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(54) **FILM FORMING METHOD FOR FORMING METAL FILM AND FILM FORMING APPARATUS FOR FORMING METAL FILM**

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(30) **Foreign Application Priority Data**

Jun. 1, 2021 (JP) ................................. 2021-092162

(51) **Int. Cl.**

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| ***C25D 17/14*** | (2006.01) |
| ***C25D 5/00*** | (2006.01) |
| ***C25D 21/12*** | (2006.01) |
| ***C25D 17/00*** | (2006.01) |

(52) **U.S. Cl.**
CPC ............... ***C25D 5/003*** (2013.01); ***C25D 5/06*** (2013.01); ***C25D 17/002*** (2013.01); ***C25D 17/14*** (2013.01); ***C25D 21/12*** (2013.01)

(58) **Field of Classification Search**
CPC ........ C25D 17/002; C25D 5/003; C25D 5/06; C25D 17/14
See application file for complete search history.

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(57) **ABSTRACT**

Provided is a method for forming a metal film capable of forming a homogeneous metal film having a uniform film thickness by stably ensuring a fluid pressure of an electrolytic solution during film formation. The method places a substrate on a mount base. While sucking a gas between the substrate and a porous film through which the electrolytic solution can pass from a suction port of a suction passage formed on the mount base, the method brings the porous film into contact with the surface of the substrate. The method interrupts the suction passage while the porous film contacts the surface of the substrate. While interrupting the suction passage, the method allows the electrolytic solution to pass through the porous film while pressing the porous film against the surface of the substrate with a fluid pressure of the electrolytic solution and deposits metal from metal ions in the passed electrolytic solution on the surface of the substrate, thereby forming the metal film.

**3 Claims, 6 Drawing Sheets**

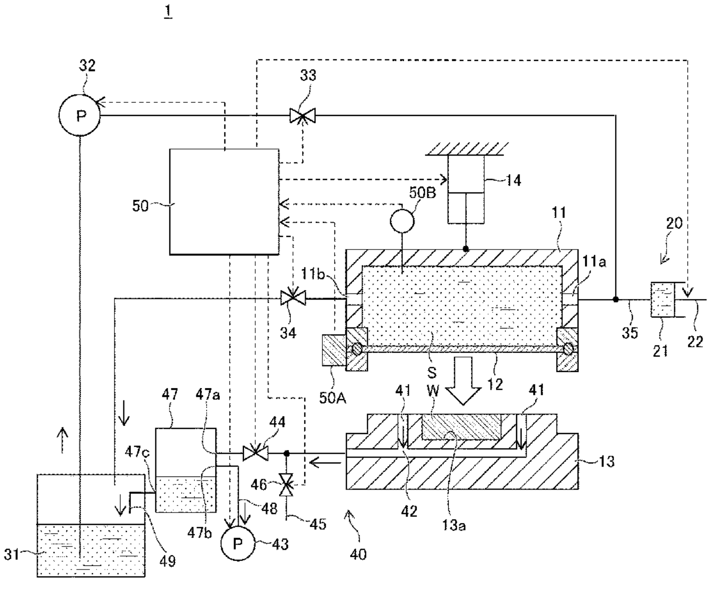


FIG. 1

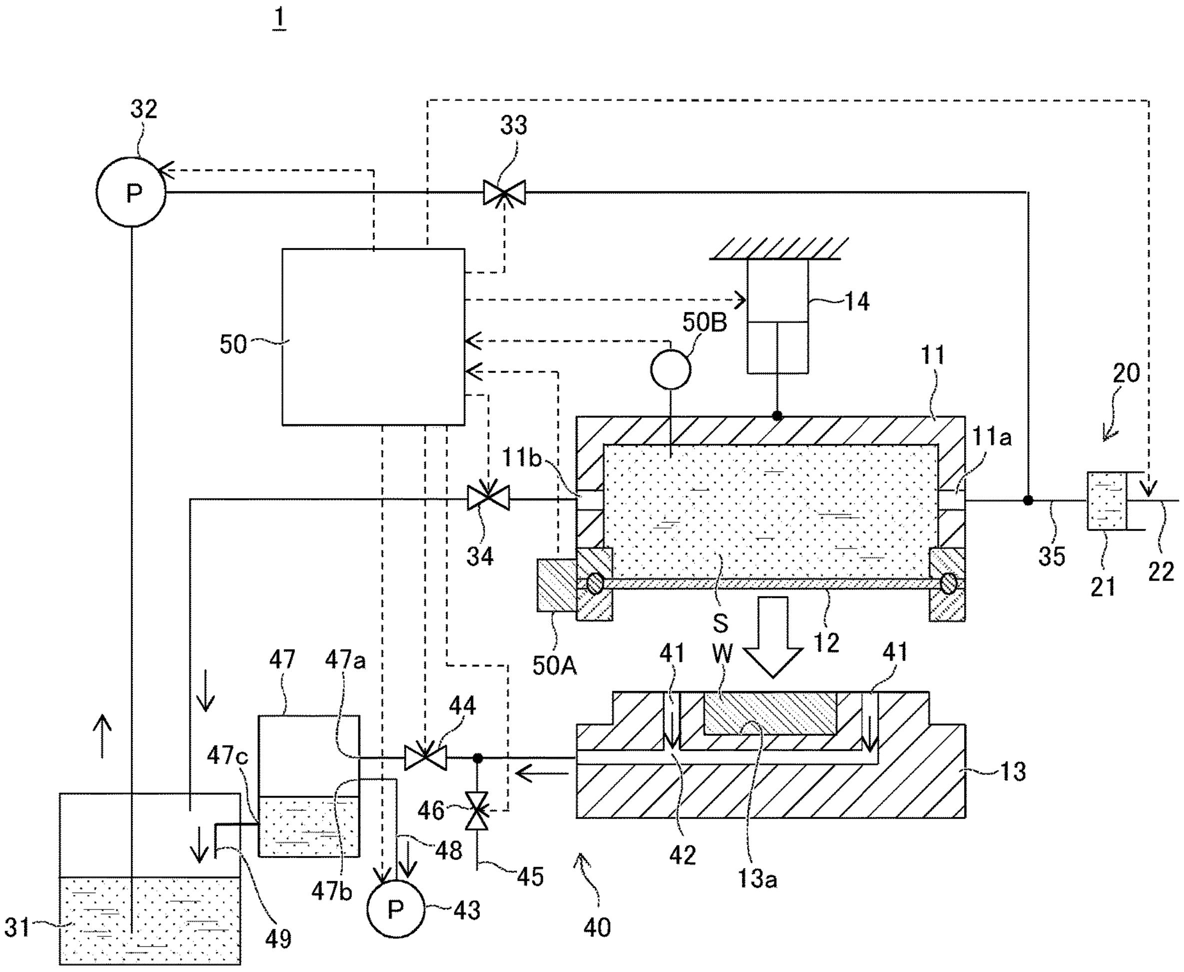

1
32
P
33
50
14
50B
11
20
11b
11a
34
35
21
22
50A
S
12
W
41
41
47
47a
44
47c
13
46
48
42
13a
45
47b
P
43
31
49
40

