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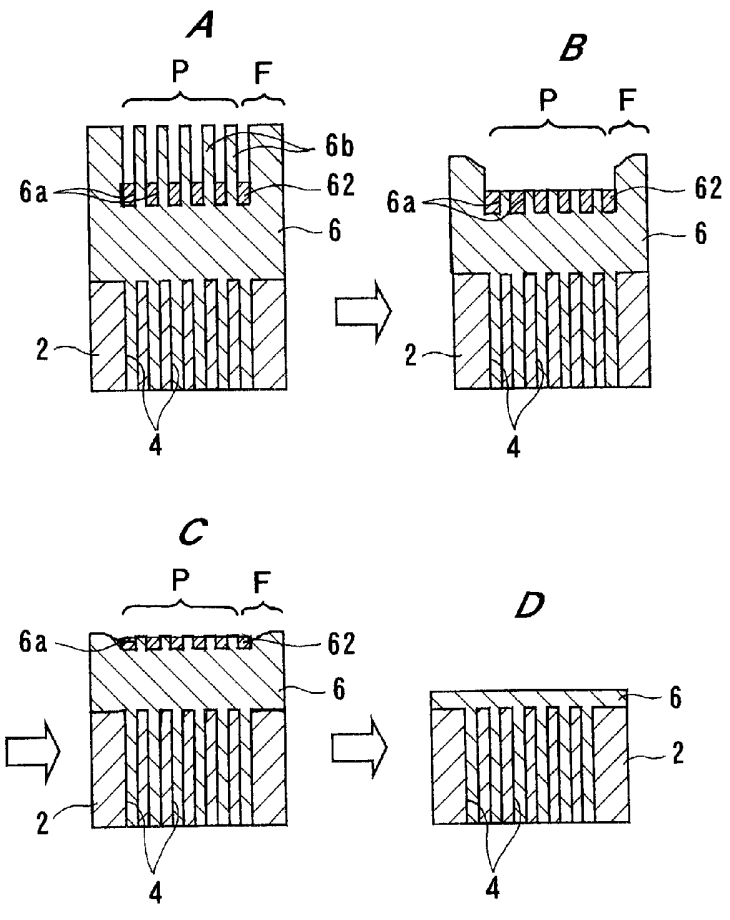

(57) Abstract: A flattening method can flatly process a surface of a metal film as an interconnect material over the entire film surface at a sufficiently high processing rate even when the metal film has initial surface irregularities. The flattening method for processing and flattening a surface of a metal film formed on a workpiece and having initial surface irregularities, including: coating only recessed portions of the initial surface irregularities of the metal film with a solid or pasty coating material; and processing the surface of the metal film by electrolytic processing using no abrasive.

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DESCRIPTION

FLATTENING METHOD AND FLATTENING APPARATUS

Technical Field

The present invention relates to a flattening method and a flattening apparatus, more particular to a flattening method and a flattening apparatus useful for processing and flattening a surface of an interconnect material (conductive film) of a metal film, such as copper film, which has been formed on a surface of a substrate, such as a semiconductor wafer, and embedded into fine interconnects recesses formed in the surface of the substrate.

Background Art

In recent years, instead of using aluminum or aluminum alloys as an interconnect material for forming circuits on a substrate such as a semiconductor wafer, there is an eminent movement towards using copper which has a low electric resistivity and high electromigration resistance. Copper interconnects are generally formed by filling copper into fine interconnects recesses formed in a surface of a substrate. There are known various techniques for forming such copper interconnects, including chemical vapor deposition (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 polishing.

FIGS. 1A through 1C illustrate, in a sequence of process steps, an example of forming such a substrate W having copper interconnects. As shown in FIG. 1A, an insulating film 2, such as an oxide film of SiO_2 or a film of low-k material, is deposited on a conductive layer 1a in which semiconductor devices are formed, which is formed on a semiconductor base 1. Contact holes 3 and trenches 4 as interconnects recesses are formed in the insulating

film 2 by the lithography/etching technique. Thereafter, a barrier layer 5 of TaN or the like is formed on the surface, and a seed layer 7 as an electric supply layer for electroplating is formed on the barrier layer 5 by sputtering, or CVD, or the like.

Then, as shown in FIG. 1B, copper plating is performed onto the surface of the substrate W to fill the contact holes 3 and the trenches 4 with copper and, at the same time, deposit a copper film 6 on the insulating film 2. Thereafter, the copper film 6, the seed layer 7 and the barrier layer 5 on the insulating film 2 are removed by chemical mechanical polishing (CMP) or the like so as to make the surface of the copper film 6 filled in the contact holes 3 and the trenches 4 and the surface of the insulating film 2 lie substantially on the same plane. Interconnects composed of the copper film 6, as shown in FIG. 1C, are thus formed in the insulating film 2.

Components in various types of equipments have recently become finer and have required higher accuracy. As sub-micron manufacturing technology is becoming common, the properties of materials are more and more influenced by the processing method. Under these circumstances, with a conventional mechanical processing method in which a processing object in a workpiece is physically destroyed and removed from the workpiece by a tool, many defects may be produced, deteriorating the properties of the workpiece. Thus, it is increasingly important to perform processing without deteriorating the properties of the materials.

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 a damaged layer and dislocation, due to plastic

deformation, so that processing can be performed without deteriorating the properties of the materials.

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.

In order to solve such problems, an electrolytic processing method has been proposed which involves providing an ion exchanger as a processing member between an electrode and a workpiece, and using a liquid having a high electric resistance, such as pure water or ultrapure water, as an electrolytic liquid in carrying out processing of the workpiece, thereby reducing the mechanical stress on the workpiece and simplifying post-cleaning (see, for example, Japanese Patent Laid-Open Publication No. 2003-145354).

Disclosure of Invention

As shown in FIG. 2A, in a substrate having a surface copper film as an interconnect material for the formation of copper interconnects, for example, there generally exist a pattern region P consisting of a large number of trenches 4 provided at a predetermined pitch in an insulating film 2, and a copper film (metal film) 6 embedded in the trenches 4 and deposited over the trenches 4 and the insulating film 2, and a field region F surrounding the pattern region P and consisting of the insulating film 2 and the copper film 6 deposited thereon. The pattern region P has initial surface irregularities which vary depending on the density, width, etc. of interconnects to be formed.

When processing and flattening the surface of the copper film 6 by electrolytic processing, the initial surface

irregularities of the copper film 6 produce a difference in the intensity of electric field between an electrode and the copper film 6. In particular, the intensity of electric field is higher in the pattern region P in which raised portions are concentrated, whereby the amount of reaction species ions, i.e. ionic substances for promoting the dissolution of a conductive film to be polished, e.g. hydroxide ions in the case of a copper conductive film, supplied is larger in the pattern region P than that in the field region F. This results in a higher processing rate of the copper film 6 in the pattern region P than that in the field region F. Further, there is no significant difference in the processing rate of copper film 6 between recessed portions 6a and raised portions 6b, together forming the irregularities, that is, the recessed portions 6a and the raised portions 6b are processed almost at the same rate. Accordingly, the initial surface irregularities will remain unremoved during processing, as shown in FIGS. 2B and 2C, and it is difficult to flatten the copper film 6 over the entire surface. If electrolytic processing is further continued, the copper embedded in the trenches 4 will be processed and removed, as shown in FIG. 2D, resulting in a decrease in the volume of interconnects and thus a rise in the resistance of interconnects.

An electrolytic processing method has therefore been employed which uses an electrolytic liquid containing a surface film-forming agent, such as an oxidizing agent or a complexing agent, in carrying out processing of such a processing object as the copper film 6. This method can suppress an electrolytic dissolution reaction within the recessed portions 6a of the copper film 6 so as to make the processing rate of the recessed portions 6a slower than that of the raised portions 6b, and thus selectively process the raised portions 6b, thereby increasing the flatness of the processed surface. According to this method, however, when a high voltage is applied in order to obtain a high processing

rate, the effect of suppressing the electrolytic reaction through the formation of a surface film is insufficient for producing an adequate surface irregularities-removing effect.

Further, since the polishing (processing) rate of the copper film 6 in the pattern region P is higher than the polishing rate of the copper film 6 in the field region F, as described above, a concave 9 can be formed in the entire copper film 6 lying in the pattern region P, as shown in FIGS. 3A through 3C. The size of the concave 9 can be considerably large depending on the configuration, etc. of the pattern region P, which makes it difficult to flatten the entire surface of the copper film 6.

A demand, therefore, exits for a technique that can equalize the polishing rate of copper film 6 in the pattern region P with the polishing rate of copper film 6 in the filed region F, as shown in FIGS. 4A and 4B, thus flatly polishing the entire surface of copper film 6 despite the presence of the pattern region P and the field region F, as shown in FIG. 4C. Various attempts made thus far, however, have proven difficulty in developing such a technique for equalizing the polishing rate of copper film 6 in the pattern region P with the polishing rate of copper film 6 in the field region F.

The present invention has been made in view of the above situation in the background art. It is therefore an object of the present invention to provide a flattening method and apparatus which can flatly process a surface of a metal film (conductive film), e.g. a copper film as an interconnect material, over the entire film surface at a sufficiently high processing rate even when the metal film has initial surface irregularities.

In order to achieve the above object, the present invention provides a flattening method for processing and flattening a surface of a metal film formed on a workpiece and having initial surface irregularities, comprising: coating only recessed portions of the initial surface irregularities of the metal film

with a solid or pasty coating material; and processing the surface of the metal film by electrolytic processing using no abrasive.

According to this flattening method, processing of recessed portions in a surface of a metal film can be suppressed by the coating of the recessed portions with a coating material so that raised portions of the metal film can be selectively processed by electrolytic processing, whereby the surface of the metal film can be flattened. Further, a sufficiently high processing rate can be obtained by using, as the coating material, a solid or pasty material which is highly adhesive to the metal film and does not separate from the metal film even when carrying out electrolytic processing at an applied voltage of e.g. not less than 10 V.

Though a common electrolytic solution may be employed in carrying out electrolytic processing, it is desirable to use ultrapure water, pure water or a liquid having an electric conductivity of not more than 500 μS/cm. This can materially reduce contamination of the surface of workpiece and can facilitate treatment of the waste liquid after processing.

In a preferred embodiment of the present invention, the flattening method further comprises removing the coating material which has not been processed by the electrolytic processing and remains on the surface of the metal film, and further processing the surface of the metal film.

When coating recessed portions in the surface of a metal film with a coating material, and processing the surface of the metal film by electrolytic processing while suppressing processing of the metal film at the recessed portions, the coating material, which may be an insulating material, can remain unremoved on the surface of the metal film. In such a case, the coating material may be removed, for example when raised portions have been removed and the coating material has become exposed, and the surface of the metal film may be subjected to further

processing, whereby a flattened metal surface free of the coating material can be obtained. The processing of the metal film surface after the removal of the coating material can be carried out by electrolytic processing using, for example, an electrolytic solution or ultrapure water, or by any other conventional processing method, such as CMP.

The coating material may be an insulating material having a resistivity of not less than 10^6 Ω·cm or a conductive material having a resistivity of not more than 10^3 Ω·cm.

The use, as the coating material, of an insulating material having a resistivity of not less than 10^6 Ω·cm (conductivity of not more than 1 μS/cm) substantially inhibits passage of an electric current through the coating material. This can inhibit electrolytic reaction at those recessed portions of the metal film which are coated with the coating material, thereby preferentially removing raised portions of the metal film. Examples of the insulating material include a photoresist, a paint, an oil-based ink and a quick-drying adhesive.

The use, as the coating material, of a conductive material having a resistivity of not more than 10^3 Ω·cm (electric conductivity of not less than 10^3 μS/cm) allows an electric current to pass through the coating material, thereby allowing electrolytic reaction to progress also at the surface of the conductive material. This allows passage of an electron current through the coating material to the recessed portions of the metal film, which makes it possible to uniformize the current density over the entire surface of the metal film and to thereby uniformly process the metal film except the coated portions. Examples of the conductive material include a conductive paint, a conductive ink, a conductive adhesive and a conductive paste. These conductive materials can be prepared by mixing a resin with conductive particles, such as fine metal particles or carbon particles, and the conductivity can be adjusted by the mixing

ratio of the conductive particles.

It is preferred that the coating material, which is either an insulating material or a conductive material, have a certain degree of processibility and be processed at a slower rate than the metal film by electrolytic processing.

In a preferred embodiment of the present invention, only the recessed portions of the initial surface irregularities of the metal film are coated with the coating material by applying the coating material onto the entire surface of the metal film, and then removing only the coating material lying on the raised portions of the initial surface irregularities.

Only the recessed portions of the initial surface irregularities of a metal film can be coated with the coating material, for example, by applying an oil-based ink, an oil paint or the like, onto the entire surface of the metal film, and then wiping off the oil-based ink, the oil paint or the like on the metal film with an alcohol or a thinner, or by applying a resist onto the entire surface of a metal film, followed by exposure and development of the resist.

In a preferred embodiment of the present invention, only the recessed portions of the initial surface irregularities of the metal film are coated with the coating material by selectively applying the coating material onto the recessed portions of the metal film.

Only the recessed portions of the initial surface irregularities of a metal film can be coated with the coating material, for example, by selectively applying an ink only onto the recessed portions of the metal film by an ink jet method.

In a preferred embodiment of the present invention, the processing of the surface of the metal film by the electrolytic processing is carried out by applying a voltage between a processing electrode, disposed close to the metal film of the workpiece, and a feeding electrode for feeding electricity to

the metal film, supplying a liquid into the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which space a processing member is present, and moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

Though a common electrolytic solution may be used as the liquid, it is desirable to use ultrapure water, pure water or a liquid having an electric conductivity of not more than 500 μS/cm. This can materially reduce contamination of the surface of a workpiece and can facilitate treatment of the waste liquid after processing.

The processing member is preferably composed of an ion exchanger or a material containing an ion exchanger.

The use of an ion exchanger or a material containing an ion exchanger for the processing member can process and flatten a surface of a metal film while promoting dissociation of water molecules in a liquid, such as ultrapure water, into hydroxide ions and hydrogen ions. It is also possible to use a CMP pad, a fixed-abrasive pad, a PVA sponge, etc. as the processing member.

In a preferred embodiment of the present invention, the processing of the surface of the metal film by the electrolytic processing is carried out by applying a voltage between a processing electrode, disposed close to the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film, supplying a liquid between the workpiece and at least one of the processing electrode and the feeding electrode, and moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

In a preferred embodiment of the present invention, the processing of the surface of the metal film by the electrolytic processing is carried out by bringing a contact member, disposed beside the processing electrode and/or the feeding electrode, into contact with the metal film surface.

By thus electrolytically processing the surface of the metal film by bringing a contact member into contact with the metal film surface, the solid or pasty coating material can be processed (removed) while adjusting the processing rate. A CMP pad, a fixed-abrasive pad, a PVA sponge, etc. can be used as the contact member. An ion exchanger or a material containing an ion exchanger may also be used.

The present invention also provides a flattening apparatus comprising: a coating material processing apparatus for coating only recessed portions of initial surface irregularities of a metal film with a solid or pasty coating material; and an electrolytic processing apparatus for processing the surface of the metal film by electrolytic processing using no abrasive.

The coating material processing apparatus is, for example, a resist processing apparatus.

The present invention also provides another flattening method for polishing and flattening a surface of a metal film (conductive film) formed on a workpiece and having a pattern region and a field region, comprising: carrying out a first polishing of the metal film surface in such a manner that the polishing rate of the metal film in the pattern region is higher than the polishing rate of the metal film in the field region; and carrying out a second polishing of the metal film surface in such a manner that the polishing rate of the metal film in the field region is higher than the polishing rate of the metal film in the pattern region.

According to this flattening method, the surface of the metal film (conductive film) can be polished flatly over the entire surface of the workpiece by mainly removing the initial surface irregularities of the metal film in the pattern region by the first polishing, and then mainly removing the surface level difference in the metal film between the pattern region and the field region by the second polishing. Most preferably,

the polishing rate of the metal film of the field region in the first polishing and the polishing rate of the metal film of the pattern region in the second polishing are both zero.

The first polishing is to be continued until the initial surface irregularities of the metal film in the pattern region is removed. When the polishing rate for the metal film of the pattern region in the first polishing is small, the thickness of the metal film, to be subjected to the second polishing to remove the surface level difference in the metal film between the pattern region and the field region, becomes undesirably small. It is, therefore, desirable to make the polishing rate in the first polishing of the metal film of the pattern region at least twice the polishing rate of the metal film of the field region so as to produce a larger surface level difference in the metal film between the pattern region and the field region.

Preferably, at least one of the first polishing and the second polishing is carried out by electrolytic processing.

This can eliminate a CMP processing or reduce the burden on CMP.

In a preferred embodiment of the present invention, the first polishing and the second polishing are carried out by applying a voltage between a processing electrode, disposed close to the surface of the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film, supplying a liquid into the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which space a processing member is present, and moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

By thus carrying out the polishing of the metal film through electrochemical interaction at a lower pressure than conventional CMP, deterioration of the properties of the metal film can be prevented. Ultrapure water, pure water, or a liquid having an

electric conductivity of not more than 500 μS/cm or an electrolytic solution is preferably used as the liquid. This can materially reduce contamination of the surface of the workpiece, and can facilitate treatment of the waste liquid and cleaning after processing.

Preferably, the processing member is composed of an ion exchanger or a material containing an ion exchanger.

In a preferred embodiment of the present invention, the first polishing is carried out while keeping the processing member in contact with the pattern region, and the second polishing is carried out while keeping the processing member contactless with the pattern region.

