface downward by the substrate holder **234** is positioned above the plating tank **232** and a given voltage is applied between the anode plate **236** (anode) and the substrate W (cathode) while the plating liquid **230** is ejected upwardly from the plating liquid ejecting pipe **238** so that the ejecting flow of the plating liquid **230** hits against the lower surface (surface to be plated) of the substrate W, whereby a plating

current is allowed to flow between the anode plate **236** and the substrate W, and a plated film is thus formed on the lower surface of the substrate W.

[**0227**] **FIGS. 37 and 38** show an example of the annealing device **140**. The annealing device **140** comprises a chamber **1002** having a gate **1000** for carrying in and carrying out the substrate W, a hot plate **1004** disposed in the chamber **1002** for heating the substrate W to e.g. 400° C., and a cool plate **1006** disposed beneath the hot plate **1004** in the chamber **1002** for cooling the substrate W by, for example, flowing a cooling water inside the hot plate **1004**. The annealing device **140** also has a plurality of vertically movable elevating pins **1008** penetrating the cool plate **1006** and extending upward and downward therefrom for placing and holding the substrate W on the upper ends thereof. The annealing device **140** further includes a gas introduction pipe **1010** for introducing an antioxidant gas between the substrate W and the hot plate **1004** during annealing, and a gas discharge pipe **1012** for discharging the gas that has been introduced from the gas introduction pipe **1010** and flowed between the substrate W and the hot plate **1004**. The pipes **1010** and **1012** are disposed on the opposite sides across the hot plate **1004**.

[**0228**] The gas introduction pipe **1010** is connected to a mixed gas introduction line **1022** which in turn is connected to a mixer **1020** where a N_2 gas introduced through a N_2 gas introduction line **1016** containing a filter **1014***a*, and a H_2 gas introduced through a H_2 gas introduction line **1018** containing a filter **1014***b*, are mixed to form a mixed gas which flows through the mixed gas introduction line **1022** into the gas introduction pipe **1010**.

[**0229**] In operation, the substrate W, which has been carried in the chamber **1002** through the gate **1000**, is held on the lifting pins **1008** and the lifting pins **1008** are raised up to a position at which the distance between the substrate W held on the lifting pins **1008** and the hot plate **1004** becomes e.g. 0.1-1.0 mm. The substrate W is then heated to e.g. 400° C. through the hot plate **1004** and, at the same time, the antioxidant gas is introduced from the gas introduction pipe **1010** and the gas is allowed to flow between the substrate W and the hot plate **1004** while the gas is discharged from the gas discharge pipe **1012**, thereby annealing the substrate W while preventing its oxidation. The annealing treatment may be completed in about several tens of seconds to 60 seconds. The heating temperature of the substrate W may arbitrarily be selected in the range of 100-600° C.

[**0230**] After completion of the annealing, the lifting pins **1008** are lowered down to a position at which the distance between the substrate W held on the lifting pins **1008** and the cool plate **1006** becomes e.g. 0-0.5 mm. By introducing a cooling water into the cool plate **1006**, the substrate W is cooled by the cool plate **1006** to a temperature of 100° C. or lower in e.g. 10-60 seconds. The cooled substrate W is sent to the next step.

[**0231**] Though in this embodiment a mixed gas of N_2 gas with several % of H_2 gas is used as the above antioxidant gas, N_2 gas may be used singly.

[**0232**] According to the substrate processing apparatus of this embodiment, a substrate W, for example, having a seed layer **7** formed in the surface (see **FIG. 85A**) is taken, one at a time, by the transport robot **38***a* out of a cassette set in the loading/unloading section **30** and, after reversing the substrate W by the reversing machine **32** according to necessity, is carried into the plating device **136**. Electrolytic copper plating, for example, is performed in the plating device **136** to form a copper film **6** (see **FIG. 85B**) as a conductor film (portion to be processed) on the surface of the substrate W. The substrate W after the plating treatment (the substrate having a conductor film such as the copper film) is transported to the cleaning device **130***e* for cleaning and drying, and is then transported to the annealing device **140**, where the substrate W is annealed by heat treatment, and the annealed substrate is transported to the electrolytic processing device **36**. Electrolytic processing of the surface (plated surface) of the substrate W is conducted in the electrolytic processing device **36** to remove unnecessary copper film **6** formed in the surface of the substrate, thereby forming copper interconnects composed of copper film **6** (see **FIG. 85C**). The substrate W after the electrolytic processing is reversed by the reversing machine **32**, according to necessity, and is transported to the cleaning device **130***d* for cleaning and drying. The cleaned substrate W is reversed by the reversing machine **32**, according to necessity, and returned to the cassette in the loading/unloading unit **30**.

[**0233**] **FIG. 39** shows a substrate processing apparatus according to yet another embodiment of the present invention provided with the electrolytic processing device **36**. According to this embodiment, between the cleaning device **130***e* and the annealing device **140**, both used also in the above-described embodiment shown in **FIG. 35**, is provided a bevel-etching device **144** for removing a material, to be processed, formed in or adhering to a peripheral portion (bevel portion and edge portion) of the substrate. The other construction is the same as in the embodiment shown in **FIG. 35**.