FIG. 2

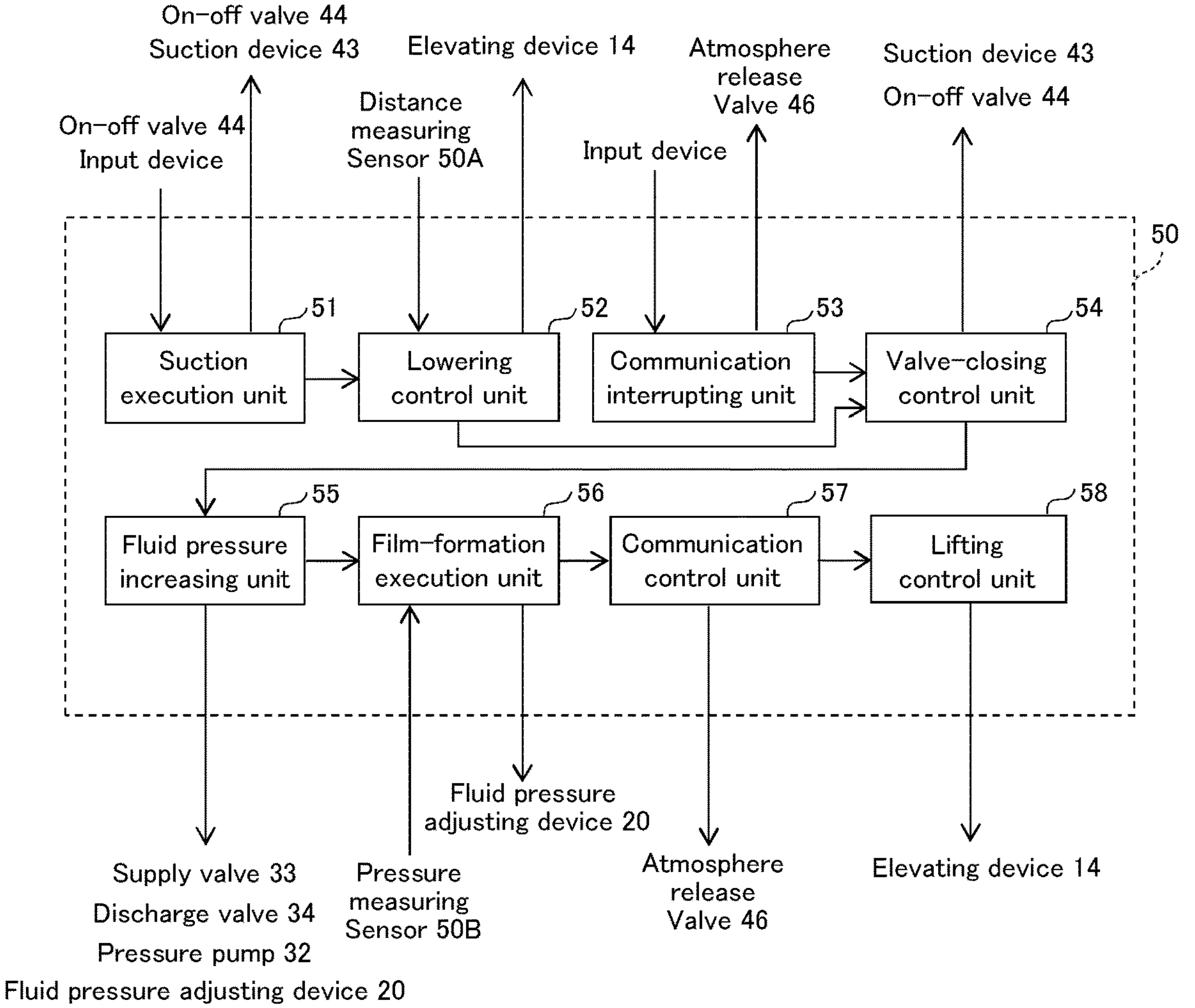

On−off valve 44
Suction device 43
Elevating device 14
Atmosphere release Valve 46
Suction device 43
On−off valve 44
On−off valve 44
Input device
Distance measuring Sensor 50A
Input device
50
51
Suction execution unit
52
Lowering control unit
53
Communication interrupting unit
54
Valve−closing control unit
55
Fluid pressure increasing unit
56
Film−formation execution unit
57
Communication control unit
58
Lifting control unit
Fluid pressure adjusting device 20
Supply valve 33
Discharge valve 34
Pressure pump 32
Fluid pressure adjusting device 20
Pressure measuring Sensor 50B
Atmosphere release Valve 46
Elevating device 14

FIG. 3

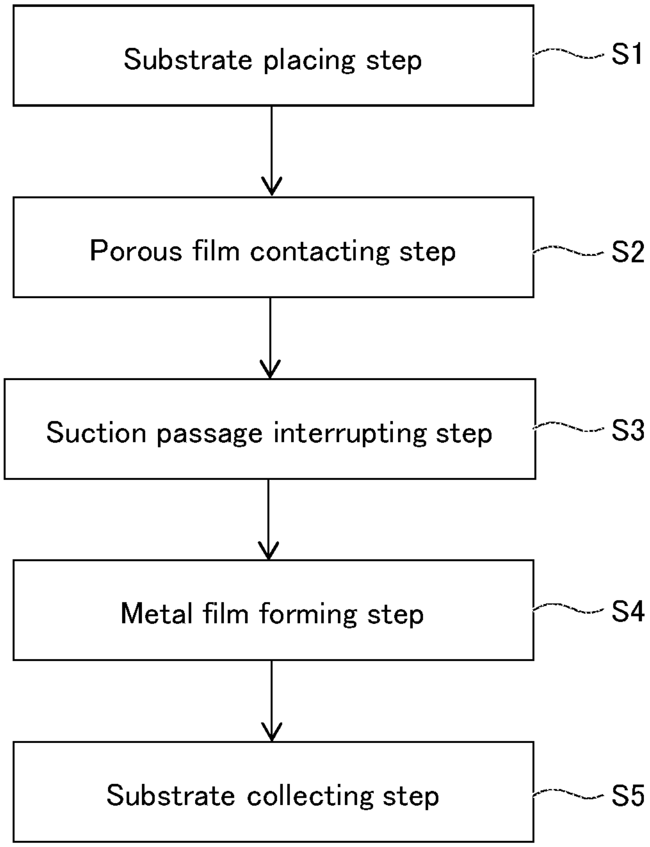

Substrate placing step
S1
Porous film contacting step
S2
Suction passage interrupting step
S3
Metal film forming step
S4
Substrate collecting step
S5

FIG. 4

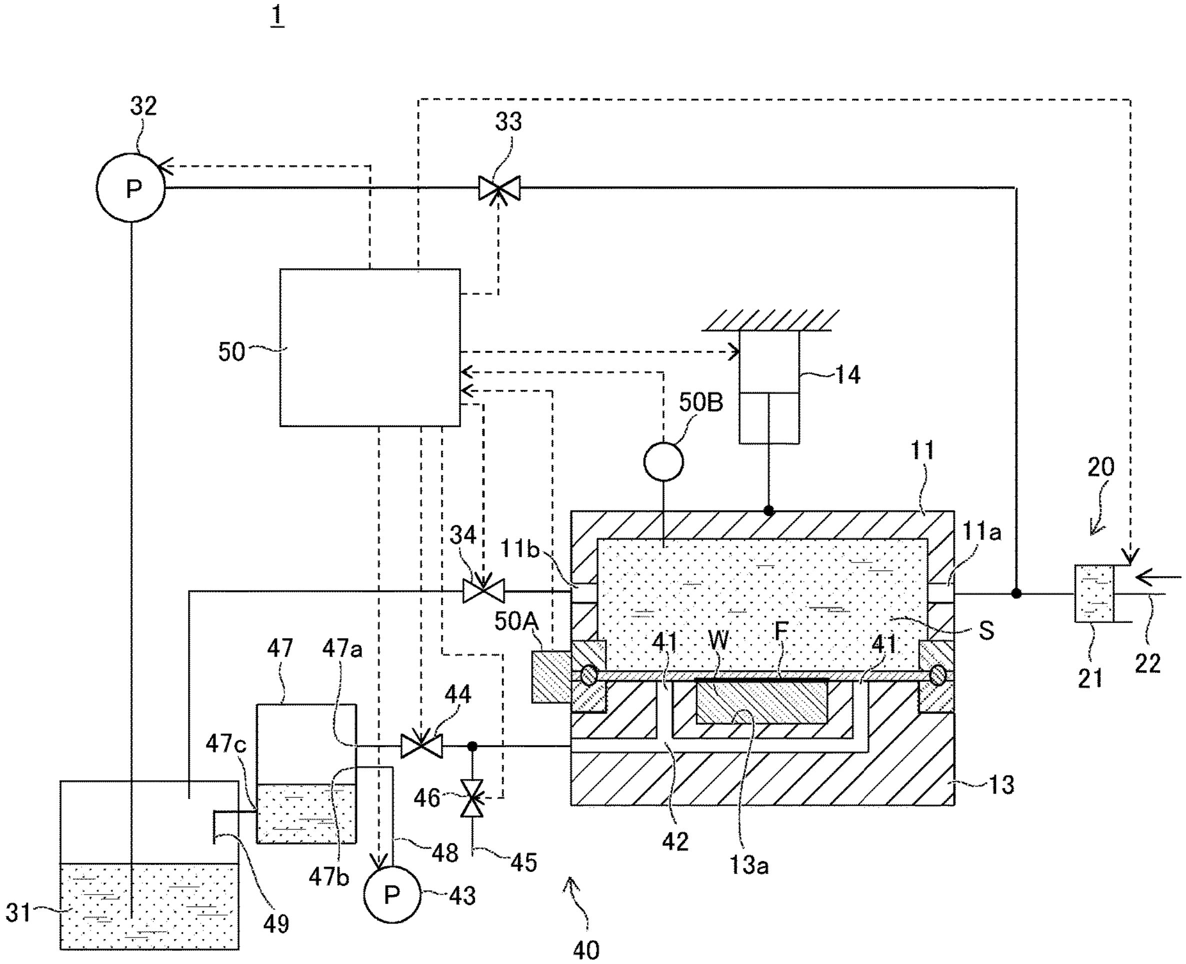
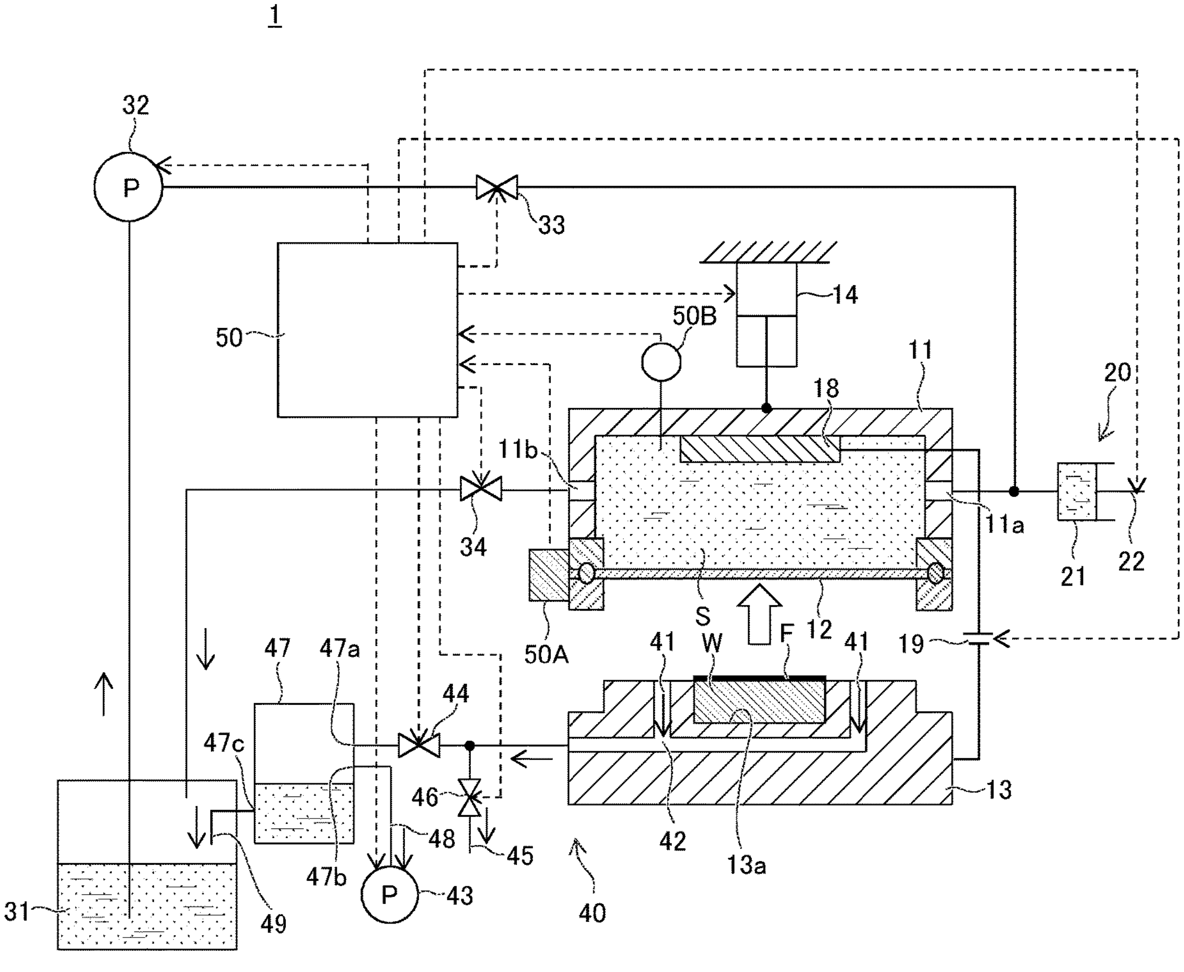