Especially when an ion exchanger or the like is used as the processing member, the second polishing can be carried out at a lower polishing rate of the metal film in the pattern region than the first polishing by carrying out the first polishing while keeping the processing member (ion exchanger or the like) in contact with the pattern region and carrying out the second polishing while keeping the processing member contactless with the pattern region. The processing member may be in contact with the field region of the metal film during the second polishing.

In order to carry out polishing while keeping the processing member contactless with the pattern region, it is necessary to make deformation of the processing member due to contact pressure small. For this purpose, a processing member having high rigidity, for example, one having high Young's modulus or one having an increased thickness to increase the moment of inertia of area, may be used. It is also possible to reduce the contact pressure between the processing member and the metal film of the field region.

In a preferred embodiment of the present invention, the first polishing is carried out while keeping the processing member in contact with the pattern region, and a resistance-forming

processing of the pattern region is carried out prior to or simultaneously with the second polishing.

By carrying out a resistance-forming processing to form a resistance in the pattern region, the polishing rate of the metal film in the pattern region can be decreased. The following are examples of the resistance-forming processing:

(1) Processing of exposing the pattern region to an oxidizing agent (H_2O_2, O_3, etc.) or a complexing agent so as to passivate or complex the metal film surface in the pattern region, thereby retarding reaction species ions reaching the metal film surface in the pattern region;

(2) Processing of introducing an additive, having insulating properties, into a processing liquid so as to coat the metal film surface in the pattern region with the additive (insulating material), thereby preventing reaction species ions from reaching the metal film surface in the pattern region; and

(3) Processing of introducing an additive, for example, a corrosion inhibitor such as BTA (benzotriazole), which inhibits reaction between reaction species ions and the metal film, into a processing liquid, thereby inhibiting the reaction itself between the reaction species ions and the metal film.

Though the resistance-forming processing is desirably effected only in the pattern region, the processing may be effected also in the field region, provided that the resistance formed can be removed from the field region by the contact pressure of the processing member or a contact member. The resistance-forming processing may be carried out either prior to or simultaneously with the second polishing.

In a preferred embodiment of the present invention, the second polishing is carried out while keeping the processing member contactless with the pattern region and simultaneously carrying out the resistance-forming processing of the pattern region.

By keeping the processing member contactless with the pattern region during the second polishing, a resistance, such as a passive film, a complex, or an insulating material, which has been formed by the resistance-forming processing on the surface of the metal film of the pattern region, can be prevented from being removed by its contact with the processing member.

At least one of the first polishing and the second polishing may be carried out while keeping a contact member, disposed in the vicinity of the processing electrode and/or the feeding electrode, in contact with the surface of the metal film of the workpiece.

In a preferred embodiment of the present invention, the first polishing and the second polishing are carried out respectively by applying a voltage between a processing electrode, disposed close to or in contact with the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film, supplying a liquid between the workpiece and at least one of the processing electrode and the feeding electrode, and moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

A resistance-forming processing may be carried out prior to or simultaneously with the second polishing. Further, the second polishing may be carried out while keeping the processing electrode contactless with the pattern region and simultaneously carrying out a resistance-forming processing of the pattern region.

At least one of the first polishing and the second polishing may be carried out while keeping a contact member, disposed in the vicinity of the processing electrode and/or the feeding electrode, in contact with the surface of the metal film of the workpiece.

At least one of the first polishing and the second polishing may also be carried out while keeping the processing electrode

at a distance of 0.05 to 50 μm from the surface of the metal film of the workpiece.

The use of an ionic reaction promoter in combination with the use of a liquid having an electric conductivity of not more than 500 μS/cm makes it possible to carry out the first polishing while keeping the processing electrode at a distance of 0.05 to 50 μm from the surface of the metal film of the workpiece. The ionic reaction promoter can hinder adsorption of a substance, which acts as an insulating additive or preservative used in resistance-forming processing and suppresses an electrolytic processing, so as to maintain the electrolytic processing (reaction). As the ionic reaction promoter, organosulfur compounds containing sulfonic group represented by the bis(3-sulfopropyl)disulfide are suitably used. If a liquid having a high electric conductivity is used, polishing of the metal film will be isotropic both in the pattern region and in the field region, that is, there will be no significant difference in the polishing rate of the metal film between the pattern region and the field region. The use of a liquid having a low electric conductivity can make the polishing of the metal film anisotropic and produce a difference in the polishing rate of the metal film between the pattern region and the field region. The ionic reaction promoter can be concentrated at portions of high electric field intensity, i.e. the top portions of the raised portions of the metal film in the pattern region. This can increase the polishing rate of the metal film in the pattern region. It has been confirmed experimentally that when carrying out electrolytic processing while changing a distance between a processing electrode and a metal film, the metal film can be polished desirably when the distance is kept between 0.05μm and 50 μm.

The end point of the first polishing can be detected by time management, detection of a table current, or image recognition.

The time management refers to processing time management, that is, the first processing is terminated after an elapse of the predetermined processing time which is determined based on a current condition.

The pattern of the pattern region, i.e. the surface irregularities of the metal film, is removed gradually with the progress of the first polishing. A point of time, at which the surface irregularities have been substantially removed or flattened, is regarded as the end point of the first polishing. For example, when polishing a metal film surface while keeping a processing member in contact with the metal film, as the metal film surface becomes flattened with the progress of polishing, the contact area between the metal film and the processing member becomes larger, whereby the table current becomes higher. The progress of polishing of the metal film can also be perceived by the change in the pattern image gradually disappearing. Thus, the end point of the first polishing can be detected by the detection of table current or by image recognition.

The present invention provides another flattening apparatus comprising: a first polishing section for polishing a surface of a metal film, formed on a workpiece and having a pattern region and a field region, in such a manner that the polishing rate of the metal film in the pattern region is higher than the polishing rate of the metal film in the field region; and a second polishing section for polishing the metal film surface in such a manner that the polishing rate of the metal film in the field region is higher than the polishing rate of the metal film in the pattern region.

Preferably, at least one of the first polishing section and the second polishing section carries out polishing by electrolytic processing.

Brief Description of Drawings

FIGS. 1A through 1C are diagrams illustrating, in a sequence of process steps, an example for the production of a substrate having copper interconnects;

FIGS. 2A through 2D are diagrams illustrating processing of a copper film as an interconnect material by a conventional electrolytic processing method;

FIGS. 3A through 3C are another diagrams illustrating polishing of a copper film as an interconnect material by a conventional electrolytic processing method;

FIGS. 4A through 4C are diagrams illustrating polishing of a copper film as an interconnect material ideally by a electrolytic processing method;

FIG. 5 is a layout plan view of a flattening apparatus according to an embodiment of the present invention;

FIG. 6 is a schematic view of a resist processing apparatus (coating material processing apparatus) of the flattening apparatus shown in FIG. 5;

FIGS. 7A through 7C are diagrams illustrating coating of recessed portions of a copper film with a coating material by the resist processing apparatus shown in FIG. 6;

FIG. 8 is a plan view of an electrolytic processing apparatus of the flattening apparatus shown in FIG. 5;

FIG. 9 is a vertical sectional view of the electrolytic processing apparatus shown in FIG. 8;

FIG. 10 is a vertical sectional view of an electrode section of the electrolytic processing apparatus shown in FIG. 8;

FIG. 11 is a cross-sectional view of the main portion of the electrode section of the electrolytic processing apparatus shown in FIG. 8, illustrating processing of a substrate with the electrode section;

FIGS. 12A through 12D are diagrams illustrating processing of a copper film as an interconnect material by a flattening

method according to an embodiment of the present invention;

FIG. 13 is a schematic view of another resist processing apparatus;

FIGS. 14A and 14B are diagrams illustrating coating of recessed portions of a copper film with a coating material by the resist processing apparatus shown in FIG. 13;

FIGS. 15A through 15D are diagrams illustrating processing of a copper film as an interconnect material by a flattening method according to another embodiment of the present invention;

FIG. 16 is a cross-sectional view of the main portion of another electrode section of the electrolytic processing apparatus;

FIG. 17 is a layout plan view of a flattening apparatus according to another embodiment of the present invention;

FIG. 18 is a plan view of an electrolytic processing apparatus of the flattening apparatus shown in FIG. 17;

FIG. 19 is a cross-sectional view of the main portion of a first electrode section (first polishing section) of the electrolytic processing apparatus shown in FIG. 18, illustrating processing of a substrate with the first electrode section;

FIG. 20 is a cross-sectional view of the main portion of a second electrode section (second polishing section) of the electrolytic processing apparatus shown in FIG. 18, illustrating processing of a substrate with the second electrode section;

FIGS. 21A through 21C are diagrams illustrating processing of a copper film as an interconnect material by a flattening method according to yet another embodiment of the present invention;

FIG. 22 is a diagram schematically showing a coated surface of a copper film in a pattern region with an additive (insulating material);

FIG. 23 is a graph showing a relationship between a table current and polishing time when carrying out a first polishing

of the present invention; and

FIGS. 24A and 24B are diagrams illustrating the change of the pattern with the progress of the first polishing.

Best Mode for Carrying Out the Invention

Preferred embodiments of the present invention will now be described in detail with reference to the drawings. The following description illustrates the case of using a substrate as a workpiece, and processing and flattening the surface of a metal film (conductive film) as a processing object, in particular, a copper film 6 (see FIG. 1B) formed as an interconnect material on the substrate. The present invention is, of course, applicable to flattening of a workpiece other than a substrate, or a metal film (conductive film) other than a copper film.

FIG. 5 is a plan view illustrating a flattening apparatus according to an embodiment of the present invention. As shown in FIG. 5, the flattening 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. 1B, which has in its surface a copper film 6 as a metal film (conductive film) to be processed, a reversing machine 32 for reversing the substrate W, a resist processing apparatus 34, as a coating material processing apparatus, for coating a resist as a coating material on a surface of the substrate W and exposing the resist, an electrolytic processing apparatus 36 for performing electrolytic processing using no abrasive, and a cleaning section 38 for cleaning and drying the processed substrate. These devices are disposed in series. A transport robot 40 as a transport device, which can move parallel to these devices for transporting and transferring the substrate W therebetween, is provided. The flattening apparatus is also provided with a monitor 42, adjacent to the loading/unloading units 30, for monitoring a voltage

applied between the bellow-described processing electrodes and the feeding electrodes during electrolytic processing in the electrolytic processing apparatus 36, or an electric current flowing therebetween.

FIG. 6 shows the resist processing apparatus (coating material processing apparatus) 34 in the flattening apparatus. As shown in FIG. 6, the resist processing apparatus 34 mainly comprises a resist application section 50 and an exposure section 52. The resist application section 50 includes a rotatable substrate stage 54 for detachably holding the substrate W with its front surface, i.e. the surface having the copper film 6 (see FIG. 1B), facing upward, a pivot arm 56 pivotably disposed above the substrate stage 54, and a resist dropping nozzle 58 which is mounted to the free end of the pivot arm 52 and moves between a processing position almost above the center of the substrate W held on the substrate stage 54 and a retreat position beside the substrate W. The exposure section 58 has a built-in ultraviolet lamp 60 and is disposed right above the substrate stage 54. Further, though not shown diagrammatically, the resist processing apparatus 34 also includes a development section for supplying a developer to the surface of the substrate W to develop the exposed resist, and a cleaning section for cleaning the substrate surface after development. If necessary, a heater stage for baking the resist e.g. at 100 to 150 °C after the cleaning of the substrate may be provided, for example, beside the resist processing apparatus 34.

According to this embodiment, a positive photoresist of insulating material, having a resistivity of not less than 10^6 Ω·cm (electric conductivity of not more than 1 μS/cm), is used as a coating material to form a coating layer, and the positive photoresist 62 is applied to the surface of the substrate W. Resists include, besides photoresists, X-ray resists and electron beam resists, which are each sensitive to light having a particular

wavelength range. Any resist can be used in the present invention. Further, resists can be classed into the positive type and the negative type according to whether the exposed portion or the non-exposed portion is dissolved by development. Though a photoresist of the positive type is used in this embodiment, a negative resist may also be used. Instead of a resist, it is also possible to use a paint, an oil-based ink (permanent marker), a quick-drying adhesive, etc.

The operation of the resist processing apparatus 34 will now be described with reference to FIGS. 7A through 7C. First, a substrate W is held with its front surface facing upward on the upper surface of the substrate stage 54. The resist dropping nozzle 58 in the retreat position beside the substrate stage 54 is moved to the processing position almost above the center of the substrate W held on the substrate stage 54. The positive photoresist 62 is then dropped from the resist dropping nozzle 58 onto almost the center of the substrate W while rotating the substrate W together with the substrate stage 54 to spin-coat the substrate W, thereby applying the positive photoresist 62 uniformly onto the surface of copper film 6 while filling the positive photoresist 62 into the recessed portions 6a of the copper film (metal film) 6 which fills trenches 4 provided in an insulating film 2 and covers the insulating film 2, as shown in FIG. 7A.

Next, after moving the resist dropping nozzle 58 from the processing position to the retreat position, the surface of the substrate W is irradiated with ultraviolet rays emitted from the ultraviolet lamp 60 of the exposure section 52, thereby exposing the resist 62a other than the resist 62b lying at the bottoms of the recessed portions 6a of the copper film 6, as shown in FIG. 7B. Thereafter, a developer is supplied to the surface of the substrate W to develop and remove the exposed resist 62a, thereby coating the recessed portions 6a of the copper

film 6 with a coating layer (insulating layer) composed of the resist (coating material) 62 (62b) of insulating material.

Thereafter, the surface of the substrate W is cleaned (rinsed) e.g. with pure water and, if necessary, the substrate W is subjected to baking e.g. at 100 to 150 °C. By baking the resist 62 and causing the solvent in the resist 62 to evaporate, the removal rate of the resist 62 in the below-described electrolytic processing can be changed. Thus, by utilizing this and adjusting the baking temperature and the baking time, it becomes possible to control the selectivity ratio between the copper film (metal film) 6 and the resist 62 in electrolytic processing to flatten the copper film 6. In general, baking at a higher temperature for a longer time results in a slower processing rate of resist.

FIG. 8 is a plan view schematically showing the electrolytic processing apparatus 36 shown in FIG. 5, and FIG. 9 is a vertical sectional view of FIG. 8. As shown in FIGS. 8 and 9, the electrolytic processing apparatus 36 includes an arm 240 that can move vertically and make a reciprocation movement in a horizontal plane, a substrate holder 242, supported at the free end of the arm 240, for attracting and holding the substrate W with its front surface facing downward (face-down), and a moveable flame 244 to which the arm 240 is attached.

A vertical-movement motor 250 is mounted on the upper end of the moveable flame 244. A ball screw 252, which extends vertically, is connected to the vertical-movement motor 250. The base 240a of the arm 240 is engaged with the ball screw 252, and the arm 240 moves up and down via the ball screw 252 by the actuation of the vertical-movement motor 250. The moveable flame 244 is connected to a ball screw 254 that extends horizontally, and moves back-and-forth in a horizontal plane with the arm 240 by the actuation of a reciprocating motor 256.

The substrate holder 242 is connected to a rotating motor

258 supported at the free end of the arm 240. The substrate holder 242 is rotated (about its own axis) by the actuation of the rotating motor 258. The arm 240 can move vertically and make a reciprocation movement in the horizontal direction, as described above, the substrate holder 242 can move vertically and make a reciprocation movement in the horizontal direction integrated with the arm 240.

A rectangular electrode section 246 is disposed below the substrate holder 242. The electrode section 246 is designed to have a slightly larger size than the diameter of the substrate W to be held by the substrate holder 242.

The hollow motor 260 is disposed below the electrode section 246. A drive end 264 is formed at the upper end portion of the main shaft 262 of the hollow motor 260 and arranged eccentrically position to the center of the main shaft 262. The electrode section 246 is rotatably coupled to the drive end 264 via a bearing (not shown) at the center portion thereof. Three or more of rotation-prevention mechanisms (not shown) are provided in the circumferential direction between the electrode section 246 and the hollow motor 260. This allows the electrode section 246 make a scroll movement (translational rotation movement) by the actuation of a hollow motor 260.

Next, the electrode section 246 will now be described in detail. FIG. 10 is a vertical sectional view of the electrode section 246. As shown in FIGS. 8 and 10, the electrode section 246 includes a plurality of electrode members 282 which extend in the X direction (see FIG.8) and are disposed in parallel at an even pitch on a tabular processing table 284.

As shown in FIG. 10, each electrode member 282 comprises an electrode 286 to be connected to the power source 248 (see FIG. 8), and an ion exchanger 290 that serves as a processing member and covers a surface of the electrode 286 integrally. The ion exchanger 290 is mounted to the electrode 286 via holding

plates 285 disposed on both sides of the electrode 286.

According to this embodiment, an ion exchanger is used as a processing member. A processing member may be composed of a material containing an ion exchange, a polishing pad such as a polyurethane form pad, e.g., IC-1000 manufactured by Rohm and Haas Electronic Materials, Inc, a fixed-abrasive pad, or a PVA sponge.

It is preferable to use an ion exchanger having good water permeability as the ion exchanger 290. By allowing pure water or ultrapure water to flow within the ion exchanger 290, 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 with hydroxide ions (or OH radicals) can be removed by the flow of water, whereby the processing efficiency can be enhanced. A water-permeable sponge-like member or a member in the form of a membrane, such as Nafion (trademark, DuPont Co.), having through-holes for permitting water to flow therethrough, for example, is used as such a water-permeable member.

The ion exchanger 290 may be composed of a non-woven fabric which has an anion-exchange group or a cation-exchange group. 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. The base material of the ion exchanger 290 may be a polyolefin such as polyethylene or polypropylene, or any other organic polymer. Further, besides the form of a non-woven

fabric, the ion exchanger may be in the form of a woven fabric, a sheet, a porous material, a net, or short fibers, etc. A strongly acidic cation-exchange fiber (non-woven fabric ion exchanger) may be disposed inside the ion exchanger 290 to enhance an ion exchange capacity.