[**0234**] **FIGS. 40 and 41** show an example of the bevel-etching device **144**. The bevel-etching device **144** comprises a substrate holder **152** which attracts and holds the substrate W with its front surface upward and rotates by the actuation of a motor **150**, a feeding electrode **156** which is connected to an anode of a power source **154**, and contacts a conductor film (portion to be processed) such as the copper film **6** formed in the surface of the substrate W to pass electricity thereto, and a column-shaped processing electrode **160** which is connected to a cathode of the power source **154**, and rotates by the actuation of a motor **158**. The processing electrode **160** is disposed beside the substrate W held by the substrate holder **152**, and can contact and detach the substrate W. Further, a groove **160***a* generally in the shape of a half circle in cross section, conforming to the peripheral configuration of the substrate W, is formed in the processing electrode **160**, and an ion exchanger **162**, as described above, is mounted on the surface of the groove **160***a* so that the surface of the ion exchanger **162** contacts or gets close to a peripheral portion of the substrate W. Furthermore, a pure water nozzle **164** is disposed near the processing electrode **160** as a pure water supply section for supplying pure water or ultrapure water between the processing electrode **160** and the peripheral portion of the substrate W.

[**0235**] The removal by electrolytic processing of a material to be processed, such as copper, formed in or adhering to the peripheral portion (bevel portion and edge portion) of the substrate W is effected by bringing the ion exchanger **162**

mounted on the processing electrode **160** into contact with or close to the peripheral portion of the substrate W held by the substrate holder **152**, and rotating the substrate holder **152** to thereby rotate the substrate W and, at the same time, rotating the processing electrode **160**, while supplying pure water or ultrapure water from the pure water nozzle **164** between the processing electrode **160** and the peripheral portion of the substrate W, and applying a given voltage between the processing electrode **160** and the feeding electrode **156**.

[**0236**] According to this substrate processing apparatus, immediately after the plating treatment is conducted onto the surface of the substrate W in the plating device **136**, the material, to be processed, such as copper formed in or adhering to the peripheral portion (bevel portion and edge portion) of the substrate W, in which a conductor film (portion to be processed) such as the copper film **6** (see **FIG. 85B**) has been formed, can be removed in the bevel-etching device **144**, and the bevel-etched substrate W can then be transported to the electrolytic processing device **36**.

[**0237**] **FIGS. 42 and 43** show another example of the bevel-etching device **144**, which can remove by electrolytic processing a material, to be processed, such as copper formed in or adhering to a peripheral portion (bevel portion and edge portion) of the substrate W and, at the same time, can rinse (clean) the front and back surfaces of the substrate W with pure water. The bevel-etching device **144** comprises a bottomed, cylindrical waterproof cover **170** having a drain **170***a* and, provided in its inside, a substrate holder **174** for holding the substrate W by spin chucks **172** which engage the substrate W at certain points in the peripheral region of the substrate and rotating the substrate W horizontally with its front surface upward, a front surface nozzle **176** which is oriented towards almost the center of the front surface of the substrate W held by the substrate holder **174**, and a back surface nozzle **178** which is oriented towards almost the center of the back surface of the substrate W. According to this embodiment, the substrate holder **174** is connected directly to the motor **150**, and the processing electrode **160** is connected directly to the motor **158**. Further, the substrate W is loaded and unloaded by a substrate transport arm **180**. The other construction is the same as in the above-described embodiment shown in **FIGS. 40 and 41**.

[**0238**] According to this embodiment, the removed by electrolytic processing of a material, to be processed, such as copper formed in or adhering to a peripheral portion (bevel portion and edge portion) of the substrate W is effected by rotating the substrate holder **174** to thereby rotate the substrate W and, at the same, rotating the processing electrode **160**, while supplying pure water or ultrapure water from the pure water nozzle **164** between the processing electrode **160** and the peripheral portion of the substrate W, and applying a given voltage between the processing electrode **160** and the feeding electrode **156**; and simultaneously therewith, rinsing (cleaning) of the front and back surfaces of the substrate W can be conducted by supplying pure water from the front surface nozzle **176** to the front surface of the substrate, and from the back surface nozzle **178** to the back surface.

[**0239**] **FIG. 44** shows a substrate processing apparatus according to yet another embodiment of the present invention provided with the electrolytic processing device **36**. In this substrate processing apparatus, a first film thickness-measuring section **168***a* for measuring the film thickness of a conductor film (portion to be processed) after the processing is provided between the reversing machine **32** and the plating device **136**, both used also in the embodiment shown in **FIG. 39**, and a second film thickness-measuring section **168***b* for measuring the film thickness of the conductor film (portion to be processed) such as copper film **6** (see **FIG. 85B**) after the plating is provided between the cleaning device **130***e* and the bevel-etching device **144**. The other construction is the same as shown in **FIG. 39**.

[**0240**] According to this substrate processing apparatus, the film thickness of a conductor film such as the copper film **6** (see **FIG. 85B**), which has been deposited on the surface of the substrate W by the plating treatment in the plating device **136**, is measured with the second film thickness-measuring section **168***b*, and the film thickness of the conductor film after the electrolytic processing in the electrolytic processing device **36** is measured with the first film thickness-measuring section **168***a*. By feeding back the results of measurement, it becomes possible to adjust the plating time and the processing time, or conduct an additional plating or electrolytic processing, whereby the film thickness of the conductor film such as copper film **6** can be made more uniform.

[**0241**] **FIGS. 45 through 47** show an electrolytic processing device according to yet another embodiment of the present invention. In this electrolytic processing device, an electrode section **302** is rotatably held to the end of a swingable arm **300** which is swingable and vertically movable. Electrolytic processing of the surface of a substrate W, which is held on the upper surface of a substrate holder **308**, is effected by a processing electrode **304** and a feeding electrode **306**, both disposed inside the electrode section **302**. Also in this embodiment, a workpiece to be processed is of course not limited to a substrate.