1
32
P
33
50
14
50B
11
20
34
11b
11a
50A
S
41
W
F
41
21
22
47
47a
44
47c
46
13
42
13a
48
45
47b
P
43
31
49
40

FIG. 5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32
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33
14
50B
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11b
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11a
21
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12
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W
41
41
19
47
47a
44
47c
46
48
45
42
13a
13
47b
P
43
40
31
49

FIG. 6

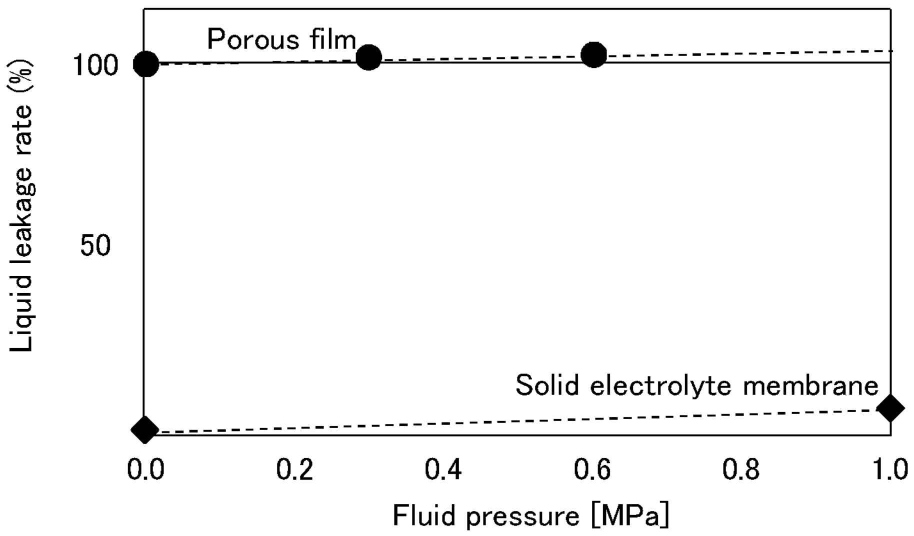
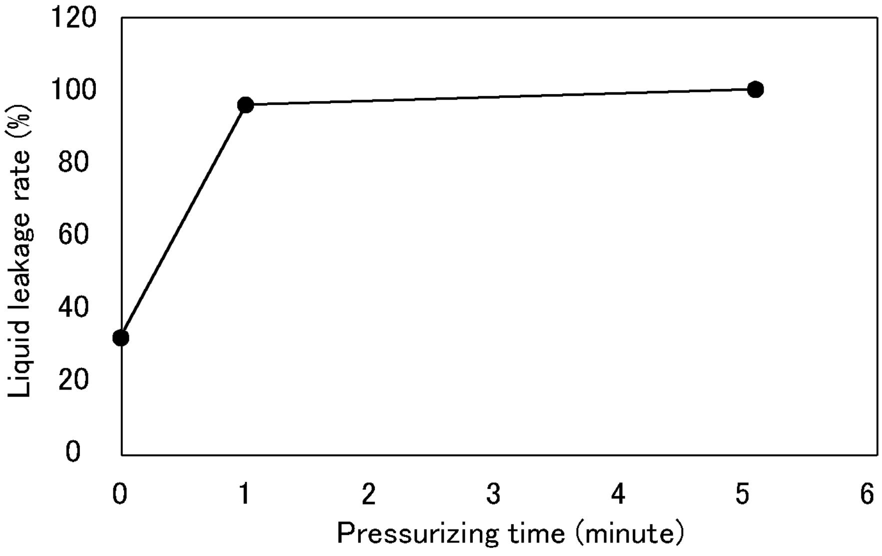

Porous film
Solid electrolyte membrane
Liquid leakage rate (%)
100
50
0.0
0.2
0.4
0.6
0.8
1.0
Fluid pressure [MPa]

FIG. 7


Liquid leakage rate (%)
120
100
80
60
40
20
0
0
1
2
3
4
5
6
Pressurizing time (minute)

# FILM FORMING METHOD FOR FORMING METAL FILM AND FILM FORMING APPARATUS FOR FORMING METAL FILM

## CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority from Japanese patent application JP 2021-092162 filed on Jun. 1, 2021, the entire content of which is hereby incorporated by reference into this application.

## BACKGROUND

### Technical Field

The present disclosure relates to a film forming method and a film forming apparatus for forming a metal film derived from metal ions contained in an electrolytic solution on a surface of a substrate by depositing metal on the surface of the substrate by electroplating or electroless plating.

### Background Art

As the film forming method for forming a metal film on a surface of a substrate, for example, a method that uses a solid electrolyte membrane for forming a metal film by electroplating is proposed in JP 6056987 B. Specifically, in the film forming method disclosed in JP 6056987 B, an electrolytic solution is allowed to pass through a solid electrolyte membrane from one side of the solid electrolyte membrane while the solid electrolyte membrane is pressed against the surface of a substrate with a fluid pressure of the electrolytic solution, and metal from metal ions contained in the passed electrolytic solution is deposited on the surface of the substrate by electroplating. Further, in the film forming method disclosed in JP 6056987 B, during film formation, the solid electrolyte membrane is sucked from the substrate side such that the solid electrolyte membrane is brought into intimate contact with the substrate.

## SUMMARY

When the solid electrolyte membrane is a porous film, however, forming a film while sucking the porous film as described in JP 6056987 B may cause the electrolytic solution to leak into the substrate side through the porous film due to the sucking. If the electrolytic solution keeps leaking into the substrate side during film formation, a stable fluid pressure may no longer be ensured. As a result, it may be difficult to form a homogeneous metal film having a uniform film thickness.

The present disclosure has been made in view of the foregoing, and provides a film forming method and a film forming apparatus for forming a metal film capable of forming a homogeneous metal film having a uniform film thickness by stably ensuring a fluid pressure of an electrolytic solution during film formation.

In view of the foregoing, the film forming method for forming a metal film according to the present disclosure is a film forming method for forming a metal film from metal ions contained in an electrolytic solution on a surface of a substrate by depositing metal on the surface of the substrate by electroplating or electroless plating. The film forming method includes at least: placing the substrate on a mount base; while sucking a gas between the substrate and a porous film from a suction port of a suction passage formed on the mount base, moving the porous film toward the substrate and bringing the porous film into contact with the surface of the substrate; interrupting the suction passage in a state where the porous film is in contact with the surface of the substrate; and in a state where the suction passage is interrupted, allowing the electrolytic solution to pass through the porous film while the porous film is pressed against the substrate with a fluid pressure of the electrolytic solution and depositing the metal from the metal ions contained in the passed electrolytic solution on the surface of the substrate, thereby forming the metal film on the surface of the substrate.

According to the film forming method for forming a metal film of the present disclosure, before forming a metal film, the substrate is placed on the mount base, and the porous film is brought into contact with the surface of the substrate while sucking a gas between the substrate and the porous film from the suction port of the suction passage formed on the mount base. This can prevent the gas (air) from being captured in between the substrate and the porous film and uniformly bring the porous film into contact with the surface of the substrate. Here, since the suction passage is interrupted in a state where the porous film is in contact with the surface of the substrate, the suction of the gas from the suction port is released. Consequently, while forming a metal film, even if the electrolytic solution is allowed to pass through the porous film while the porous film is pressed against the surface of the substrate with a fluid pressure of the electrolytic solution, it is possible to prevent the passed electrolytic solution from continuously flowing to the suction passage from the suction port. In this way, it is possible to uniformly press the porous film against the surface of the substrate in a state where the fluid pressure of the electrolytic solution is stably maintained and to uniformly supply the passed electrolytic solution to the surface of the substrate, and thus it is possible to form a homogeneous metal film having a more uniform film thickness on the surface of the substrate.

In some embodiments, after the forming the metal film, the interrupted suction passage is allowed to be communicated to atmosphere and the porous film is separated from the substrate after the suction passage is communicated to the atmosphere.

According to this embodiment, as described above, the pressure in the suction passage may be maintained at a negative pressure due to the suction of a gas after the suction passage is interrupted in a state where the porous film is in contact with the surface of the substrate and until film formation is completed. Then, after the forming the metal film, the interrupted suction passage is allowed to be communicated to atmosphere so that the pressure in the suction passage can be reset to the atmospheric pressure. Consequently, after the forming the metal film, it is possible to reduce the likelihood that the porous film is less likely to be separated from the substrate due to the negative pressure in the suction passage.

In some embodiments, in the bringing the porous film into contact with the surface of the substrate, the electrolytic solution having been sucked into the suction passage together with the gas during suction of the gas is separated from the gas. According to this embodiment, the electrolytic solution can be collected and reused by separating, from the gas, the electrolytic solution sucked into the suction passage together with the gas.

