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(54) **ELECTROPLATING METHOD USING COMBINATION OF VIBRATIONAL FLOW IN PLATING BATH AND PLATING CURRENT OF PULSE**

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(57) **ABSTRACT**

In an electroplating method, a plating target article (X) disposed so as to be in contact with plating bath **(14)** is set as a cathode while a metal member disposed so as to be in contact with the plating bath **(14)** is set as an anode, and a voltage is applied between the cathode and the anode while vibrational flow is induced by vibrating vibrational vanes **(16*f*)** which are fixed in multi-stage style to a vibrating rod **(16*e*)** vibrating in the plating bath **(14)** interlockingly with vibration generating means **(16*d*)**. Plating current flowing from the anode through the plating bath **(14)** to the cathode is pulsed and alternately set to one of a first state where the plating current keeps a first value **I1** for a first time **T1** and a second state where the plating current keeps a second value **I2** having the same polarity as the first value **I1** for a second time **T2**, the first value **I1** being five or more times larger than the second value **I2**, and the first time **T1** being three or more times longer than the second time **T2.**

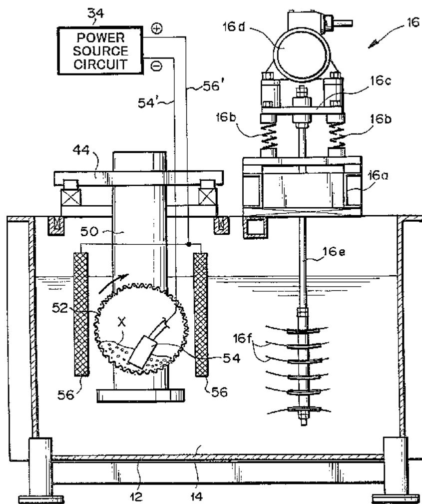


FIG.1

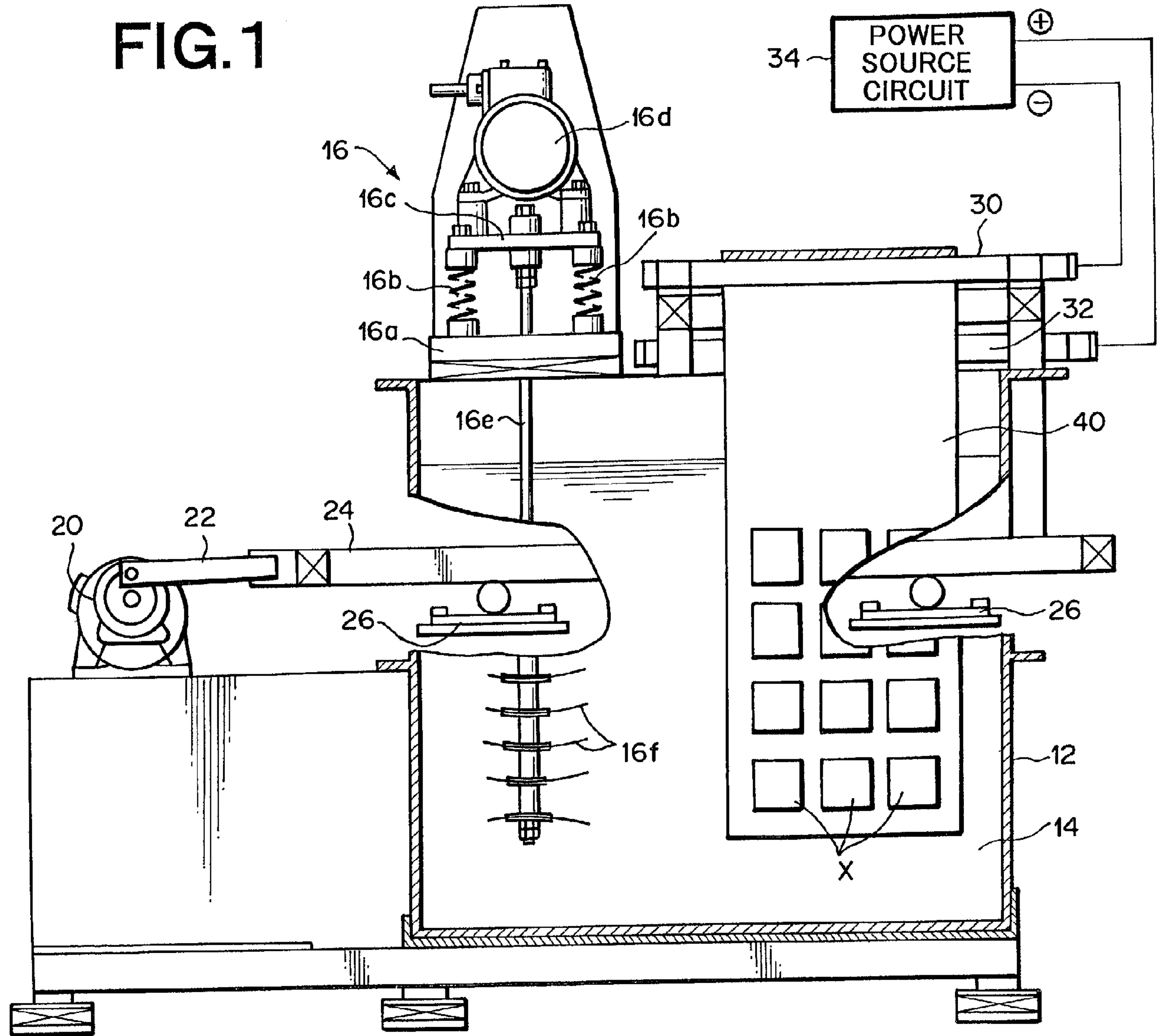


FIG.2

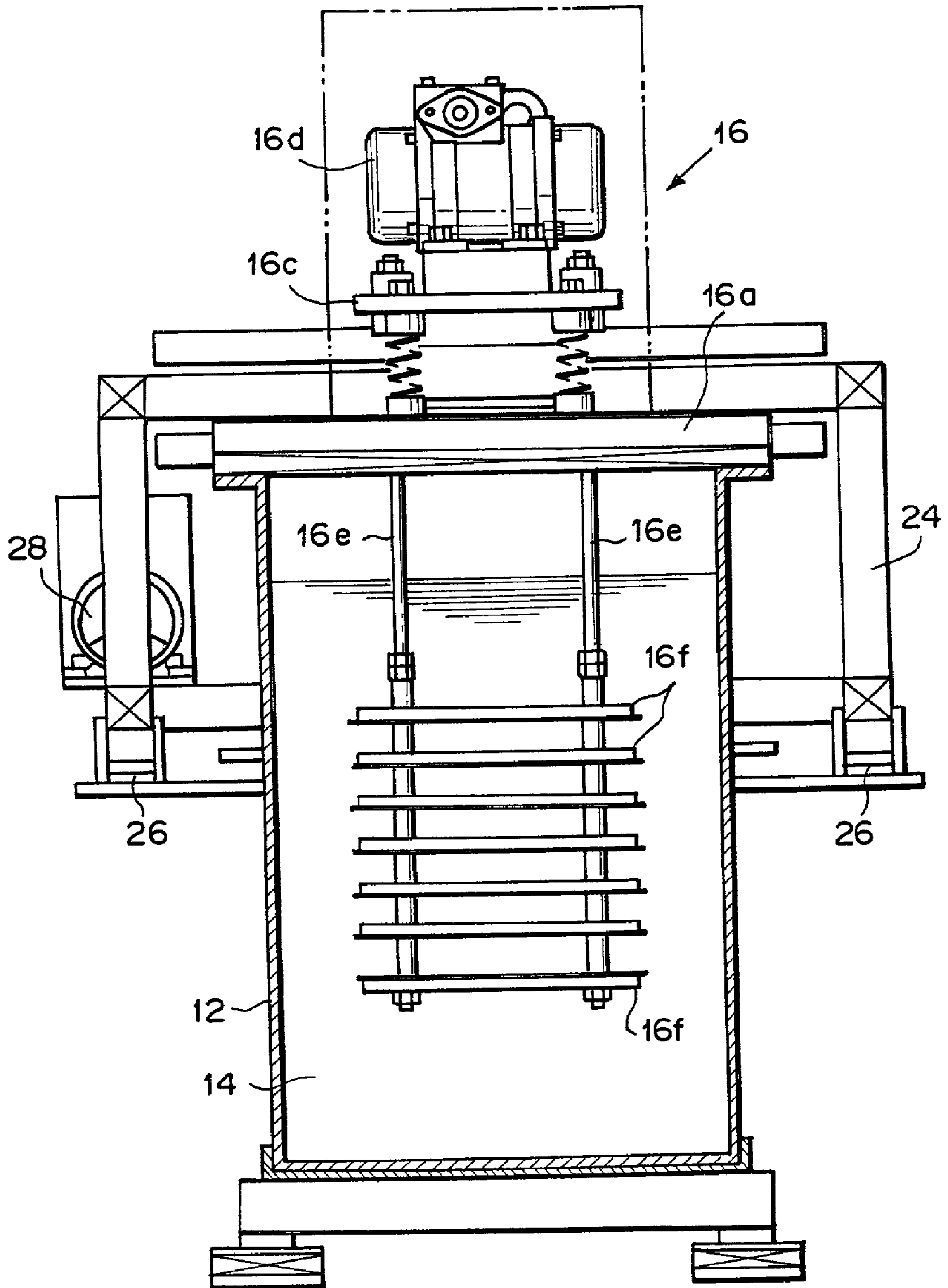


FIG.3

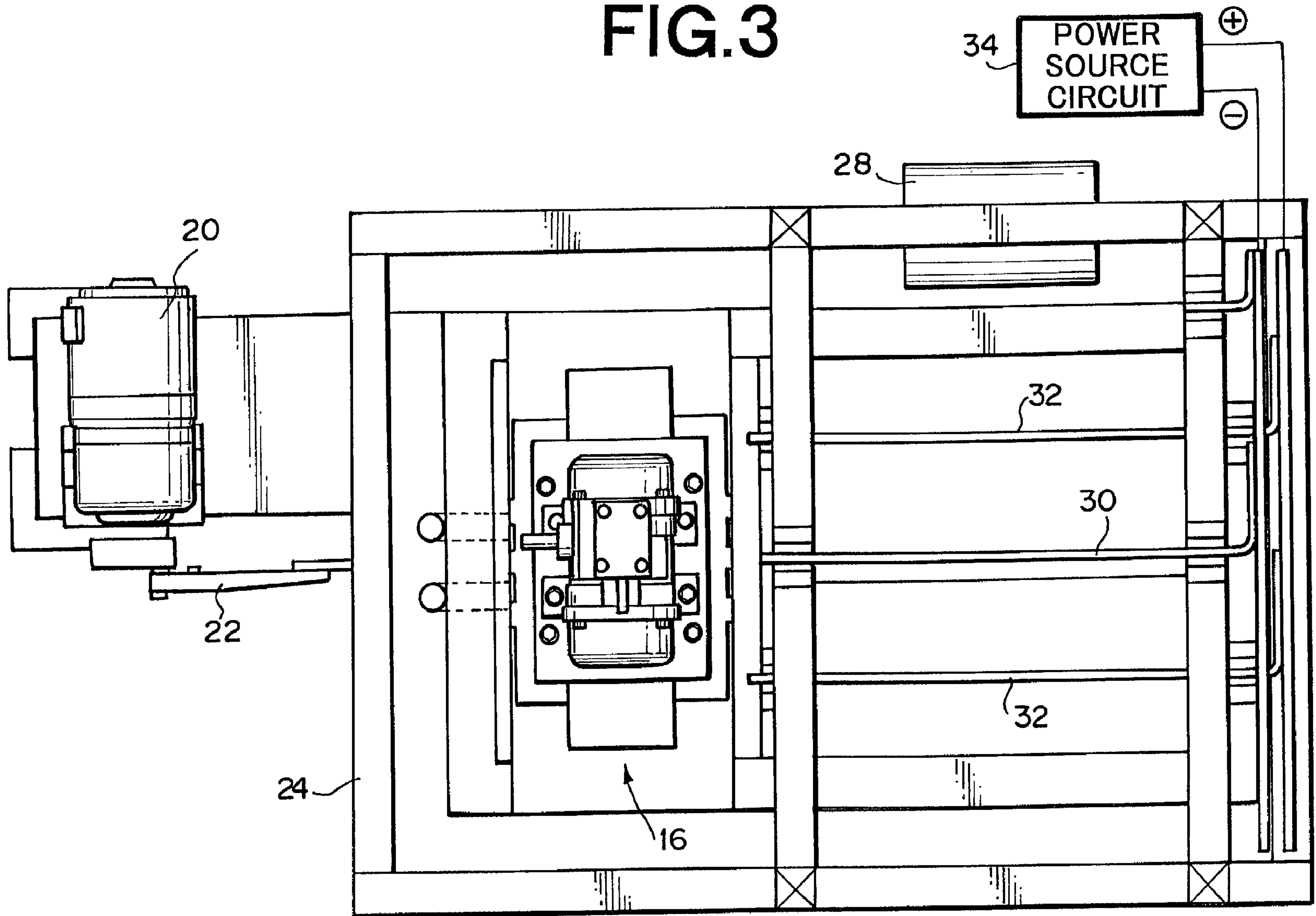


FIG.4

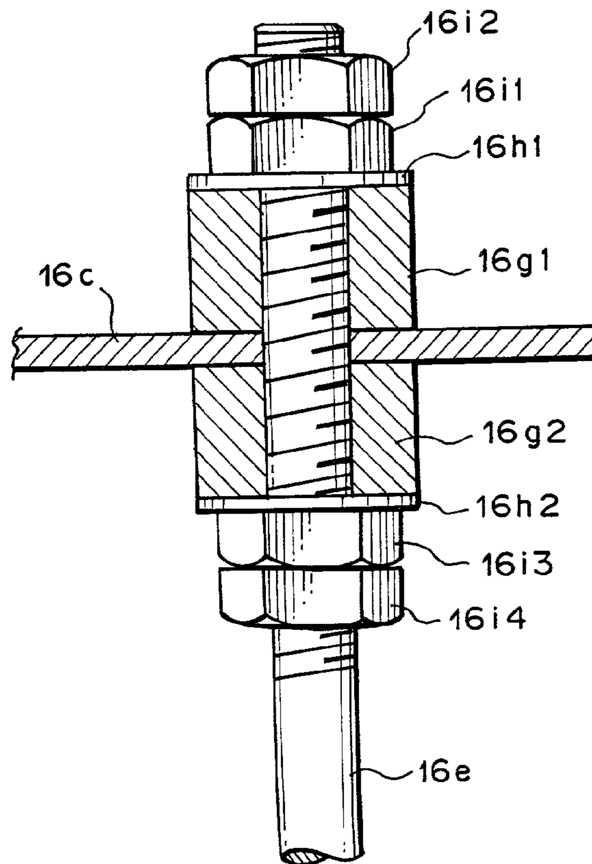


FIG.5

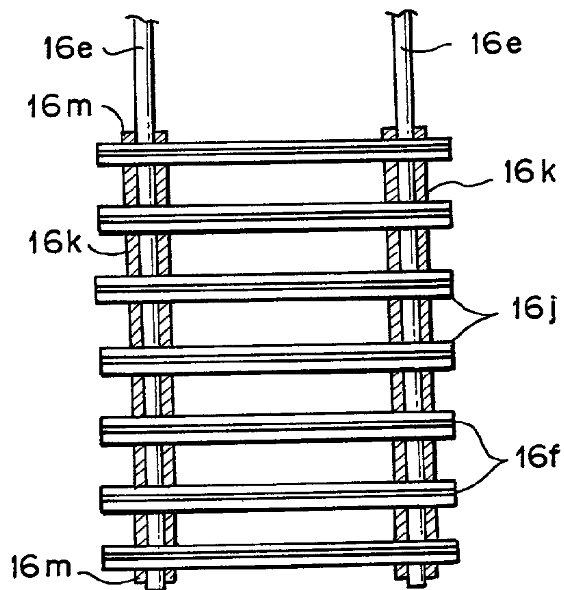