[**0242**] In this electrolytic processing device, a pair of electrodes **310**, both in the shape of a rectangular flat plate, is fixed in the electrode section **302** so that the electrodes **310** face, in parallel, the substrate W held by the substrate holder **308**. One electrode plate **310** connected to the cathode of a power source **312** becomes the processing electrode **304**, and the other electrode plate **310** connected to the anode of the power source becomes the feeding electrode **306**. This applies to processing of e.g. copper, because electrolytic processing of copper proceeds on the cathode side. As described above, depending upon a material to be processed, the cathode side can be a feeding electrode and the anode side can be a processing electrode. The surfaces of the processing electrode (cathode) **304** and the feeding electrode (anode) **306** are respectively covered with an ion exchanger **314***a*, **314***b* both as described above. Further, a pure water nozzle **316** is provided as a liquid supply section for supplying pure water or ultrapure water between the substrate W held by the substrate holder **308** and the processing and feeding electrodes **304**, **306**.

[**0243**] According to this embodiment, the ion exchanger **314***a* on the processing electrode side and the ion exchanger **314***b* on the feeding electrode side are spaced, and contact the substrate W respectively. By thus disposing the ion exchangers **314***a*, **314***b* separately in the space between the processing electrode **304** and the substrate (workpiece)

Wand between the feeding electrode **306** and the substrate (workpiece) W, and using ultrapure water as a processing liquid, the processing efficiency can be best enhanced.

[**0244**] In this connection, when an ion exchanger of an integral type, i.e. a processing electrode **304** and a feeding electrode **306** are mounted to one ion exchanger, is used in electrolytic processing, the so-called short (virtually a flow of ions) between a processing electrode **304** and a feeding electrode **306** will occur, resulting in a decrease in the amount of ions that act on the surface of a workpiece, thereby lowering the processing efficiency. In using such an integral type of ion exchanger, the "short" may be reduced by making the distance between the processing electrode and the feeding electrode larger. However, the portion of the ion exchanger not participating in processing becomes larger, whereby a uniform processing rate over the entire processing surface area is obtained with difficulty.

[**0245**] The base material of the ion exchangers **314***a*, **314***b* may be a nonwoven fabric, a woven fabric, a sheet or a porous material. As shown in **FIG. 48**, the ion exchanger **314***a* or the ion exchanger **314***b* may be mounted on the rectangular processing electrode **304** or feeding electrode **306** by wrapping the ion exchanger around the lower portion of the electrode. Also in a case where the processing electrode **304** and feeding electrode **306** are in a column shape, as shown in **FIG. 49**, the ion exchangers **314***a*, **314***b*, which are composed of e.g. a nonwoven fabric, a woven fabric, a sheet or a porous material, may be each mounted on the respective electrodes by wrapping the ion exchanger around the electrode.

[**0246**] It is preferred to supply ultrapure water from the pure water nozzle **316** rather than pure water. Further, as described above, use may be made of an electrolytic solution obtained by adding an electrolyte to pure water or ultrapure water, or a liquid having an electric conductivity of not more than 500 μS/cm obtained by adding an additive such as a surfactant to pure water or ultrapure water.

[**0247**] According to this embodiment, a substrate W, e.g. a substrate having an its surface a conductor film (portion to be processed) such as the copper film **6** shown in **FIG. 85**B, is held with its front surface upward by the substrate holder **308**, and the ion exchangers **314***a*, **314***b*, respectively covering the surface of the processing electrode **304** and the surface of the feeding electrode **306** of the electrode section **302**, are brought into contact with or close to the surface of the substrate W. While rotating the substrate W via the substrate holder **308** and, at the same time, rotating the electrode section **302**, pure water or ultrapure water is supplied between the substrate W and the processing and feeding electrodes **304**, **306**, and a given voltage is applied between the processing electrode **304** and the feeding electrode **306**, thereby conducting electrolytic processing of the conductor film such as copper film **6** just under the processing electrode (cathode) **304**.

[**0248**] In the electrolytic processing device of this embodiment, as in the above-described embodiment shown in **FIGS. 28 and 29**, a regeneration section **320** is provided beside the substrate holder **30**, which includes a regeneration tank **318** filled with e.g. a dilute acid solution, and regenerates the ion exchangers **314***a*, **314***b* mounted on the lower surface of the electrode section **302** such that they respectively cover the surface of the processing electrode **304** and the surface of the feeding electrode **306**.

[**0249**] As shown in **FIG. 50**, it is possible to adhere or laminate porous bodies **322***a*, **322***b*, which are in the form of e.g. a film and excellent in flatness, to the respective surfaces (lower surfaces) of the ion exchangers **314***a*, **314***b*. A woven fabric may be used instead of the porous bodies **322***a*, **322***b*. The lamination of such a material can further enhance the flatness of the processed surface of the substrate W. The porous bodies **322***a*, **322***b* and the woven fabric may be ion exchangers.

[**0250**] As shown in **FIG. 51**, it is possible to conduct electrolytic processing by bringing the processing electrode **304** and the feeding electrode **306**, which are not covered with the ion exchangers **314***a*, **314***b*, close to the substrate W, and supplying pure water or ultrapure water, or a liquid having an electric conductivity of not more than 500 μS/cm between the processing and feeding electrodes **304**, **306** and the substrate W.

[**0251**] Further, as shown in **FIG. 52**, it is possible to use an AC power source **312***a* so that the pair of the electrode plates **310** can alternate between the processing electrode **304** and the feeding electrode **306**. Moreover, as shown in **FIG. 53**, it is possible to conduct electrolytic processing of a conductor film by filling a water tank **182** with a liquid **18** such as pure water or ultrapure water, immersing a substrate W, e.g. a substrate having in its surface a conductor film such as the copper film **6** shown in **FIG. 85**B, with its front surface upward, in the liquid **18**, and bringing the processing electrode **304** and the feeding electrode **306** close to the substrate W.