This specification discloses a film forming apparatus for suitably performing the above-described film forming method for forming a metal film. The film forming apparatus for forming a metal film of the present disclosure is a film forming apparatus for forming a metal film from metal ions contained in an electrolytic solution on a surface of a substrate by depositing metal on the surface of the substrate by electroplating or electroless plating. The film forming apparatus includes at least: a housing configured to store the electrolytic solution; a porous film attached to the housing so as to seal the electrolytic solution stored in the housing and to be opposed to the substrate; a fluid pressure adjusting device configured to adjust a fluid pressure of the electrolytic solution stored in the housing; a mount base configured to have the substrate placed thereon, the mount base including a suction passage with a suction port for sucking a gas between the substrate and the porous film; an elevating device configured to move the housing upward and downward with respect to the mount base; a suction device coupled to the suction passage via an on-off valve and configured to suck a fluid in the suction passage; and a control device configured to control at least adjustment of a fluid pressure by the fluid pressure adjusting device, upward and downward movement of the elevating device, suction by the suction device, and opening and closing of the on-off valve. The control device includes at least: a suction execution unit configured to execute suction by the suction device in a state where the on-off valve is open; a lowering control unit configured to control lowering of the housing by the elevating device to a position where the porous film comes into contact with the substrate during suction by the suction device; a valve-closing control unit configured to control the on-off valve to be closed after the porous film comes into contact with the substrate; a fluid pressure increasing unit configured to make the fluid pressure adjusting device increase the fluid pressure of the electrolytic solution after the on-off valve is closed; and a film-formation execution unit configured to form the metal film on the surface of the substrate while maintaining the increased fluid pressure.

According to the film forming apparatus for forming a metal film of the present disclosure, while the suction execution unit executes suction by the suction device in a state where the on-off valve is open, the lowering control unit controls lowering (lowering amount) of the housing by the elevating device to the position where the porous film comes into contact with the substrate. This can prevent the gas (air) from being captured in between the substrate and the porous film and uniformly bring the porous film into contact with the surface of the substrate. Next, the valve-closing control unit controls the on-off valve to be closed after the porous film comes into contact with the substrate. Thus, the suction of the gas from the suction port is released.

Next, after the on-off valve is closed, the fluid pressure increasing unit increases the fluid pressure of the electrolytic solution in the housing by using the fluid pressure adjusting device. Consequently, while forming a metal film, even if the electrolytic solution is allowed to pass through the porous film while the porous film is pressed against the surface of the substrate with a fluid pressure of the electrolytic solution in the housing, it is possible to prevent the passed electrolytic solution from continuously flowing to the suction passage from the suction port. In this way, it is possible to uniformly press the porous film against the surface of the substrate in a state where the fluid pressure of the electrolytic solution is stably maintained and to uniformly supply the passed electrolytic solution to the surface of the substrate, and thus it is possible to form a homogeneous metal film having a more uniform film thickness on the surface of the substrate by the film-formation execution unit.

In some embodiments, the suction passage is coupled to a communication passage for allowing the suction passage to be communicated to atmosphere; the communication passage is provided with an atmosphere release valve for allowing the suction passage to be communicated to atmosphere and for interrupting the suction passage communicated to atmosphere; and the control device further includes: a communication interrupting unit configured to control the atmosphere release valve to be closed to interrupt the suction passage communicated to atmosphere before the suction execution unit starts suction and until the lowering control unit brings the porous film into contact with the substrate; a communication control unit configured to control the atmosphere release valve to be open to allow the suction passage to be communicated to atmosphere after the film-formation execution unit forms the metal film; and a lifting control unit configured to control lifting of the housing by the elevating device after the suction passage is communicated to atmosphere by the communication control unit.

According to this embodiment, before suction is started and until the porous film comes into contact with the substrate, the communication interrupting unit controls the atmosphere release valve to be closed to interrupt the suction passage communicated to atmosphere. This allows stable suction by the suction device since the suction passage is not communicated to atmosphere. After the film-formation execution unit forms a metal film, the communication control unit controls the atmosphere release valve to be open to allow the suction passage to be communicated to atmosphere. This can reset the pressure in the suction passage to the atmospheric pressure after film formation, even if it is maintained at a negative pressure due to the suction of a gas after the suction passage is interrupted and until film formation is completed. Consequently, even if lifting of the housing by the elevating device is controlled, it is possible to reduce the likelihood that the porous film is less likely to be separated from the substrate due to the negative pressure in the suction passage.

In some embodiments, the film forming apparatus further includes: a gas-liquid separator provided downstream of the on-off valve and configured to separate the electrolytic solution from the gas; and a collection tank configured to collect the separated electrolytic solution.

According to this embodiment, it is possible to separate, from the gas, the electrolytic solution sucked into the suction passage together with the gas via the gas-liquid separator. Since the separated electrolytic solution is collected in the collection tank, the electrolytic solution stored in the collection tank can be reused. In particular, when the electrolytic solution containing a gas is supplied to the housing for reuse, it is difficult to stably increase the fluid pressure of the electrolytic solution since the gas is a compressible fluid. In this embodiment, however, it is possible to supply the electrolytic solution separated from the gas to the housing and to stably increase the pressure of the electrolytic solution in the housing during film formation.

According to the film forming method and the film forming apparatus for forming a metal film of the present disclosure, it is possible to form a homogeneous metal film having a uniform film thickness by stably ensuring a fluid pressure of an electrolytic solution during film formation.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cross-sectional view of a film forming apparatus for forming a metal film according to a first embodiment of the present disclosure, illustrating the state of the film forming apparatus having a substrate mounted thereon;

FIG. **2** is a block diagram of a control device of the film forming apparatus shown in FIG. **1**;

FIG. **3** is a flowchart of a film forming method for forming a metal film using the film forming apparatus shown in FIG. **1**;

FIG. **4** is a schematic conceptual view illustrating a film forming step of forming a metal film shown in FIG. **3**;

FIG. **5** is a schematic cross-sectional view of a film forming apparatus for forming a metal film according to a second embodiment of the present disclosure, illustrating the state of the film forming apparatus having a substrate mounted thereon after the film forming step of forming a metal film and before collecting the substrate;

FIG. **6** is a graph showing a result of a liquid leakage rate of an electrolytic solution to an applied pressure to the substrate with the fluid pressure of the electrolytic solution when the film forming apparatus shown in FIG. **1** is used and a solid electrolyte membrane is used instead of the porous film of the film forming apparatus shown in FIG. **1**; and

FIG. **7** is a graph showing a result of a liquid leakage rate of an electrolytic solution to a pressurizing time on the substrate in the film forming apparatus shown in FIG. **1**.

## DETAILED DESCRIPTION

Hereinafter, first and second embodiments according to the present disclosure will be described with reference to FIG. **1** to FIG. **5**. It should be noted that dashed lines in FIG. **1**, FIG. **4**, and FIG. **5** express signal lines of control signals output from a control device **50** and signal lines of signals output from a distance measuring sensor **50**A and a pressure measuring sensor **50**B.

### First Embodiment

A film forming method and a film forming apparatus **1** for forming a metal film F of the present embodiment are applied when forming a metal film F derived from metal ions contained in an electrolytic solution S on a surface of a substrate W by depositing metal on the surface of the substrate W by electroless plating. Herein, the electroless plating is a film deposition (forming) method for forming a film through chemical reduction, in contrast to electroplating for electrolytic deposition by means of electricity. The electroless plating includes, for example, displacement plating that uses a difference in ionization tendency between a metal forming a substrate and metal ions contained in an electrolytic solution and autocatalytic reduction plating that uses a reducing agent having a reduction capability.

Hereinafter, first, the film forming apparatus **1** for forming the metal film F of the present embodiment will be described with reference to FIG. **1** and FIG. **2**, and then the film forming method for forming the metal film F of the present embodiment will be described with reference to FIG. **1** to FIG. **4**.

1. Regarding Film Forming Apparatus **1**

FIG. **1** is a schematic cross-sectional view of the film forming apparatus **1** for forming the metal film F according to the first embodiment of the present disclosure, illustrating the state of the film forming apparatus **1** having a substrate W mounted thereon. FIG. **2** is a block diagram of the control device **50** of the film forming apparatus **1** shown in FIG. **1**.

The film forming apparatus **1** of the present embodiment is a film forming apparatus (plating apparatus) for forming the metal film F via a porous film **12** by electroless plating, and is used when forming the metal film F on the surface of the substrate W. The film forming apparatus **1** is also used when continuously forming the metal film F on the surfaces of a plurality of substrates W.

As for the substrate W, when the electroless plating is displacement plating, a metal material made of a less noble metal (i.e., a metal at a higher position in the electrochemical series) than the metal ions contained in the electrolytic solution S may be used for the substrate W. In addition, a layer made of a less noble metal than the metal ions contained in the electrolytic solution S may be formed on the surface of the substrate body of the substrate W. In this case, for the substrate body, a more noble metal material than the metal ions contained in the electrolytic solution S or a resin material, and the like may be used. In one example, when the metal ions contained in the electrolytic solution S are Au ions, the substrate W may have a Ni plating layer formed on the surface of the substrate body made of Cu.

When the electroless plating is autocatalytic reduction plating, as long as the material of the substrate W has a catalytic effect of facilitating oxidation of a reducing agent, a metal material or a resin material, and the like may be used for the substrate W. In addition, a layer made of a metal serving as a catalyst may be formed on the surface of the substrate body of the substrate W. In this case, a metal material and a resin material not having a catalytic effect may be used for the substrate body of the substrate W. In one example, when the metal ions contained in the electrolytic solution S are Ni ions, the substrate W may have a Pd plating layer serving as a catalyst formed on the surface of the substrate body made of Cu.

As shown in FIG. **1**, the film forming apparatus **1** includes at least a housing **11**, a porous film **12**, a mount base **13**, an elevating device **14**, a fluid pressure adjusting device **20**, a suction unit **40**, and a control device **50**.