The non-woven fabric carrying a strongly basic anion-exchange group can be prepared by, for example, the following method: A polyolefin non-woven 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 non-woven 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, chloromethylstyrene, or the like. The amount of the graft polymerization can be controlled with 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 non-woven fabric after graft polymerization to the weight of the non-woven 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.

The non-woven fabric carrying a strongly acidic cation-exchange group can be prepared by the following method: As in the case of the non-woven fabric carrying a strongly basic anion-exchange group, a polyolefin non-woven 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 non-woven 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.

The base material of the ion exchanger 290 may be a polyolefin such as polyethylene or polypropylene, or any other organic polymer. Further, besides the form of a non-woven fabric, the ion exchanger 290 may be in the form of a woven fabric, a sheet, a porous material, or short fibers, etc. 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 polymer 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 and 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.

By using a non-woven fabric having an anion-exchange group or a cation-exchange group as the ion exchanger 290, it becomes possible that a liquid, such as pure water or ultrapure water, can freely move within the non-woven fabric and easily arrive at the active points in the non-woven 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 the liquid, such as pure water or ultrapure

water, the hydroxide ions produced by the water dissociation can be efficiently carried to the surfaces of the electrodes 286, whereby a high electric current can be obtained even with a low voltage applied.

When the ion exchangers 290 have only one of anion-exchange groups and cation-exchange groups, 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, an anion exchanger carrying an anion-exchange group and a cation exchanger carrying a cation-exchange group may be superimposed, or the ion exchangers 290 may carry both of an anion-exchange group and a cation-exchange group per se, whereby a range of materials to be processed can be broadened and the formation of impurities can be restrained.

According to this embodiment, the electrodes 286 of the electrode members 282 are connected alternately to the cathode and to the anode of the power source 248. For example, electrodes 286a (see FIG. 10) are connected to the cathode of the power source 248, and electrodes 286b (see FIG. 10) are connected to the anode. When processing copper, for example, the electrolytic processing action occurs on the cathode side, and therefore the electrodes 286 connected to the cathode become processing electrodes 286a, and the electrodes 286 connected to the anode become feeding electrodes 286b. Thus, according to this embodiment, the processing electrodes 286a and the feeding electrodes 286b are disposed in parallel and alternately.

Depending upon the material to be processed, the electrodes connected to the cathode of the power source may serve as feeding electrodes, and the electrodes connected to the anode may serve as processing electrodes. Thus, when the material to be processed is copper, molybdenum or iron, for example, the electrolytic processing action occurs on the cathode side, and therefore electrodes 286a connected to the cathode of the power source

becomes processing electrodes, and electrodes 286b connected to the anode becomes feeding electrodes. On the other hand, when the material to be processed is aluminum or silicon, for example, the electrolytic processing action occurs on the anode side, and therefore the electrodes 286b connected to the anode of the power source become processing electrodes and the electrodes 286a connected to the cathode become feeding electrodes.

By thus providing the processing electrodes 286a and the feeding electrodes 286b alternately in the Y direction of the electrode section 246 (direction perpendicular to the long direction of the electrode member 282), provision of a feeding section for feeding electricity to the copper film (metal film) 6 (see FIG. 1B) of the substrate W is no longer necessary, and processing of the entire surface of the substrate W becomes possible. Further, by changing the positive and negative of the voltage applied between the electrodes 286 in a pulse form, it becomes possible to dissolve the electrolysis products, and improve the flatness of the processed surface through the multiplicity of repetition of processing.

With respect to the electrodes 286 of the electrode members 282, oxidation or dissolution thereof due to an electrolytic reaction may be a problem. In view of this, as a material for the electrodes, it is possible to use, besides the conventional metals and metal compounds, carbon, relatively inactive noble metals, conductive oxides or conductive ceramics, preferably. 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 nonmetals. 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.

As shown in FIG. 10, a flow passage 292, for supplying pure water, preferably ultrapure water, to the processing surface, is provided in the interior of the processing table 284 of the electrode section 246. The flow passage 292 is connected, via a pure water supply tube 294, to a pure water supply source (not shown). Support members 296 are provided on both sides of each electrode member 282, and contact member 298, for contacting the surface (lower surface) of the substrate W, is provided on the upper surface of each support member 296. A through-hole 296a, communicating with the flow passage 292, is formed in the support member 296 and the contact member 298, so that pure water, preferably ultrapure water, is supplied through the through-holes 296a to between the substrate W and the ion exchangers 290 of the electrode members 282.

A CMP pad, a fixed-abrasive pad, a PVA sponge, etc. can be used as the contact member 298. An ion exchanger or a material containing an ion exchanger may also be used.

According to this electrolytic processing apparatus 36, as shown in FIG. 11, the substrate W is brought into contact with the upper surfaces of the contact members 298 while pressing the substrate W against the ion exchangers 290 at a certain degree of pressure. Thus, the pressing force of the substrate W is received by the contact members 298 so that the contact area between the substrate W and the ion exchangers 290 does not change. This can prevent the substrate W from tilting and equalize the contact areas, enabling uniform processing. The processing rate

of the coating material, such as resist, can be adjusted with contact members 298.

Through-hole 300, which extends from the flow passage 292 and reaches to the ion exchanger 290, is provided in the interior of the electrode 286 of each electrode members 282. With this arrangement, a liquid, such as pure water or ultrapure water, in the flow passage is supplied to the ion exchangers 290 via Through-holes 300.

The present invention is not limited to electrolytic processing using an ion exchanger. For example, when an electrolytic solution is employed as a processing liquid, it is possible to attach to the surface of an electrode a processing member other than an ion exchanger, such as a soft polishing pad or a non-woven fabric.

In operation of the electrolytic processing apparatus 36, the substrate W held by the substrate holder 242 is brought into contact with the surfaces of the ion exchangers 290 of the electrode section 246 and upper surfaces of the contact members 298, as shown in FIG. 11. In this state, the substrate W held by substrate holder 242 is rotated and the electrode section 246 is allowed to make a scroll movement by the actuation of the hollow motor 260, while pure water or ultrapure water is supplied between the substrate W and the electrode members 282 via through-holes 296a of the support members 296. Pure water or ultra pure water supplied via through-holes 300 of the electrode members 290 is held in the ion exchangers 290. According to the embodiment, pure water or ultrapure water supplied to the ion exchangers 290 is discharged from the ends in the long direction of each electrode member 282. A given voltage is applied from the power source 248 to between the processing electrodes 286a and the feeding electrodes 286b, thereby carrying out electrolytic processing of the copper film (metal film 6) deposited on the surface of the substrate W.

A description will now be given of electrolytic processing by the flattening apparatus of this embodiment. First, a cassette housing substrates W, each having a surface copper film 6 as a metal film to be processed, which fills trenches 4 formed in an insulating film 2 and covers the surface of the insulating film 2, as shown in FIG. 1B, is set in the loading/unloading section 30, and one substrate W is taken by the transport robot 40 out of the cassette. As shown in FIG. 12A, the copper film 6 has a pattern region P with a large number of recessed portions 6a and raised portions 6b, and a field region F surrounding the pattern region P. The transport robot 40 transports the substrate W to the resist processing apparatus (coating material processing apparatus) 34. In the resist processing apparatus 34, the recessed portions 6a of the copper film 6 are coated with the coating layer (insulating layer) composed of the resist (coating material) 62 of insulating material in the above-described manner, according to this embodiment. Thereafter, the resist 62 is subjected to baking at a predetermined temperature for a predetermined time in order to adjust the removal rate of resist 62 in electrolytic processing.

The transport robot 40 receives the substrate W after baking from the resist processing apparatus 34 and, as necessary, transports the substrate W to the reversing machine 32, where the substrate W is reversed so that its front surface having the copper film 6 faces downward.

The transport robot 40 receives the reversed substrate W and transports it to the electrolytic processing apparatus 36, where the substrate W is attracted and held by the substrate holder 242. Next, the vertical-movement motor 250 is actuated to lower the substrate holder 242 so as to bring the substrate W held by the substrate holder 242 into contact with the contact members 298 and the ion exchangers 290 of the electrode section 246. Thereafter, the rotating motor 258 is actuated to rotate

the substrate W and, at the same time, the hollow motor 260 is actuated to allow the electrode section 246 to make a scroll movement while pure water or ultrapure water is supplied between the substrate W and the ion exchangers 290.

A given voltage is applied from the power source 248 to between the processing electrodes 286a and the feeding electrodes 286b to carry out electrolytic processing at the processing electrodes (cathodes) 286a by the actuation of hydrogen ions or hydroxide ions produced by the ion exchangers 290. The recessed portions 6a in the pattern region P of the copper film 6 is coated with the resist (coating material) 62 which is an insulating material and thus is hard to process by electrolytic processing. Accordingly, those portions of the copper film 6, which are not coated with the resist (coating material) 62, are preferentially processed in the electrolytic processed, whereby the surface of the copper film 6 is gradually flattened.

In particular, when electrolytic processing of the copper film 6, which fills the trenches 4 formed in the insulating film 2 and covers the surface of the insulating film 2, is carried out with the bottoms of the recessed portions 6a in the pattern region P of the copper film 6 coated with the resist (coating material) 62 of insulating material, as shown in FIG. 12A, the raised portions 6b in the pattern region P of the copper film 6 are first preferentially processed, whereby the pattern region P is gradually flattened, as shown in FIG. 12B. As processing further progresses, processing of the copper film 6 in the pattern region P is suppressed and the copper film 6 in the field region F is preferentially processed, whereby the pattern region P and the field region F are flattered with the resist (coating material) 62 of insulating material slightly left in the recessed portions 6a in the pattern region P of the copper film 6, as shown in FIG. 12C. As processing further progresses, the resist 62 remaining in the recessed portions 6a in the pattern region P

of the copper film 6 is removed and the surface of the copper film 6 is flattened, as shown in FIG. 12D.

By using as the resist 62 to form a coating layer (insulating layer) a material which is highly adhesive to the copper film 6 and does not separate from the copper film 6 even when carrying out electrolytic processing by applying such a high voltage as not less than 10V between the processing electrodes 286a and the feeding electrodes 286b, a sufficiently high processing rate can be obtained while maintaining the electrolytic reaction-suppressing effect of the resist 62.

As will be appreciated from the foregoing, it is preferred that a coating material, such as the resist 62, of insulating material, have a certain degree of processibility and be electrolytically processed at a slower rate than a metal film, such as the copper film 6. By adjusting the selectivity ratio between the processing rate of resist 62 and the processing rate of copper film 6 in electrolytic processing, the surface of the copper film 6 can be flattened without leaving the resist 62 on the copper film 6.

As described above, the processing rate of the resist (coating material) 62 can be adjusted also by moving the copper film 6 and the contact members 298 relative to each other while keeping them in contact so as to rub off the surface of the coating material with the contact members 298. This holds also for the below-described embodiments.

According to this embodiment, the copper film 6 and the resist 62 are processed in a continuous manner to flatten the surface of the copper film 6 without leaving the resist 62. However, there is a case where for some reason, for example due to the processing rate of the resist 62, it is difficult to flatten the surface of the copper film 6 without leaving the resist 62 by continuous processing. In such a case, it is possible to remove the resist 62 in a separate process, for example, when the surface

of the copper film 6 is flattened both in the pattern region P and in the field region F and the resist 62 has become exposed on the surface of the copper film 6, as shown in FIG. 12C, and then further process the surface of the copper film 6, thereby flattening the surface of the copper film 6 without leaving the resist 62, as shown in FIG. 12D. The processing after the removal of the resist 62 may be carried out by electrolytic processing using, for example, an electrolytic solution or ultrapure water, or by any other conventional method such as CMP.

As described above, it is also possible to remove the resist 62, which is exposed on the surface of the copper film 6, as shown in FIG. 12C, with the contact members 298 by moving the copper film 6 and the contact members 298 relative to each other while keeping them in contact.

After the completion of electrolytic processing, the processing electrodes 286a and the feeding electrodes 286b are disconnected from the power source 248, and the rotation of the substrate holder 242 and the scroll movement of the electrode section 246 are stopped. Thereafter, the substrate holder 242 is raised, and the arm 240 is moved to transfer the substrate W to the transport robot 40. The transport robot 40 transports the substrate W to the reversing machine 32 to reverse the substrate W, as necessary, and returns the substrate W to the cassette of the loading/unloading section 30.

Pure water, which is supplied between the substrate W and the ion exchangers 290 during electrolytic processing, herein refers to a water having an electric conductivity of not more than 10 μS/cm, for example. Ultrapure water refers to a water having an electric conductivity of not more than 0.1 μS/cm, for example. The use of pure water or ultrapure water containing no electrolyte during electrolytic processing can prevent extra 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 exchangers 290 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.

It is possible to use, instead of pure water or ultrapure water, a liquid having an electric conductivity of not more than 500 μS/cm e.g., an electrolytic solution obtained by adding an electrolyte to pure water or ultrapure water. The use of 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.

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 exchangers 290, 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.

FIG. 13 shows another resist processing apparatus as a coating material processing apparatus. As shown in FIG. 13, the resist processing apparatus (coating material processing apparatus) 34a comprises the same resist application section 50 as used in the resist processing apparatus 34 shown in FIG. 6, and a resist wiping section 70. The resist wiping section 70 includes a rotary plate 72 rotatably and vertically movably disposed above the substrate stage 54 of the resist application section 50, and a wiping pad 74 mounted face down on the lower surface of the rotary plate 72.

According to this resist processing apparatus 34a, while rotating a substrate W together with the substrate stage 54, a resist 62 is dropped from the resist dropping nozzle 58 onto almost the center of the substrate W held face up on the upper surface of the substrate stage 54 to spin-coat the substrate surface, thereby applying the resist 62 uniformly onto the surface of a copper film (metal film) 6 while filling the resist 62 into the recessed portions 6a of the copper film 6 which fills trenches 4 provided in an insulating film 2 and covers the insulating film 2, as shown in FIG. 14A. Next, the rotary plate 72 is lowered while rotating it to rub the surface (lower surface) of the wiping pad 74 against the surface of the resist 62, thereby removing the resist 62 lying on the raised portions 6b of the copper film 6 while leaving the resist 62 lying within the recessed portions 6a, as shown in FIG. 14B. Only the recessed portions 6a of the copper film 6 are thus coated with a coating layer composed of the resist (coating material) 62.

When thus spin-coating the substrate W by dropping the resist 62 onto the surface of the substrate W and then rotating the substrate W, the resist 62 is applied thicker on the recessed portions 6a of the copper film 6 than on the raised portions 6b. For example, in the case of a pattern having an interconnect width of 9 μm and a spacing of 1 μm, it is possible to make the

difference in the thickness of resist 62 between the interconnect area and the spacing area not less than 400 nm. Accordingly, only the resist 62 lying on the raised portions 6b of the copper film 6 can be selectively removed by rubbing the surface (lower surface) of the wiping pad 74 against the surface of the resist 62.

According to this embodiment, any resist other than a positive photoresist can be used as a coating material.

As with the preceding embodiment, it is possible to provide a heater stage e.g. beside the resist processing apparatus 34a, and bake the resist 62 e.g. at 100 to 150°C in order to adjust the removal rate of the resist 62 in electrolytic processing.

Though in this embodiment a resist of insulating material, having a resistivity of not less than 10^6 Ω·cm (electric conductivity of not more than 1 μS/cm), is used as a coating material to form a insulating layer (coating layer), it is also possible to use a conductive material having a resistivity of not more than 10^3 Ω·cm (electric conductivity of not less than 10^3 μS/cm) to form a conductive layer (coating layer). Examples of the conductive material include a conductive paint, a conductive ink, a conductive adhesive and a conductive paste. These conductive materials can be prepared by mixing a resin with conductive particles, such as fine metal particles or carbon particles, and the conductivity can be adjusted by the mixing ratio of the conductive particles.

Also in the case of using a conductive material as a coating material 64, the recessed portions 6a of the copper film (metal film) 6, which fills the trenches 4 provided in the insulating film 2 and covers the surface of the insulating film 2, are first coated with the coating material 64, as shown in FIG. 15A. The coating may be carried out, for example, by applying a conductive ink, such as a permanent marker, onto the entire surface of the copper film 6, and then wiping off the conductive ink on the

surface of the copper film 6 with an alcohol or a thinner, or by selectively applying a conductive ink only onto the recessed portions 6a of the copper film 6 by an ink jet method.

Thereafter, the substrate W, in which the recessed portions 6a of the copper film 6 are coated with a coating layer (conductive layer) composed of the coating material 64, is subjected to electrolytic processing to flatten the surface of the copper film 6. In the case where the raised portions 6b of the copper film (metal film) 6 in the pattern region P protrude from the surface of the coating material 64, as shown in FIG. 15A, the raised portions 6b and the copper film 6 of the field region F are preferentially processed, whereby the pattern region P and the field region F are flattened as shown in FIG. 15B. As processing further progresses, electrolytic reaction occurs also at the surface of the coating material 64 and an electron current flows through the coating material 64 also to the copper film 6 of the recessed portions 6a. Therefore, the current density in the entire surface, including the coating material 64, of the copper film 6 becomes more uniform, whereby the entire surface of the copper film 6 is processed more uniformly, as shown in FIG. 15C. As processing further progresses, the coating material 64 remaining in the recessed portions 6a in the pattern region P of the copper film 6 is removed and the surface of the copper film 6 is flattened.