[**0252**] As described above, in the electrolytic processing of copper, for example, the processing proceeds on the surface (lower surface) of the processing electrode **304** as a cathode. Accordingly, when the processing electrode (cathode) **304** and the feeding electrode (anode) **306** are disposed in the chord direction of the substrate W, as shown in **FIG. 54**A, and the substrate W is rotated, it is necessary to locate the feeding electrode (anode) **306** on the upstream side in the rotating direction of the substrate. This is because if the portion of the substrate surface facing the processing electrode (cathode) **304** is electrolytically processed to remove the conductor film, it becomes impossible to supply electricity from the feeding electrode **306**. It will be understood that there is no such restriction in the case of disposing the processing electrode (cathode) **304** and the feeding electrode (anode) **306** in the radial direction of the substrate as shown in **FIG. 54**B, and in the case of using an AC power source as shown in **FIG. 52**.

[**0253**] As shown in **FIG. 55**, it is possible to integrally cover the surface of the processing electrode **304** and the surface of the feeding electrode **306** with one ion exchanger **314***c*. This can facilitate the production of the processing electrode **304** and the feeding electrode **306**, and can further lower the electric resistance.

[**0254**] Alternatively, electrolytic processing may be carried out by disposing an ion exchanger **314***d* above a substrate W such that it covers the entire surface of the substrate W, as shown in **FIG. 56**, and either supplying pure water or ultrapure water from the pure water nozzle **316** to the ion exchanger **314***d* so as to impregnate the ion exchanger **314***d* with pure water or ultrapure water, or continuously immerse the ion exchanger **314***d* in pure water or ultrapure water, and placing the processing electrode **304**

and the feeding electrode **306** on the upper surface of the ion exchanger **314***d*. This makes it possible to change with ease the ion exchanger **314***d* when it is stained after the electrolytic processing. Though not figured, it is also possible to dispose an ion exchange so that it covers part of the surface of the substrate, and place the processing electrode **304** and the feeding electrode **306** on the upper surface of the ion exchanger.

[**0255**] In this case, as shown in **FIGS. 57 and 58**, it is possible to stretch a long sheet form of an ion exchanger **314***e* between a supply shaft **324** and a rewind shaft **326**, both disposed on the opposite sides across the substrate holder **308**, and rewind the ion exchanger **314***e* sequentially by rotating the rewind shaft **326** through a rewind motor **327**. This makes it possible to change the ion exchanger in a successive manner. This embodiment shows a case in which an electrolytic processing device having a similar construction to that of **FIG. 5**, but the substrate holder **46** and the electrode section **48** having substantially the same diameter, is used and a pure water nozzle **74***a*, extending in the width direction of the ion exchanger **314***e*, over the entire length thereof, is disposed upstream of the electrode section **48** in the flow direction of the ion exchanger **314***e*. In this embodiment shown in **FIGS. 57 and 58**, the ion exchanger **314***e* may be taken up intermittently at a low speed. Alternatively, it is possible to fix the ion exchanger **314***e* to the electrode section **48** during processing, and rewind the ion exchanger by a given length when it is worn or when impurities accumulate on it, thereby providing a fresh processing surface.

[**0256**] Further, as shown in **FIGS. 59 and 60**, it is possible to mount rectangular electrode portions **328** on the ion exchanger **314***e* of a long sheet form by printing or lamination at a given pitch in the long direction of the ion exchanger so that when the ion exchanger **314***e* is taken up by one-time use length, one of two adjacent electrode portions **328** may be connected to the cathode of the power source **312** (see **FIG. 55**) to become the processing electrode **304**, and the other one may be connected to the anode to become the feeding electrode **306**. This eliminates the need to provide electrode sections separately, and thus can simplify the device.

[**0257**] Further, as shown in **FIG. 61**, the processing electrode **304** may be in the shape of a column, and may be surrounded by a ring-shaped feeding electrode **306**. In the case of copper, for example, the electrolytic processing thereof proceeds just under the cathode. Accordingly, it is preferred to dispose the processing electrode **304** and the feeding electrode **306** so that the electric current can flow between the electrodes **304**, **306** through the shortest route. By disposing the electrodes such that the feeding electrode **306** surrounds the processing electrode **304**, all the electric currents can flow from the feeding electrode **306** to the processing electrode **304**-through the shortest routes, whereby the current efficiency can be enhanced and the power consumption can be reduced. Further, though not figured, it is also possible to surround a column-shaped feeding electrode with a ring-shaped processing electrode. This holds also for the below-described embodiments.

[**0258**] It is also possible to surround a prismatic processing electrode **304** with a rectangular frame-shaped feeding electrode **306** as shown in **FIG. 62**. Further, as shown in **FIG. 63**, the prismatic processing electrode **304** may be surrounded with a plurality of prismatic feeding electrodes **306**. The above-described example of the shape and the disposition of electrodes shown in FIGS. **46** to **56** and FIGS. **61** to **63** are applicable to the electrolytic processing device in **FIG. 45**.

[**0259**] **FIGS. 64 and 65** show an electrolytic processing device according to yet another embodiment of the present invention. In this electrolytic processing device, the processing electrode **304** and the feeding electrode **306** are both in the shape of a column, and ion exchangers **314***f*, **314***g* are mounted on the peripheral surface of the processing electrode **304** and on the peripheral surface of the feeding electrode **306**, respectively. The processing electrode **304** and the feeding electrode **306** are disposed in parallel at a given distance such that their central axes are parallel to the substrate W. In operation, pure water or ultrapure water is supplied from the pure water nozzle **316** between the processing electrode **304** and the feeding electrode **306**, while the processing electrode **304** and the feeding electrode **306** are allowed to rotate in such opposite directions that the rotating electrodes enwind the pure water or ultrapure water supplied from the pure water nozzle **316**.