FIG.6

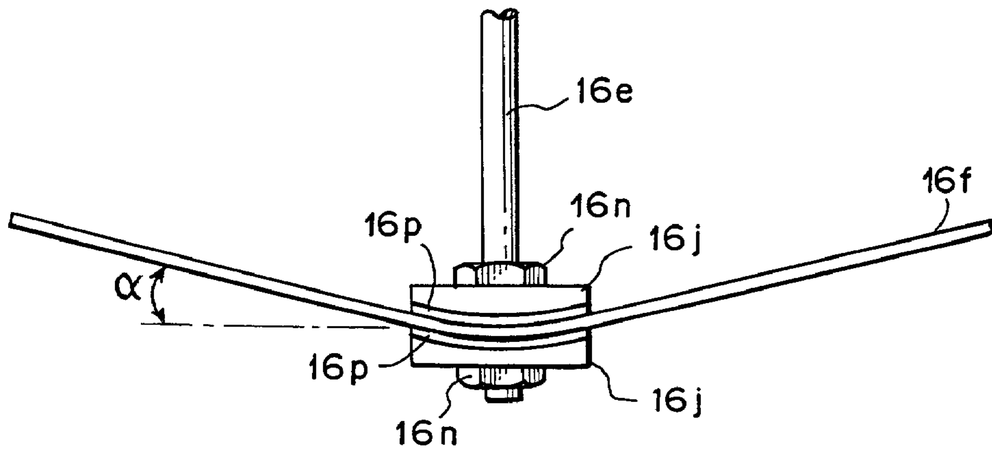


FIG.7

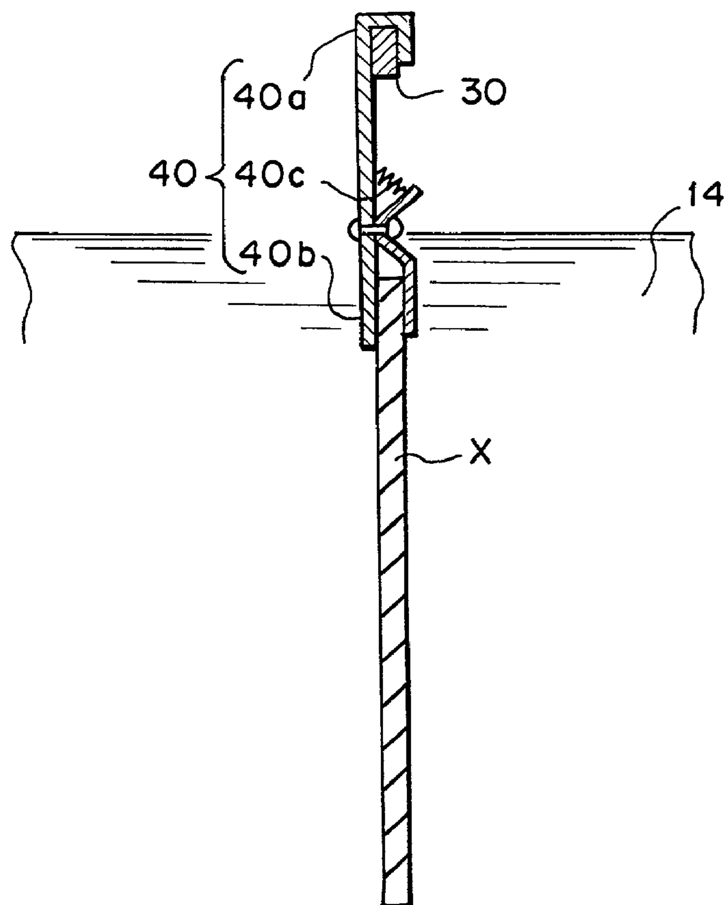


FIG.8

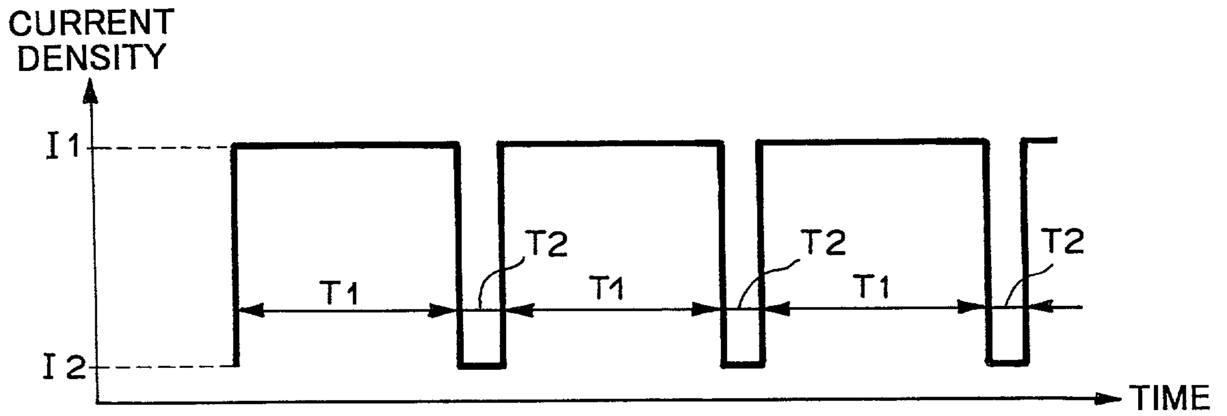


FIG.9

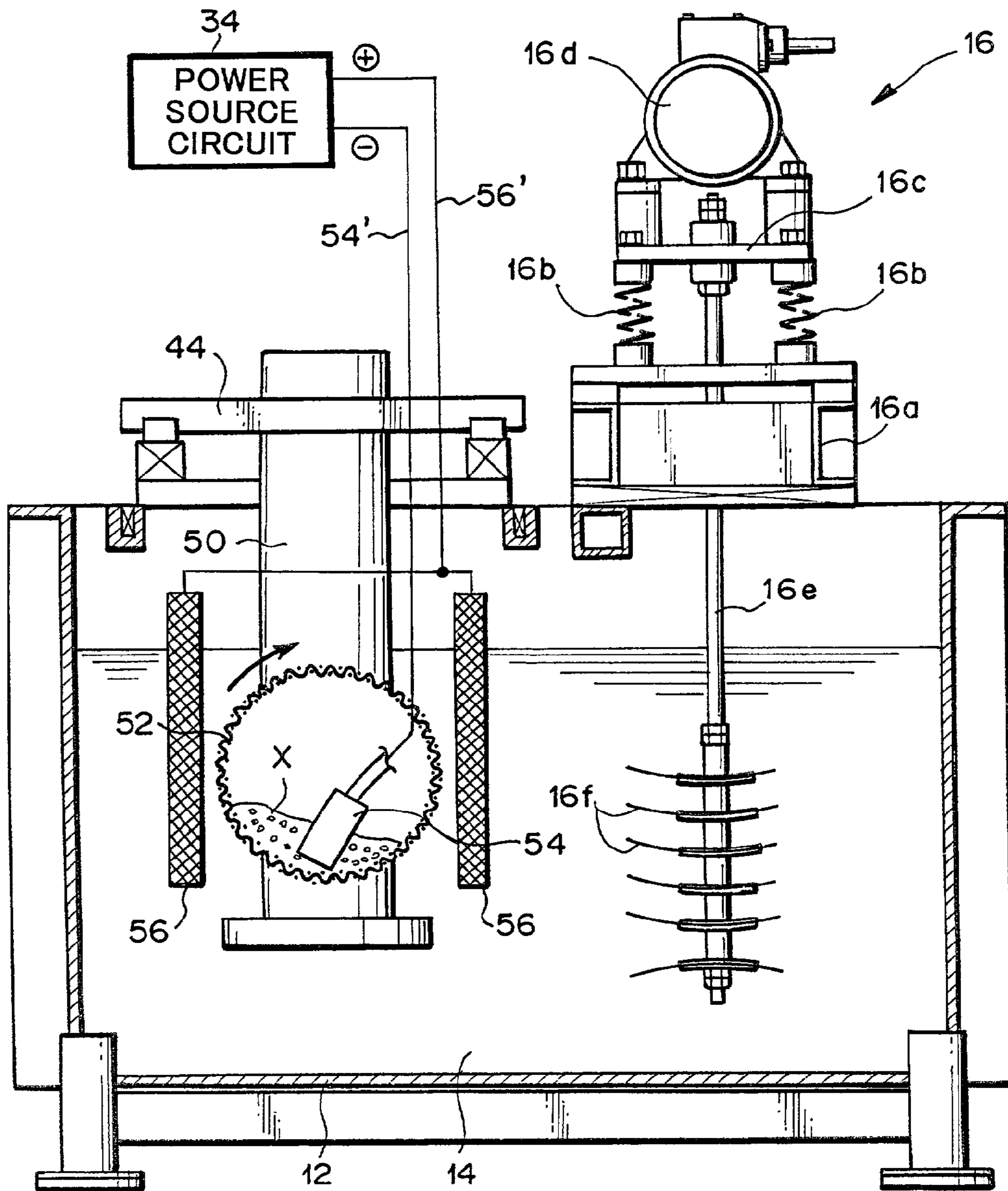


FIG.10

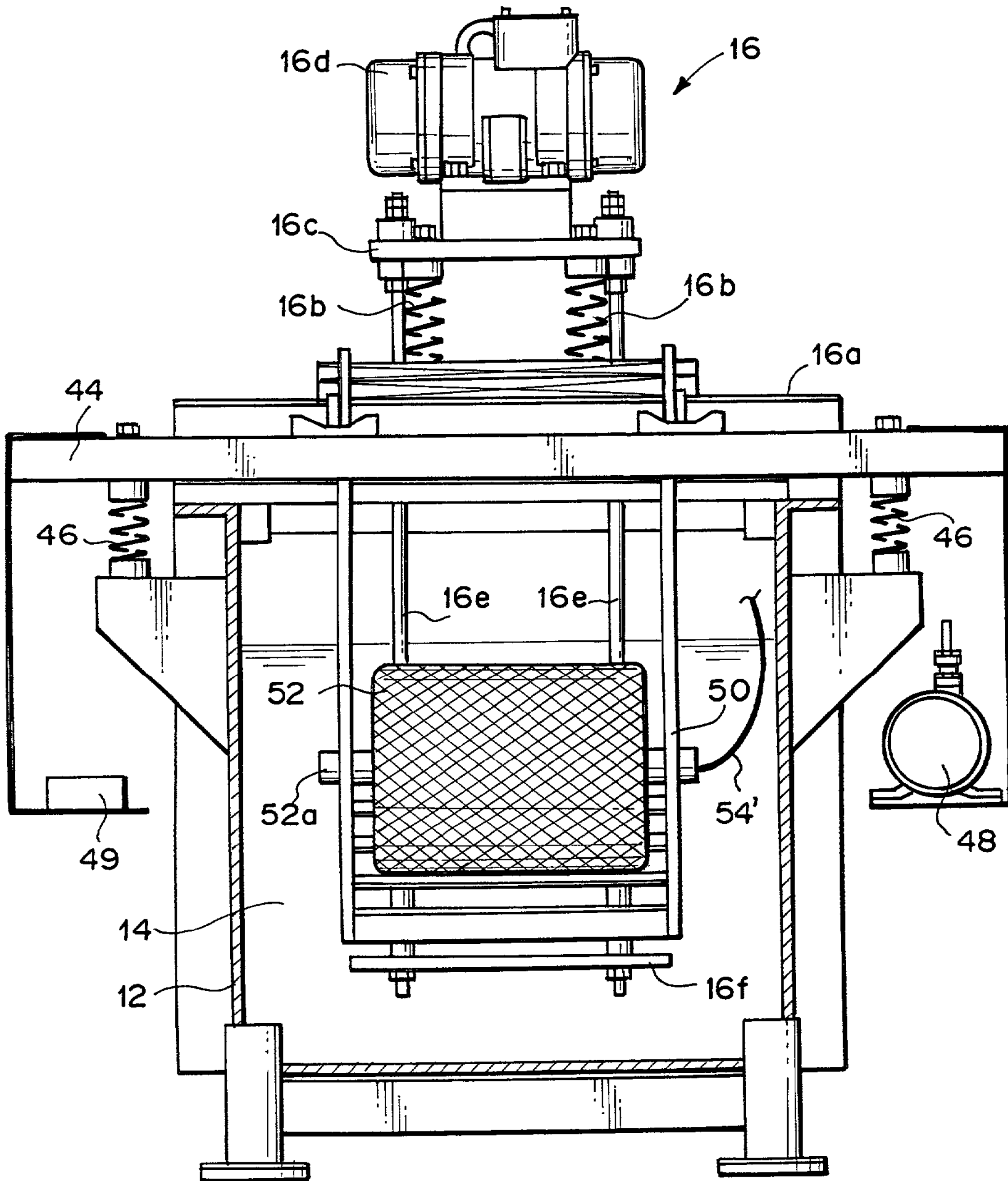


FIG.11

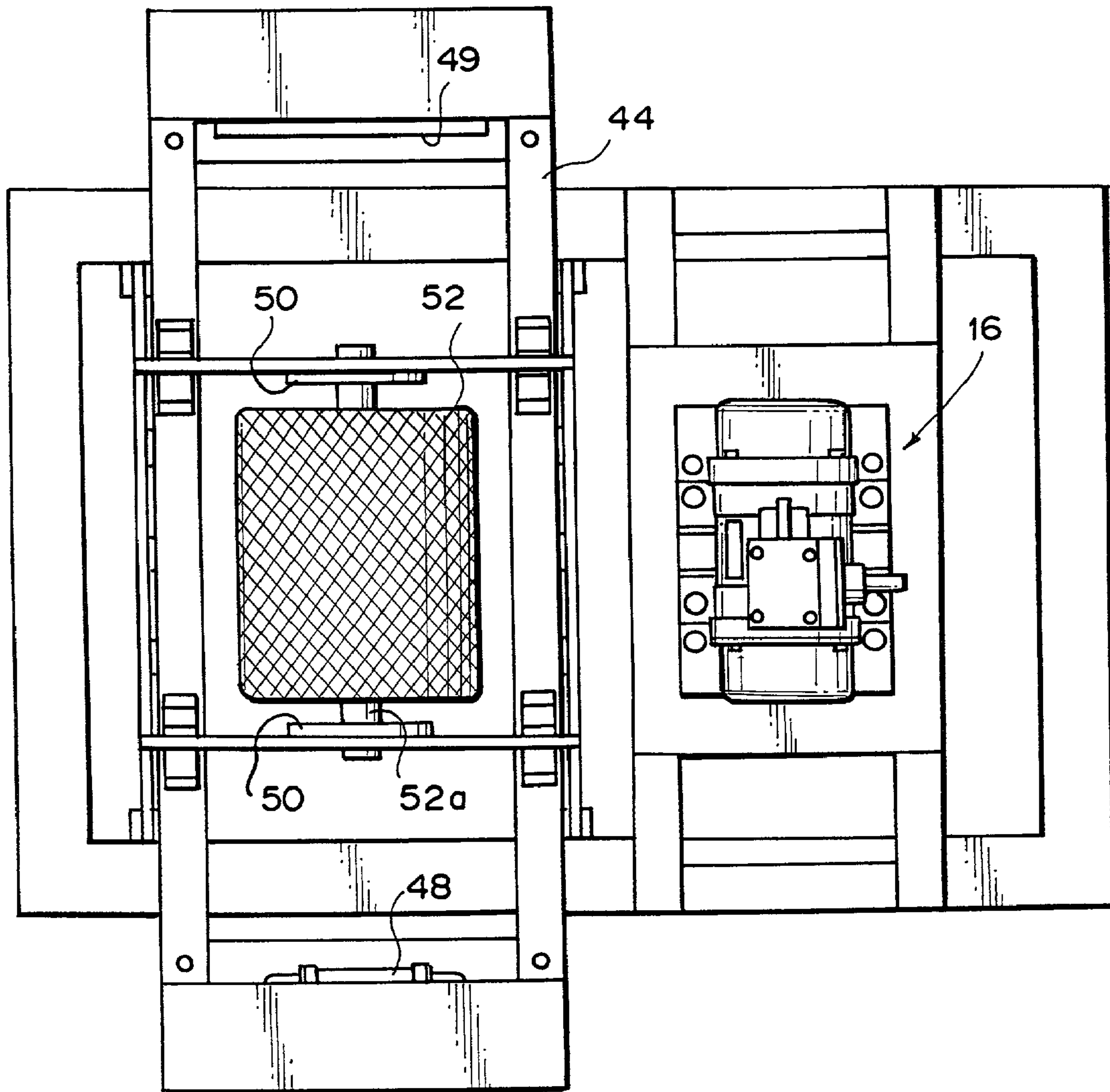


FIG.12

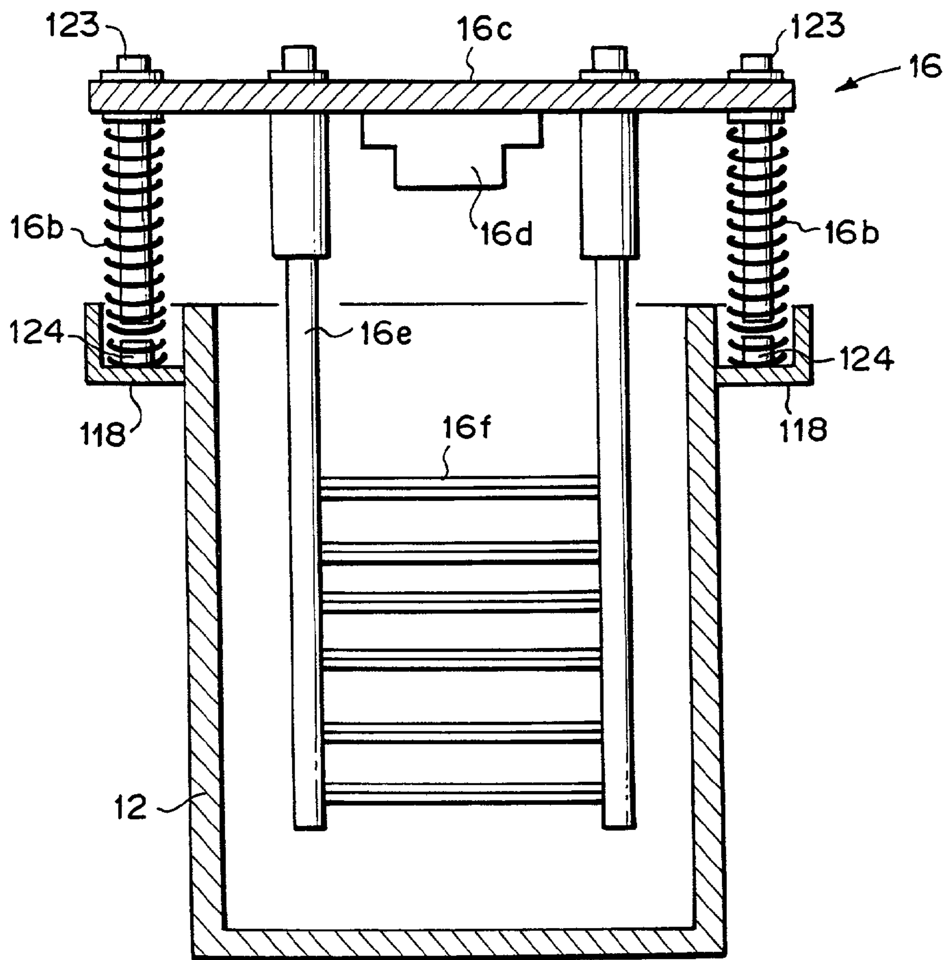


FIG.13

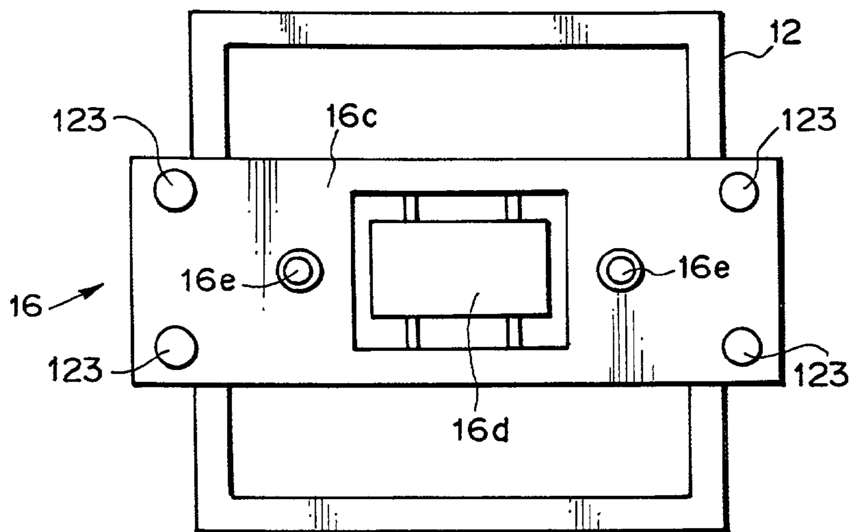


FIG. 14

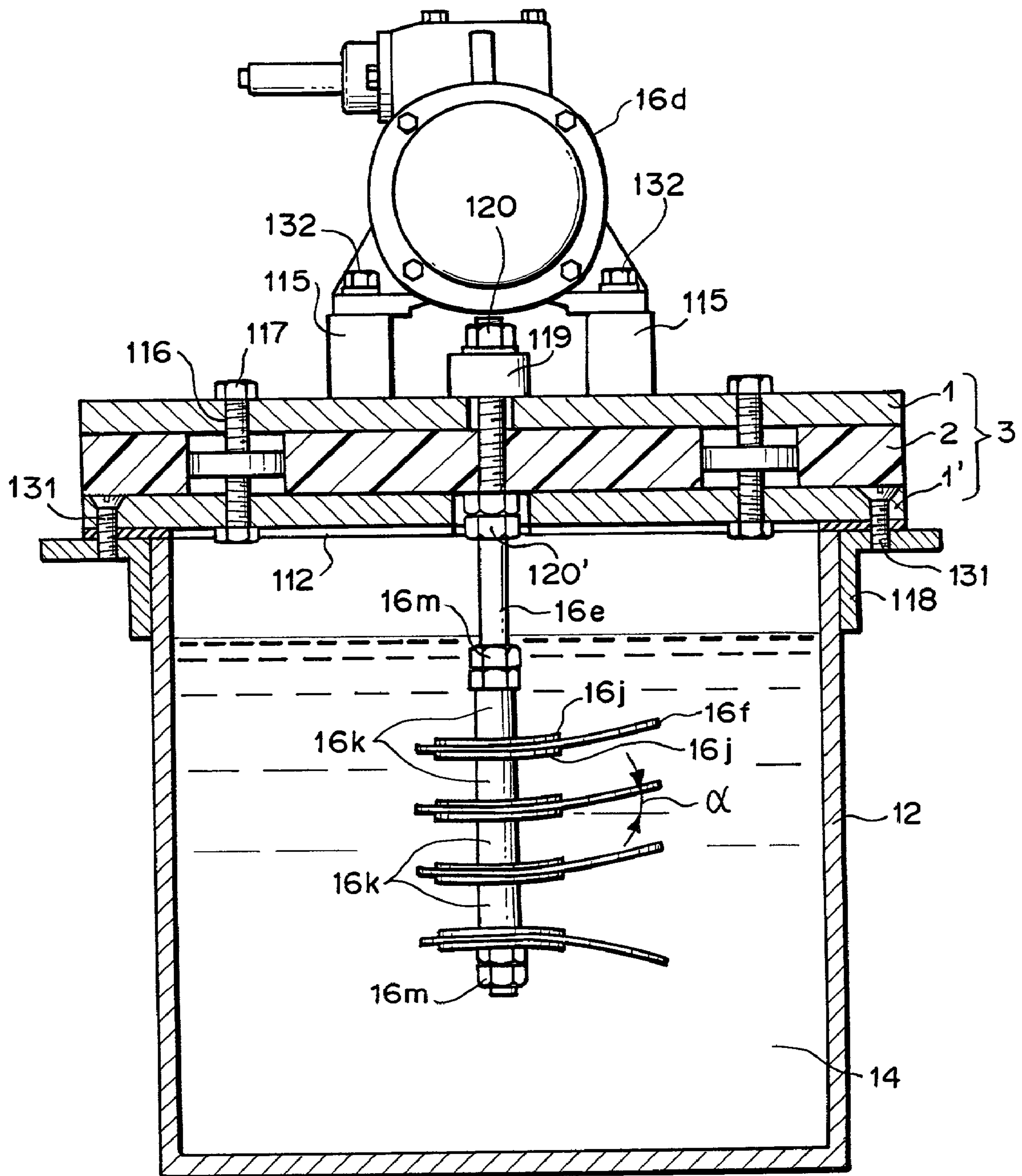


FIG. 15

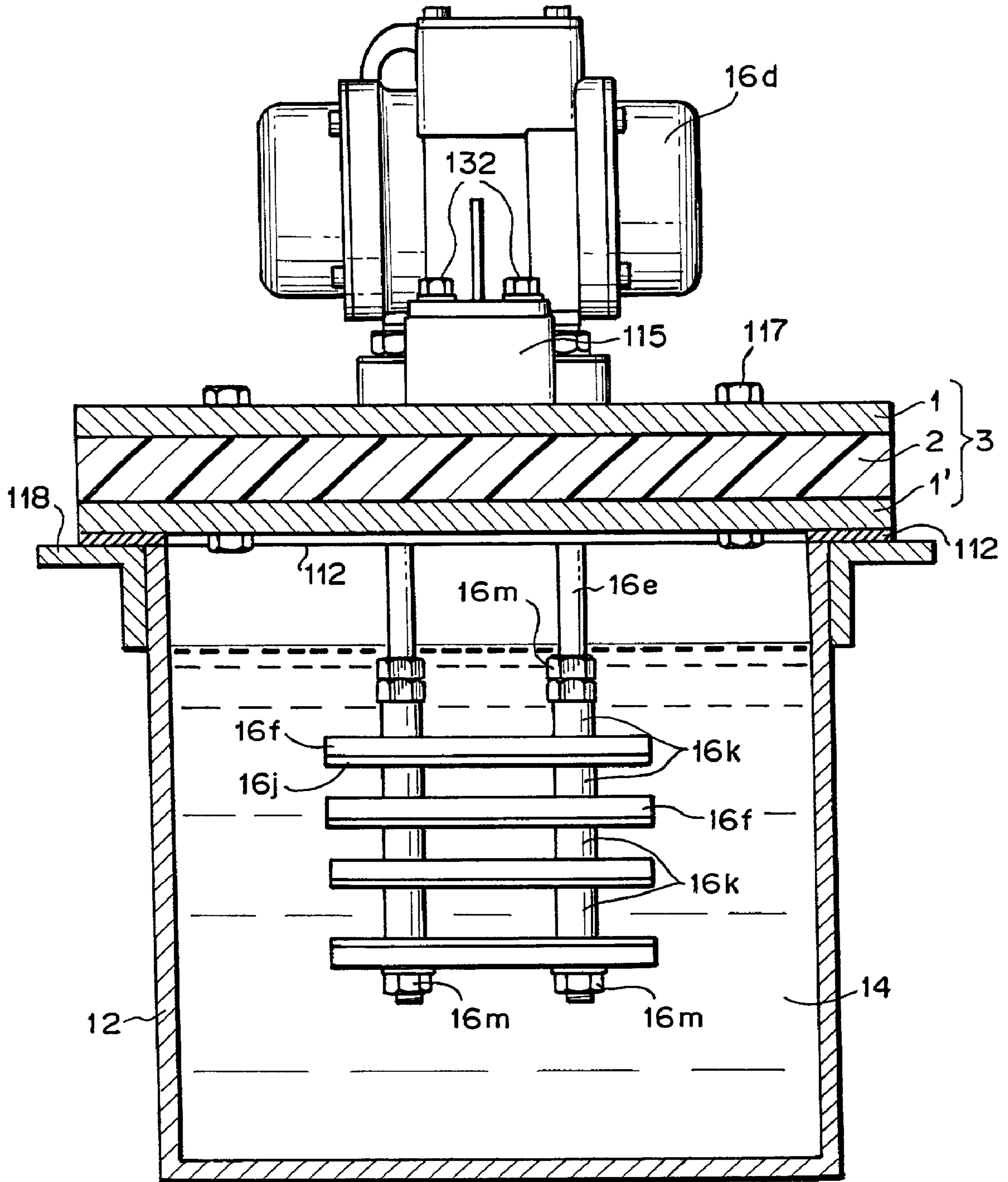


FIG. 16

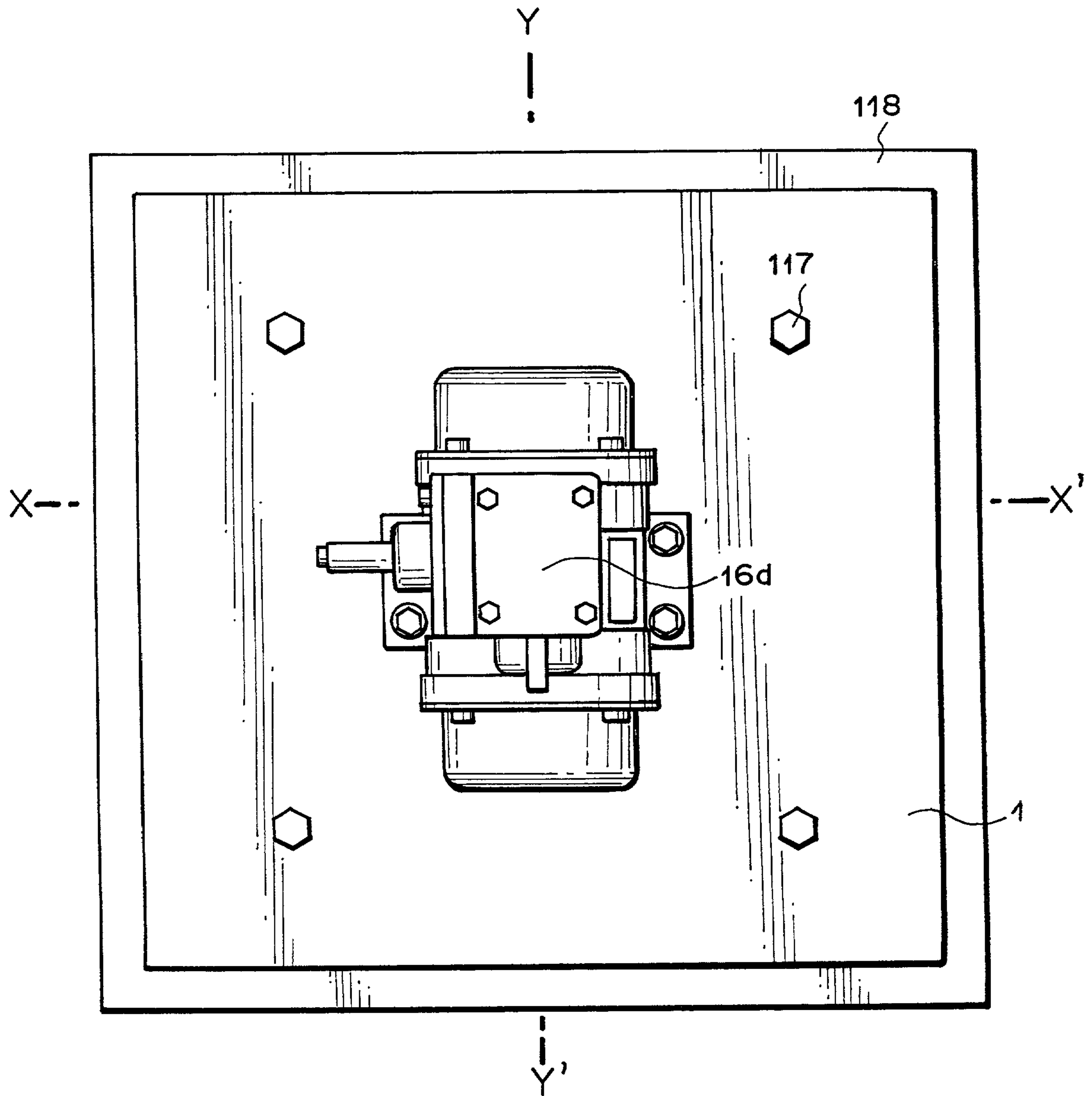


FIG.17A

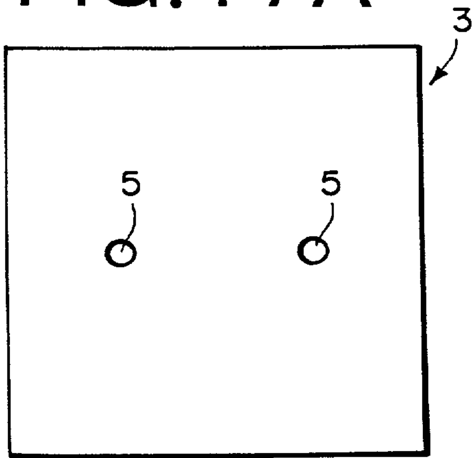


FIG.17B

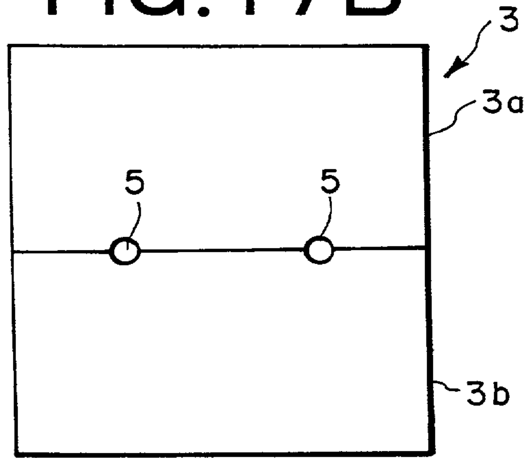


FIG.17C

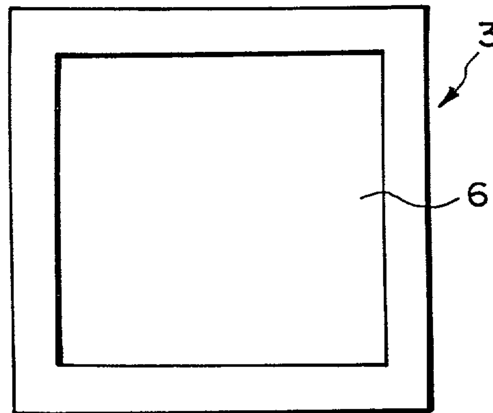


FIG.18A

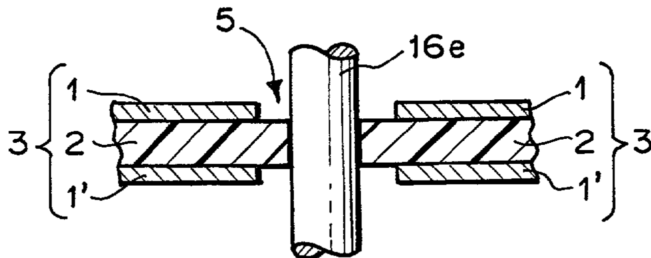


FIG.18B

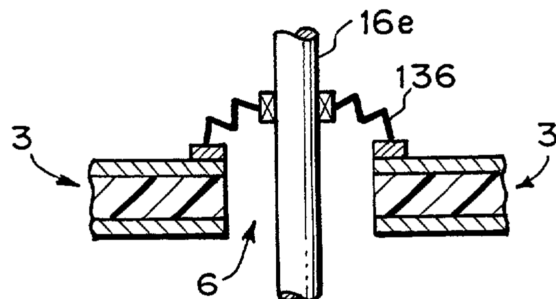