The housing **11** is configured to store an electrolytic solution. The porous film **12** is attached to the housing **11** so as to seal the electrolytic solution S stored in the housing **11** and to be opposed to the substrate W (specifically, the mount base **13**). More specifically, the porous film **12** is attached to the housing **11** such that one of the surfaces of the porous film **12** contacts the electrolytic solution S stored in the housing **11** and the other one of the surfaces of the porous film **12** faces the substrate W. The porous film **12** is a film that allows the electrolytic solution S to pass therethrough in the thickness direction and has a plurality of pores through which the electrolytic solution S can pass.

The thickness of the porous film **12** may be, for example, 10 μm or more and 200 μm or less, and specifically, 20 μm or more and 160 μm or less. The average pore diameter of the porous film **12** may be, for example, 0.1 μm or more and 100 μm or less, and the pore may be a micropore having an average pore diameter of 20 to 100 nm, for example. As long as the electrolytic solution S can pass through (permeate) the porous film **12** in the thickness direction via the pores of the porous film **12** by increasing the fluid pressure of the electrolytic solution S in the housing **11**, the pore diameter of the porous film **12** is not particularly limited thereto.

In addition, in the present embodiment, the porous film **12** need not have an ion exchange functional group (a cation exchange functional group or an anion exchange functional group) like a solid electrolyte. Thus, the porous film **12** has almost no polarity and the metal ions contained in the electrolytic solution S can pass through the pores without being trapped in the porous film. Such a porous film **12** can be applied to any of the cases where the metal ions contained in the electrolytic solution S are cations, anions, or nonions. For the porous film **12**, a polyolefin resin can be used. Examples of the polyolefin resin may include a polyethylene resin, a polypropylene resin, or a resin of mixture thereof.

Meanwhile, a solid electrolyte having an ion exchange functional group may be used for the porous film **12**. As long as metal ions can pass through the solid electrolyte by bringing the solid electrolyte into contact with the electrolytic solution S and metal derived from the metal ions can be deposited on the surface of the substrate W, the solid electrolyte is not particularly limited. Examples of the solid electrolyte may include a fluorine-based resin, such as Nafion (registered trademark) available from DuPont, a hydrocarbon resin, a polyamide resin, or a resin having cation exchange functionality, such as Selemion (CM, CMD, CMF series) available from AGC Inc.

The electrolytic solution S is a solution supplied to one side of the porous film **12** and containing at least metal ions of the metal to be deposited for the metal film F by electroless plating. It should be noted that the electrolytic solution S for displacement plating or autocatalytic reduction plating is commercially available as a plating solution. Such a commercially available plating solution may be used for the electrolytic solution S.

When the electroless plating is displacement plating, the metal of the metal ions contained in the electrolytic solution S is a more noble metal (i.e., a metal at a lower position in the electrochemical series) than the material of the substrate W. For example, when the substrate W is made of Cu, the metal of the metal ions may be Ag, Pt, or Au, or the like.

When the electroless plating is autocatalytic reduction plating, the electrolytic solution S contains metal ions of the metal to be deposited for the metal film F and a reducing agent. Examples of the metal of the metal ions may include Ag, Pt, or Au, or the like, but are not limited thereto as long as the metal has a catalytic effect. Examples of the reducing agent may include hypophosphorous acid or dimethylamine borane. The electrolytic solution S may further contain a stabilizer, a complexing agent, and a reducing agent, for example.

As described above, the housing **11** includes a space for storing the electrolytic solution S and has the electrolytic solution S stored therein, and the porous film **12** is attached to the housing **11**. The housing **11** is provided with a supply port **11***a* to supply the electrolytic solution S and a discharge port **11***b* to discharge the electrolytic solution S.

The mount base **13** is configured to have the substrate W placed thereon at a position opposed to the porous film **12**. In the present embodiment, the mount base may have conductivity or nonconductivity. The mount base **13** has a suction passage **42** with a suction port **41**. The suction port **41** and the suction passage **42** will be described later.

In addition, the mount base **13** includes a housing recess **13***a* for housing the substrate W. The housing recess **13***a* has a depth equal to the thickness of the substrate W. Accordingly, when the substrate W is housed in the housing recess **13***a*, the substrate W and the mount base **13** may be disposed such that the surface of the substrate W is flush with the surface of the mount base **13**. This can reduce stress excessively applied to the porous film **12** during film formation.

The elevating device **14** is configured to move the housing **11** upward and downward with respect to the mount base **13** (see FIG. **1**, FIG. **4**). In the present embodiment, the elevating device **14** is configured to move the housing **11** upward and downward between a position where the porous film **12** is spaced apart from the substrate W and a position where the porous film **12** comes into contact with the substrate W, and is disposed above the housing **11**. As long as the elevating device **14** can move the housing **11** upward and downward, the elevating device **14** can be configured by a hydraulic or pneumatic cylinder, a motor-driven actuator, a linear guide and a motor, for example.

The fluid pressure adjusting device **20** is configured to adjust the fluid pressure of the electrolytic solution S stored in the housing **11**. The fluid pressure adjusting device **20** includes a cylinder **21** and a piston **22** and is coupled to the supply port **11***a* of the housing **11** via a pipe **35** on the supply system side, which will be described later. The fluid pressure adjusting device **20** can adjust the fluid pressure of the electrolytic solution S stored in the housing **11** by moving the piston **22** back and forth with respect to the cylinder **21** as will be described later.

It should be noted that although the example of the fluid pressure adjusting device **20** including the cylinder **21** and the piston **22** is described herein, the fluid pressure adjusting device **20** is not limited thereto. For example, when a discharge valve **34** is a pressure control valve, the fluid pressure adjusting device **20** may pressurize the electrolytic solution S in the housing **11** with a predetermined pressure using the discharge valve **34** and a pressure pump **32** while supplying and discharging the electrolytic solution S as will be described later. However, to easily achieve high pressure, to improve precision in pressure control, and to suppress pulsation, the fluid pressure adjusting device **20** may include the cylinder **21** and the piston **22**.

Furthermore, the film forming apparatus **1** of the present embodiment includes a collection tank **31** coupled to the supply port **11***a* and the discharge port **11***b* via the pipe **35**. The pressure pump **32** is provided between the collection tank **31** and the supply port **11***a*. In addition, a supply valve **33** for interrupting the pipe **35** on the supply system side is provided between the pressure pump **32** and the supply port **11***a*, and the discharge valve **34** for interrupting the pipe **35** on the discharge system side is provided between the discharge port **11***b* and the collection tank **31**.

The collection tank **31** is a tank that stores the electrolytic solution S and supplies the stored electrolytic solution S to the housing **11**. The pressure pump **32** is a pump that sucks the electrolytic solution S from the collection tank **31** and pressure feeds the electrolytic solution S into the housing **11** via the supply port **11***a*. The supply valve **33** and the discharge valve **34** are valves for supplying and discharging the electrolytic solution S stored in the housing **11** in the open position and for ensuring the hermeticity of the housing **11** in the closed position. Examples of the supply valve **33** and the discharge valve **34** may include a solenoid valve.

The electrolytic solution S fed by the pressure pump **32** from the collection tank **31** passes through the supply valve **33** and flows into the housing **11** from the supply port **11***a*. Then, the electrolytic solution S introduced into the housing **11** flows through the housing **11** from the supply port **11***a* to the discharge port **11***b* to be discharged from the discharge port **11***b*, and returns to the collection tank **31** after passing through the discharge valve **34**.

The suction unit **40** has a function of sucking a gas (for example, air) between the substrate W and the porous film **12** from the side of the mount base **13**. This can prevent the gas from being captured in between the surface of the substrate W and the porous film **12**. The suction unit **40** includes at least the suction passage **42** with the suction port **41**, a suction device **43**, and an on-off valve **44**.

One end of the suction passage **42** is provided with a suction port **41**. The portion including the suction port **41** of the suction passage **42** is formed on the mount base **13**. The position, shape, and the number of the suction port **41** are not particularly limited as long as the gas between the substrate W and the porous film **12** can be sucked. For example, a plurality of suction ports **41** may be formed on the surface of the mount base **13** at regular intervals around the substrate W. The other end of the suction passage **42** is coupled to the suction device **43** via a gas-liquid separator **47** which will be described later. The gas-liquid separator **47** is coupled to the collection tank **31** for collecting the separated electrolytic solution S.

The suction device **43** is a device coupled to the suction passage **42** via the gas-liquid separator **47** and configured to suck a fluid (a gas and the electrolytic solution S) in the suction passage **42**. The suction device **43** can suck the gas in the suction passage **42** by sucking the gas separated on the gas phase side of the gas-liquid separator **47**. Examples of the suction device **43** may include a vacuum pump, but are not limited thereto as long as it can suck a fluid.

The suction passage **42** is provided with the on-off valve **44**. The on-off valve **44** is provided between the suction port **41** and the gas-liquid separator **47** for interrupting the suction passage **42**. When the on-off valve **44** is in the open position, suction by the suction device **43** can pass a fluid through the suction passage **42**. Meanwhile, when the on-off valve **44** is in the closed position, the flow of the fluid in the suction passage **42** is interrupted.

In the present embodiment, the suction unit **40** further includes a communication passage **45**, an atmosphere release valve **46**, and the gas-liquid separator **47**. The communication passage **45** is a passage communicated to atmosphere and coupled to the suction passage **42** between the suction port **41** and the on-off valve **44**. The atmosphere release valve **46** is a valve (for example, solenoid valve) provided in the communication passage **45** for allowing the suction passage **42** to be communicated to atmosphere via the communication passage **45** and for interrupting the suction passage **42** communicated to atmosphere. When the atmosphere release valve **46** is in the open position, the suction passage **42** can be communicated to atmosphere via the communication passage **45**. Meanwhile, when the atmosphere release valve **46** is in the closed position, the suction passage **42** communicated to atmosphere via the communication passage **45** is interrupted.