Also in this case, it is preferred that the coating material 64, which is a conductive material, have a certain degree of processibility and be electrolytically processed at a slower rate than a metal film, such as the copper film 6. By adjusting the selectivity ratio between the processing rate of coating material 64 and the processing rate of copper film 6 during electrolytic processing, the surface of the copper film 6 can be flattened without leaving the coating material 64 on the copper film 6.

As with the above-described embodiment, it is also possible to remove the coating material 64 in a separate process, for example, when the coating material 64 has become exposed on the surface of the copper film 6, and then further process the surface of the copper film 6, or to remove the coating material 64, which has become exposed on the surface of the copper film 6, with the contact members 298 by moving the copper film 6 and the contact members 298 relative to each other while keeping them in contact.

FIG. 16 shows the main portion of another electrode section of the electrolytic processing apparatus. The electrode section 246a of this electrolytic processing apparatus differs from the electrode section 246 of the above-described electrolytic processing apparatus in the following respects:

The electrode section 246a includes a plurality of electrodes 302 extending parallel to each other. The electrodes 302 are arranged in parallel at a given pitch on a tabular processing table in an exposed state, i.e. without being covered with an ion exchanger or the like. The electrodes 302 are connected alternately to the cathode and to the anode of a power source. When processing copper, for example, the electrodes 302a connected to the cathode of the power source serve as processing electrodes and the electrodes 302b connected to the anode serve as feeding electrodes.

A flow passage for supplying a liquid (electrolytic liquid), such as pure water, to a processing surface is formed in the interior of the processing table of the electrode section 246b, and the flow passage is connected, via a liquid supply pipe, to a liquid supply source. Support members 310 are provided on both sides of each electrode 302, and a contact member 312, for contacting a surface (lower surface) of a substrate W, is provided on the upper surface of each support member 310. A through-hole 314, communicating with the flow passage, is formed in the support member 310 and the contact member 312, and a through-hole 316,

communicating with the flow passage, is formed in the electrode 302, so that the liquid, such as pure water, is supplied through the through-holes 314, 316 to between the substrate W and the electrodes 302.

A CMP pad, a fixed-abrasive pad, a PVA sponge, etc. can be used as the contact member 312. An ion exchanger or a material containing an ion exchanger may also be used.

Electrolytic processing with the electrode section 246b is carried out while keeping the substrate W, held by the substrate holder 242 (see FIGS. 8 and 9), in contact with the surfaces of the contact members 312. The distance D between the substrate W and the electrodes 302 during electrolytic processing is kept not less than 0.05μm and not more than 50 μm without contact therebetween.

During the electrolytic processing, pure water, ultrapure water or a liquid having an electric conductivity of not more than 500 μS/cm is supplied between the substrate W and the electrodes 302.

The present invention enables a simple flattening of a metal film surface at a high speed. In particular, a surface of a metal film (conductive film), e.g. a copper film as an interconnect material, can be flatly processed over the entire film surface at a sufficiently high processing rate even when the metal film has initial surface irregularities.

FIG. 17 is a plan view illustrating a flattening apparatus according to another embodiment of the present invention. As shown in FIG. 17, the flattening apparatus comprises a pair of loading/unloading units 130, a reversing machine 132 for reversing the substrate W, an electrolytic processing apparatus 138 which has a first polishing section 134 and a second polishing section 136 and serves as a polishing apparatus, and a cleaning section 140 for cleaning and drying the substrate W after electrolytic processing. These devices are disposed in series.

A transport robot 142 as a transport device, which can move parallel to these devices for transporting and transferring the substrate W therebetween, is provided. The flattening apparatus is also provided with a control section 144, adjacent to the loading/unloading units 30, for monitoring a voltage applied between the processing electrodes and the feeding electrodes or an electric current flowing therebetween, or detecting a table current.

FIG. 18 is a plan view schematically showing the electrolytic processing apparatus (polishing apparatus) 138 shown in FIG. 17. As shown in FIGS. 18, the electrolytic processing apparatus 138 includes an arm 240 that can move vertically and make a reciprocation movement in a horizontal plane, a substrate holder 242, supported at the free end of the arm 240, for attracting and holding the substrate W with its front surface facing downward (face-down), and a moveable flame 244 to which the arm 240 is attached, as with the electrolytic processing apparatus 36 shown in FIGS. 8 and 9.

A vertical-movement motor 250 is mounted on the upper end of the moveable flame 244 so that the arm 240 moves up and down by the actuation of the vertical-movement motor 250. The moveable flame 244 per se is connected to a ball screw 254, which extends horizontally, so that the moveable flame 244 and the arm 240 move back-and-forth in a horizontal plane by the actuation of a reciprocating motor 256. The substrate holder 242 is connected to a rotating motor 258 supported at the free end of the arm 240. The substrate holder 242 is rotated (about its own axis) by the actuation of the rotating motor 258.

Below the substrate holder 242 are disposed a rectangular first electrode section 246b which, together with the substrate holder 242, constitutes the first polishing section 134, and a rectangular second electrode section 246c which, together with the substrate holder 242, constitutes the second polishing

section 136. The substrate holder 242 moves between a position right above the first electrode section 246b and a position right above the second electrode section 246c.

As with the electrode section 246 of the electrolytic processing apparatus 36 shown in FIGS. 8 and 9, the first electrode section 246b and the second electrode section 246c make a scroll movement (translational rotation) by the actuation of a hollow motor.

The first electrode section 246b has the same construction as the electrode section 246 of the electrolytic processing apparatus 36 shown in FIGS. 8 and 9. As shown in FIG. 19, the substrate W is brought into contact with the upper surfaces of the contact members 298 while pressing the substrate W against the ion exchangers 290, covering the electrodes 286, at a certain degree of pressure. Thus, the pressing force of the substrate W is received by the contact members 298 so that the contact area between the substrate W and the ion exchangers 290 does not change. This can prevent the substrate W from tilting and equalize the contact areas, enabling uniform processing.

Each ion exchanger (processing members) 290 of the first electrode section 246b has an elasticity so that when the substrate W is pressed against the ion exchanger 290 at a certain degree of pressure and is brought into contact with the upper surfaces of the contact members 298, the ion exchanger 290 contacts the surfaces of the raised portions 6b of the copper film (metal film) 6 in the pattern region P, shown in FIG. 21A, and can keep contacting the surfaces of the raised portions 6b during processing, thereby selectively polishing the raised portions 6b and flattening the surface of the copper film 6 in the pattern region P, as shown in FIG. 21B.

In the operation of the first polishing section 134 having such a construction, the substrate W held by the substrate holder 242 is brought into contact with the upper surfaces of the contact

members 298 and also with the surfaces of the ion exchangers 290 of the first electrode section 246b, as shown in FIG. 19, thereby bringing the ion exchangers 290 into contact with the surfaces of the raised portions 6b of the copper film (metal film) 6 in the pattern region P, shown in FIG. 21A. While rotating the substrate W held by the substrate holder 242 and allowing the first electrode section 246b to make a scroll movement, pure water or ultrapure water is supplied from the through-holes 296a of the support members 296 to between the substrate W and the electrode members 282, and pure water or ultrapure water is supplied through the through-holes 300 of the electrodes 286 into the ion exchangers 290. A given voltage is applied from the power source 248 (see FIG. 18) to between the processing electrodes 286a and the feeding electrodes 286b to carry out the first polishing (electrolytic processing) of the copper film (metal film) 6, deposited on the surface of the substrate W, at the processing electrodes (cathodes) 286a by the action of hydrogen ions or hydroxide ions produced by the ion exchangers 290.

In the polishing, the intensity of electric field is higher in the pattern region P, in which raised portions are concentrated, than in the field region F, and therefore the amount of reaction species ions supplied is larger in the pattern region P than in the field region F, leading to a higher processing rate of the copper film 6 in the pattern region P than in the field region F.

It is also possible to use an electrolytic liquid prepared by adding an ionic reaction promoter to pure water, ultrapure water or the like. The ionic reaction promoter will concentrate at portions of high electric field intensity, i.e. the top portions of the raised portions 6b of the copper film 6 in the pattern region P, thus increasing the polishing rate of the raised portions 6b of the copper film 6 in the pattern region P. This can provide

a sufficiently high polishing (processing) rate ratio for the metal film 6 between the pattern region P and the filed region F.

Particularly, the first polishing by the first polishing section 134 is continued until the initial surface irregularities of the copper film 6 in the pattern region P are removed. When the polishing rate for the copper film of the pattern region P in the first polishing is small, the thickness of the copper film 6, to be subjected to the second polishing to remove the surface level difference in the copper film 6 between the pattern region P and the field region F, becomes undesirably small. It is, therefore, desirable to make the polishing rate in the first polishing of the copper film 6 of the pattern region P at lease twice the polishing rate of the copper film 6 of the field region F so as to produce a larger surface level difference in the metal film between the pattern region P and the filed region F, i.e. produce a thicker copper film 6, in the first polishing. This can be met by adding an ionic reaction promoter to an electrolytic liquid (liquid), such as pure water or ultrapure water.

FIG. 20 shows the main portion of the second electrode section 246c that constitutes the second polishing section 136. The second electrode section 246c differs from the first electrode section 246b in that an ion exchanger 290a, which has high rigidity and shows little elastic deformation, is used as a processing member, and that the height of the support member 296, having the contact member 298 mounted on the upper surface, is made higher so that when the substrate W is brought into contact with the upper surface of the contact member 298 at a certain degree of pressure, the ion exchanger 290a does not contact the surface of the copper film (metal film) 6 of the pattern region P, shown in FIG. 21B. The ion exchanger 290a may contact the surface of the copper film 6 of the field region F.

In the operation of the second polishing section 136, the

substrate W held by the substrate holder 242 is brought into contact with the surfaces of the contact members 298 of the second electrode section 246c, as shown in FIG. 20. The ion exchangers 290a do not contact the surface of the copper film (metal film) 6 of the pattern region P, shown in FIG. 21B. The ion exchangers 290a, however, may contact the surface (metal film) 6 of the field region F, shown in FIG. 21B.

As with the first polishing section 134, while rotating the substrate W held by the substrate holder 242 and allowing the second electrode section 246c to make a scroll movement, pure water or ultrapure water is supplied between the substrate W and the electrode members 282, and pure water or ultrapure water is supplied into the ion exchangers 290a. A given voltage is applied between the processing electrodes 286a and the feeding electrodes 286b to carry out electrolytic processing (second polishing) of the copper film (metal film) 6, deposited on the surface of the substrate W, at the processing electrodes (cathodes) 286a.

Since the ion exchangers 290a are not in contact with the surface of the copper film (metal film) 6 of the pattern region P, shown in FIG. 21B, during the polishing, the polishing rate of the copper film 6 of the pattern region P is lower than that of the field region F and the copper film 6 of the field section F is selectively polished, whereby the surface level difference in the copper film 6 between the pattern region P and the field region F is removed and the copper film 6 is flattened, as shown in FIG. 21C.

The surface of the copper film 6 can thus be flattened over the entire surface of the substrate W by mainly removing the initial surface irregularities of the copper film 6 in the pattern region P by the first polishing, and then mainly removing the surface level difference in the copper film 6 between the pattern region P and the field region F by the second polishing.

Upon the second polishing, a resistance-forming processing may preferably be carried out to form a resistance on the surface of the copper film 6 in the pattern region P, thereby decreasing the polishing rate of the copper film (metal film) 6 in the pattern region P and producing a larger difference in the polishing rate between the field region F and the pattern region P. An example of the resistance-forming processing involves the use of a processing liquid (electrolytic liquid), prepared by adding an oxidizing agent (H_2O_2, O_3, etc.) or a complexing agent to pure water, ultrapure water or the like, so as to passivate or complex the surface of the copper film 6 in the pattern region P, thereby retarding reaction species ions reaching the surface of the copper film 6 in the pattern region P.

Another processing involves the use of a processing liquid (electrolytic liquid), prepared by adding an additive having insulating properties to pure water, ultrapure water or the like, so as to coat the surface of the copper film 6 with the additive (insulating material) 10 in the pattern region P, as shown in FIG. 22, thereby preventing reaction species ions from reaching the surface of the copper film 6 in the pattern region P.

Yet another processing involves the use of a processing liquid (electrolytic liquid), prepared by adding an additive, for example a corrosion inhibitor such as BTA (benzotriazole), which inhibits reaction between reaction species ions and the copper film 6, to pure water, ultrapure water or the like, so as to inhibit the reaction itself between the reaction species ions and the copper film 6.

Though such a processing, especially passivation or complexing of the surface of the copper film 6, or coating of the copper film 6 with the additive (insulating material) 10, is desirably effected only in the pattern region P, the processing may be effected also in the field region F, provided that the resistance formed can be removed from the field region F by the

contact pressure of the ion exchangers (processing members) 290a or the contact members 298. Since the ion exchangers 290a are kept contactless with the pattern region P during the second polishing, a resistance, such as a passive film, a complex or an insulating material, which has been formed on the surface of the copper film 6 in the pattern region P, is not removed by its contact with the ion exchangers 290a. On the other hand, the resistance, such as a passive film, formed on the surface of the copper film 6 in the field region F can be removed by the contact pressure of the contact members 298 which are kept in contact with the field region F during the second polishing.

In the case of not providing the contact members 298, it is possible to allow the ion exchangers 290a to be in contact with the field region F during the second polishing so as to remove the resistance, such as a passive film, formed on the surface of the copper film 6 in the filed region F, by the contact pressure of the ion exchangers 290a.

Though in this embodiment the resistance-forming processing in the pattern region P is carried out simultaneously with the second polishing, it may be carried out prior to the second polishing.

In the operation of the flattening apparatus of this embodiment, the substrate holder 242 holding the substrate W is moved to a first polishing position right above the first electrode section 246b. The substrate holder 242 is then lowered so as to bring the substrate W, held by the substrate holder 242, into contact with the surfaces of the contact members 298 and the ion exchangers 290 of the first electrode section 246b, thereby bringing the ion exchangers 290 into contact with the surfaces of the raised portions 6b of the copper film (metal film) 6 of the pattern region P, shown in FIG. 21A. Thereafter, while rotating the substrate W and allowing the first electrode section 246b to make a scroll movement, pure water or ultrapure

water, optionally containing an ionic reaction promoter, is supplied between the substrate W and the ion exchangers 290.

A given voltage is applied from the power source 248 to between the processing electrodes 286a and the feeding electrodes 286b to carry out the first polishing (electrolytic processing) at the processing electrodes (cathodes) 286a by the action of hydrogen ions or hydroxide ions produced by the ion exchangers 290, in such a manner that the polishing rate of the copper film 6 in the pattern region P is higher than the polishing rate of the copper film 6 in the field region F. The first polishing is terminated when the raised portions 6b of the copper film 6 in the pattern region P have been selectively polished and the initial surface irregularities have been removed, as shown in FIG. 21B.

According to this embodiment, an electric current (table current), which is fed to cause the scroll movement of the processing table 284, is detected with the control section 144 to detect the end point of the first polishing. Specifically, as the surface irregularities of the cupper film 6 become smaller and flattened with the progress of the first polishing, the contact area between the copper film 6 and the ion exchangers (processing members) 290 becomes larger, whereby the table current becomes higher, as shown in FIG. 23. The end point of the first polishing can be determined by a point of time at which the table current detected has reached a predetermined value.

The end point of the first polishing may also be detected by image recognition. As the first polishing progresses, the pattern image of the surface of the copper film 6 changes from a clear pattern image 12 as shown in FIG. 24A to a faint pattern image 12 as shown in FIG. 24B and gradually disappears. Accordingly, the end point of the first polishing can be detected by image recognition of the copper film 6 being processed by a camera disposed above the processing table 284 (see FIG. 10),

or by image recognition of the copper film 6 of a substrate W, which is made to overhang the processing table 284 during processing, by a camera disposed beside the processing table 284. Alternatively, the end point of the first polishing may be detected by time management.

After completion of the first polishing, the processing electrodes 286a and the feeding electrodes 286b of the first electrode section 246b are disconnected from the power source 248, and the rotation of the substrate holder 242 and the scroll movement of the first electrode section 246b are stopped. The substrate holder 242 is raised and moved to a second polishing position right above the second electrode section 246c, and is then lowered so as to bring the substrate W, held by the substrate holder 242, into contact with the surfaces of the contact members 298 of the second electrode section 246c. As shown in FIG. 20, however, the ion exchanger 290a are not brought into contact with the surface of the copper film (metal film) 6 of the pattern region P, shown in FIG. 21B. Thereafter, while supplying pure water or ultrapure water, optionally containing an oxidizing agent, a complexing agent or an additive having insulating properties, between the substrate W and the ion exchangers 290a, the second polishing (electrolytic processing) of the surface of the copper film 6 is carried out in the same manner described above. The first polishing (electrolytic polishing) and the second polishing (electrolytic polishing) may also be carried out using the same electrode section.

Since the ion exchangers 290a are not in contact with the surface of the copper film (metal film) 6 of the pattern region P, shown in FIG. 21B, during the second polishing, the polishing rate of the copper film 6 is decreased and lower in the pattern region P than in the field region F. The polishing rate of the copper film (metal film) 6 in the pattern region P can be further decreased by optionally carrying out the resistance-forming

processing to form a resistance on the surface of the copper film 6 in the pattern region P. The copper film 6 of the field section F is thus selectively polished, whereby the surface level difference in the copper film 6 between the pattern region P and the field region F is removed and the surface of the copper film 6 is flattened, as shown in FIG. 21C.

The end point of the second polishing can be detected, for example, by determining the processing amount through detection of a change in frictional force due to the removal of the surface level difference.

After completion of the second polishing, the processing electrodes 286a and the feeding electrodes 286b of the second electrode section 246c are disconnected from the power source 248, and the rotation of the substrate holder 242 and the scroll movement of the second electrode section 246c are stopped. Thereafter, the substrate holder 242 is raised, and the arm 240 is moved to transfer the substrate W to the transport robot 142. The transport robot 142 transports the substrate W to the reversing machine 132 to reverse the substrate W, as necessary, and returns the substrate W to the cassette of the loading/unloading section 130.