FIG.19A

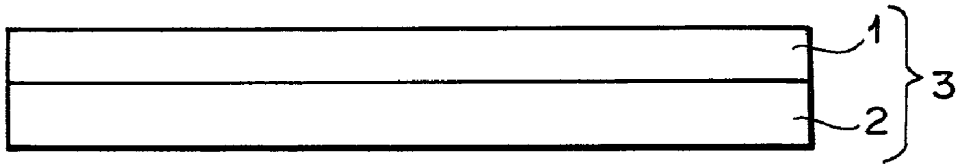


FIG.19B

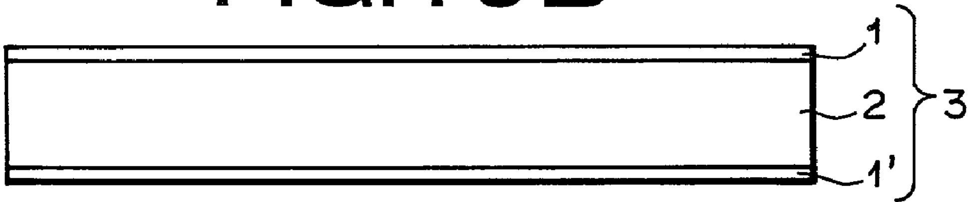


FIG.19C

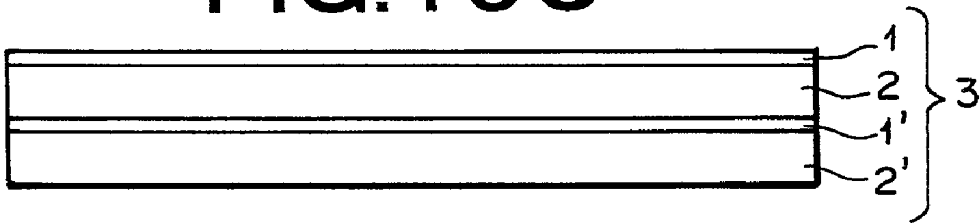


FIG.19D

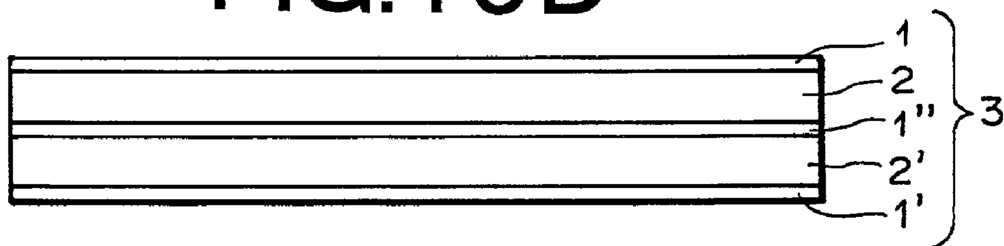


FIG.19E

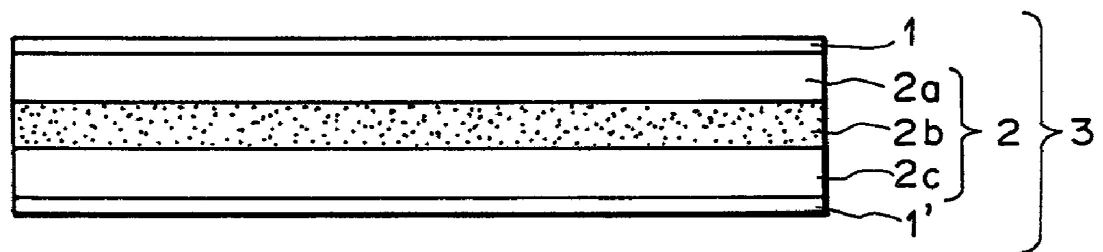


FIG.20

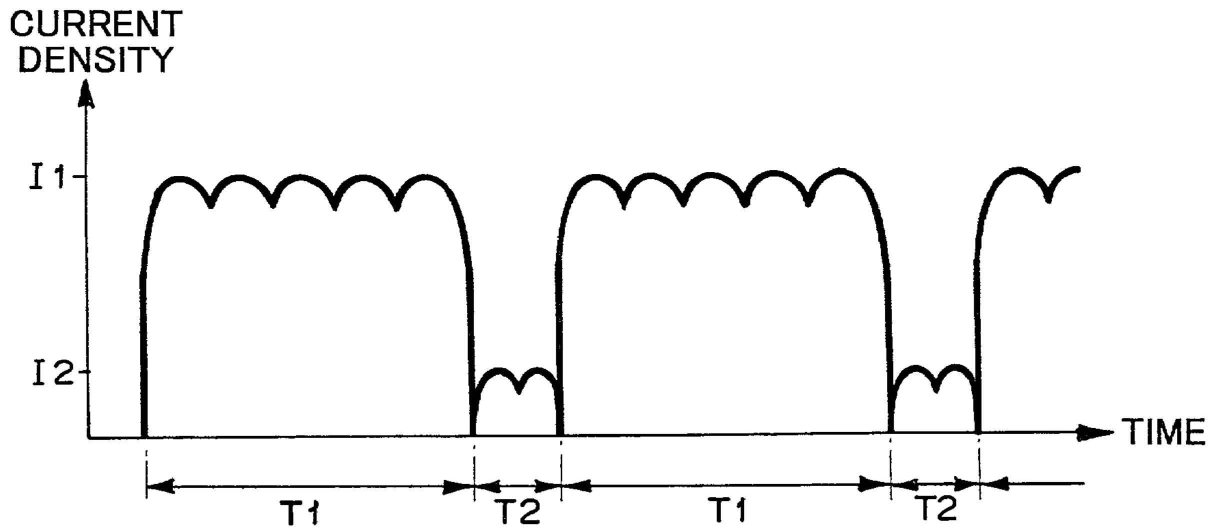


FIG.21

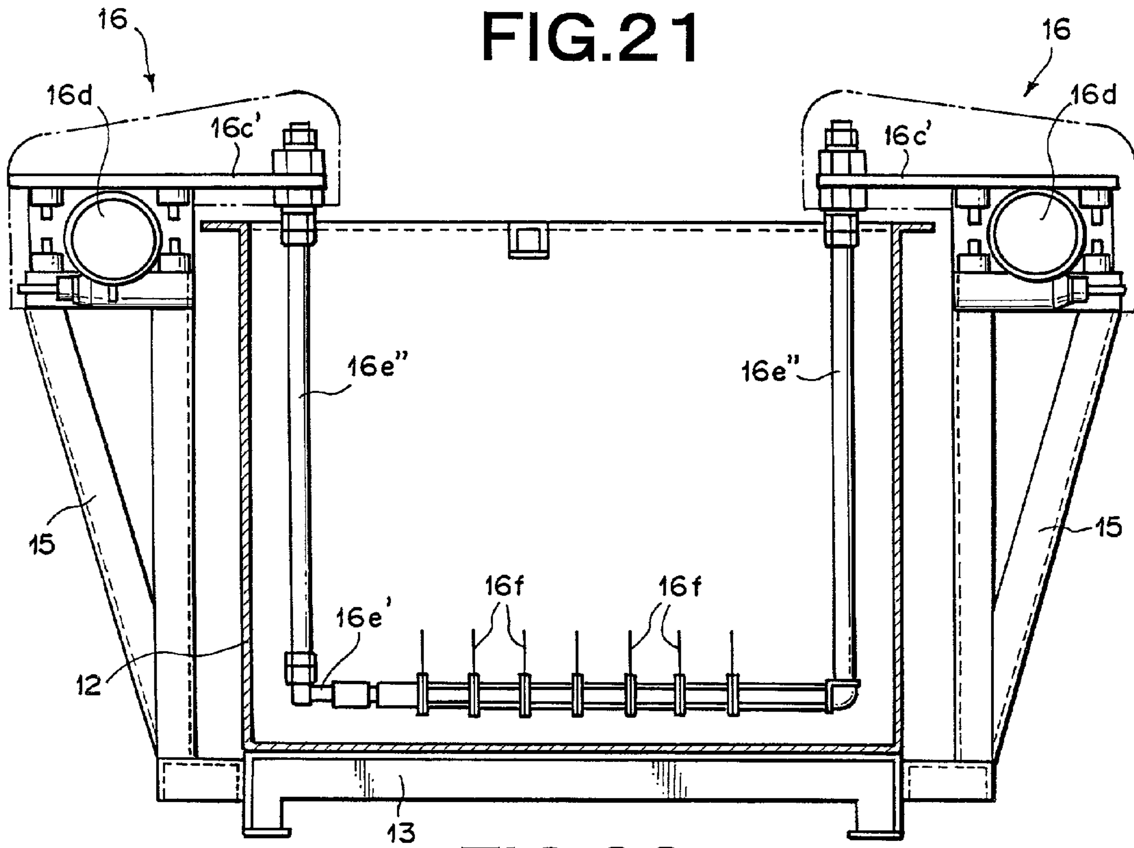


FIG.22

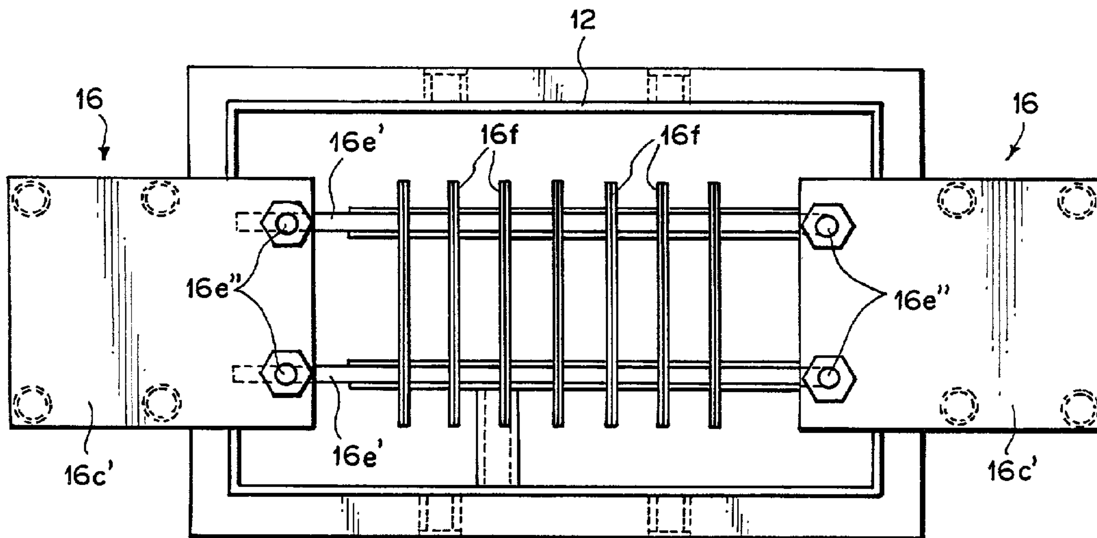
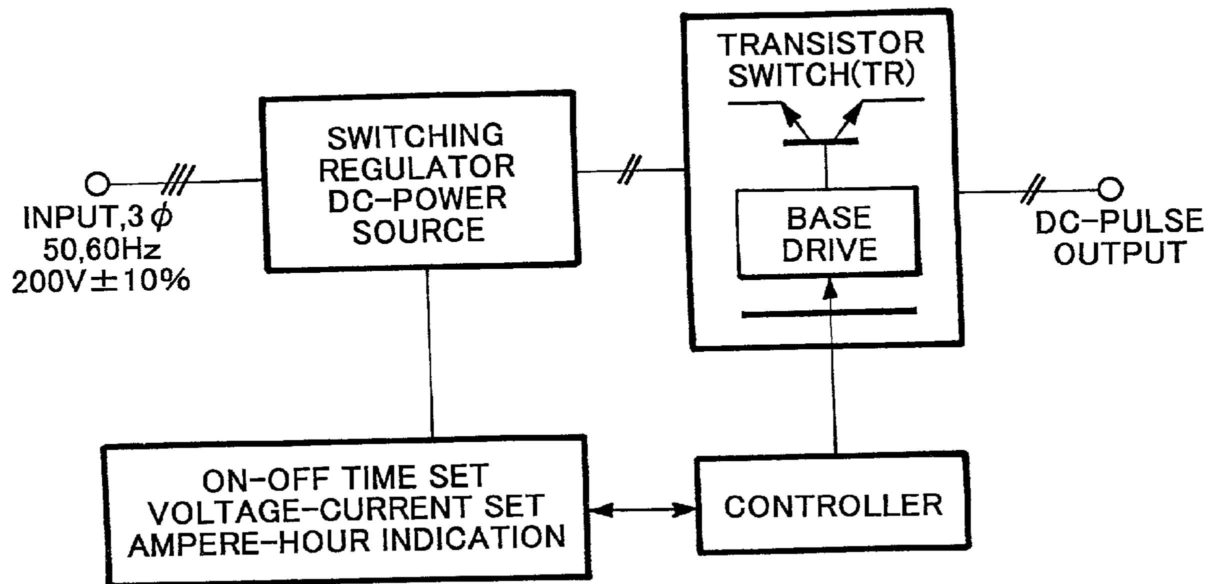


FIG.23



ELECTROPLATING METHOD USING COMBINATION OF VIBRATIONAL FLOW IN PLATING BATH AND PLATING CURRENT OF PULSE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a plating method, and particularly to a plating method using a specific combination of a physical condition of a plating bath and an electric condition of plating current.