[**0260**] According to this embodiment, electrolytic processing is carried out by rotating a substrate W, which is in contact with or close to the ion exchangers **314***f*, **314***g*, and, at the same time, rotating the processing electrode **304** and the feeding electrode **306** around their own central axes, while supplying pure water or ultrapure water between the processing electrode **304** and the feeding electrode **306**, and applying a given voltage between the processing electrode **304** and the feeding electrode **306**. In the electrolytic processing, reaction products of the electrode reaction or electrochemical reaction can accumulate with the progress of reaction and impede the useful reaction. According to this embodiment, however, a flow of pure water or ultrapure water on the surface of the substrate can be produced by supplying pure water or ultrapure water between the column-shaped electrodes **304**, **306** rotating in such opposite directions that the electrodes enwind the supplied water, and the flow of pure water or ultrapure water can effectively discharge the unnecessary products. Further, the use of the column-shaped electrodes **304**, **306** disposed in the above manner allows a linear contact or proximity between the electrodes **304**, **306** and the substrate W, which can enhance the flatness of the processed surface.

[**0261**] **FIGS. 66 and 67** show a variation of the above electrolytic processing device shown in **FIGS. 64 and 65**. In this electrolytic processing device, electrodes with a length substantially equal to the diameter of a substrate W are used as the column-shaped processing electrode **304** and feeding electrode **306**, and the processing electrode **304** and the feeding electrode are allowed to rotate in the opposite directions through a motor **200** and a pair of spur gears **202***a*, **202***b* that engage each other. Further, this electrolytic processing device includes a bottomed, cylindrical waterproof cover **204** having a drain **204***a* and, provided in its inside, a substrate holder **208** for holding the substrate W by spin chucks **206** which engage the substrate W at certain points in the periphery region of the substrate W and rotating the substrate W horizontally with its front surface upward, and a back surface nozzle **210** which is oriented towards almost the center of the back surface of the substrate W. The

substrate holder **208** is connected directly to the motor **212**. The substrate W is loaded and unloaded by a substrate transport arm **214**. The other construction is the same as shown in **FIGS. 64 and 65**.

[**0262**] According to this embodiment, electrolytic processing of the surface of the substrate W is conducted while rotating the substrate holder **208** to thereby rotate the substrate W and, at the same time, rotating the processing electrode **304** and the feeding electrode **306** around their own central axes; and simultaneously therewith, rinsing (cleaning) of the back surface of the substrate W can be conducted by supplying pure water from the back surface nozzle **210** to the back surface of the substrate W.

[**0263**] **FIG. 68** shows an electrolytic processing device according to yet another embodiment of the present invention. In this electrolytic processing device, a column-shaped electrode that can rotate about its central axis, the axis being parallel to the substrate W, is used as the processing electrode **304**. An ion exchanger **314***f* is mounted on the outer peripheral surface of the processing electrode **304**. Pure water or ultrapure water is supplied from the pure water nozzle **316** between the processing electrode **304** and the substrate W. Further, a feeding chuck **330** for supplying electricity, which directly contacts a conductor film formed in the surface of the substrate to supply electricity thereto, is used as the feeding electrode **306**. The feeding chuck **330** connects a feeding electrode positioned beneath the back surface of the substrate W to the conductor film of the substrate W. Even when the back surface of the substrate W is composed of an insulator film such as a SiO_2 film, supply of the electricity from the back surface side becomes possible by using the feeding chuck **330**.

[**0264**] **FIG. 69** shows an electrolytic processing device according to yet another embodiment of the present invention. In this electrolytic processing device, an electrode in the shape of a flat rectangular plate is used as the processing electrode **304**. The ion exchanger **314***a* is mounted on the surface of the electrode facing a substrate W. Pure water or ultrapure water is supplied from the pure water nozzle **316** between the processing electrode **304** and the substrate W. Further a contact pin-like electrode, which directly contacts a conductor film (portion to be processed) such as the copper film **6** (see **FIG. 85B**) formed in the surface of the substrate W to supply electricity thereto, is used as the feeding electrode **306**. The feeding electrode **306** should preferably have such a contact area that does not leave its trace on the conductor film after the direct contact between the feeding electrode **306** and the conductor film. It is possible to bring the feeding electrode **306** into contact with a conductor film such as the copper film **6** formed in the bevel portion of the substrate W, thereby removing the conductor film formed in the bevel portion of the substrate W in the later bevel-etching step.

[**0265**] **FIGS. 70 and 71** show another embodiment of an electrolytic processing device according to the present invention in which electricity is supplied from the front surface side of the bevel portion. This electrolytic processing device differs from the electrolytic processing device shown in **FIGS. 28 and 29** in the following points:

[**0266**] The substrate holder **46**, disposed below the electrode section **48**, is designed to hold a substrate W with its front surface upward and rotate by the actuation of the motor **68**, and is provided with feeding electrodes **306**, which contact the peripheral portion of the substrate W placed on the substrate holder **46**, in certain positions along the circumferential direction of the substrate holder **46**. The feeding electrodes **306** are connected to an anode extending from the power source **80**.

[**0267**] On the other hand, the vertically movable, swingable and rotatable electrode section **48** is provided with a processing electrode **304** (**50**) which is connected to a cathode extending from the power source **80** through the hollow portion formed in the drive shaft **66** to the slip ring **78**, and further extending from the slip ring **78** through the hollow portion of the hollow motor **70**. An ion exchanger **314***a* (**56**) is mounted on the surface (lower surface) of the processing electrode **304** (**50**) The other construction is the same as shown in **FIGS. 28 and 29**.