Though in this embodiment the substrate holder 242 and the first electrode section 246b constitute the first polishing section 134, and the substrate holder 242 and the second electrode section 246c constitute the second polishing section 136, sharing the substrate holder 242, it is also possible to carry out the first polishing and the second polishing by using separate electrolytic processing apparatuses.

Further, it is possible to use a cartridge-type processing table and change it for a new one during polishing while holding a substrate W with the substrate holder 242.

The first polishing and the second polishing may also be carried out by using, as the first electrode section 246b and

the second electrode section 246c, the electrode section 246a shown in FIG. 16 and supplying different liquids (electrolytic liquids) between a substrate W and the electrodes 302 which are kept at a distance D of 0.05 to 50 μm without contact therebetween.

In particular, in carrying out the first polishing, a processing liquid prepared by adding an ionic reaction promoter to e.g. pure water, ultrapure water or a liquid having an electric conductivity of not more than 500 μS/cm, is supplied between a substrate W and the electrodes 302. This makes it possible to carry out the first polishing with the polishing rate of the copper film (metal film) 6 in the pattern region P, shown in FIG. 21A, higher than the polishing rate of the copper film 6 in the field region F. In this regard, if a liquid having a high electric conductivity is used, polishing of the copper film 6 will be isotropic both in the pattern region P and in the field region F, that is, there will be no significant difference in the polishing rate of the copper film 6 between the pattern region P and the field region F. The use of a liquid having such a low electric conductivity as not more than 500 μS/cm can make the polishing of the copper film 6 anisotropic and produce a difference in the polishing rate of the copper film 6 between the pattern region P and the field region F. Further, the ionic reaction promoter can be concentrated at portions of high electric field intensity, i.e. the top portions of the raised portions 6b of the copper film 6 in the pattern region P. This can increase the polishing rate of the copper film 6 in the pattern region P.

In the second polishing, a processing liquid prepared by adding an oxidizing agent (H_2O_2, O_3, etc.) or a complexing agent, an additive having insulating properties, or an additive which inhibits reaction between reaction species ions and the copper film 6, as necessary, to e.g. pure water, ultrapure water or a liquid having an electric conductivity of not more than 500

μS/cm, is supplied between the substrate W and the electrodes 302, thereby carrying out resistance-forming processing of the pattern region P simultaneously with the second polishing. The resistance-forming processing can decrease the polishing rate of the copper film (metal film) 6 in the pattern region P, shown in FIG. 21B, producing a larger difference from the polishing rate of the copper film 6 in the field region F.

If the resistance, such as passivation, complexing, or coating with an additive (insulating material) is effected also on the surface of the copper film 6 of the field region F, the resistance formed can be removed from the field region F by the contact pressure of the contact members 312.

Also in this embodiment, while rotating the substrate W, held by the substrate holder 242 and kept in contact with the contact members 312 of the electrode section 246a, and allowing the electrode section 246a to make a scroll movement, a processing liquid, e.g. a liquid (electrolytic liquid) having an electric conductivity of not more than 500 μS/cm, containing an ionic reaction promoter, is supplied between the substrate W and the electrodes 302, and a given voltage is applied between the processing electrodes 302a and the feeding electrodes 302b to carry out the first polishing of the copper film (metal film) 6, deposited on the surface of the substrate W, at the processing electrodes (cathodes) 302a.

Thereafter, while rotating the substrate W, held by the substrate holder 242 and kept in contact with the contact members 312 of the electrode section 246a, and allowing the electrode section 246a to make a scroll movement, a liquid (electrolytic liquid) having an electric conductivity of not more than 500 μS/cm, optionally containing an oxidizing agent, a complexing agent, or an additive having insulating properties, or the like, is supplied between the substrate W and the electrodes 302, and a given voltage is applied between the processing electrodes

302a and the feeding electrodes 302b to carry out the second polishing (electrolytic processing) of the copper film 6.

The present invention enables a simple flattening of a metal film surface. In particular, the surface of a metal film (conductive film), e.g. a copper film as an interconnect material, can be flatly processed over its entire surface even when the metal film has initial surface irregularities.

While the present invention has been described with reference to the embodiments thereof, it will be appreciated by those skilled in the art that changes could be made to the embodiments within the technical concept of the present invention.

Industrial Applicability

The present invention is useful for processing and flattening a surface of a metal film which has been formed on a surface of a substrate and embedded into fine interconnects recesses formed in the surface of the substrate.

CLAIMS

1. A flattening method for processing and flattening a surface of a metal film formed on a workpiece and having initial surface irregularities, comprising:

coating only recessed portions of the initial surface irregularities of the metal film with a solid or pasty coating material; and

processing the surface of the metal film by electrolytic processing using no abrasive.

2. The flattening method according to claim 1 further comprising removing the coating material which has not been processed by the electrolytic processing and remains on the surface of the metal film, and further processing the surface of the metal film.

3. The flattening method according to claim 1, wherein the coating material is an insulating material having a resistivity of not less than 10^6 Ω·cm or a conductive material having a resistivity of not more than 10^3 Ω·cm.

4. The flattening method according to claim 1, wherein only the recessed portions of the initial surface irregularities of the metal film are coated with the coating material by applying the coating material onto the entire surface of the metal film, and then removing only the coating material lying on the raised portions of the initial surface irregularities.

5. The flattening method according to claim 1, wherein only the recessed portions of the initial surface irregularities of the metal film are coated with the coating material by selectively applying the coating material onto the recessed portions of the metal film.

6. The flattening method according to claim 1, wherein the processing of the surface of the metal film by the electrolytic processing is carried out by:

applying a voltage between a processing electrode, disposed close to the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film;

supplying a liquid into the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which space a processing member is present; and

moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

7. The flattening method according to claim 6, wherein the processing member is composed of an ion exchanger or a material containing an ion exchanger.

8. The flattening method according to claim 6, wherein the processing of the surface of the metal film by the electrolytic processing is carried out by bringing a contact member, disposed beside the processing electrode and/or the feeding electrode, into contact with the metal film surface.

9. The flattening method according to claim 1, wherein the processing of the surface of the metal film by the electrolytic processing is carried out by:

applying a voltage between a processing electrode, disposed close to the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film;

supplying a liquid between the workpiece and at least one of the processing electrode and the feeding electrode; and

moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

10. The flattening method according to claim 9, wherein the processing of the surface of the metal film by the electrolytic processing is carried out by bringing a contact member, disposed beside the processing electrode and/or the feeding electrode, into contact with the metal film surface.

11. A flattening apparatus comprising:

a coating material processing apparatus for coating only recessed portions of initial surface irregularities of a metal film with a solid or pasty coating material; and

an electrolytic processing apparatus for processing the surface of the metal film by electrolytic processing using no abrasive.

12. The flattening apparatus according to claim 11, wherein the coating material processing apparatus comprises a resist processing apparatus.

13. A flattening method for polishing and flattening a surface of a metal film formed on a workpiece and having a pattern region and a field region, comprising:

carrying out a first polishing of the metal film surface in such a manner that the polishing rate of the metal film in the pattern region is higher than the polishing rate of the metal film in the field region; and

carrying out a second polishing of the metal film surface in such a manner that the polishing rate of the metal film in the field region is higher than the polishing rate of the metal film in the pattern region.

14. The flattening method according to claim 13, wherein at least one of the first polishing and the second polishing is carried out by electrolytic processing.

15. The flattening method according to claim 13, wherein the first polishing and the second polishing are carried out by:

applying a voltage between a processing electrode, disposed close to the surface of the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film;

supplying a liquid into the space between the workpiece and at least one of the processing electrode and the feeding electrode, in which space a processing member is present, and

moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

16. The flattening method according to claim 15, wherein the processing member is composed of an ion exchanger or a material containing an ion exchanger.

17. The flattening method according to claim 15, wherein the first polishing is carried out while keeping the processing member in contact with the pattern region, and the second polishing is carried out while keeping the processing member contactless with the pattern region.

18. The flattening method according to claim 15, wherein the first polishing is carried out while keeping the processing member in contact with the pattern region, and a resistance-forming processing of the pattern region is carried out prior to or simultaneously with the second polishing.

19. The flattening method according to claim 15, wherein the second polishing is carried out while keeping the processing member contactless with the pattern region and simultaneously carrying out a resistance-forming processing of the pattern region.

20. The flattening method according to claim 15, wherein at least one of the first polishing and the second polishing is carried out while keeping a contact member, disposed in the vicinity of the processing electrode and/or the feeding electrode, in contact with the surface of the metal film of the workpiece.

21. The flattening method according to claim 13, wherein the first polishing and the second polishing are carried out respectively by:

applying a voltage between a processing electrode, disposed close to or in contact with the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film;

supplying a liquid between the workpiece and at least one of the processing electrode and the feeding electrode; and

moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

22. The flattening method according to claim 21, wherein a resistance-forming processing of the pattern region is carried out prior to or simultaneously with the second polishing.

23. The flattening method according to claim 21, wherein the second polishing is carried out while keeping the processing electrode contactless with the pattern region and simultaneously carrying out a resistance-forming processing of the pattern region.

24. The flattening method according to claim 21, wherein at least one of the first polishing and the second polishing is carried out while keeping a contact member, disposed in the vicinity of the processing electrode and/or the feeding electrode, in contact with the surface of the metal film of the workpiece.

25. The flattening method according to claim 21, wherein at least one of the first polishing and the second polishing is carried out while keeping the processing electrode at a distance of 0.05 to 50 μm from the surface of the metal film of the workpiece.

26. The flattening method according to claim 13, wherein the end point of the first polishing is detected by time management, detection of a table current, or image recognition.

27. A flattening apparatus comprising:

a first polishing section for polishing a surface of a metal film, formed on a workpiece and having a pattern region and a field region, in such a manner that the polishing rate of the metal film in the pattern region is higher than the polishing rate of the metal film in the field region; and

a second polishing section for polishing the metal film surface in such a manner that the polishing rate of the metal film in the field region is higher than the polishing rate of the metal film in the pattern region.

28. The flattening apparatus according to claim 27, wherein at least one of the first polishing section and the second polishing section carries out polishing by electrolytic processing.

AMENDED CLAIMS

[received by the International Bureau on 17 May 2006 (17.05.06)]

1. (Amended) A flattening method for processing and flattening a surface of a metal film formed on a workpiece and having initial surface irregularities, comprising:

coating only recessed portions of the initial surface irregularities of the metal film with a pasty coating material; and

processing the surface of the metal film by electrolytic processing.

2. The flattening method according to claim 1 further comprising removing the coating material which has not been processed by the electrolytic processing and remains on the surface of the metal film, and further processing the surface of the metal film.

3. The flattening method according to claim 1, wherein the coating material is an insulating material having a resistivity of not less than 10^6 Ω·cm or a conductive material having a resistivity of not more than 10^3 Ω·cm.

4. The flattening method according to claim 1, wherein only the recessed portions of the initial surface irregularities of the metal film are coated with the coating material by applying the coating material onto the entire surface of the metal film, and then removing only the coating material lying on the raised portions of the initial surface irregularities.

9. The flattening method according to claim 1, wherein the processing of the surface of the metal film by the electrolytic processing is carried out by:

applying a voltage between a processing electrode, disposed close to the metal film of the workpiece, and a feeding electrode for feeding electricity to the metal film;

supplying a liquid between the workpiece and at least one of the processing electrode and the feeding electrode; and

moving the workpiece relative to at least one of the processing electrode and the feeding electrode.

10. The flattening method according to claim 9, wherein the processing of the surface of the metal film by the electrolytic processing is carried out by bringing a contact member, disposed beside the processing electrode and/or the feeding electrode, into contact with the metal film surface.

11. (Amended) A flattening apparatus comprising:

a coating material processing apparatus for coating only recessed portions of initial surface irregularities of a metal film with a pasty coating material; and

an electrolytic processing apparatus for processing the surface of the metal film by electrolytic processing.

12. The flattening apparatus according to claim 11, wherein the coating material processing apparatus comprises a resist processing apparatus.

26. The flattening method according to claim 13, wherein the endpoint of the first polishing is detected by time management, detection of a table current, or image recognition.

27. A flattening apparatus comprising:

a first polishing section for polishing a surface of a metal film, formed on a workpiece and having a pattern region and a field region, in such a manner that the polishing rate of the metal film in the pattern region is higher than the polishing rate of the metal film in the field region; and

a second polishing section for polishing the metal film surface in such a manner that the polishing rate of the metal film in the field region is higher than the polishing rate of the metal film in the pattern region.

28. The flattening apparatus according to claim 27, wherein at least one of the first polishing section and the second polishing section carries out polishing by electrolytic processing.

29. (Added) A flattening method for processing and flattening a surface of a metal film formed on a workpiece and having initial surface irregularities, comprising:

coating only recessed portions of the initial surface irregularities of the metal film with a solid or pasty insulating coating material having a resistivity of not less than $10^6\ \Omega\cdot cm$; and

processing the surface of the metal film by electrolytic processing.

30. (Added) The flattening method according to claim 29 further comprising removing the coating material which has not been processed by the electrolytic processing and remains on the surface of the metal film, and further processing the surface

of the metal film.

31. (Added) A flattening apparatus comprising:

a coating material processing apparatus for coating only recessed portions of initial surface irregularities of a metal film with a solid or pasty insulating coating material having a resistivity of not less than 10^6 Ω·cm; and

an electrolytic processing apparatus for processing the surface of the metal film by electrolytic processing.