The gas-liquid separator **47** is a device provided downstream of the on-off valve **44** and having a function of separating a fluid mixture of a gas and the electrolytic solution S into a gas and the electrolytic solution S. The gas-liquid separator **47** has a space for storing a fluid, where a gas accumulates in the upper part and the electrolytic solution S accumulates in the lower part. In addition, the gas-liquid separator **47** is provided with a gas-liquid inlet port **47***a* that is coupled to the other end of the suction passage **42**. In addition, a gas outlet port **47***b* and a liquid outlet port **47***c* are provided on the gas phase side and the liquid phase side of the gas-liquid separator **47**, respectively. The gas outlet port **47***b* is coupled to the suction device **43** via the gas outlet passage **48**. Meanwhile, the liquid outlet port **47***c* is coupled to the collection tank **31** via the liquid outlet passage **49**.

In this suction unit **40**, when the on-off valve **44** is in the open position, the suction passage **42** is communicated to the gas-liquid separator **47** and the suction device **43**. At this time, the suction passage **42** is communicated to the gas-liquid separator **47** and the collection tank **31**.

With the above-described configuration, as will be described later, when a gas is sucked into the suction passage **42** during suction, the sucked gas is sucked into the suction device **43** via the gas-liquid separator **47**. Meanwhile, when the electrolytic solution S is sucked into the suction passage **42** together with the gas, the fluid mixture of the sucked gas and electrolytic solution S is separated into the gas and the electrolytic solution S by the gas-liquid separator **47**. The separated gas is sucked into the suction device **43**, and the separated electrolytic solution S is discharged to the collection tank **31**. Since the discharged electrolytic solution S is supplied again to the inside of the housing **11**, leaking electrolytic solution S can be efficiently collected.

In the present embodiment, the film forming apparatus **1** further includes a distance measuring sensor **50**A, a pressure measuring sensor **50**B, and a control device **50** to stop suction of the gas by the suction unit **40** during film formation.

The distance measuring sensor **50**A is a displacement sensor, such as a proximity sensor, for measuring a distance between the porous film **12** and the substrate W, and is attached to the housing **11**. Examples of the distance measuring sensor **50**A may include a sensor utilizing infrared rays, electromagnetic waves, or magnetism. The pressure measuring sensor **50**B is a sensor for measuring a pressure (fluid pressure) adjusted by the fluid pressure adjusting device **20**, and is attached to the housing **11**. The distance measuring sensor **50**A and the pressure measuring sensor **50**B are electrically coupled to the control device **50** such that the control device **50** receives, as signals, measurement values obtained by the distance measuring sensor **50**A and the pressure measuring sensor **50**B.

The control device **50** is a device configured to control at least the upward and downward movement of the elevating device **14**, suction by the suction device **43**, adjustment of the fluid pressure by the fluid pressure adjusting device **20**, and opening and closing of the on-off valve **44**. The control device **50** basically includes, as hardware, an operation unit, such as a CPU or the like, a storage unit, such as RAM, ROM, or the like. The operation unit calculates control signals to the suction device **43**, the fluid pressure adjusting device **20**, and the on-off valve **44** based on the signals of the distance measuring sensor **50**A and the pressure measuring sensor **50**B, and outputs the calculated signals. The storage unit stores, for example, a preset range of a predetermined distance between the porous film **12** and the substrate W and a preset range of an applied pressure (fluid pressure) during film formation, or the like.

In the present embodiment, the control device **50** is electrically coupled to the elevating device **14**, the fluid pressure adjusting device **20**, the supply valve **33**, the discharge valve **34**, the suction device **43**, the on-off valve **44**, the atmosphere release valve **46**, and the pressure pump **32** such that the control device **50** can control them.

As shown in FIG. **2**, the control device **50** includes, as software, at least a suction execution unit **51**, a lowering control unit **52**, a valve-closing control unit **54**, a fluid pressure increasing unit **55**, and a film-formation execution unit **56**. Furthermore, when the film forming apparatus **1** includes the atmosphere release valve **46**, the control device **50** includes, as software, a communication interrupting unit **53**, a communication control unit **57**, and a lifting control unit **58**.

First, in response to an input signal (instruction signal of starting film formation) from an input device, the control device **50** executes the following software process. The suction execution unit **51** executes suction by the suction device **43** in a state where the on-off valve **44** is open. Specifically, when the suction device **43** is a vacuum pump, for example, the suction execution unit **51** drives the vacuum pump in response to a signal indicating that the on-off valve **44** is open. It should be noted that although the on-off valve **44** is in the open position when the film forming apparatus is not driven, the suction execution unit **51** opens the on-off valve **44** when the on-off valve **44** is in the closed position. Furthermore, the suction execution unit **51** transmits a suction start signal indicating starting suction to the lowering control unit **52**.

The lowering control unit **52** controls lowering of the housing **11** by the elevating device **14** to the position where the porous film **12** comes into contact with the substrate W based on an output signal of the distance measuring sensor **50**A. After the elevating device **14** starts lowering the housing **11**, at a timing when the distance measured by the distance measuring sensor **50**A is equal to the preset distance, the lowering control unit **52** determines that the porous film **12** has come into contact with the substrate W. At this timing, the lowering control unit **52** stops the lowering by the elevating device **14** and transmits a lowering stop signal to the valve-closing control unit **54**.

In the present embodiment, through such control, the porous film **12** can be moved toward the substrate W and brought into contact with the surface of the substrate W while the gas between the substrate W and the porous film **12** is sucked from the suction port **41** of the suction passage **42** formed on the mount base **13**. Consequently, it is possible to prevent the gas (air) from being captured in between the substrate W and the porous film **12**.

Before the suction execution unit **51** starts suction and until the lowering control unit **52** brings the porous film **12** into contact with the substrate W, the communication interrupting unit **53** controls the atmosphere release valve **46** to be closed to interrupt the suction passage **42** communicated to atmosphere. It should be noted that when the atmosphere release valve **46** is in the closed position, the communication interrupting unit **53** maintains the closed state of the atmosphere release valve **46**. The valve-closing control of the atmosphere release valve **46** by the communication interrupting unit **53** may be performed, for example, in response to a film formation start input signal from an input device, or may be performed, for example, in response to a lowering start signal by the lowering control unit **52**, though not shown in FIG. **2**. As long as the valve-closing control of the atmosphere release valve **46** can be performed before the suction execution unit **51** starts suction and until the lowering control unit **52** brings the porous film **12** into contact with the substrate W, the valve-closing timing is not particularly limited. It should be noted that the communication interrupting unit **53** may transmit a signal indicating the completion of valve-closing of the atmosphere release valve **46** to the valve-closing control unit **54**, as appropriate.

The valve-closing control unit **54** controls the on-off valve **44** to be closed after the lowering control unit **52** brings the porous film **12** into contact with the substrate W in the present embodiment. Specifically, in response to a lowering stop control signal of the lowering control unit **52** and, as appropriate, a valve-closing completion control signal of the communication interrupting unit **53**, the valve-closing control unit **54** controls the on-off valve **44** to be closed. Alternatively, instead of the control signal, the valve-closing control unit **54** may control the on-off valve **44** to be closed directly in response to a detection signal from the distance measuring sensor **50**A (i.e., a signal of detecting that the porous film **12** has come into contact with the substrate W) and, as appropriate, a closed state detection signal from the atmosphere release valve **46**.

Herein, the valve-closing control unit **54** may stop suction by the suction device **43** or continue suction by the suction device **43** after closing the on-off valve **44**. This interrupts the suction passage **42** (the flow of the gas flowing through the suction passage **42** is interrupted). Consequently, as will be described later, it is possible to suppress leakage of the electrolytic solution S via the porous film **12** caused by the suction during film formation, and thus stabilize the fluid pressure of the electrolytic solution S in the housing **11**. The valve-closing control unit **54** transmits a valve-closing completion signal indicating that the valve-closing of the on-off valve **44** is completed to the fluid pressure increasing unit **55**. The valve-closing control unit **54** may transmit a valve-closing completion signal in response to the closed state of the on-off valve **44** from the on-off valve **44** or may transmit a valve-closing control signal to the on-off valve **44** and then transmit a valve-closing completion signal after a lapse of a predetermined time.

After controlling the on-off valve **44** to be closed, the fluid pressure increasing unit **55** increases the fluid pressure of the electrolytic solution S by the fluid pressure adjusting device **20**. Specifically, in response to a signal of the valve-closing control unit **54**, the fluid pressure increasing unit **55** stops the driving of the pressure pump **32** and closes the supply valve **33** and the discharge valve **34** in the open position. This makes the interior of the housing **11** hermetically sealed.

Next, the fluid pressure increasing unit **55** moves the piston **22** of the fluid pressure adjusting device **20** toward the cylinder **21**. Accordingly, the electrolytic solution S is pressure fed into the hermetically sealed housing **11**, and then the electrolytic solution S stored in the housing **11** is pressurized. Consequently, the porous film **12** can be uniformly pressed against the substrate W with the fluid pressure of the electrolytic solution S during film formation. Furthermore, the fluid pressure increasing unit **55** transmits a fluid pressure increase signal indicating the increase in the fluid pressure to the film-formation execution unit **56**.

The film-formation execution unit **56** forms the metal film F on the surface of the substrate W while maintaining the increased fluid pressure. Specifically, in response to a fluid pressure increase signal, the film-formation execution unit **56** receives a signal of the pressure measuring sensor **50**B and, when the fluid pressure reaches a predetermined fluid pressure, stops the forward movement of the piston **22** of the fluid pressure adjusting device **20** based on the signal of the pressure measuring sensor **50**B. This can maintain the predetermined fluid pressure. The range of the predetermined fluid pressure may be set in advance and stored in the storage unit of the control device **50**, and the film-formation execution unit **56** may load the registered range of the predetermined fluid pressure from a registering unit.