[**0268**] According to this embodiment, the electrode holder **48** is lowered so as to bring the ion exchanger **314***a* (**56**) into contact with or close to the surface of the substrate W held by the substrate holder **46**. While supplying pure water or ultrapure water to the upper surface of the substrate, a given voltage is applied through the power source **80** between the processing electrode **304** (**50**) and the feeding electrode **306**, the substrate holder **46** and the electrode section are rotated and at the same time, the swingable arm **44** is swung to move the electrode section along the upper surface of the substrate W, thereby effecting electrolytic processing of the surface of the substrate W.

[**0269**] **FIGS. 72 and 73** show an electrolytic processing device according to yet another embodiment of the present invention which is used as a bevel-etching device. The construction of this electrolytic processing device is basically the same as the above-described electrolytic processing device shown in **FIG. 69**. In this electrolytic processing device, the ion exchanger **314***a* mounted on the processing electrode **304** contacts or gets close to the bevel portion of the substrate W, and the feeding electrode **306** directly contacts a conductor film (portion to be processed) such as the copper film **6** formed in the surface of the substrate W. The processing electrode **304** may either be a thick one as shown in **FIG. 72**, or a thin one as shown in **FIG. 73**. The bevel-etching processing can obtain the conductor layer such as the copper **6** with a sharp profile (step) **6***a*, as shown in **FIG. 74**.

[**0270**] **FIGS. 75 and 76** show an electrolytic processing device according to yet another embodiment of the present invention which is used as a bevel-etching device. This electrolytic processing device differs from the electrolytic processing device shown in **FIGS. 42 and 43** in that: In this electrolytic processing device, an non-rotatable flat plate-shaped electrode, having in the lower surface a curved portion **160***b* conforming to the configuration of the upper half of the bevel portion of a substrate W, is used as the processing electrode **160**, and a contact pin-like electrode is used as the feeding electrode **156**. The ion exchanger **162** is mounted on the lower surface of the processing electrode **160**. The ion exchanger **162** is brought into contact with or close to the bevel portion of the substrate W, thereby electrolytically processing the upper half of the bevel portion of the substrate W. The other construction is the same as shown in **FIGS. 42 and 43**. According to this embodiment, simultaneously with the electrolytic polishing of the

upper half of the bevel portion, rinsing (cleaning) of the front and back surfaces of the substrate can be carried out.

[0271] **FIG. 77** shows a variation of the above electrolytic processing device. This electrolytic processing device differs from the above electrolytic processing device shown in **FIGS. 75 and 76** in the use of a thicker processing electrode **160**. The other construction is the same as shown in **FIGS. 75 and 76**.

[0272] As shown in **FIG. 78**, it is preferred to monitor with voltmeters **332***a*, **332***b* the voltage between the processing electrode **304** and the ion exchanger **314***a* and the voltage between the ion exchanger **314***a* and the conductor film (portion to be processed) such as the copper film **6** (see **FIG. 85B**), and feed back the monitored values to a controller **334** so as to keep the voltages constant, and also to monitor with an ammeter **336** the electric current flowing between the processing electrode **304** and the feeding electrode **306**, and feedback the monitored values to the controller **334** so as to allow a constant current to flow between the processing electrode **304** and the feeding electrode **306**. This makes it possible to restrain side reactions on the surface of the electrode or on the surface of the conductor film such as copper film to thereby prevent the formation of impurities. If impurities are formed on the surface of the electrode, a decrease in the processing rate can be avoided by keeping a constant electric current.

[0273] When electrolytic processing of a substrate W, for example the substrate W of **FIG. 85B** having the copper film **6** formed in the surface, is conducted at a controlled constant current value, the current density (current value per unit area) increases upon the decrease in processing area at the time of exposure of the interconnect pattern composed of copper layer **6** (as shown in **FIG. 85**C, copper is present only in the trench), whereby the removal processing rate inevitably increases. With the electrolytic processing of the substrate at a controlled constant current, the removal processing rate thus varies before and after the exposure of interconnect pattern, making the processing control in the vicinity of such exposure difficult. Further, upon processing of the copper film **6** on the interconnect pattern, the voltage applied increases with the decrease in film thickness. Too high an applied voltage can cause electric discharge. Also from the viewpoint of power consumption, a low voltage is preferred.

[0274] When the processing is conducted at a controlled constant voltage, on the other hand, the current value decreases with the exposure of interconnect pattern, whereby it becomes possible to suppress the rise of current density. Further, because of constancy of voltage, there is no fear of electric discharge. Furthermore, since the current value decreases with the decrease of film thickness, there is no increase of power consumption. However, since the current value charges, the processing rate changes with time. When the current value becomes too low, the mode of processing can change from removal processing to oxide film formation.

[0275] When the processing is conducted at a controlled constant current density, the processing rate does not change before and after the exposure of interconnect pattern, thus enabling removal processing at a constant processing rate. In order to make this control, however, it is necessary to grasp beforehand the area of the exposed interconnect pattern, and make a control of changing (virtually decreasing) the current value at a particular moment. It would therefore be difficult to respond to the variety of interconnect patterns.

[0276] In view of the above and making use of the advantages of the above controlling methods, it may be consider to first make the constant-current control until the vicinity of the exposure of interconnect pattern in view of the easy processing control because of the constant processing rate, and then change it to the constant-voltage control which is free from the fear of a rise in voltage and which can suppress the rise of current density.