FIG. 1A

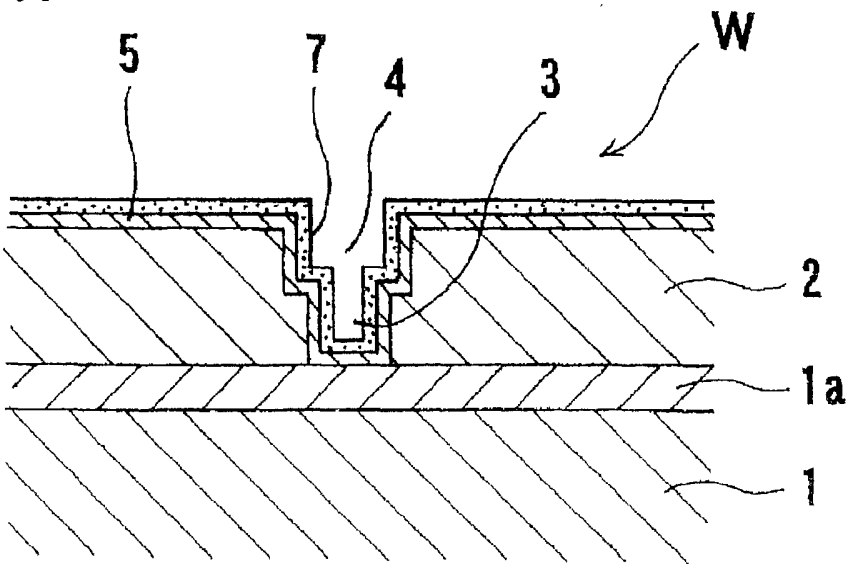

FIG. 1B

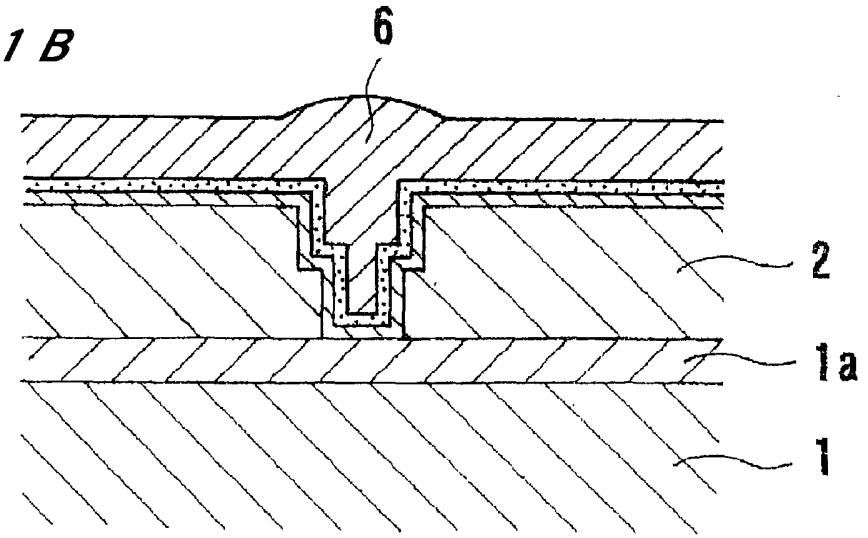

FIG. 1C

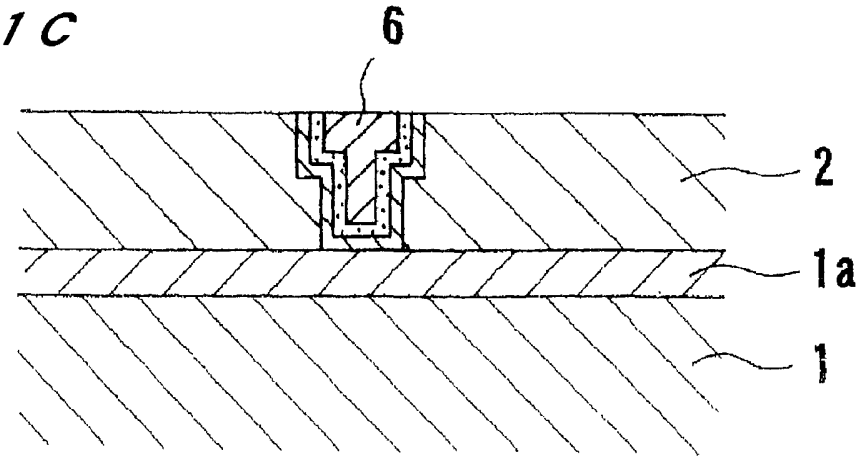

FIG. 2A

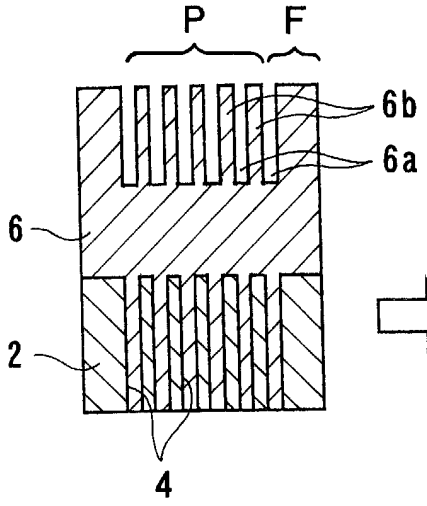

FIG. 2B

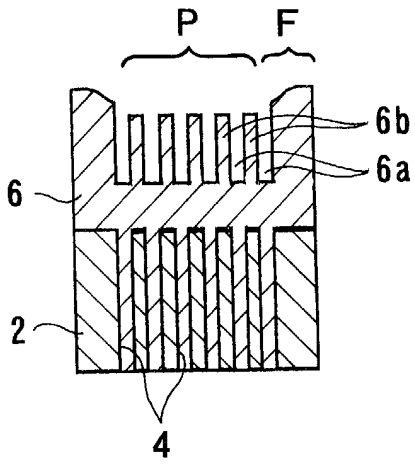

FIG. 2C

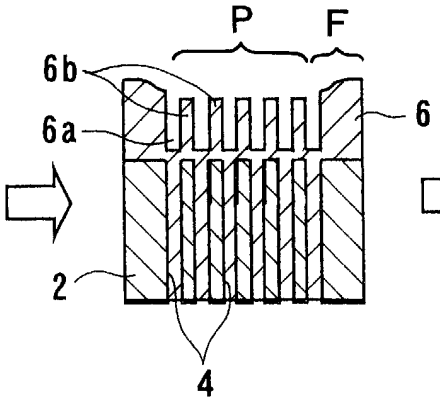

FIG. 2D

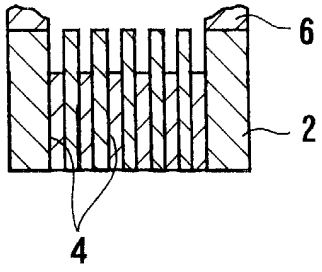

FIG. 3A

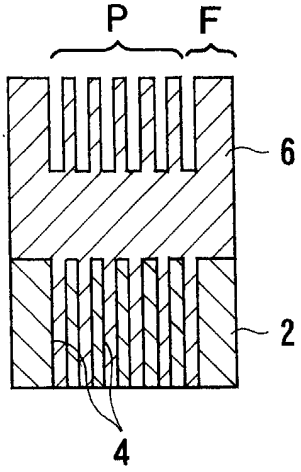

FIG. 3B

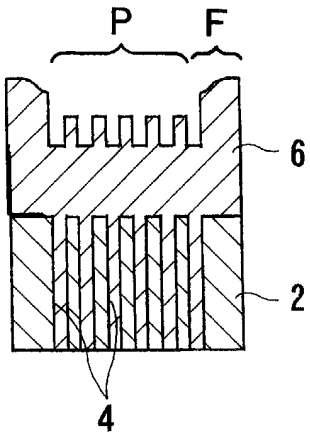

FIG. 3C

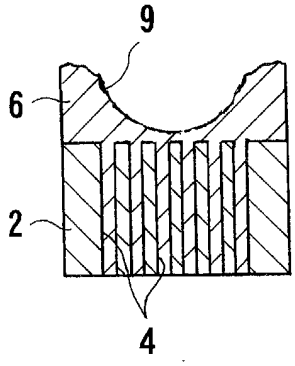

FIG. 4A

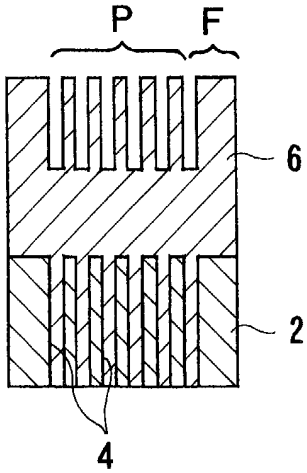

FIG. 4B

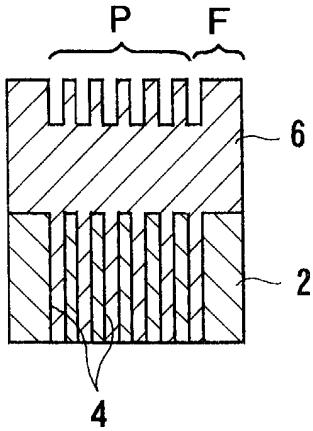

FIG. 4C

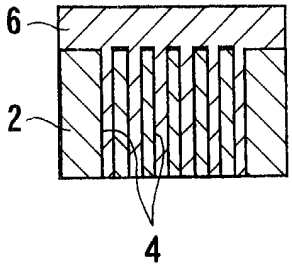

FIG. 5

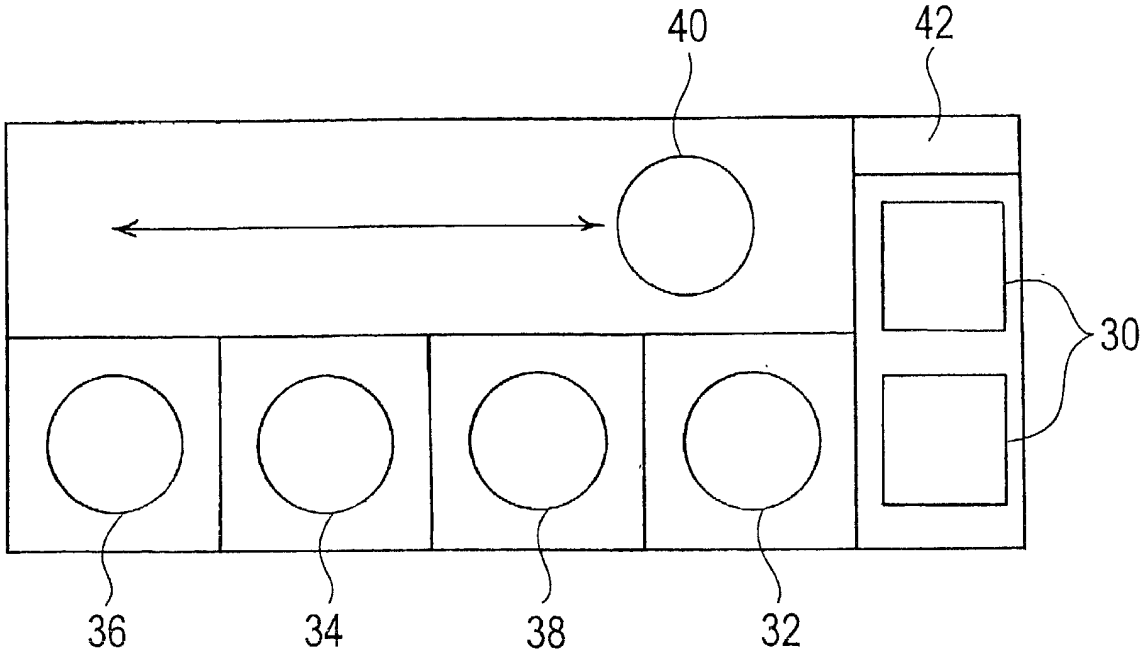

FIG. 6

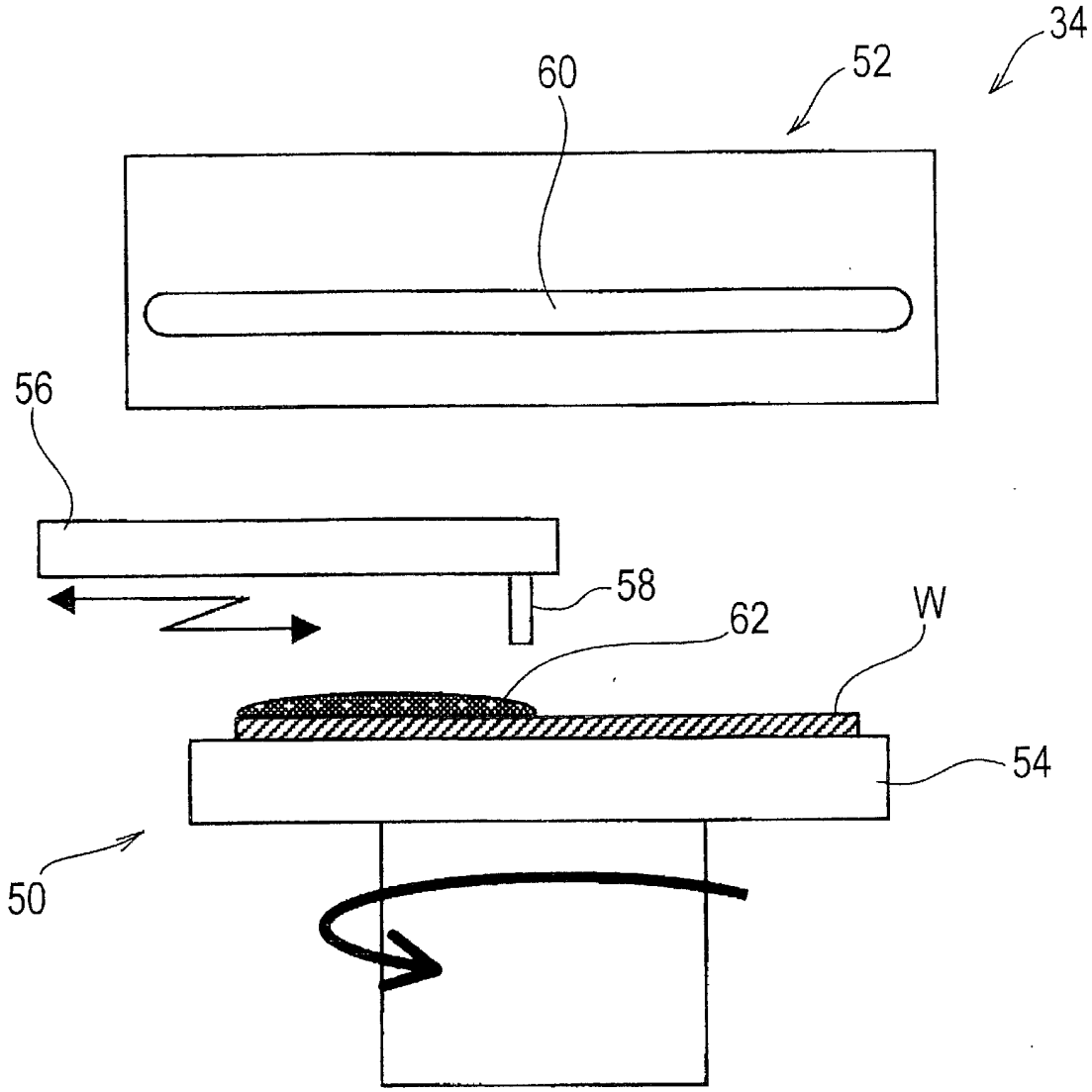

FIG. 7A FIG. 7B FIG. 7C

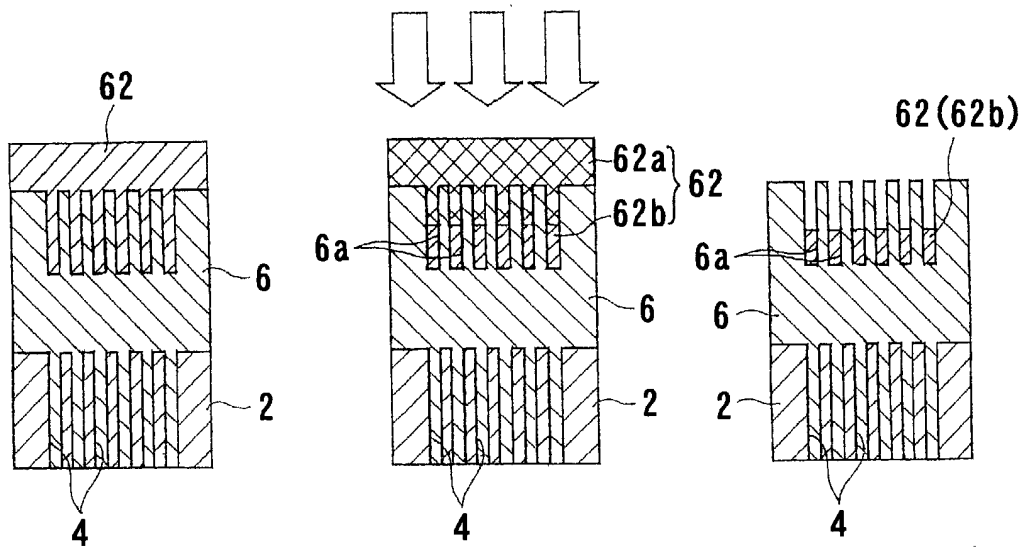

FIG. 8

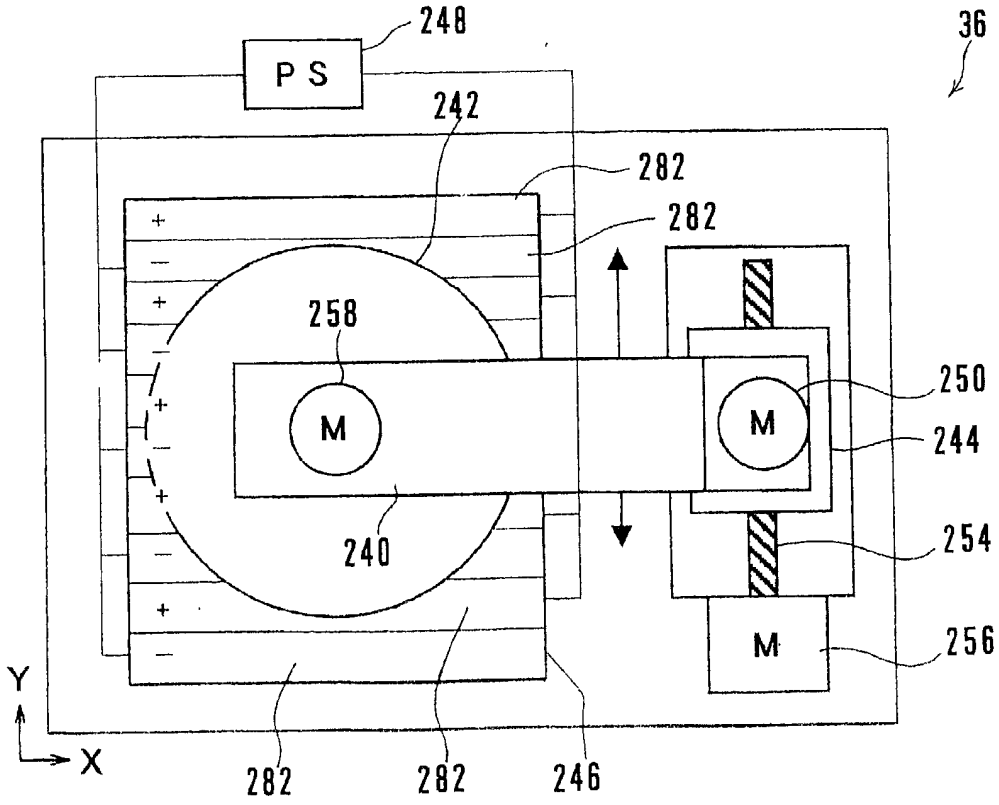

FIG. 9

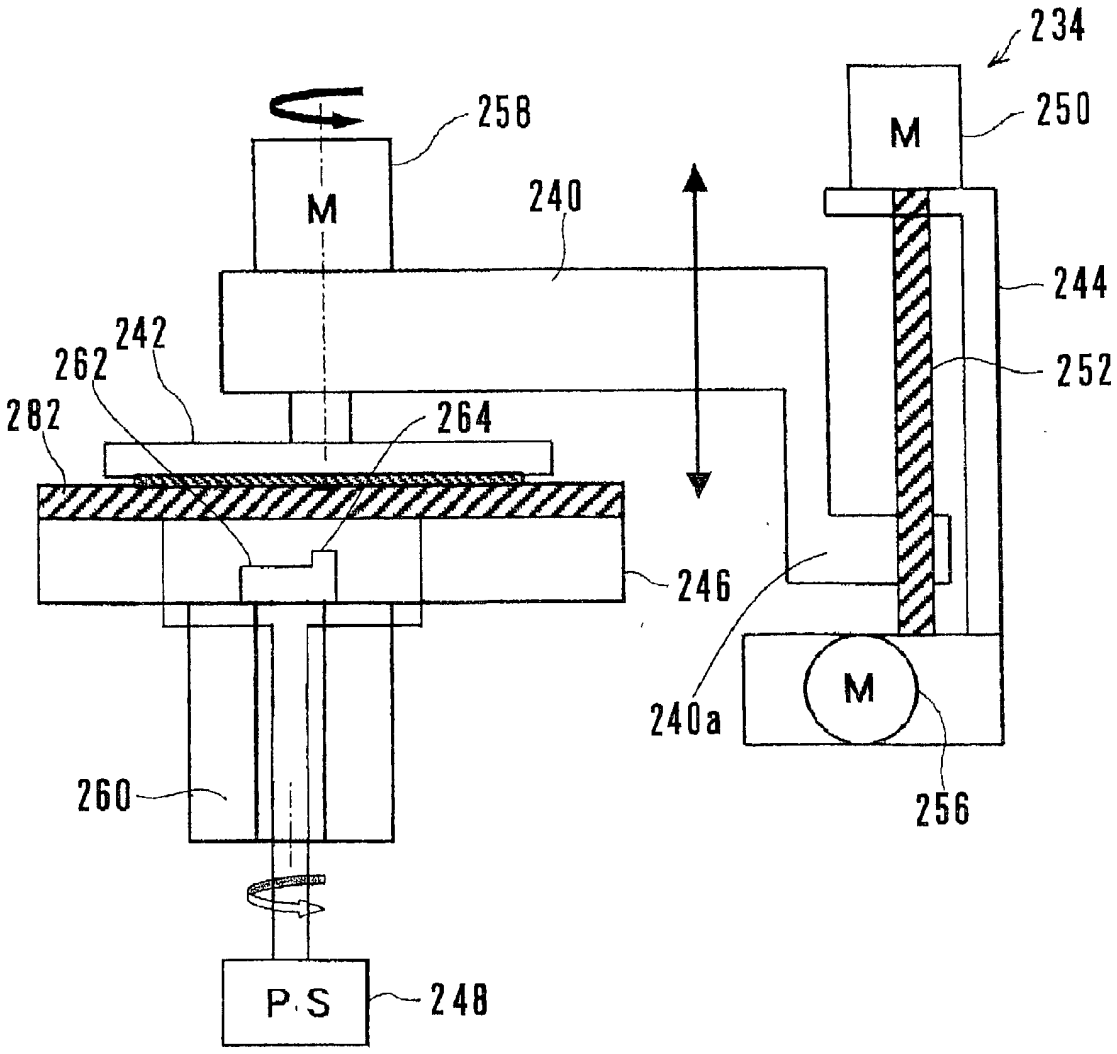
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FIG. 10