[0003] 2. Description of the Related Art

[0004] An electroplating technique of forming a film of electrically conductive material on the surface of an article has been broadly used in the manufacturing industry of articles such as electronic parts, etc. Particularly, in order to satisfy requirements of miniaturization and high functionality to electronic parts, conductive patterns to be formed on the surfaces (containing the inner surface of through hole, the inner surface of blind via hole) of articles have been required to be formed finely.

[0005] For example, the microstructure design of wiring patterns is promoted in connection with decrease of the pitches of input/output terminals due to the high-integration design of semiconductor devices, and in connection with this promotion, it has been required that the through hole and the blind via hole are designed to have an inner diameter of 100 μm or less, further 50 μm or less, still further 30 μm or less. Further, a large aspect ratio of 5 or more, further 8 or more has been required to the through hole and the blind via hole.

[0006] For example, in order to reduce the capacity between wires which occurs due to the microstructure design of wires required in connection with the high-integration design, copper wires are used in place of aluminum wires which have been hitherto used, and a damascene method using electroplating to form copper multi-layered wires has been used. In this method, it has been required to perform copper deposition in very small blind via holes having the inner diameter of 1 μm or less.

[0007] Further, it has been required that a pair of electrode films are formed on the surface of a chip part having a dimension of about 0.3 mm.

[0008] Particularly, the applicant of this application has proposed a plating method that is effectively applicable to articles having microstructured parts such as fine holes, etc. (see JP(A)-11-189880). According to this method, vibrational flow induced in a plating bath and bubbling induced by a diffusing pipe are used in combination. This method is also effectively applicable to electroless plating as well as electroplating.

[0009] However, in this method, it is required to dispose the diffusing pipe in a plating tank in which the plating bath is accommodated, and also it is required to establish an air pipe to the diffusing pipe. Therefore, the amount of the plating bath and the dimension of the plating tank must be relatively increased, so that the plating apparatus itself must be designed in large size.

[0010] Besides, DC power source is generally used as power source for the electroplating. In order to enhance the quality of plating films, there has been proposed a technique of carrying out plating while the plating current is periodically varied. In this method, positive-polarity current and negative-polarity current alternately flows. That is, a plating film is temporarily formed by supplying the positive-polarity current, and then projecting portions of minute uneven portions on the surface of the plating film thus formed are concentratively and partially melted by supplying the negative-polarity current. The above operation is repeated to achieve a high-quality plating film that has a flat surface and no defects such as minute voids or the like. According to this method, however, the surface portion of the plating film which is temporarily formed is removed and thus this method has a disadvantage in enhancement of the film forming speed (that is, the enhancement of the plating treatment speed).

[0011] It is a recent tendency that conductive patterns are designed in a further microstructure design, and when a plating film having such a conductive pattern is formed, defects or unevenness in film thickness is liable to occur. Therefore, it has been more and more difficult to keep the excellent quality of the plating film.

[0012] The applicant of this application has also proposed a plating method of carrying out chrome-plating while vibrationally stirring the plating bath, and a plating method of accommodating many articles to be plated (hereinafter referred to as "plating target articles") in a barrel and carrying out chrome-plating while vibrationally stirring the plating bath (see JP(A)-7-54192 and JP(A)-6-330395).

[0013] However, these methods use direct current as plating current, and these publications have no specific disclosure on the application of these methods to minute plating target articles such as articles each of which has a width (the dimension in the traverse direction to the longitudinal direction) of 5 mm or less, for example, 0.3 to 1.0 mm. In the barrel plating process for these minute plating target articles, the plating target articles are overlapped with one another in the barrel, and thus the distribution of plating liquid to desired plating film forming portions of the plating target articles is extremely lowered. Therefore, there are a lot of technical difficulty for these minute plating target articles beyond comparison with plating target articles having relatively large widths, and a further improvement must be made in point of the film forming speed and the evenness of film thickness.

SUMMARY OF THE INVENTION

[0014] Therefore, an object of the present invention is to provide a plating method which can form a plating film having a microstructured conductive pattern with high quality so that the plating film has no defect and is not uneven in film thickness.

[0015] Another object of the present invention is to provide a plating method which can form a high-quality plating film having a microstructured conductive pattern at high speed.

[0016] Another object of the present invention is to provide a plating method which can efficiently form a high-quality plating film having a microstructured conductive pattern by a relatively small apparatus.

[0017] In order to attain the above objects, according to the present invention, there is provided an electroplating

method, characterized in that a plating target article disposed so as to be in contact with plating bath is set as a cathode while a metal member disposed so as to be in contact with the plating bath is set as an anode, and a voltage is applied between the cathode and the anode while vibrational flow is induced by vibrating vibrational vanes which are fixed in one-stage or multi-stage style to a vibrating rod vibrating in the plating bath interlockingly with vibration generating means, wherein plating current flowing from the anode through the plating bath to the cathode is pulsed and alternately set to one of a first state where the plating current keeps a first value **I1** for a first time **T1** and a second state where the plating current keeps a second value **I2** having the same polarity as the first value **I1** for a second time **T2**, the first value **I1** being five or more times larger than the second value **I2**, and the first time **T1** being three or more times longer than the second time **T2**.

[**0018**] In an aspect of the present invention, the first value **I1** is 6 to 25 times as large as the second value **I2**, and the first time **T1** is 4 to 25 times as long as the second time **T2**. In an aspect of the present invention, the first value **I1** is set to 0.01 to 300 seconds. In an aspect of the present invention, the vibrational vanes are vibrated at an amplitude of 0.05 to 10.0 mm and a vibration frequency of 200 to 1500 revolutions per minute. In an aspect of the present invention, the vibrational vanes are vibrated so that the vibrational flow of the plating bath has a three-dimensional flow rate of 150 mm/second or more. In an aspect of the present invention, the vibration generating means vibrates at 10 to 500 Hz.

[**0019**] In an aspect of the present invention, the plating target article is vibrated at an amplitude of 0.05 to 5.0 mm and a vibration frequency of 100 to 300 revolutions per minute. In an aspect of the present invention, the plating target article is swung at a swinging width of 10 to 100 mm and a swinging frequency of 10 to 30 times per minute.

[**0020**] In an aspect of the present invention, the plating target article has a face to be plated having a microstructure of a dimension of 50 μm or less.

[**0021**] In an aspect of the present invention, a plurality of plating target articles are accommodated in a holding container, the holding container having small holes through which liquid of the plating bath is allowed to pass and being equipped with an electrically conductive member which is brought into contact with the plating target articles to make current flow through the plating target articles, and wherein the holding container is rotated around the rotational center corresponding to a non-vertical direction in the plating bath to roll the plating target articles in said holding container to thereby repeat the contact and separation between each of the plating target articles and the electrically conductive member.

[**0022**] In an aspect of the present invention, the width of each of the plating target articles is equal to 5 mm or less.

[**0023**] According to the electroplating method of the present invention, even when a plating conductive pattern is minute, a plating film having uniformity in thickness and no defect can be formed with high quality. Further, according to the present invention, a high-quality plating film of microstructured conductive pattern can be obtained at high speed. Still further, according to the present invention, a high-quality plating film of microstructured conductive pattern can be efficiently obtained by a relatively small apparatus.

BRIEF DESCRIPFION OF THE DRAWINGS

[**0024**] **FIG. 1** is a cross-sectional view showing the construction of a plating apparatus to which a first embodiment of a plating method according to the present invention is applied;

[**0025**] **FIG. 2** is a cross-sectional view showing the construction of the plating apparatus to which the first embodiment of the plating method according to the present invention is applied;

[**0026**] **FIG. 3** is a plan view showing the construction of the plating apparatus to which the first embodiment of the plating method according to the present invention is applied;

[**0027**] **FIG. 4** is an enlarged cross-sectional view showing the fixing portion of a vibration transmitting rod to a vibrating member;

[**0028**] **FIG. 5** is an enlarged cross-sectional view of the fixing portion of a vibrating vane to the vibration transmitting rod;

[**0029**] **FIG. 6** is a diagram showing a modification of the fixing portion of the vibrating vane to the vibration transmitting rod;

[**0030**] **FIG. 7** is a cross-sectional view showing a modification of fixing a plating target article to a cathode bus bar;

[**0031**] **FIG. 8** is a graph showing variation of plating current flowing through the plating target article;

[**0032**] **FIG. 9** is a cross-sectional view showing the construction of a plating apparatus to which a second embodiment of the plating method of the present invention is applied;

[**0033**] **FIG. 10** is a cross-sectional view showing the construction of the plating apparatus to which the second embodiment of the plating method of the present invention is applied;

[**0034**] **FIG. 11** is a plan view showing the construction of the plating apparatus to which the second embodiment of the plating method of the present invention is applied;

[**0035**] **FIG. 12** is a cross-sectional view showing a plating apparatus used for the embodiment of the plating method of the present invention;

[**0036**] **FIG. 13** is a partially-notched plan view of the plating apparatus of **FIG. 12**;

[**0037**] **FIG. 14** is a cross-sectional view showing the fixing of a vibrational flow inducing portion constituting the plating apparatus to a plating tank;

[**0038**] **FIG. 15** is a cross-sectional view showing the fixing of the vibrational flow inducing portion constituting the plating apparatus to the plating tank;

[**0039**] **FIG. 16** is a plan view showing the fixing of the vibrational flow inducing portion constituting the plating apparatus to the plating tank;

[**0040**] **FIGS. 17A** to **17**C are plan views showing a laminated member;

[**0041**] **FIGS. 18A and 18B** are cross-sectional views showing a state that the top portion of the plating tank is closed by the laminated member;

[0042] **FIGS. 19A** to **19**E are diagrams showing the laminated memeber;

[0043] **FIG. 20** is a graph showing variation of plating current flowing through a plating target article;

[0044] **FIG. 21** is a cross-sectional view showing a modification of the vibrational flow inducing portion;

[0045] **FIG. 22** is a plan view showing the vibrational flow inducing portion of **FIG. 21**; and

[0046] **FIG. 23** is a diagram showing an example of a power source for pulse plating.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0047] Preferred embodiments according to the present invention will be described hereunder with reference to the accompanying drawings. In the figures, the members or portions having the same functions are represented by the same reference numerals.

[0048] **FIGS. 1 and 2** are cross-sectional views showing the construction of a plating apparatus to which a first embodiment of a plating method according to the present invention will be applied, and **FIG. 3** is a plan view of the plating apparatus shown in **FIGS. 1 and 2**.

[0049] In these figures, reference numeral **12** represents a plating tank, and plating bath **14** is stocked in the plating tank **12**. Reference numeral **16** represents a vibrational flow generator or vibrational flow inducing portion. The vibrational flow generator **16** includes a base stand **16***a* fixed to the plating tank **12** through a vibration proof rubber, coil springs **16***b* serving as vibration absorption members which are fixed to the base stand at the lower ends thereof, a vibrating member **16***c* fixed to the upper ends of the coil springs **16***b*, a vibrating motor **16***d* serving as vibration generating means fixed to the vibrating member **16***c*, a vibration transmitting rod **16***e* fixed to the vibrating member at the upper end thereof, and vibrating vanes **16***f* fixed to the lower half portion of the vibration transmitting rod so as to be immersed in the plating bath **14**. Further, a rod-shaped guide member may be disposed in each of the coil springs **16***b* as shown in **FIG. 12**.

[0050] The vibrating motor **16***d* vibrates at frequencies of 10 to 500 Hz, preferably 20 to 60 Hz, more preferably 30 to 50 Hz under the control based on an inverter, for example. The vibration generated by the vibrating motor **16***d* is transmitted through the vibrating member **16***c* and the vibration transmitting rod **16***e* to the vibrating vanes **16***f*. The tip edge of each vibrating vane **16***f* vibrates at a desired oscillation frequency in the plating bath **14**. The vibration is generated as if each vibrating vane **16***f* bends from the base portion fixed to the vibration transmitting rod **16***e* toward the tip edge thereof. The amplitude and frequency of the vibration are different from those of the vibrating motor **16***d*, and determined in accordance with the dynamical characteristics of the vibration transmission passage and the mutual action characteristics between each vibrating vane and the plating bath **14**. In the present invention, the amplitude is preferably in the range of 0.05 to 10.0 mm, for example 0.1 to 10.0 mm, and the frequency is preferably in the range of 200 to 1500 revolutions per minute, for example 200 to 800 revolutions per minute.

[0051] **FIG. 4** is an enlarged cross-sectional view showing the fixing portion of the vibration transmitting rod **16***e* to the vibrating member **16***c*. Nuts **16***i***1**, **16***i***2**; **16***i***3**, **16***i***4** are fixed through vibrational stress dispersing members **16***g***1**, **16***g***2** and washers **16***h***1**, **16***h***2** to a male screw portion of the upper portion of the vibration transmitting rod **16***e* from both the upper and lower sides of the vibrating member **16***c*. The vibrational stress dispersing members **16***g***1**, **16***g***2** are formed of rubber, for example.

[0052] **FIG. 5** is an enlarged cross-sectional view showing the fixing portions of the vibrating vanes **16***f* to the vibration transmitting rod **16***e*. Vibrating vane fixing members **16***j* are disposed at both the upper and lower sides of each of seven vibrating vanes **16***f*. Further, a spacer ring **16***k* for setting the interval between the vibrating vanes **16***f* is interposed between the neighboring vibrating vanes **16***f* through the fixing members **16***j*. Nuts **16***m* which are fitted to male screws formed on the vibration transmitting rod **16***e* are disposed at the upper side of the uppermost vibrating vane **16***f* and the lower side of the lowermost vibrating vane **16***f*.

[0053] **FIG. 6** is a diagram showing a modification of the fixing portions of the vibrating vanes **16***f* to the vibration transmitting rod **16***e*.

[0054] In this modification, each vibrating vane **16***f* is individually fixed to the vibration transmitting rod **16***e* by nuts **16***n* disposed at both the upper and lower sides of each vibrating vane **16***f*. An elastic member sheet **16***p* formed of fluororesin or fluorinated rubber may be interposed between each vibrating vane **16***f* and the fixing member **16***j* to prevent the vibrating vanes **16***f* from being damaged.

[0055] As shown in **FIG. 6**, the lower surface (press face) of the upper fixing member **16***j* is designed to have a convex cylindrical shape, and the upper surface (press face) of the lower fixing member **16***j* is designed to have a concave cylindrical shape corresponding to the above convex cylindrical shape. Therefore, a part of each vibrating vane **16***f* which is pressed by the fixing members **16***j* from the upper and lower sides is bent, and the tip portion of the vibrating vane **16***f* intersects the horizontal plane at an angle α. The angle α may be set to a value in the range from $-30°$ to $30°$, preferably in the range from $-20°$ to $20°$. Particularly, the angle α is preferably set to a value in the range from $-30°$ to $-5°$ or from $5°$ to $30°$, preferably in the range from $-20°$ to $-10°$ or from $10°$ to $20°$. When the press faces of the fixing members **16***j* are the plane face, the angle α is set to $0°$. The angle α is not necessarily equal to the same value among all the vibrating vanes **16***f*. For example, as shown in **FIG. 1, a** negative angle value may be set to one or two lower vibrating vanes **16***f* (i.e., the vibrating vanes **16***f* are bent downwardly, that is, they are bent in the opposite direction to that of **FIG. 6**) while a positive angle value is set to the other vibrating vanes **16***f* (i.e., they are bent in the same direction as that of **FIG. 6**).

[0056] The vibrating vanes **16***f* may be formed of elastic metal plates, synthetic resin plates or rubber plates. The thickness of each vibrating vane **16***f* is set so that the tip edge portion of each vibrating vane **16***f* exhibits a flutter phenomenon (a state as if the vibrating vanes are fluttered). When the vibrating vanes **16***f* are formed of metal plates such as stainless steel plate or the like, the thickness thereof may be set to 0.2 to 2 mm. When the vibrating vanes **16***f* are formed of synthetic resin plates or rubber plates, the thickness thereof may be set to 0.5 to 10 mm.

[0057] In FIGS. **1** to **3**, a swinging motor **20** is connected to a swinging frame **24** through a link rod **22**. The swinging frame **24** is disposed so as to be reciprocally movable in the horizontal direction (the right-and-left direction in **FIG. 1**) on rails **26**. A vibrating motor **28** is fixed to the swinging frame **24**. Further, a cathode bus bar **30** and an anode bus bar **32** are fixed to the swinging frame **24** while they are kept insulated from the swinging frame **24**, and they are connected to a negative-electrode terminal and a positive-electrode terminal of a power source circuit **34**. The power source circuit **34** can generate a rectangular voltage from an AC voltage. Such a power source circuit has a rectifying circuit using a transistor and it is known as a pulse power source device.