[0277] **FIGS. 79 and 80** show an electrolytic processing device according to yet another embodiment of the present invention, which is adapted for electrolytic processing of a substrate W in which a conductor film (portion to be processed) such as a copper film is formed over the entire peripheral surface. In this electrolytic processing device, a processing electrode **304** and a feeding electrode **306**, both in the shape of a flat rectangular plate, are disposed in the opposite positions across the substrate W. Thus, in this embodiment, the electrode plate located on the upper surface side of the substrate W and connected to the cathode of a power source **312** functions as the processing electrode **304**, and the electrode plate located on the lower surface side of the substrate W and connected to the anode functions as the feeding electrode **306**. Ion exchangers **314***a*, **314***b* are mounted on the surface of the processing electrode **304** facing the substrate W and on the surface of the feeding electrode **306** facing the substrate W, respectively. A pure water nozzle **316***a* for supplying pure water or ultrapure water between the processing electrode **304** and the substrate W is provided on the upper surface side of the substrate W, and a pure water nozzle **316***a* for supplying pure water or ultrapure water between the feeding electrode **306** and the substrate W is provided on the lower surface side of the substrate W.

[0278] In operation, the ion exchangers **314***a*, **314***b*, respectively mounted on the processing electrode **304** and on the feeding electrode **306**, are brought into contact with or close to the substrate W, and pure water or ultrapure water is supplied from the pure water nozzle **316***a* between the processing electrode **304** and the substrate W, and from the pure water nozzle **316***b* between the feeding electrode **306** and the substrate W, thereby electrolytic processing the part of the substrate W facing the processing electrode **304**; and either one or both of the substrate W and the processing electrode **304** are allowed to move so as to effect electrolytic processing of the entire surface of the substrate W on the side of the processing electrode **304**. The feeding electrode **306** may be connected directly to the substrate W. Further, as with the preceding embodiments, an electrolytic solution or a liquid having an electric conductively of not more than **500** pS/cm may be used instead of pure water or ultrapure water.

[0279] **FIGS. 81 and 82** show an electrolytic processing device according to yet another embodiment of the present invention. This electrolytic processing device employs, as the processing electrode **304**, a column-shaped one whose peripheral surface is covered with an ion exchanger **314***f* and which can rotate about its central axis, the central axis being parallel to the substrate W. The other construction is the same as shown in **FIGS. 79 and 80**. The use of such a

column-shaped rotatable processing electrode **304** allows the processing electrode **304** to linearly contact or get close to the substrate W, whereby the flatness of the process surface can be enhanced.

[**0280**] **FIGS. 83 and 84** show an electrolytic processing device according to yet another embodiment of the present invention. This electrolytic processing device uses, as the processing electrode **304**, an electrode in a spherical or oval spherical shape that can rotate about its central axis, the central axis being perpendicular to the substrate W. The lower half of the processing electrode **304** is covered with an ion exchanger **314***h*. The other construction is the same as shown in **FIGS. 79 and 80**. The use of such a spherical or oval spherical processing electrode **304**, which allows the ion exchanger **314***h* to contact or get close to the substrate W at a point, enables processing at a point or of a curved surface. Further, the uniformity of the processed surface can be enhanced by rotating the spherical processing electrode. Of course, such a spherical processing electrode may be used also in the preceding embodiments and, in addition, it is also possible to use a spherical or over spherical form of feeding electrode.

[**0281**] According to the present invention, as described hereinabove, electrolytic processing of a workpiece, such as a substrate, can be effected through electrochemical action, in the place of CMP treatment, for example, without causing any physical defects in the workpiece that would impair the properties of the workpiece. The present electrolytic processing device can effectively remove (clean) matter adhering to the surface of the workpiece such as a substrate. Accordingly, the present invention can omit a CMP treatment entirely or at least reduce a load upon CMP. Furthermore, the electrolytic processing of a substrate can be effected even by solely using pure water or ultrapure water. This obviates the possibility that impurities such as an electrolyte will adhere to or remain on the surface of the substrate, can simplify a cleaning process after the removal processing, and can remarkably reduce a load upon waste liquid disposal.

[**0282**] Although certain preferred embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

INDUSTRIAL APPLICABILITY

[**0283**] This invention relates to an electrolytic processing device useful for processing a conductive material present in the surface of a substrate, especially a semiconductor wafer, or for removing impurities adhering to the surface of a substrate, and a substrate processing apparatus provided with the electrolytic processing device.

1. An electrolytic processing device, comprising:

a processing electrode brought into contact with or close to a workpiece;

a feeding electrode for supplying electricity to the workpiece;

an ion exchanger disposed in at least one of spaces between the workpiece and said processing electrode, and between the workpiece and said feeding electrode;

a power source for applying a voltage between said processing electrode and said feeding electrode; and

a liquid supply section for supplying liquid to the space between the workpiece and at least one of said processing electrode and said feeding electrode, in which said ion exchanger is present.

2. The electrolytic processing device according to claim 1, wherein said liquid is pure water, liquid having electric conductivity of not more than **500** pS/cm.

3. The electrolytic processing device according to claim 1, wherein said ion exchanger is disposed separately in the space between said processing electrode and the workpiece, and in the space between said feeding electrode and the workpiece.

4. The electrolytic processing device according to claim 1, wherein said ion exchanger is disposed, as an integrated structure, in both of the spaces between said processing electrode and the workpiece, and between said feeding electrode and the workpiece.

5. The electrolytic processing device according to claim 1, wherein said ion exchanger covers the surface, to be processed, of the substrate, and is disposed in both of the spaces between said processing electrode and the workpiece, and between said feeding electrode and the workpiece.

6. The electrolytic processing device according to claim 5, wherein said ion exchanger is stretched between a supply shaft and a rewind shaft, and is taken up sequentially.

7. The electrolytic processing device according to claim 6, wherein said processing electrode and said feeding electrode are mounted alternately on said ion exchanger at a given pitch along the length of said ion exchanger.