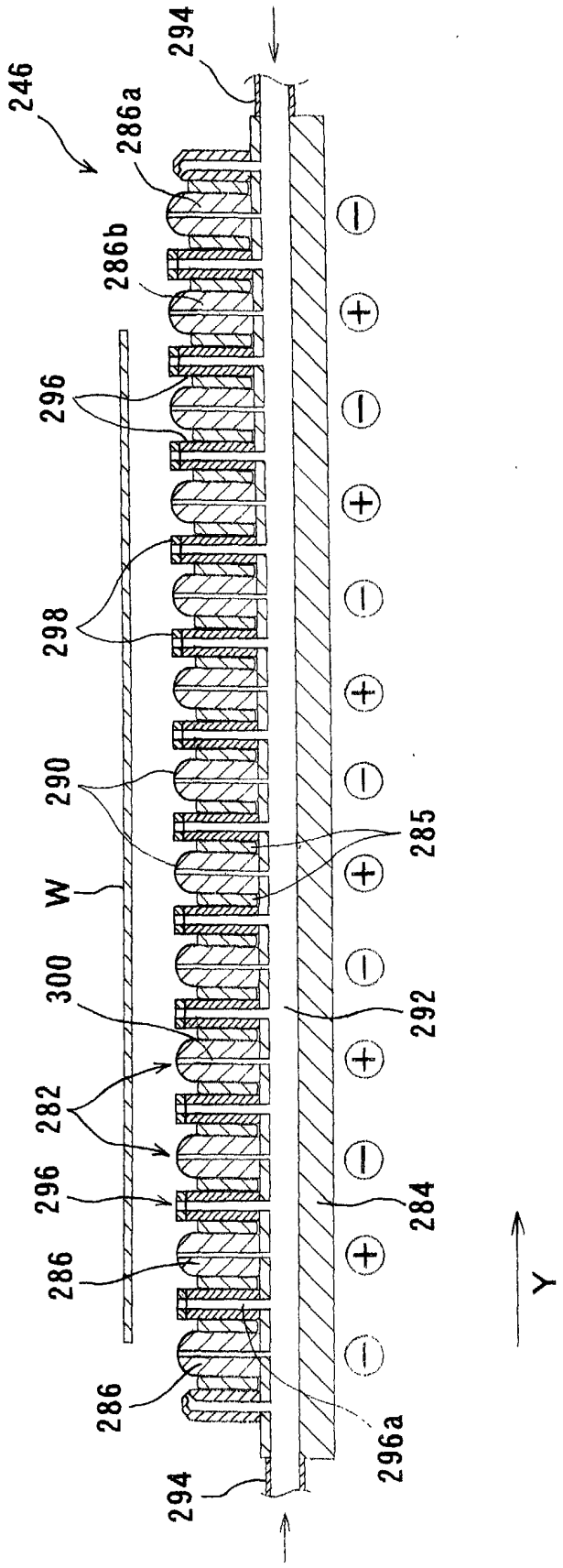
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FIG. 11