It should be noted that when the fluid pressure changes in response to the signal of the pressure measuring sensor **50**B during film formation, the film-formation execution unit **56** may control the fluid pressure adjusting device **20** to maintain the predetermined fluid pressure at a constant level. In addition, the film-formation execution unit **56** moves back the piston **22** of the fluid pressure adjusting device **20** with respect to the cylinder **21** when the film formation ends. This sucks the electrolytic solution S stored in the hermetically sealed housing **11** and thus the stored electrolytic solution S is decompressed. As a result, the electrolytic solution S in the pressurized state with the fluid pressure is released. Furthermore, the film-formation execution unit **56** transmits a film formation end signal indicating the end of film formation to the communication control unit **57**.

After the film-formation execution unit **56** forms the metal film F, the communication control unit **57** controls the atmosphere release valve **46** to be open to allow the suction passage **42** to be communicated to atmosphere. This can reset the pressure in the suction passage **42** to the atmospheric pressure after film formation, even if it is maintained at a negative pressure due to the suction of a gas after the suction passage **42** is interrupted and until film formation is completed. Consequently, even if lifting of the housing **11** by the elevating device **14** is controlled, it is possible to reduce the likelihood that the porous film **12** is less likely to be separated from the substrate W due to the negative pressure in the suction passage **42**. The communication control unit **57** receives the film formation end signal from the film-formation execution unit **56** and transmits a communication signal indicating that the suction passage **42** has been communicated to atmosphere to the lifting control unit **58**.

After the suction passage **42** is allowed to be communicated to atmosphere by the communication control unit **57**, the lifting control unit **58** controls the lifting of the housing **11** by the elevating device **14** until the porous film **12** is spaced apart from the substrate W. It should be noted that the lifting control unit **58** receives a communication signal from the communication control unit **57**.

2. Regarding Film Forming Method for Forming Metal Film F

FIG. **3** is a flowchart of the film forming method for forming the metal film F using the film forming apparatus **1** shown in FIG. **1**. FIG. **4** is a schematic conceptual view illustrating a film forming step S**4** of forming the metal film F shown in FIG. **3**. Hereinafter, the film forming method for forming the metal film F according to the first embodiment will be described with reference to the flow of the steps shown in FIG. **3**.

2-1. Regarding Substrate W Placing Step S1

The film forming method for forming the metal film F according to the present embodiment first performs a substrate W placing step S**1**. In this step, as shown in FIG. **1**, the substrate W is placed on the mount base **13**. Specifically, while the housing **11** is disposed above the mount base **13**, the substrate W is placed on the housing recess **13***a* of the mount base **13**. Accordingly, the substrate W is placed in a position opposed to the porous film **12**.

When the substrate W is placed, the supply valve **33** and the discharge valve **34** are opened and the pressure pump **32** is driven. Accordingly, the electrolytic solution S is supplied from the collection tank **31** into the housing **11** via the supply port **11***a*, then the electrolytic solution S having passed through the housing **11** is discharged from the housing **11** via the discharge port **11***b*, and the discharged electrolytic solution S is returned to the collection tank **31**.

Though not shown, the control device **50** may further include a supply/discharge execution unit for supplying and discharging the electrolytic solution S as described above, and the supply/discharge execution unit may open the supply valve **33** and the discharge valve **34** and drive the pressure pump **32** as described above.

2-2. Regarding Porous Film 12 Contacting Step S2

Next, the method performs a porous film **12** contacting step S**2**. In this step, as shown in FIG. **1**, while the suction execution unit **51** executes suction of the gas between the substrate W and the porous film **12** from the suction port **41** of the suction passage **42** formed on the mount base **13**, the lowering control unit **52** moves the porous film **12** toward the substrate W to bring the porous film **12** into contact with the surface of the substrate W.

Specifically, in response to a film formation start input signal from an input device (not shown), the suction execution unit **51** drives the suction device **43**. It should be noted that when the on-off valve **44** is in the open position before the suction device **43** is driven, the suction execution unit **51** maintains the open state of the on-off valve **44**, whereas when the on-off valve **44** is in the closed position, the suction execution unit **51** opens the on-off valve **44**. In the same manner, when the atmosphere release valve **46** is in the open position before the suction device **43** is driven, the communication interrupting unit **53** closes the atmosphere release valve **46**, whereas when the atmosphere release valve **46** is in the closed position, the communication interrupting unit **53** maintains the closed state of the atmosphere release valve **46**. This interrupts the suction passage **42** communicated to atmosphere via the communication passage **45**, and allows suction of the gas or the like into the suction passage **42** via the suction port **41**.

Once the suction execution unit **51** starts suction, the lowering control unit **52** drives the elevating device **14** to lower the housing **11** to the position where the porous film **12** uniformly comes into contact with the substrate W placed on the housing recess **13***a* based on an output signal of the distance measuring sensor **50**A.

Through such a series of control in the porous film **12** contacting step S**2**, the gas sucked from the suction port **41** can be sucked into the suction passage **42** from the suction port **41** together with the electrolytic solution S having passed through the porous film **12**. The gas having passed through the suction passage **42** flows into the gas-liquid separator **47** from the gas-liquid inlet port **47***a* and then is sucked by the suction device **43** via the gas outlet passage **48** from the gas outlet port **47***b* formed on the gas phase side. In this way, by sucking the gas between the substrate W and the porous film **12** until the porous film **12** comes into contact with the substrate W, it is possible to prevent the gas (air) from being captured in between the substrate W and the porous film **12** and uniformly bring the porous film **12** into contact with the surface of the substrate W.

Meanwhile, the electrolytic solution S separated from the gas in the gas-liquid separator **47** is introduced into the collection tank **31** from the liquid outlet port **47***c* formed on the liquid phase side via the liquid outlet passage **49**. The electrolytic solution S stored in the collection tank **31** can be reused.

Herein, the gas phase of the gas-liquid separator **47** is at a negative pressure due to the suction device **43**, and thus the gas contained in the liquid phase of the electrolytic solution S can easily be removed. Consequently, the pressure of the electrolytic solution S in the housing **11** can stably be increased in a film forming step S**4**, which will be described later, since a gas as a compressible fluid is separated from the electrolytic solution S to be returned to the housing **11** from the collection tank **31** for reuse.

2-3. Regarding Suction Passage 42 Interrupting Step S3

Next, the method performs a suction passage **42** interrupting step S**3**. In this step, the suction passage **42** is interrupted in a state where the porous film **12** is brought into contact with the surface of the substrate W in the contacting step S**2** (see FIG. **4**). Specifically, in response to a lowering stop signal of the housing **11** from the lowering control unit **52**, the valve-closing control unit **54** closes the on-off valve **44** in the open position. This can prevent any more air and electrolytic solution S or the like from flowing into the suction passage **42**.

The valve-closing control unit **54** transmits a valve-closing completion signal to the fluid pressure increasing unit **55** at a timing when the valve-closing is completed. Herein, the driving of the suction device **43** may be continued or the driving of the suction device **43** may be stopped at a timing when the on-off valve **44** is closed. This interrupts the suction passage **42** and thus stops the suction at the suction port **41**.

2-4. Regarding Metal Film F Forming Step S4

Next, the method performs a metal film F forming step S**4**. In this step, as shown in FIG. **4**, in a state where the suction passage **42** is interrupted, the electrolytic solution S is allowed to pass through the porous film **12** from one side of the porous film **12** while the porous film **12** is pressed against the surface of the substrate W with the fluid pressure of the electrolytic solution S. Accordingly, metal from the metal ions contained in the passed electrolytic solution S is deposited on the surface of the substrate W by electroless plating, thereby forming the metal film F on the surface of the substrate W.

Specifically, first, the fluid pressure increasing unit **55** having received the valve-closing completion signal stops the driving of the pressure pump **32** and closes the supply the valve **33** and the discharge valve **34** in the open position. This stops supplying and discharging the electrolytic solution S and makes the interior of the housing **11** hermetically sealed.

In this hermetically sealed state, the fluid pressure increasing unit **55** moves the piston **22** of the fluid pressure adjusting device **20** toward the cylinder **21**. This increases the fluid pressure of the electrolytic solution S stored in the hermetically sealed housing **11**. The fluid pressure increasing unit **55** transmits a fluid pressure increase signal to the film-formation execution unit **56**.

The film-formation execution unit **56** having received the fluid pressure increase signal receives a pressure signal of the pressure measuring sensor **50**B and, when the fluid pressure reaches a predetermined fluid pressure, stops the above-described forward movement of the piston **22** based on the received pressure signal. This can maintain the electrolytic solution S in the housing **11** at the predetermined fluid pressure, and thus the porous film **12** can be pressed against the substrate W being in contact with the porous film **12** with the maintained fluid pressure during film formation.

As a result, the porous film **12** is allowed to follow the surface of the substrate W, and to pass the electrolytic solution S therethrough while uniformly pressurizing the surface of the substrate W, whereby metal derived from metal ions contained in the electrolytic solution S can be deposited and the metal film F can be formed on the substrate W. It should be noted that the film thickness of the metal film F can be adjusted by setting in advance the contact time (specifically, metal deposition time) for which the porous film **12** is in contact with the substrate W.

In the present embodiment, as described above, since the metal film F is formed in a state where the suction passage **42** is interrupted, it is possible to reduce the likelihood that the electrolytic solution S passes through the porous film **12** due to suction. This can suppress shortage of the fluid pressure (applied pressure) caused by leakage of the electrolytic solution S. As a result, an excellent metal film F can be formed while ensuring a stable fluid pressure.

When the film formation ends, the film-formation execution unit **56** moves back the piston **22** of the fluid pressure adjusting device **20** with respect to the cylinder **21** to make the fluid pressure adjusting device **20** release the pressurized state with the fluid pressure. The film-formation execution unit **56** transmits a film formation end signal to the communication control unit **57**.

2-5. Regarding Substrate W Collecting Step S5

Next, the method performs a substrate W collecting step S**5**. In this step, the interrupted suction passage **42** is allowed to be communicated to atmosphere, and after the suction passage **42** is communicated to atmosphere, the porous film **12** is separated from the substrate W having the metal film F formed thereon.