[0058] In the present invention, a circuit for rectifying AC current (containing adding DC components) and then outputting the rectified current is used as the power source circuit (power source device) used to generate plating current. As such a power source device or rectifier may be used a transistor adjustment type power source, a dropper type power source, a switching power source, a silicon rectifier, an SCR rectifier, a high-frequency type rectifier, an inverter digital control type rectifier (for example, Power Master produced by Chuo Seisakusho Co., Ltd.), KTS series produced by Sansha Denki Seisakusho Co., Ltd., an RCV power source produced by Shikoku Denki Co., Ltd., a device which comprises a switching regulator type power source and a transistor switch and supplies rectangular pulse current by switching on/off the transistor switch, a high-frequency switching power source (in which AC current is converted to DC current through a diode, then high frequency of 20 to 30 KHz are applied to a transformer to carry out the rectification and smoothing again, and then the output is taken out), a PR type rectifier, a high-frequency control type high-speed pulse PR power source (for example, HiPR series produced by Chiyoda Co., Ltd. or the like.

[0059] Here, the current waveform will be described. In order to implement both the increase in plating speed and the improvement of the characteristics of plating films, it is important to select the wave form of plating current. The voltage and current conditions required for the electroplating are varied in accordance with the type of plating, the composition of plating bath and the dimension of the plating tank, and thus they cannot be sweepingly specified. However, if the plating voltage is set to a DC voltage of 2 to 15V, it can sufficiently cover the whole at present. Therefore, four kinds of rated output voltage of the plating DC current (6V, 8V, 12V, 15V) are standardized in the industry. The voltage below the above rated can be adjusted, and thus a power source for generating a rated voltage which has a slightly extra voltage with respect to a desired voltage value required for plating is preferably selected. In the industry, the rated output current from 500 A, 1000 A till about 2000 A to 10000 A are standardized as the rated output current of the power source, and the other current values are provided in the form of production to order. It is better that the required current capacity of the power source is determined as the desired current density of plating target article x the surface area of the plating target article in accordance with the type and surface area of the plating target article, and a proper standard power source satisfying the above required current capacity is selected.

[0060] The pulse wave is originally defined as a pulse having a sufficiently shorter width w than its period T. However, this definition is not strict. The pulse wave contains waves other than the square wave. The operating speed of elements used in a pulse circuit is increased, and the pulse width of ns (10^{-9}s) or less can be treated. As the pulse width is smaller, it is more difficult to keep the front and rear edges of the waves sharp. This is because the pulse contains high-frequency components.

[0061] A saw-tooth wave, a ramp wave, a triangular wave, a composite wave, a rectangular wave (square wave), etc. are known as the types of pulse waves, and particularly the present invention preferably uses the rectangular wave in consideration of the efficiency of electricity and smoothing.

[0062] **FIG. 23** shows an example of a pulse plating power source. As shown in **FIG. 23**, it contains a switching regulator type DC power source and a transistor switch, and rectangular pulse current is supplied to a load by switching on/off the transistor switch at high speed.

[0063] The cathode bus bar **30** is mechanically and electrically connected to the upper portion of an electrically conductive holding member **40** for holding a plating target article X. The lower portion of the plating target article holding member **40** is immersed in the plating bath **14**, and the plating target article X is electrically connected to this portion and held by a clamp or the like. As not shown, an anode metal member (for example, which is accommodated in a plastic basket) is mechanically and electrically connected to the anode bus bar **32**, and the lower portion thereof is immersed in the plating bath **14**. Various well-known methods, shapes and structures may be used as the methods of fixing the plating target article to the cathode bus bar and fixing the anode metal member to the anode bus bar and the shapes and structures of the cathode bus bar and the anode bus bar.

[0064] **FIG. 7** is a cross-sectional view showing a modification of the fixing of the plating target article to the cathode bus bar. In this modification, the electrically conductive holding member **40** is designed to have a hook portion **40***a* which is provided at the upper portion thereof and fitted to the cathode bus bar **30**, a clamp portion **40***b* which is provided at the lower portion thereof and pinches the plating target article X, and a compression spring **40***c* for generating the clamp force of the clamp portion.

[0065] In FIGS. **1** to **3**, the swinging frame **24** and the holding member **40**, and further the plating target article X secured to the swinging frame **24** and the holding member **40** are swung at a swinging width of 10 to 100 mm and a swinging frequency of 10 to 30 times per minute by actuating the swinging motor **20**. Further, the vibrating motor **28** is vibrated at a frequency of 10 to 60 Hz, preferably at a frequency of 20 to 35 Hz under the control using an inverter, for example. The vibration occurring in the vibrating motor **28** is transmitted to the plating target article X through the swinging frame **24** and the holding member **40**, whereby the plating target article X is vibrated at an amplitude of 0.05 to 5.0 mm, for example 0.1 to 5.0 mm, and a vibration frequency of 100 to 300 revolutions per minute.

[0066] **FIG. 8** is a graph showing the variation of plating current (current density) flowing through the plating target article X due to a voltage applied across the cathode bus bar **30** and the anode bus bar **32** by the power source circuit **34**.

[0067] As shown in FIG. 8, the plating current is shaped to have such a rectangular pulse train that a first state where the plating current keeps a first value I1 for a first time T1 and a second state where the plating current keeps a second value I2 (<I1) for a second time T2 appear alternately. Here, the first value I1 and the second value I2 have the same polarity. I1 is five or more times as large as I2 (for example, six or more times, e.g. six times to 25 times), preferably eight times to 20 times. T1 is three or more times as long as T2 (for example, four or more times, e.g. 4 times to 25 times), preferably six times to 20 times. Such plating current and the vibrational flow of the plating bath 14 caused by the vibrational flow generator 16 are combined with each other, whereby excellent quality and a high film forming speed can be achieved even for the plating of minute conductive structure patterns.

[0068] The first value I1 and the first time T1 are properly determined in accordance with the type of plating (for example, copper sulfate plating, copper cyanide plating, copper pyrophosphate plating, nickel plating, black nickel plating, nickel sulfamate plating, chromium plating, zinc cyanide plating, no cyanide zinc plating, alkaline tin plating, acidic tin plating, silver plating, gold cyanide plating, acidic gold plating, copper-zinc alloy plating, nickel-iron alloy plating, tin-lead alloy plating, palladium plating, solder plating or the like), the composition of the plating bath or the like. For example, I1 may be set to a value in the range of 0.01 to 100[A/dm^2], and T1 may be set to a value in the range from 0.01 to 300[Second], e.g. from 3 to 300[Second]. However, these parameters are not limited to specific values. The optimum I1, I2, T1, T2 may vary in a broad range in accordance with the type of plating, the composition of the plating bath or the like. For example, they may vary due to variation of the composition of the plating bath in the progress of the plating treatment.

[0069] The plating bath 14 is selected in the same way as the well-known electroplating method in accordance with a plating film to be formed. For example, in the case of the copper sulfate plating, the following may be used as through hole bath:

[0070] Copper sulfate: 60 to 100 g/L (liter)

[0071] Sulfuric acid: 170 to 210 g/L

[0072] Brightener: proper amount

[0073] Chlorine ion: 30 to 80 mL/L

[0074] The following may be used as normal bath for the copper sulfate plating:

[0075] Copper sulfate: 180 to 250 g/L

[0076] Sulfuric acid: 45 to 60 g/L

[0077] Brightener: proper amount

[0078] Chlorine ion: 20 to 80 m/L

[0079] Further, in the case of the nickel plating, the following may be used as barrel bath:

[0080] Nickel sulfate: 270 g/L

[0081] Nickel chloride: 68 g/L

[0082] Boric acid: 40 g/L

[0083] Magnesium sulfate: 225 g/L

[0084] The following may be used as normal bath for the nickel plating:

[0085] Nickel sulfate: 150 g/L

[0086] Ammonium chloride: 15 g/L

[0087] Boric acid: 15 g/L

[0088] The following may be used as Watts bath for the nickel plating:

[0089] Nickel sulfate: 240 g/L

[0090] Ammonium chloride: 45 g/L

[0091] pH: 4 to 5

[0092] bath temperature: 45 to 55° C.

[0093] Further, in the case of the acidic tin plating, the following may be used as sulfate bath:

[0094] Stannous sulfate: 50 g/L

[0095] Sulfuric acid: 100 g/L

[0096] Cresolsulfonic acid: 100 g/L

[0097] Gelatin: 2 g/L

[0098] β-naphthol: 1 g/L

[0099] Electronic parts, mechanical parts, etc. may be used as articles X to be plated, and the articles X are not limited to specific ones. The present invention is remarkably effectively applied to a case where a plating film having a microstructure is formed. Particularly, the following cases may be considered as the plating of these articles X: formation of a plating conductive film onto the inner surface of a minute blind via hole or through hole having an inner diameter of 100 μm or less (for example, 20 to 100 μm, or particularly 50 μm or less, further 30 μm or less, e.g. 10 μm, 5 μm, 3 μm, etc.) and having a depth of 10 to 100 μm for example in a multi-layered wiring board; formation of a conductive film in a minute groove to form a high-density wiring pattern having a pitch of 50 μm or less (for example, 20 to 50 μm, or particularly 30 μm or less, further 20 μm or less, e.g. 10 μm, 5 μm, etc.), the minute groove having a width of 30 μm or less (particularly 20 μm or less, further 10 μm or less, e.g. 5 μm, 3 μm, etc.) and depth of 7 to 70 μm for example; formation of an embedded conductive film into an extremely minute blind via hole having an inner diameter of about 0.3 μm or less or into an extremely minute groove having a width of 0.1 μm and depth of 1.5 μm by copper damascene method when multi-layered wires of a semiconductor device are formed; formation of minute electrode bumps disposed in a high-density arrangement in a semiconductor device; etc. The improving effect of the present invention is particularly remarkable when it is applied to the structure having a high aspect ratio, for example 3 or more, especially 5 or more.

[0100] Further, an extremely small article having an average diameter of 5 to 500 μm may be used as the plating target article X. Here, the average diameter is defined as the average value of representative dimensions in the three directions that cross to one another at right angles. As this type of plating target article X may be provided metal powder such as copper powder, pre-treated aluminum powder or iron powder, synthetic resin powder such as ABS resin powder or the like which is treated to have electrical

conductivity, ceramic chips which are treated to have electrical conductivity, etc. Further, other electronic parts, mechanical parts, metal powder alloy, minute particulate inorganic/organic pigment, metal balls, etc. may be also provided.

[0101] For example, Ni plating films may be formed on metal particles such as Cu particles each having a diameter of about 300 μm, or an Au plating film or an Ag plating film may be formed on an Ni plating film to form a composite plating film.

[0102] Further, when a plating target article is made of electrically insulating material such as plastic or the like, a conductive base (primer) forming treatment is carried out as a pre-treatment of the electroplating. However, in the case of a microstructured plating face having a high aspect ratio, an uniform and excellent conductive base could not be formed even if the conductive base forming treatment is carried out by normal electroless plating. Therefore, the thickness of the plating film obtained by the electroplating is liable to be non-uniform. In order to avoid this problem, the conductive base forming treatment may be carried out by sputtering or vacuum deposition. However, in this case, since the treatment is carried out in a pressure-reduced apparatus, there occur such difficulties that the cost of the treatment apparatus rises up and a mass-production treatment and a continuous treatment cannot be performed. On the other hand, if the conductive base forming treatment using the electroless plating or the like is carried out while vibrational flow is induced in treatment liquid by using the same means as the vibrational flow generating means used in the present invention, a highly uniform conductive base can be formed on even a microstructured plating face having a high aspect ratio. Accordingly, by combining the conductive base forming treatment and the electroplating method of the present invention, the process from the pre-treatment to the electroplating treatment can be continuously carried out, and thus the productivity can be enhanced more and more.

[0103] According to the plating method of the present invention, the distribution of the plating bath into microstructure recess portions can be enhanced by the vibrational flow which is induced in the plating bath **14** by the vibrational flow generator **16**, and also the uniformity in film thickness can be enhanced by pulsing the plating current density so that a first pulse state and a second pulse state where the pulsed current density has the same polarity as that of the first pulse state although it is sufficiently lower than that of the first state. Therefore, there can be suppressed occurrence of non-uniformity in film thickness due to concentrated plating film formation at the projecting portions or edge portions and also occurrence of defects such as gas pits, etc. in through holes or via holes as in the case of the DC plating process, and high surface glossiness can be achieved. Further, there can be prevented such a phenomenon that a plating film which has been temporarily formed is partially dissolved as in the case of the pulse plating current whose polarity is inverted. Therefore, a high-speed film forming process can be carried out and the construction of the manufacturing apparatus can be simplified. Accordingly, desired plating films can be efficiently formed with low fraction defective at high speed on broad plating target articles.

[0104] Further, according to the present invention, short-circuit can be prevented by the action of the vibrational flow occurring in the plating bath **14** even when the distance between the plating target article X and the anode metal member is short to increase the current density. This is considered as a factor to form a plating film with an excellent yield and at high speed without inducing disadvantages such as burning, scorching, etc.

[0105] In order to attain such an excellent action, it is remarkably preferable that the three-dimensional flow rate of the vibrational flow of the plating bath **14** is equal to or greater than 150 mm per second. Such a high three-dimensional flow rate can be effectively implemented by inducing the vibrational flow in the plating bath. It is difficult to implement this three-dimensional flow rate by using a normal stirrer, and even when it is implemented, an extremely large scale apparatus is needed.

[0106] In this embodiment, the effect can be further enhanced by swinging and/or vibrating the plating target article X through the swing and/or vibration of the swinging frame **24**. However, an excellent effect can be obtained even when the plating target article X is neither swung nor vibrated. If the cathode bus bar **30**, the anode bus bar **32**, the plating target article X, the anode metal member, etc. are supported without using the swinging frame **24**, the swinging motor **20** and the vibrating motor **28**, the construction of the apparatus can be further simplified. When the plating target article X has a plate shape of a relatively large dimension or length as a whole such as a multi-layered wiring board or the like, the effect can be enhanced by swinging the plating target article X along the in-plane direction thereof.

[0107] **FIGS. 9 and 10** are cross-sectional views showing the construction of a plating apparatus to which a second embodiment of the plating method according to the present invention is applied, and **FIG. 11** is a plan view showing the plating apparatus shown in **FIGS. 9 and 10**. This embodiment is different from the first embodiment shown in FIGS. **1** to **8** in the way to hold the plating target article X and the way to supply current to the plating target article, and it uses a so-called barrel plating method.

[0108] In FIGS. **9** to **11**, a vibrating frame **44** is fitted to a plating tank **12** through a coil spring **46** as a vibration absorption member. The vibrating frame **44** is fitted to a vibrating motor **48** and a balance weight **49** used to keep a weight balance with the vibrating motor **48**. A barrel **52** is fitted to the vibrating frame **44** through a support member **50**. The barrel **52** is rotatably fitted to the support member **50**, and rotated in the direction indicated by an arrow of **FIG. 9** by driving means (not shown). Many minute plating target articles X are accommodated in the barrel **52**. Many small holes are formed on the outer peripheral surface of the barrel **52** so that the plating target articles X are prevented from passing through the small holes, but the liquid of the plating bath **14** is allowed to pass through the small holes. A cathode conductive member **54** is disposed in the barrel **52** so as to extend to the lower portion of the barrel **52**. The cathode conductive member **54** is connected to a negative-electrode terminal of a power source circuit **34** via an insulated coated wire **54'** which passes through a pipe member **52*a*** fixed to the barrel **52** at the rotational center of the barrel **52**. The cathode conductive member **54** is not rotated even when the barrel is rotated, and thus the plating target articles X which are rolled through the rotation of the

barrel repetitively be in contact with and separate from the cathode conductive member **54**.

[**0109**] Reference numeral **56** represents an anode metal member having a lower portion immersed in the plating bath **14**. The anode metal member **56** is accommodated in a plastic cage, for example, and is connected to a positive-electrode terminal of the power source circuit **34** through an insulated coated wire **56**'. As shown in **FIG. 9**, the anode metal member **56** is disposed at both the sides of the barrel **52**, however, it may be disposed at one side of the anode metal member **56**.