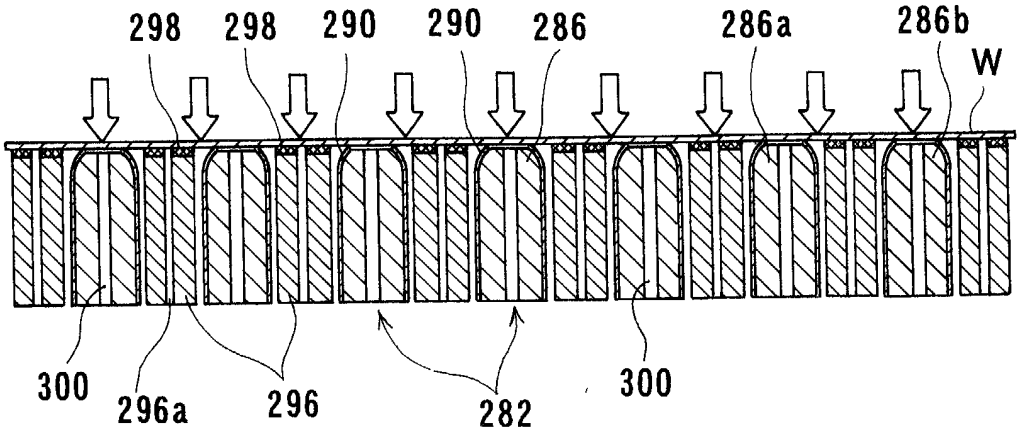

FIG. 12A

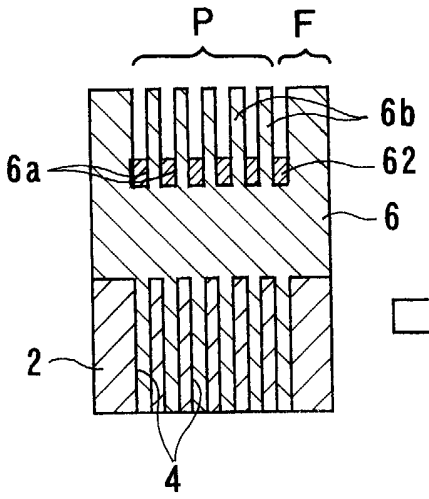

FIG. 12B

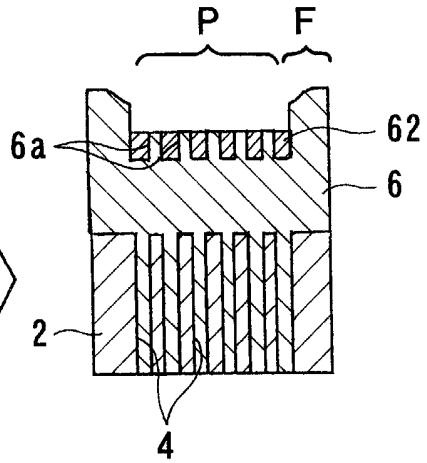

FIG. 12C

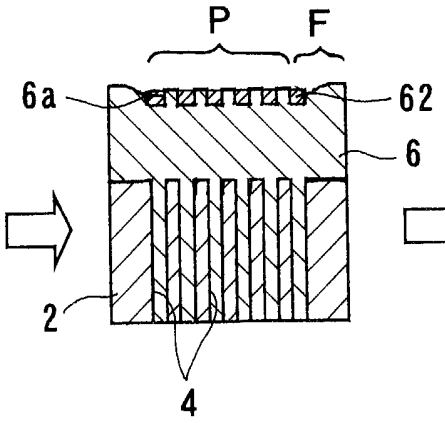

FIG. 12D

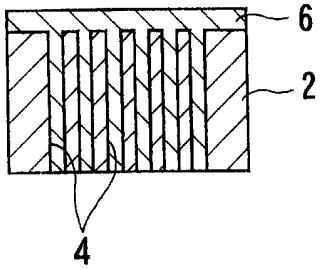

FIG. 13

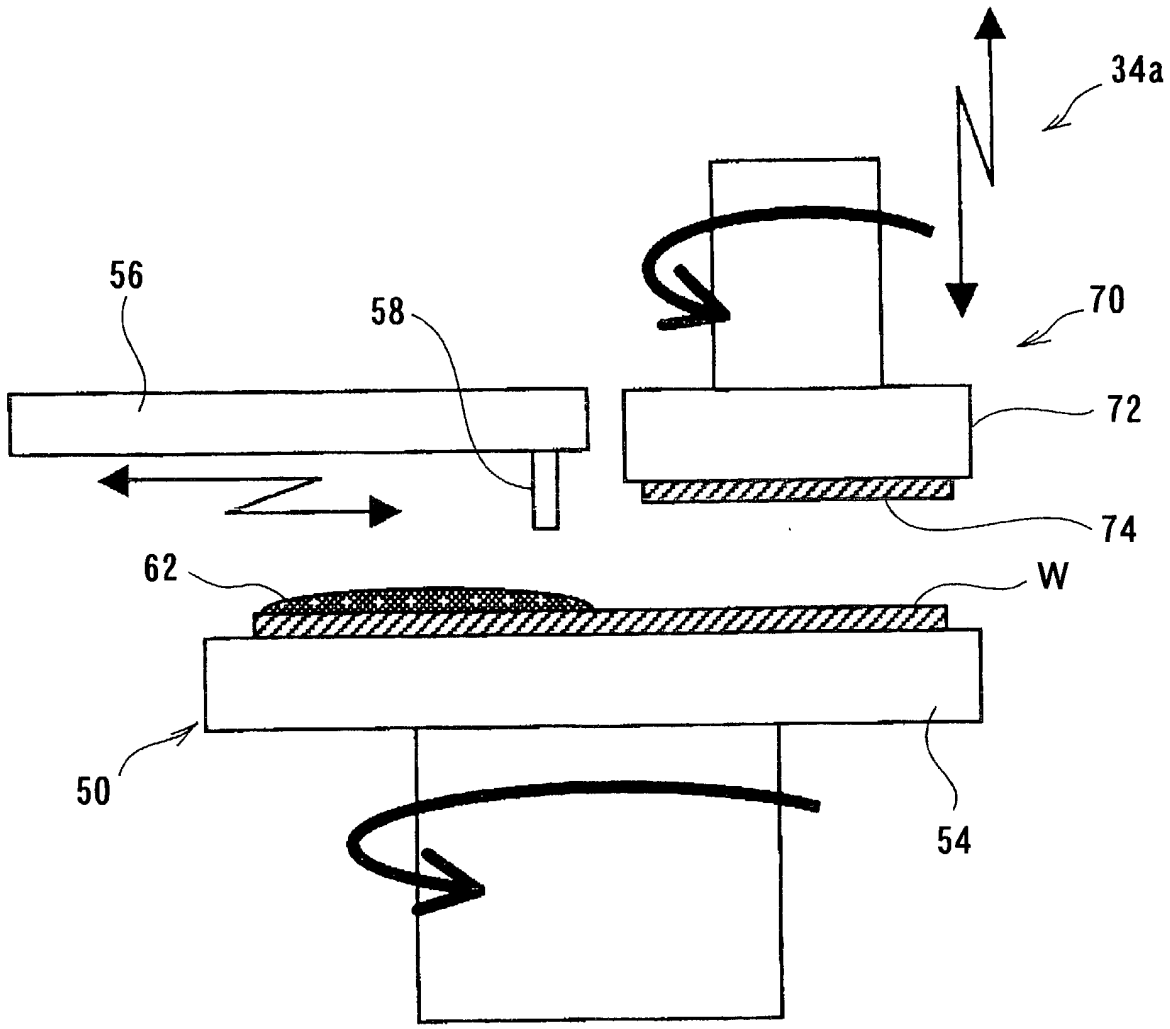

FIG. 14A

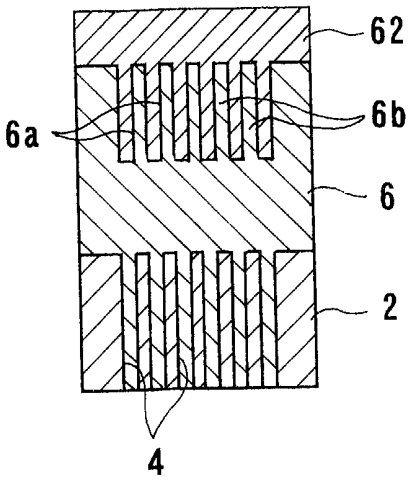

FIG. 14B

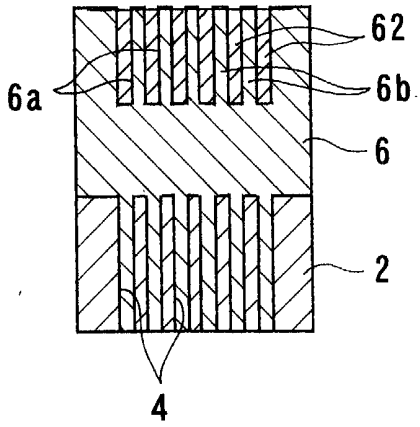

FIG. 15A

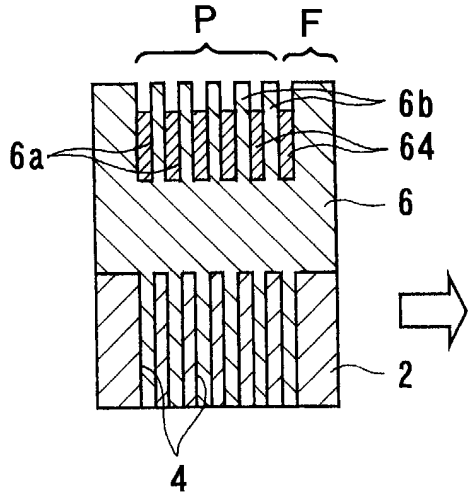

FIG. 15B

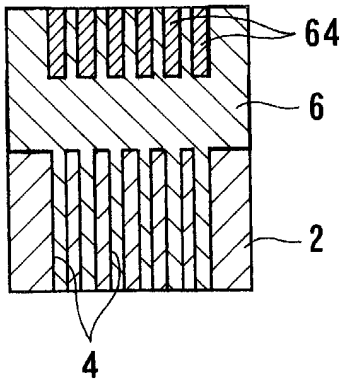

FIG. 15C

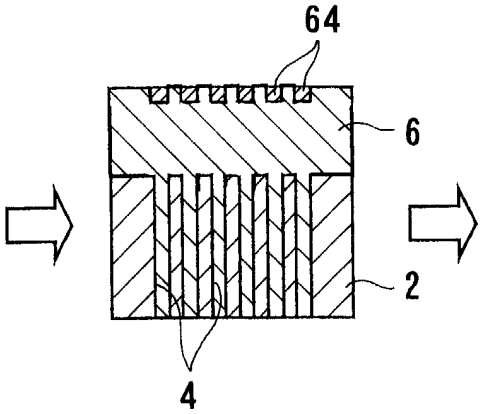

FIG. 15D

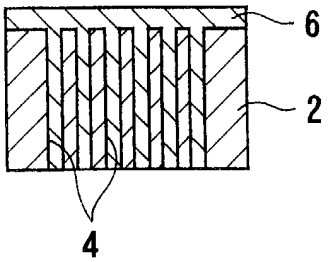

FIG. 16

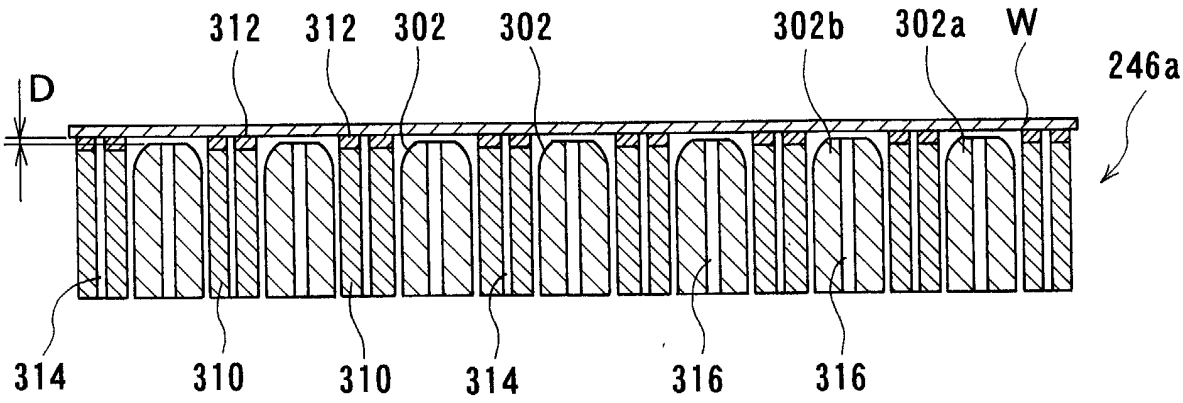

FIG. 17

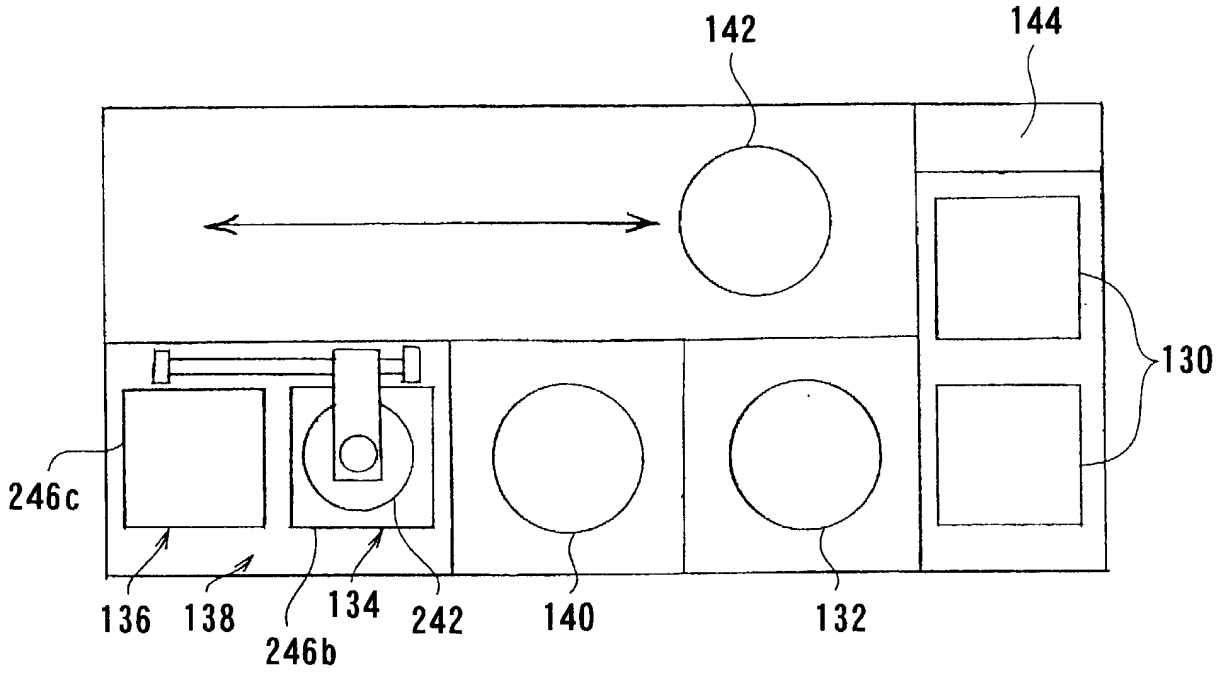

FIG. 18

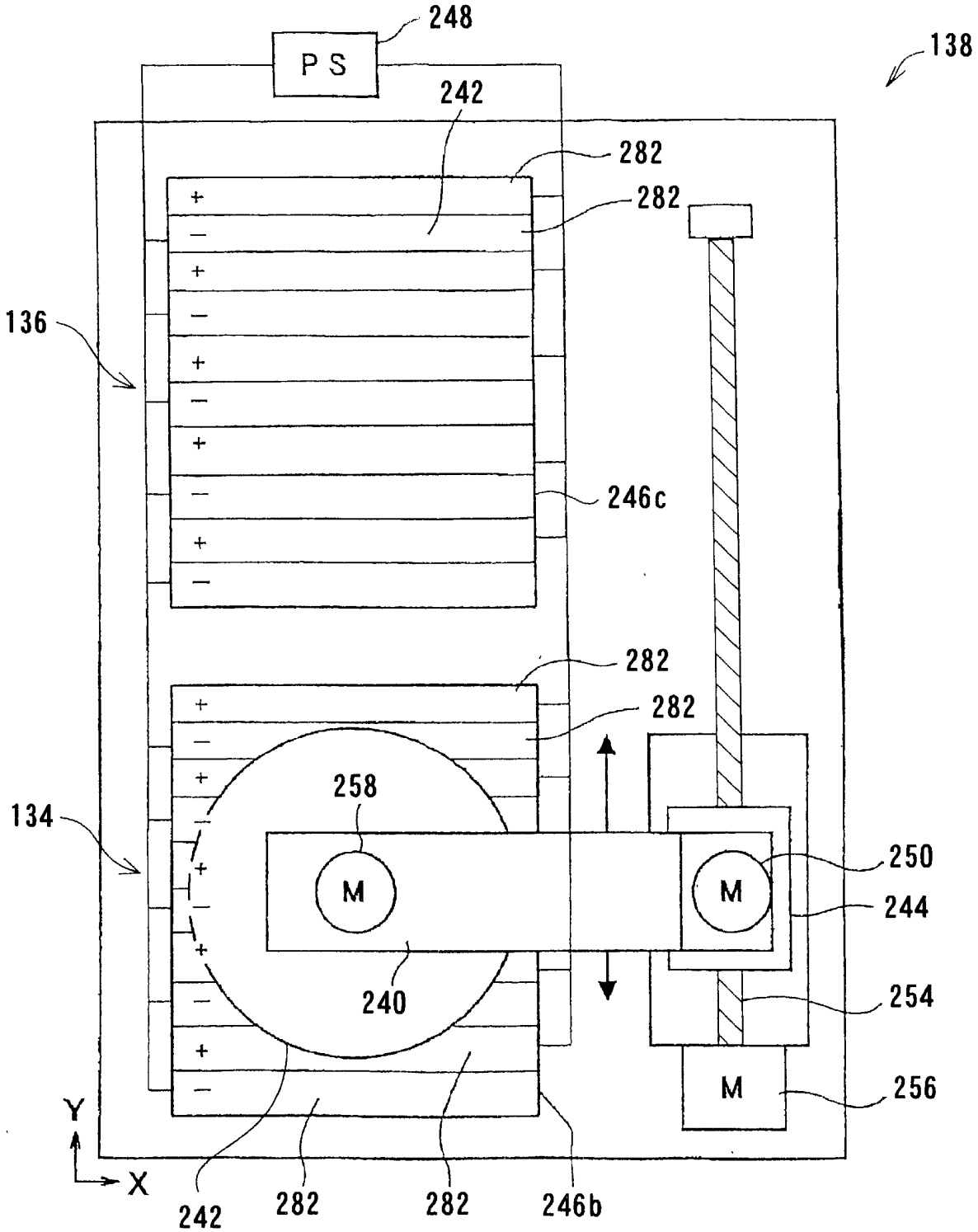
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FIG. 19

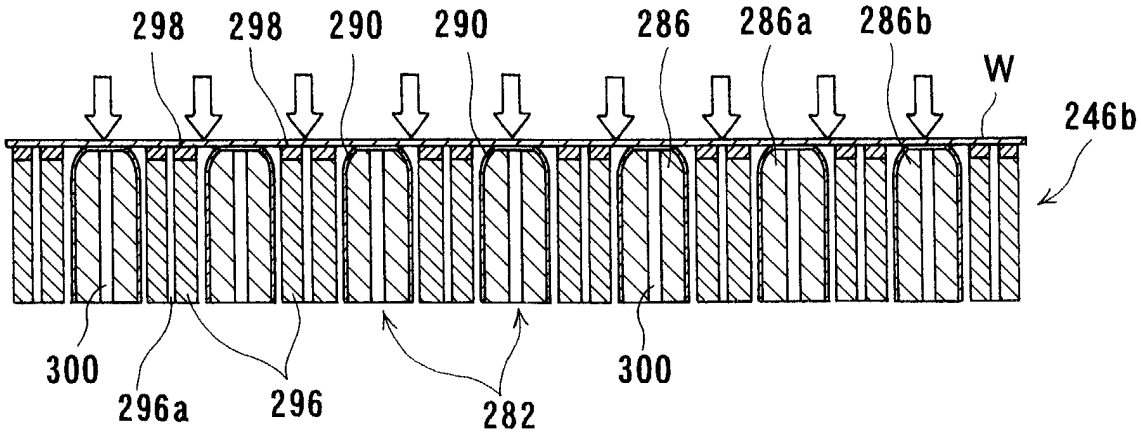
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FIG. 20

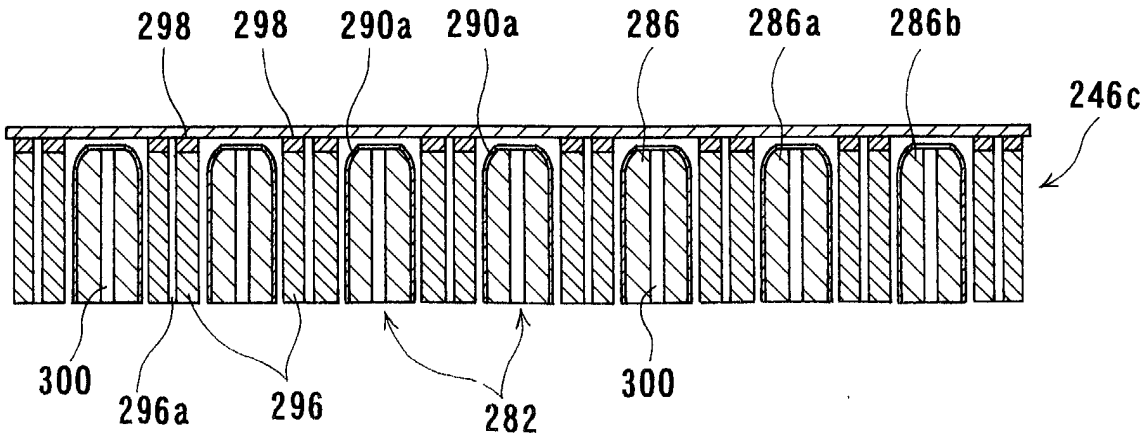
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FIG. 21A

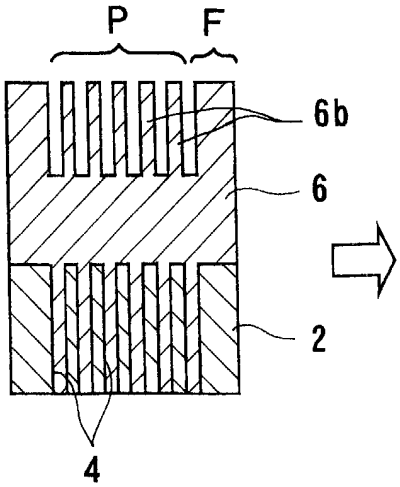


FIG. 21B

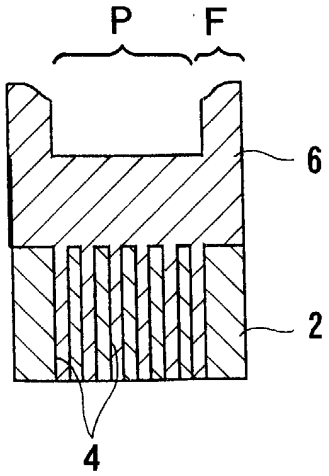


FIG. 21C

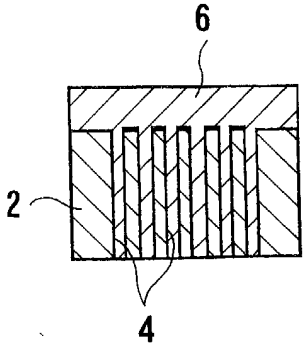


FIG. 22

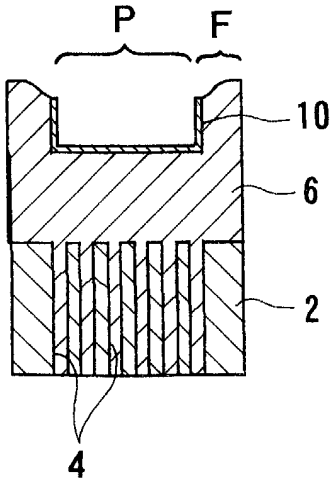


FIG. 23

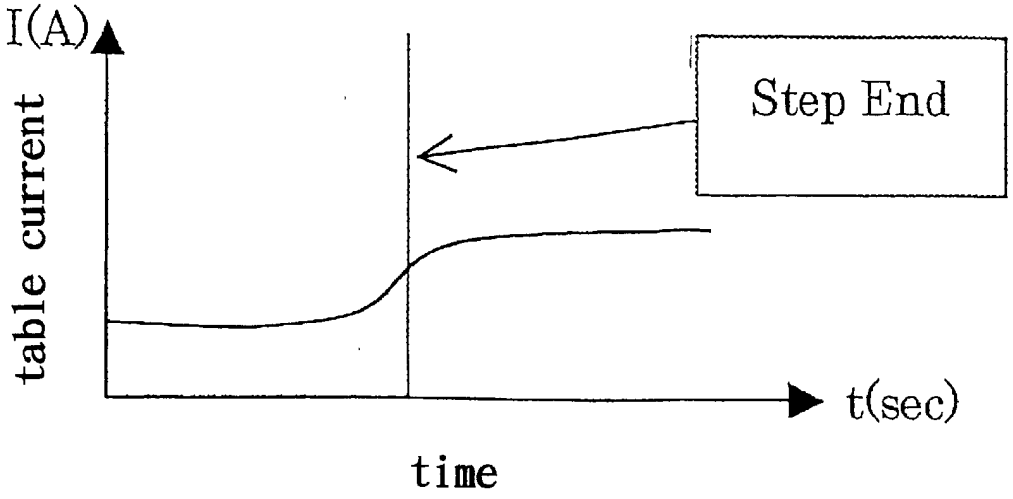


FIG. 24A

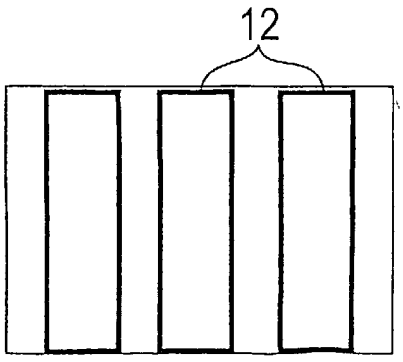
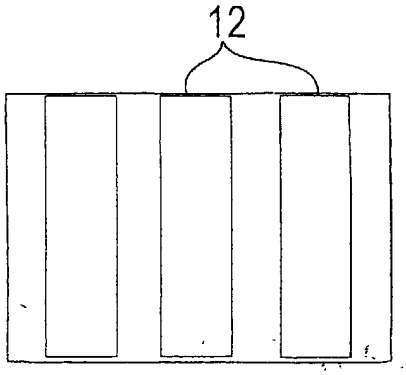


FIG. 24B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2005/023989

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. *H01L21/3205(2006.01), C25F3/16(2006.01), C25F7/00(2006.01), H01L21/306(2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. *H01L21/3205(2006.01), C25F3/16(2006.01), C25F7/00(2006.01), H01L21/306(2006.01)*

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2006
Registered utility model specifications of Japan 1996-2006
Published registered utility model applications of Japan 1994-2006

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2004/034456 A1 (TOKYO ELECTRON LIMITED) 2004.04.22, See whole document, Figs. 1-2G & JP 2004-134601 A	1, 3-5, 11 6-10
X Y	WO 2003/017330 A2 (ACM RESEARCH, INC.) 2003.02.27, See whole document, Figs. 3-6 & JP 2005-500687 A & US 2004/0253809 A1 & EP 1423868 A2 & CA 2456225 A1 & CN 1543668 A & TW 569330 A & KR 2004030147 A	1-4, 11-12 6-10
X Y A	WO 2003/080898 A1 (EBARA CORPORATION) 2003.10.02, See whole document, Figs. 1-55 & US 2004/0129569 A1 & EP 1489204 A1 & TW 200305470 A & KR 2004104545 A & CN 1656257 A	27-28 6-10 15-25

☑ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10.03.2006	20.03.2006

Name and mailing address of the ISA/JP	Authorized officer	
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Tomokazu Hayakawa Telephone No. +81-3-3581-1101 Ext. 3462	4M 9733

INTERNATIONALSEARCHREPORT

International application No.
PCT/JP2005/023989

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	WO 2004/034452 A1 (EBARA CORPORATION) 2004.04.22, See whole document, Figs. 1-30 & JP 2006-502310 A	27-28 6-10 15-25
X Y A	WO 2004/095571 A1 (EBARA CORPORATION) 2004.11.04, See whole document, Figs. 1-51 & JP 2004-327561 A	27-28 6-10 15-25
X A	US 6693036 B1 (Sony Corporation) 2004.02.17, See whole document, Figs. 9-24 & JP 2001-077117 A & TW 507318 A & KR 2001030284 A	27-28 13-26
A	US 2002/0016064 A1 (Naoki KOMAI) 2002.02.07, See whole document, Figs. 1-4 & JP 2001-338926 A & TW 512454 A & KR 2001107786 A	1-28
A	JP 2004-111940 A (TOKYO SEIMITSU CO., LTD.) 2004.04.08, See whole document, Figs. 2-3 (Family: none)	1-28

INTERNATIONALSEARCHREPORT

International application No.
PCT/JP2005/023989

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Claims 1-12 relate to a flattening method and a flattening apparatus, comprising coating recessed portions of a surface with a coating material and processing the surface by electrolytic processing.

Claims 13-28 relate to a flattening method and a flattening apparatus, comprising two step polishing.

There is no technical relationship among those inventions involving one or more of the same or corresponding technical features. Therefore, these groups of inventions are not so linked as to form a single general inventive concept.

1. ☑ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☑ No protest accompanied the payment of additional search fees.