8. The electrolytic processing device according to claim 1, wherein said ion exchanger has water-absorbing properties.

9. The electrolytic processing device according to claim 1, wherein said ion exchanger has one or both of an anion-exchange ability and a cation-exchange ability.

10. The electrolytic processing device according to claim 1, wherein said ion exchanger is covered with a porous body.

11. The electrolytic processing device according to claim 1, further comprising a regeneration section for regenerating said ion exchanger.

12. An electrolytic processing device comprising:

a processing electrode brought into contact with or close to a workpiece;

a feeding electrode for supplying electricity to the workpiece;

a power source for applying a voltage between said processing electrode and said feeding electrode; and

a liquid supply section for supplying pure water or a liquid having an electric conductivity of not more than 500 μS/cm between the workpiece and said processing electrode.

13. The electrolytic processing device according to claim 2 or **12**, wherein said pure water is ultrapure water.

14. The electrolytic processing device according to claim 1 or **12**, wherein at least one of said processing electrode and said feeding electrode is in the shape of a flat rectangular plate.

15. The electrolytic processing device according to claim 1 or **12**, wherein at least one of said processing electrode and said feeding electrode is in the shape of a column, and is

disposed such that a central axis thereof is parallel to the surface, to be processed, of the workpiece.

16. The electrolytic processing device according to claim 1 or **12**, wherein at least one of said processing electrode and said feeding electrode is in a spherical or oval spherical shape.

17. The electrolytic processing device according to claim 1 or **12**, wherein at least one of said processing electrode and said feeding electrode has a depressed portion or a raised portion conforming to the configuration of the workpiece, and processing of the workpiece is conducted by allowing the workpiece to face said depressed portion or said raised portion.

18. The electrolytic processing device according to claim 1 or **12**, wherein at least one of between said processing electrode and the workpiece, and between said feeding electrode and the workpiece make a relative movement.

19. The electrolytic processing device according to claim 18, wherein said relative movement is rotation, reciprocation, eccentric rotation or scroll movement, or a combination thereof.

20. The electrolytic processing device according to claim 1 or **12**, wherein said processing electrode and said feeding electrode are disposed such that one of the electrodes surrounds the other.

21. The electrolytic processing device according to claim 1 or **12**, wherein at least one of said processing electrode and said feeding electrode is in the shape of a fan.

22. The electrolytic processing device according to claim 1 or **12**, wherein at least one of said processing electrode and said feeding electrode is disposed linearly or in a circle.

23. A substrate processing apparatus, comprising:

a substrate carry-in and carry-out section for carrying in and carrying out a substrate;

an electrolytic processing device; and

a transport device for transporting the substrate between said substrate carry-in and carry-out section and said electrolytic processing device;

wherein said electrolytic processing device comprises a processing electrode brought into contact with or close to a workpiece, a feeding electrode for supplying electricity to the workpiece, an ion exchanger disposed in at least one of a spaces between the workpiece and said processing electrode, and between the workpiece and said feeding electrode, a power source for applying a voltage between said processing electrode and said feeding electrode, and a liquid supply section for supplying a liquid to the space between the workpiece and at least one of said processing electrode and said feeding electrode, in which said ion exchanger is present.

24. A substrate processing apparatus, comprising:

a substrate carry-in and carry-out section for carrying in and carrying out a substrate;

an electrolytic processing device; and

a transport device for transporting the substrate between said substrate carry-in and carry-out section and said electrolytic processing device;

wherein said electrolytic processing device comprises a processing electrode brought into contact with or close to a workpiece, a feeding electrode for supplying electricity to the workpiece, a power source for applying a voltage between said processing electrode and said feeding electrode, and a liquid supply section for supplying pure water or a liquid having an electric conductivity of not more than 500 μS/cm between the workpiece and said processing electrode.

25. The substrate processing apparatus according to claim 23 or **24**, further comprising a cleaning device for cleaning the processed substrate by said electrolytic processing device.

26. The substrate processing apparatus according to claim 23 or **24**, further comprising a CMP device for chemical mechanical polishing the surface of the substrate.

27. The substrate processing apparatus according to claim 26, further comprising a cleaning device for cleaning the polished substrate by said CMP device.

28. The substrate processing apparatus according to claim 23 or **24**, further comprising a film-forming device for forming a film as a portion to be processed in the surface of the substrate.

29. The substrate processing apparatus according to claim 28, further comprising at least one of a cleaning device for cleaning the portion to be processed having been formed by said film-forming device and an annealing device for annealing said portion to be processed.

30. The substrate processing apparatus according to claim 29, further comprising a bevel-etching device for etching the portion to be processed formed in or adhering to a peripheral portion of the substrate.

31. The substrate processing apparatus according to claim 30, wherein said etching of the portion to be processed in the bevel-etching device is conducted by electrolytic processing.

32. The substrate processing apparatus according to claim 26, further comprising a film thickness-measuring section for measuring a film thickness of the portion to be processed during or after the polishing in said CMP device.

33. The substrate processing apparatus according to claim 28, further comprising a film thickness-measuring section for measuring the film thickness of the portion to be processed during or after the film formation in the film-forming device.

34. The substrate processing apparatus according to claim 28, wherein the film formation in the film-forming device is conducted by plating.

35. The substrate processing apparatus according to claim 23 or **24**, further comprising a monitor for monitoring at least one of electrolytic current and electrolytic voltage when the voltage is applied between said feeding electrode and said processing electrode.

36. The substrate processing apparatus according to claim 23 or **24**, further comprising a drying device for finally drying the processed substrate.

37. The substrate processing apparatus according to claim 35, wherein said monitor further monitors a change in the state of the substrate being processed to detect the end point of processing.

38. The substrate processing apparatus according to claim 23 or **24**, further comprising a film-thickness detection section for detecting the end point of processing.

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