[**0110**] The vibrating motor **48** is vibrated at the same amplitude and frequency as the vibrating motor **28** described above, and the plating target articles X are vibrated at an amplitude of 0.05 to 5.0 mm, for example 0.1 to 5.0 mm, and a vibrational frequency of 100 to 300 revolutions per minute. In this embodiment, the effect is also further enhanced by vibrating the plating target articles through the vibration of the vibrating frame **44**. However, an excellent effect can be achieved without vibrating the plating target articles X. The construction of the apparatus can be further simplified by supporting the support member **50** and the barrel **52** without using the vibrating frame **44**, the vibrating motor **48**, etc.

[**0111**] In this embodiment, the plating current density is set in the same way as described with reference to **FIG. 8**. In this embodiment, the plating current in the first pulse state or second pulse state or the plating current varying in the shift process between the first pulse state and the second pulse state is supplied to each plating target article X when each plating target article X is brought into contact with the cathode conductive member **54**. If only the current density at the contact time is continuously displayed, the same current density as shown in **FIG. 8** is obtained on average, and thus the same effect as the first embodiment can be obtained.

[**0112**] This embodiment is more effectively applied to a case where formation of electrode films on plating target articles X having extremely small dimensions, for example, chip parts such as ceramic chip capacitors of about 0.6 mm×0.3 mm×0.2 mm in dimension or the like, or formation of plating films on pins of about 0.5 mm in diameter x about 20 mm in length is carried out on a large number of plating target articles at the same time. As described above, when such a minute article that the dimension in the direction traversing the longitudinal direction, that is, the width is equal to 5 mm or less, further 2 mm or less, still further 1 mm or less is used as the plating target article, the improving effect in the uniformity of the plating film thickness and the film forming speed is greater. Besides, metal powder alloy, inorganic/organic pigment particulates, metal balls may be targeted as the plating target articles.

[**0113**] As a matter of course, a desired pre-treatment is carried out before the electroplating method of the present invention is carried out. The pre-treatment is carried out in the same manner as the well-known electroplating method.

[**0114**] Further, a vibrational flow generator disclosed in JP(A)-11-189880 (in which vibrating vanes are disposed at the bottom portion of a plating tank, and vibration is transmitted from a vibrating motor through a vibration transmitting frame to the vibrating vanes to vibrate the vibrating vanes in the horizontal direction, as described with reference to **FIGS. 7 and 8** of this publication) or ones disclosed in publications other than the above publication may be properly used as the vibrational flow generator having the vibrating vanes for generating vibrational flow in the plating path in the method of the present invention.

[**0115**] For example, vibrational flow generators shown in **FIGS. 21 and 22** may be used. In **FIGS. 21 and 22**, two vibrational flow generators **16** are supported by a support frame **15** fixed to a support stand **13** on which a plating tank **12** is mounted. In each of the vibrational flow generators **16**, the upper end portion of a vibration transmitting rod **16***e*" extending in the up-and-down direction is fixed to a vibrating member **16***c*' for receiving vibration transmitted from a vibrating motor **16***d*. The vibration transmitting rod **16***e*" extends into the plating tank **12**, and the end portion of the vibration transmitting rod **16***e*' in the horizontal direction is fixed to the lower end of the vibration transmitting rod **16***e*". The vibration transmitting rods **16***e*' are commonly used by the two vibrational flow generators **16**, and vibrating vanes **16***f* extending in the up-and-down direction are fixed to the vibration transmitting rods **16***e*'. The vibration is transmitted from the vibrating motors **16***d* through the vibrating members **16***c*' and the vibration transmitting rods **16***e*" and **16***e*' to the vibrating vanes **16***f* to vibrate the vibrating vanes **16***f* in the horizontal direction.

[**0116**] **FIG. 12** is a cross-sectional view showing another embodiment of the plating apparatus used in the embodiment of the plating method according to the present invention, and **FIG. 13** is a partially notched plan view of the plating apparatus of **FIG. 12**. In this embodiment, the construction of the vibrational flow generator **16** is different from that of the above embodiment. That is, the lower end of a coil spring **16***d* is fixed to a fixing member **118** fixed to the upper end edge portion of the plating tank **12**, and a vibrating motor **16***d* is fixed to the lower side of a vibrating member **16***c* to which the upper end of the coil spring **16***b* is fixed. A lower guide member **124** whose lower end is fixed to the fixing member **118** and an upper guide member **123** whose upper end is fixed to the vibrating member **16***c* are disposed in the coil spring **16***b* so as to be spaced from each other at a proper distance.

[**0117**] **FIGS. 14 and 15** are cross-sectional views of another embodiment of the fixing portion of the vibrational flow generator to the plating tank in the plating apparatus used in the embodiment of the plating method according to the present invention, and **FIG. 16** is a plan view of this embodiment. **FIGS. 14 and 15** are views taken along lines X-X' and Y-Y' of **FIG. 16**, respectively. In these figures, the cathode, anode, power source circuit, etc. for plating are not shown.

[**0118**] In this embodiment, a laminated member **3** made of a rubber plate **2** and metal plates **1**, **1**' is used as a vibration absorbing member instead of the coil spring **16***b* of the above embodiments. The laminated member **3** is formed by fixing the metal plate **1**' via a rubber vibration insulator **112** to a support member **118** connected to the upper end of the plating tank **12** by means of a bolt **131**, disposing the rubber plate **2** on the metal plate **1**', disposing the metal plate **1** on the rubber plate **2**, and fixing the metal plates **1**, **1**' and rubber plate **2** by means of a bolt **116** and nut **117** to be integrated.

[**0119**] A vibrating motor **16***d* is fixed to the metal plate **1** via a support member **115** by a bolt **132**. The upper end

portion of a vibration transmitting rod **16***e* is connected via a rubber ring **119** to the laminated member **3**, especially to the metal plate **1** and rubber plate **2**. That is, the upper side metal plate **1** functions as the vibrating member **16***c* of the embodiment of **FIG. 1**, etc., and the lower side metal plate **1'** functions as the base stand **16***a* of the embodiment of **FIG. 1**, etc. The laminated member **3** containing the metal plate **1**, **1'**, especially the rubber plate **2**, has the same vibration absorbing function as the coil spring **16***b* of the embodiment of **FIG. 1**, etc.

[0120] **FIGS. 17A** to **17C** show schematic plan views of an embodiment of the laminated member **3**. In the embodiment of **FIG. 17A** corresponding to the above embodiment of FIGS. **14** to **16**, there is provided a hole **5** through which the vibration transmitting rod **16***e* passes. In the embodiment of **FIG. 17B**, the laminated member **3** comprises a first portion **3***a* and a second portion **3***b*, the facing edges of which are contacted with each other. According to this embidiment, the vibration transmitting rod **16***e* can be easily set to the laminated member **3** through the hole **5** thereof when assembling the apparatus. In the embodiment of **FIG. 17C**, the laminated member **3** is formed so as to have a ring shape corresponding to the shape of the upper edge portion of the plating tank **12**, and has an opening **6** positioned at the center thereof.

[0121] According to the embodiments of **FIGS. 17A and 17B**, the plating tank **12** is sealed with the laminated member **3**, and therefore gas evaporated from the plating bath **14** and plating liquid splashed from the plating bath **14** are prevented from leaking to the environment.

[0122] **FIGS. 18A and 18B** show cross-sectional views of the above sealing of the plating tank with the laminated member **3**. In the embodiment of **FIG. 18A**, the sealing of the plating tank **12** is performed by contacting the inner surface of the hole **5** of the rubber plate **2** with the vibration transmitting rod **16***e*. In the embodiment of **FIG. 18B**, there is provided a flexible sealing member **136** attached to the opening **6** of the laminated member **3** and the vibration transmitting rod **16***e* to seal the space existing therebetween.

[0123] **FIGS. 19A** to **19E** show examples of the laminated member **3** as the vibration absorbing member. The laminated member **3** of **FIG. 19B** is the same as that of FIGS. **14** to **16**. The laminated member **3** of **FIG. 19A** comprises metal plate **1** and rubber plate **2**. The laminated member **3** of **FIG. 19C** comprises upper metal plate **1**, upper rubber plate **2**, lower metal plate **1'** and lower rubber plate **2'**. The laminated member **3** of **FIG. 19D** comprises upper metal plate **1**, upper rubber plate **2**, intermediate metal plate **1"**, lower rubber plate **2'** and lower metal plate **1'**. The number of the metal plate or rubber plate is 1 to 5 for example. In the present invention, the vibration absorbing member may be formed only of the rubber plate(s).

[0124] Examples of material of the metal plates **1**, **1'**, **1"** are stainless steel, iron, copper, aluminum, suitable alloys, etc. The thickness of the metal plates **1**, **1'**, **1"** is 10 to 40 mm for example. However, the metal plate, for example the intermediate metal plate **1"**, which is not fixed to any member other than the member constituting the laminated member may be made so thinner as to have the thickness of 0.3 to 10 mm for example.

[0125] Material of the rubber plate **2**, **2'** is, for example, synthetic rubber or vulcanized natural rubber, and preferably rubber vibration isolator defined in JIS K6386 (1977), especially having static modulus of elasticity in shear of 4 to 22 kgf/cm^2, preferably 5 to 10 kgf/cm^2, and ultimate elongation of 250% or more.

[0126] Examples of synthetic rubber are chloroprene rubber, nitrile rubber, nitrile-chloroprene rubber, styrene-chloroprene rubber, acrylonitrile-butadiene rubber, isoprene rubber, ethylene-propylene-diene rubber, epichlorohydrin rubber, alkylene oxide rubber, fluororubber, silicone rubber, urethane rubber, polysulfide rubber, phosphorus rubber (flame-retarded rubber). The thickness of the rubber plate is 5 to 60 mm for example.

[0127] The laminated member **3** of **FIG. 19E** comprises upper metal plate **1**, lower metal plate **1'**, and rubber plate **2** which comprises an upper solid rubber layer **2***a*, sponge rubber layer **2***b* and lower solid rubber layer **2***c*. One of the upper and lower solid rubber layers **2***a*, **2***c* may be omitted. Alternatively, a plurality of sponge rubber layers and a plurality of solid rubber layers may be used in the rubber plate.

[0128] **FIG. 20** is a graph showing a modification of the variation of the plating current (current density) flowing through the plating target article X due to the voltage applied across the cathode bus bar **30** and the anode bus bar **32** by the power source circuit **34**. In this modification, the current density waveforms of the first and second states are not the rectangular form as shown in **FIG. 8**, but contain a little pulsation as shown in **FIG. 20**. Such pulsation is based on the construction of the power source circuit **34**, and the plating current used in the present invention may be pulsated current as shown in **FIG. 20**. The peak values in the first and second states may be used as the current values I1 and I2 in the first and second states, respectively.

[0129] In the present invention, the power source circuit **34** may comprise a voltage supply system for the first state and another voltage supply system for the second state. In this case, the voltages of these voltage supply systems are alternately output (i.e., this power source circuit is functionally equivalent to the switching operation of two power source devices).

[0130] The combination technique of the vibrational flow of the plating bath and the pulsed plating current as described above may be applied to an anodizing method, an electrolytic polishing method, an electrolytic degreasing method, etc. in which the surface treatment of target objects is carried out by utilizing current flow in a treatment bath. The target objects are disposed at the anode side or cathode side in accordance with the treatment content. By using this combination technique, the surface treatment on target articles having microstructures can be excellently performed.

[0131] The present invention will be described in more detail with the following examples.

EXAMPLE 1

[0132] The apparatus described with reference to FIGS. **1** to **3** was used. Here, a vibrating motor of 150 W×200V×3ϕ was used as the vibrating motor **16***d*, a plating tank having a volume of 300 liters was used as the plating tank **12**, and Power Master (available from Chuo Seisakusho, Co., Ltd.) was used as the power source circuit **34**.

[0133] 8-Inch (diameter of 200 mm) silicon wafers which were subjected to a predetermined pre-treatment by the conventional method were used as the plating target articles X, and a process of forming copper-embedded conductive film in blind via holes coated with a copper seed layer in the copper damascene method was carried out. Many blind via holes were formed in a titanium nitride insulation layer of 0.35 μm in thickness to have an inner diameter of 0.24 μm.

[0134] The following through hole bath of copper sulfate plating was used as the plating bath **14**:

[0135] Copper sulfate: 75 g/L

[0136] Sulfuric acid: 190 g/L

[0137] Brightener: proper amount

[0138] Chlorine ion: 40 mL/L

[0139] The vibrating motor **16*d*** of the vibrational flow generator **16** was vibrated at 45 Hz to vibrate the vibrating vanes **16*f*** at an amplitude of 0.2 mm and a vibration frequency of 650 revolutions per minute in the plating bath **14**. Further, the vibrating motor **28** was vibrated at 25 Hz to vibrate the plating target articles X at an amplitude of 0.15 mm and a vibration frequency of 200 revolutions per minute in the plating bath **14**. The three-dimensional flow rate in the plating bath at this time was measured as 200 mm/second by a three-dimensional electromagnetic flowmeter ACM300-A (available from Alec Electronics Co., Ltd.).

[0140] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied I1=6[A/wafer]=3[A/dm^2], I2=0.6 [A/wafer], T1=10[second], T2=1[second].

[0141] When the treatment was carried out for 10 minutes, it was found on the basis of a current flowing test, microscopy and other tests that excellent copper plating films of about 10 μm in thickness were formed and embedded in all the blind via holes.

COMPARATIVE EXAMPLE 1-1

[0142] The same treatment as Example 1, except for the condition: T2=0[second], was carried out. It was proved from the current flowing test, microscopy and other tests that excellent embedding of copper plating film was carried out in some (58%) of the many blind via holes, however, was not carried out in the other blind via holes.

COMPARATIVE EXAMPLE 1-2

[0143] The same treatment as Example 1, except that the vibrational flow generator **16** was not actuated, was carried out. It was proved from the current flowing test, microscopy and other tests that excellent embedding of copper plating film was carried out in some (10%) of the many blind via holes, however, was not carried out in the other blind via holes (defectives due to burning, scorching or the like occurred).

EXAMPLE 2

[0144] The plating conductive films were formed on the inner surfaces of through holes by using the apparatus described with reference to FIGS. **1** to **3** (the vibrating motor **16*d***, the plating tank **12** and the power source circuit **34** were the same as Example 1) and using as the plating target article X an A4-size multi-layered wiring board which was subjected to the pre-treatment by the conventional method. Many through holes had an inner diameter of 30 μmϕ and an aspect ratio of **10**.

[0145] The following normal bath of copper sulfate plating was used as the plating bath **14**:

[0146] Copper sulfate: 200 g/L

[0147] Sulfuric acid: 50 g/L

[0148] Brightener: proper amount

[0149] Chlorine ion: 60 mL/L

[0150] The vibrating motor **16*d*** of the vibrational flow generator **16** was vibrated at 50 Hz to vibrate the vibrating vanes **16*f*** at an amplitude of 0.2 mm and a vibration frequency of 700 revolutions per minute in the plating bath **14**. Further, the vibrating motor **28** was vibrated at 25 Hz to vibrate the plating target articles X at an amplitude of 0.15 mm and a vibration frequency of 200 revolutions per minute in the plating bath **14**. Further, the swinging motor **20** was driven to swing the plating target articles X at a swinging width of 30 mm and a swinging frequency of 20 times per minute. The three-dimensional flow rate in the plating bath at this time was measured as 200 mm/second by the three-dimensional electromagnetic flowmeter ACM300-A.

[0151] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied I1=4[A/dm^2], I2=0.4[A/dm^2], T1=180[second], T2=20[second].

[0152] When the treatment was carried out for 10 minutes, it was found on the basis of a current flowing test, microscopy and other tests that excellent copper plating films were formed in 99.9% through holes.

COMPARATIVE EXAMPLE 2-1

[0153] The same treatment as Example 2, except for the condition: T2=0[second], was carried out. It was proved from the current flowing test, microscopy and other tests that excellent copper plating films were formed over the overall length in some (50%) of the many through holes, however, no excellent copper plating film was formed in the other through holes.

COMPARATIVE EXAMPLE 2-2

[0154] The same treatment as Example 2, except that the vibrational flow generator **16** was not actuated, was carried out. It was proved from the current flowing test, microscopy and other tests that excellent copper plating films were formed in some (10%) of the many through holes, however, no excellent copper plating film was formed in the other through holes (defectives due to burning, scorching or the like occurred).

EXAMPLE 3

[0155] The apparatus described with reference to FIGS. **9** to **11** (the vibrating motor **16*d***, the plating tank **12** and the power source circuit **34** were the same as Example 1), and 800 ceramic chips of 0.6 mm×0.3 mm×0.2 mm in dimension which were subjected to the pre-treatment by the conventional method were used as plating target articles X. Nickel plating films to form electrode films were formed on the end

surfaces at both ends of each ceramic chip in the longitudinal direction thereof and on a part (an area located within 0.1 mm from both the end surfaces) of the 0.6 mm×0.3 mm surface adjacent to the end surfaces.

[**0156**] The following barrel bath was used as the nickel plating bath **14**:

[**0157**] Nickel sulfate: 270 g/L

[**0158**] Nickel chloride: 68 g/L

[**0159**] Boric acid: 40 g/L

[**0160**] Magnesium sulfate: 225 g/L

[**0161**] The vibrating motor **16***d* of the vibrational flow generator **16** was vibrated at 55 Hz to vibrate the vibrating vanes **16***f* at an amplitude of 0.2 mm and a vibration frequency of 750 revolutions per minute in the plating bath **14**. The vibrating motor **48** was vibrated to vibrate the target plating articles at an amplitude of 0.15 mm and a vibration frequency of 250 revolutions per minute in the plating bath **14**. The three-dimensional flow rate in the plating bath at this time was measured as 210 mm/second by the three-dimensional electromagnetic current meter ACM300-A. The barrel **52** having a mesh opening ratio of 20% was used, and the rotational number of the barrel was set to 10 rpm.

[**0162**] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied **I1**=0.4[A/dm^2], **I2**=0.04[A/dm^2], **T1**=20[second], **T2**=2[second].

[**0163**] When the treatment was carried out at 50° C. for 30 minutes, it was found on the basis of a current flowing test, microscopy and other tests that excellent nickel plating films of about 2 μm in thickness were formed in all the ceramic chips.

COMPARATIVE EXAMPLE 3-1

[**0164**] The same treatment as Example 3, except for the condition: **T2**=0[second], was carried out. It was proved from the current flowing test, microscopy and other tests that excellent nickel plating films were formed in some (12%) of the ceramic chips, however, no excellent nickel plating film was formed in the other ceramic chips.

COMPARATIVE EXAMPLE 3-2

[**0165**] The same treatment as Example 3, except that the vibrational flow generator **16** was not actuated, was carried out. It was proved from the current flowing test, microscopy and other tests that excellent nickel plating films were formed in some (60%) of the ceramic chips, however, no excellent nickel plating film was formed in the other ceramic chips.

EXAMPLE 4

[**0166**] In place of the nickel plating, tin plating was carried out in the same way as Example 3. The following sulfate bath of acidic tin plating was used as the plating bath **14**:

[**0167**] Stannous sulfate: 50 g/L

[**0168**] Sulfuric acid: 100 g/L

[**0169**] Cresolsulfonic acid: 100 g/L

[**0170**] Gelatin: 2 g/L

[**0171**] β-naphthol 1 g/L

[**0172**] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied **I1**=0.4[A/dm^2], **I2**=0.04[A/dm^2], **T1**=20[second], **T2**=2[second].

[**0173**] When the treatment was carried out at 50° C. for 60 minutes, it was found on the basis of a current flowing test, microscopy and other tests that excellent tin plating films were formed in all the ceramic chips.

COMPARATIVE EXAMPLE 4-1

[**0174**] The same treatment as Example 4, except for the condition: **T2**=0[second], was carried out. It was proved from the current flowing test, microscopy and other tests that excellent tin plating films were formed in some (10%) of the ceramic chips, however, no excellent tin plating film was formed in the other ceramic chips.

COMPARATIVE EXAMPLE 4-2

[**0175**] The same treatment as Example 4, except that the vibrational flow generator **16** was not actuated, was carried out. It was proved from the current flowing test, microscopy and other tests that excellent tin plating films were formed in some (57%) of the ceramic chips, however, no excellent tin plating film was formed in the other ceramic chips.

EXAMPLE 5

[**0176**] The apparatus described with reference to FIGS. **9** to **11** (the vibrating motor **16***d*, the plating tank **12** and the power source circuit **34** were the same as Example 1), and 30 brass pins of 0.5 mmφ in outer diameter and 20 mm in length which were subjected to the pre-treatment by the conventional method were used as plating target articles X. Nickel plating films were formed on the outer surfaces of the pins.

[**0177**] The following barrel bath was used as the nickel plating bath **14**:

[**0178**] Nickel sulfate: 270 g/L

[**0179**] Nickel chloride: 68 g/L

[**0180**] Boric acid: 40 g/L

[**0181**] Magnesium sulfate: 225 g/L

[**0182**] The vibrating motor **16***d* of the vibrational flow generator **16** was vibrated at 45 Hz to vibrate the vibrating vanes **16***f* at an amplitude of 0.2 mm and a vibration frequency of 500 revolutions per minute in the plating bath **14**. The vibrating motor **48** was vibrated to vibrate the target plating articles at an amplitude of 0.15 mm and a vibration frequency of 200 revolutions per minute in the plating bath **14**. The three-dimensional flow rate in the plating bath at this time was measured as 200 mm/second by the three-dimensional electromagnetic current meter ACM300-A. The barrel **52** having a mesh opening ratio of 20% was used, and the rotational number of the barrel was set to 10 rpm.

[**0183**] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied **I1**=3[A/dm^2], **I2**=0.3[A/dm^2], **T1**=30[second], **T2**=3[second].

[**0184**] When the treatment was carried out at 50° C. for 20 minutes, it was found on the basis of the measurement of the thickness of the nickel plating films, current flowing test,

microscopy and other tests that excellent nickel plating films having excellent uniformity in thickness were formed in all the pins.

COMPARATIVE EXAMPLE 5-1

[0185] The same treatment as Example 5, except for the condition: T2=0[second], was carried out. It was proved from the measurement of the thickness of the nickel plating films, the current flowing test, microscopy and other tests that excellent nickel plating films were formed on some (17%) of the pins, however, no excellent nickel plating film was formed on the other pins.

COMPARATIVE EXAMPLE 5-2

[0186] The same treatment as Example 5, except that the vibrational flow generator **16** was not actuated, was carried out. It was proved from the measurement of the thickness of the nickel plating films, the current flowing test, microscopy and other tests that excellent nickel plating films were formed in some (60%) of the pins, however, no excellent nickel plating film was formed on the other pins (defectives due to burning, scorching or the like occurred).

EXAMPLE 6

[0187] The apparatus described with reference to FIGS. **9** to **11** (the vibrating motor **16*d***, the plating tank **12** and the power source circuit **34** were the same as Example 1), and about 30000 spheres of acrylonitrile-butadiene-styrene copolymer (ABS resin) each of which had a diameter of 3 mmϕ and was subjected to the pre-treatment (containing a degreasing treatment and a charging treatment) by the conventional method were used as plating target articles X. Copper plating films were formed on the outer surfaces of the spheres.

[0188] The following was used as the plating bath **14**:

[0189] Copper sulfate: 200 g/L

[0190] Sulfuric acid: 50 g/L

[0191] Brightener: proper amount

[0192] Chlorine ion: 40 mL/L

[0193] The vibrating motor **16*d*** of the vibrational flow generator **16** was vibrated at 40 Hz to vibrate the vibrating vanes **16*f*** at an amplitude of 0.2 mm and a vibration frequency of 700 revolutions per minute in the plating bath **14**. The vibrating motor **48** was vibrated to vibrate the target plating articles X at an amplitude of 0.15 mm and a vibration frequency of 250 revolutions per minute in the plating bath **14**. The three-dimensional flow rate in the plating bath at this time was measured as 210 mm/second by the three-dimensional electromagnetic current meter ACM300-A. The barrel **52** having a mesh opening ratio of 20% was used, and the rotational number of the barrel was set to 10 rpm.

[0194] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied I1=0.5[A/dm^2], I2=0.04[A/dm^2], T1=30[second], T2=3[second].

[0195] When the treatment was carried out at 50° C. for 30 minutes, it was found on the basis of the measurement of the thickness of the copper plating films, current flowing test, microscopy and other tests that excellent copper plating films having excellent uniformity in thickness were formed in 99.5% spheres.

COMPARATIVE EXAMPLE 6-1

[0196] The same treatment as Example 6, except for the condition: T2=0[second], was carried out. It was proved from the measurement of the thickness of the copper plating films, the current flowing test, microscopy and other tests that excellent copper plating films were formed in some (40%) of the spheres, however, no excellent copper plating film was formed in the other spheres.

COMPARATIVE EXAMPLE 6-2

[0197] The same treatment as Example 6, except that the vibrational flow generator **16** was not actuated, was carried out. It was proved from the measurement of the thickness of the copper plating films, the current flowing test, microscopy and other tests that excellent copper plating films were formed in some (50%) of the spheres, however, no excellent copper plating film was formed in the other spheres.

EXAMPLE 7

[0198] The apparatus described with reference to FIGS. **1** to **3** was used. Here, a vibrating motor of 150 W×200V×3ϕ was used as the vibrating motor **16*d***, a plating tank having a volume of 300 liters was used as the plating tank **12**, and Power Master PMD1 (available from Chuo Seisakusho, Co., Ltd.) was used as the power source circuit **34**.

[0199] A silicon wafer having a size of 40 mm×40 mm and a thickness of 1 mm which was subjected to a predetermined pre-treatment by the conventional method was used as the plating target article X, on the surface of which many blind via holes each having an inner diameter of 20 μm and a depth of 70 μm were formed.

[0200] The following through hole bath of copper sulfate plating was used as the plating bath **14**:

[0201] Copper sulfate: 75 g/L

[0202] Sulfuric acid: 190 g/L

[0203] Brightener: proper amount

[0204] Chlorine ion: 40 mL/L

[0205] In the plating tank **12**, an aeration tube made of ceramics having an outer diameter of 75 mmϕ, an inner diameter of 50 mmϕ, a length of 500 mmm, a pore size of 50 to 60 μm and a porosity of 33 to 38% was disposed to generate air bubbles in the plating bath **14**.

[0206] The vibrating motor **16*d*** of the vibrational flow generator **16** was vibrated at 40 Hz to vibrate the vibrating vanes **16*f*** at an amplitude of 0.1 mm and a vibration frequency of 650 revolutions per minute in the plating bath **14**. Further, the vibrating motor **28** of 75 W×200V×3ϕ was vibrated at 25 Hz to vibrate the plating target articles X at an amplitude of 0.15 mm and a vibration frequency of 200 revolutions per minute in the plating bath **14**. The three-dimensional flow rate in the plating bath at this time was measured as 200 mm/second by the three-dimensional electromagnetic flowmeter ACM300-A.

[0207] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1**, **I2**, **T1**, **T2** shown in **FIG. 8** satisfied I1=1.5[A/wafer], I2=0.1[A/wafer], T1=0.08[second], T2=0.02[second].

[0208] When the treatment was carried out for 2.5 hours, it was found on the basis of the current flowing test, microscopy and other tests that copper plating films having

a uniform thickness of about 7 μm were formed in all the inner surfaces of the blind via holes.

COMPARATIVE EXAMPLE 7

[0209] The same treatment as Example 7, except for the condition: T2=0[second], was carried out. It was proved from the current flowing test, microscopy and other tests that the openings of the blind via holes were sealed with the copper plating films.

EXAMPLE 8

[0210] The same treatment as Example 7, except that a high frequency vibrating motor was used as the vibrating motor **16*d***, the vibrating motor **16*d*** was vibrated at 150 Hz to vibrate the vibrating vanes **16*f*** at an amplitude of 0.2 mm and a vibration frequency of 1200 revolutions per minute in the plating bath **14**, and the treatment time was 1.5 hours.

[0211] It was proved from the current flowing test, microscopy and other tests that the copper plating films having a uniform thickness of about 7 μm were formed in all the inner surfaces of the blind via holes.

EXAMPLE 9

[0212] An epoxy resin plate for wiring board was used as the plating target article X, on the surface of which many blind via holes each having an inner diameter of 15 μm and a depth of 40 μm were formed.

[0213] As the pre-treatment for the electroplating treatment, degreasing water washing-etching-water washing-neutralizing-water washing-catalyst-water washing-accelarator-water washing-electroless copper plating were conducted to make the plating target article X electically conductive. Furthermore, water washing-activating-water washing strike plating were conducted. In the electroless copper plating and strike plating, the vibrational flow was generated in the plating treatment liquid by means of the same vibrational flow generator as described with reference to FIGS. **1** to **3**.

[0214] The electroplating treatment was carried out in the same manner as Example 7, except that the swinging motor **20** was actuated to swing the plating target article X at a swinging width of 30 mm and a swinging frequency of 20 times per minute in the plating bath **14**. The three-dimensional flow rate in the plating bath was measured as 200 mm/second by the three-dimensional electromagnetic flowmeter ACM300-A.

[0215] The plating current of rectangular waveform was supplied by the power source circuit **34** so that **I1, I2, T1, T2** shown in **FIG. 8** satisfied I1=4.5[A/dm^2], I2=0.4[A/dm^2], T1=0.08[second], T2=0.015[second].

[0216] When the treatment was carried out for 1 hour, it was found on the basis of the current flowing test, microscopy and other tests that copper plating films were excellently formed and embedded in all the blind via holes.

COMPARATIVE EXAMPLE 8

[0217] The same treatment as Example 9, except for the condition: T2=0[second], was carried out. It was proved from the current flowing test, microscopy and other tests that the openings of the blind via holes were sealed with the copper plating films, however, voids remained in the innermost of the blind via holes.

What is claimed is:

1. An electroplating method, characterized in that a plating target article disposed so as to be in contact with plating bath is set as a cathode while a metal member disposed so as to be in contact with the plating bath is set as an anode, and a voltage is applied between the cathode and the anode while vibrational flow is induced by vibrating vibrational vanes which are fixed in one-stage or multi-stage style to a vibrating rod vibrating in the plating bath interlockingly with vibration generating means, wherein plating current flowing from the anode through the plating bath to the cathode is pulsed and alternately set to one of a first state where the plating current keeps a first value **I1** for a first time T1 and a second state where the plating current keeps a second value **I2** having the same polarity as the first value **I1** for a second time **T2**, the first value **I1** being five or more times larger than the second value **I2**, and the first time **T1** being three or more times longer than the second time **T2**.

2. The electroplating method as claimed in claim 1, wherein the first value **I1** is 6 to 25 times as large as the second value **I2**, and the first time **T1** is 4 to 25 times as long as the second time **T2**.

3. The electroplating method as claimed in claim 1, wherein the first value **I1** is set to 0.01 to 300 seconds.

4. The electroplating method as claimed in claim 1, wherein the vibrational vanes are vibrated at an amplitude of 0.05 to 10.0 mm and a vibration frequency of 200 to 1500 revolutions per minute.

5. The electroplating method as claimed in claim 1, wherein the vibrational vanes are vibrated so that the vibrational flow of the plating bath has a three-dimensional flow rate of 150 mm/second or more.

6. The electroplating method as claimed in claim 1, wherein the vibration generating means vibrates at 10 to 500 Hz.

7. The electroplating method as claimed in claim 1, wherein the plating target article is vibrated at an amplitude of 0.05 to 5.0 mm and a vibration frequency of 100 to 300 revolutions per minute.

8. The electroplating method as claimed in claim 1, wherein the plating target article is swung at a swinging width of 10 to 100 mm and a swinging frequency of 10 to 30 times per minute.

9. The electroplating method as claimed in claim 1, wherein the plating target article has a face to be plated having a microstructure of a dimension of 50 μm or less.

10. The electroplating method as claimed in claim 1, wherein a plurality of plating target articles are accommodated in a holding container, said holding container having small holes through which liquid of the plating bath is allowed to pass and being equipped with an electrically conductive member which is brought into contact with the plating target articles to make current flow through the plating target articles, and wherein said holding container is rotated around the rotational center corresponding to a non-vertical direction in the plating bath to roll the plating target articles in said holding container to thereby repeat the contact and separation between each of the plating target articles and said electrically conductive member.

11. The electroplating method as claimed in claim 10, wherein the width of each of the plating target articles is equal to 5 mm or less.

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