Specifically, the communication control unit **57** having received the film formation end signal opens the atmosphere release valve **46**. This allows the suction passage **42** in the negative pressure state from the suction port **41** to the on-off valve **44** to be communicated to atmosphere via the communication passage **45**, and makes the pressure in the suction passage **42** at the atmospheric pressure. The communication control unit **57** transmits a communication signal to the lifting control unit **58**.

The lifting control unit **58** having received the communication signal controls the elevating device **14** to lift the housing **11** (see FIG. **1**). In this way, it is possible to reset the pressure in the suction passage **42** to the atmospheric pressure after film formation, even if it is maintained at a negative pressure due to the suction of a gas after the suction passage **42** is interrupted and until film formation is completed. Consequently, even if the lifting of the housing **11** by the elevating device **14** is controlled, it is possible to reduce the likelihood that the porous film **12** is less likely to be separated from the substrate W due to the negative pressure in the suction passage **42** and prevent damage of the porous film **12**.

## Second Embodiment

With reference to FIG. **5**, a film forming apparatus **1** and a film forming method for forming a metal film F according to the second embodiment will be described. FIG. **5** is a schematic cross-sectional view of the film forming apparatus **1** for forming the metal film F according to the second embodiment of the present disclosure, illustrating the state of the film forming apparatus **1** having the substrate W mounted thereon. Since the block diagram of the control device **50** of the film forming apparatus **1** according to the second embodiment is substantially equal to that of the first embodiment, only a difference in the block diagram of the control device according to the second embodiment will briefly be described.

The present embodiment is different from the first embodiment in that metal is deposited on the surface of the substrate W from the metal ions contained in the electrolytic solution S by electroplating. Therefore, the following mainly describes the difference, and the devices and parts equal to those of the foregoing first embodiment are denoted by the same reference numerals to omit detailed description thereof.

As shown in FIG. **5**, the film forming apparatus **1** of the second embodiment includes a metal anode **18** and a power supply unit **19** that applies voltage across the anode **18** and the substrate W as a cathode, in addition to the components of the film forming apparatus **1** of the foregoing first embodiment. In the present embodiment, the porous film **12** is disposed between the anode **18** and the substrate W as a cathode, and a constant voltage is applied across the anode **18** and the substrate W by the power supply unit **19** in a state where the porous film **12** is in contact with the surface of the substrate W, thus allowing current to flow between the anode **18** and the substrate W during film formation. The substrate W is made of a conductive metal material, such as Cu, Ni, Ag, or Au, for example.

The anode **18** is housed in the housing **11** and the electrolytic solution S is disposed between the anode **18** and the porous film **12**. When the anode **18** and the porous film **12** are spaced apart from each other, the anode **18** may be in the form of a plate, and may be either a soluble anode made of the same material (e.g., Cu) as the metal film F, or an anode made of a material (e.g., Ti) that is insoluble in the electrolytic solution S. Meanwhile, though not shown, when the anode **18** and the porous film **12** are in contact with each other, the anode **18** may be an anode made of a porous body that allows the electrolytic solution S to pass therethrough and supplies metal ions to the porous film **12**.

It should be noted that when the anode **18** is pressed against the porous film **12**, deposition may not be uniform due to variations in the pressing force of the anode **18** against the porous film **12**. Thus, the anode **18** may be configured to be spaced apart from the porous film **12**.

A negative electrode of the power supply unit **19** may be electrically coupled to the mount base **13** or, though not shown, may be electrically coupled to the substrate W, as long as it can be conductively coupled to the substrate W. However, when a nonconductive mount base **13** is used, specifically, the negative electrode may be electrically coupled to the substrate W. A positive electrode of the power supply unit **19** is electrically (conductively) coupled to the anode **18** incorporated into the housing **11**. It should be noted that as long as film formation can be performed, the power supply unit **19** may be either a DC power supply or an AC power supply. The power supply unit **19** is electrically coupled to the control device **50** so that the control device **50** can control it.

The electrolytic solution S is not particularly limited as long as it is a solution containing metal ions of the metal to be deposited for the metal film F by electroplating. Examples of the metal of the metal ions may include Cu, Ni, Ag, or Au. In addition, the electrolytic solution S may contain such metal dissolved (ionized) with an acid, such as nitric acid, phosphoric acid, succinic acid, sulfuric acid, pyrophosphoric acid, or the like.

The configuration of the control device **50** of the present embodiment is equal to that of the control device **50** of the first embodiment. However, the film-formation execution unit **56** of the present embodiment is different from that of the first embodiment in that the film-formation execution unit **56** of the present embodiment controls voltage application by the power supply unit **19**, in addition to the configuration of the first embodiment. Specifically, the film-formation execution unit **56** makes the power supply unit **19** apply voltage across the anode **18** and the substrate W to form the metal film F while maintaining the increased fluid pressure as described above. In addition, when the film formation ends, the film-formation execution unit **56** makes the fluid pressure adjusting device **20** release the pressurized state as described above and makes the power supply unit **19** release the application of voltage across the anode **18** and the substrate W.

The film forming method for forming the metal film F of the present embodiment is performed in the same manner as the film forming method of the foregoing first embodiment. However, the present embodiment is different from the first embodiment in that in the metal film F forming step, during film formation, the method performs application of voltage across the anode **18** and the substrate W and releasing of the application in the present embodiment.

Specifically, in the metal film F forming step of the present embodiment, first the fluid pressure of the electrolytic solution S in the housing **11** is increased by the fluid pressure increasing unit **55** and then the fluid pressure is maintained in a state where the suction passage **42** is interrupted as described above. While maintaining this state, the film-formation execution unit **56** makes the power supply unit **19** apply a constant voltage across the anode **18** and the substrate W to form the metal film F. This can form the metal film F derived from metal ions on the surface of the substrate W.

When the film formation ends, the film-formation execution unit **56** makes the fluid pressure adjusting device **20** release the pressurized state and makes the power supply unit **19** release the application of voltage across the anode **18** and the substrate W as described above. After that, the film-formation execution unit **56** transmits a film formation end signal to the communication control unit **57**.

Also in the second embodiment, it is needless to mention that the same effect as the one produced by the film forming method and the film forming apparatus **1** for forming the metal film F described in the first embodiment can be obtained.

## EXAMPLES

Hereinafter, examples of the present disclosure will be described.

### Example

Using the film forming apparatus for forming the metal film of the first embodiment shown in FIG. **1**, a metal film was formed by displacement plating along the film forming method for forming a metal film of the foregoing first embodiment. For an electrolytic solution and a porous film, an Au plating solution (TDS-25 available from C. Uyemura & Co., Ltd.) for displacement plating and a porous film (Poreflon WPW-045-80 available from Sumitomo Electric Industries, Ltd.) were used. A film formation process was conducted under a film formation time of 10 minutes, an applied pressure by a fluid pressure of 0.2 MPa. For a substrate, a Cu plate subjected to Ni plating was used.

When the gas between the substrate and the porous film was sucked in the porous film contacting step, the on-off valve was opened, the atmosphere release valve was closed, and the vacuum pump as a suction device was driven. In addition, in the suction passage interrupting step, the driving of the vacuum pump was maintained, and the on-off valve in the open position was closed. In this state, in the film forming step, a metal film was formed, and then the leakage of the electrolytic solution into the suction passage and the maintenance of pressure (fluid pressure) during film formation were confirmed. In addition, the film formation property of the formed metal film (Au film) was confirmed.

### Comparative Example

In the same manner as Example, a metal film was formed, and then the leakage of the electrolytic solution into the suction passage, the maintenance of pressure, and the film formation property of the formed metal film were confirmed. However, Comparative Example was different from Example in that the suction passage interrupting step was not performed in Comparative Example. Specifically, in Comparative Example, in a state where the driving of the vacuum pump was maintained and the on-off valve was open, a metal film was formed.

[Result and Consideration]

When the suction passage was interrupted and the suction of a gas was stopped as in Example, liquid leakage of the electrolytic solution in the housing was suppressed. As a result, a constant pressure was maintained in the housing and an Au film was favorably formed on the substrate. In contrast, when the suction state of the suction passage was maintained as in Comparative Example, liquid leakage of the electrolytic solution in the housing via the porous film was found, and after a lapse of 1 minute from the start of film formation, a decrease in the pressure of the electrolytic solution in the housing was found. It was considered that the formation of the Au film was unfavorable for this reason.

Here, as a confirmation test, a liquid leakage rate when using the film forming apparatus shown in FIG. **1** and a liquid leakage when using a solid electrolyte membrane as a nonporous film instead of the porous film of the film forming apparatus shown in FIG. **1** were measured in a state where the vacuum pump was driven and the on-off valve was open. When measuring a liquid leakage rate, a pressure at each level shown in FIG. **6** was continuously applied to the substrate via the electrolytic solution at room temperature for 10 minutes in a state where a porous film or a nonporous film (solid electrolyte membrane) was in contact with the surface of the substrate. The results are shown in FIG. **6**. It should be noted that the liquid leakage rate indicates a rate of the electrolytic solution in the suction passage to the volume of the interior of the suction passage. Furthermore, by using the film forming apparatus shown in FIG. **1**, the electrolytic solution was heated at 70° C. and the applied pressure was maintained at 0.2 MPa, and a liquid leakage rate was measured for each pressurizing time shown in FIG. **7**. It should be noted that when the pressurizing time was 0 minutes, the electrolytic solution was not pressurized. The results are shown in FIG. **7**.

As shown in FIG. **6**, when a porous film was used, liquid leakage was confirmed, and as shown in FIG. **7**, it was found that increasing the pressurizing time caused oozing of the electrolytic solution from the porous film even with a slight fluid pressure via the porous film. In view of these results, it is deemed that suction from the suction port may not be performed during film formation so that the electrolytic solution is less likely to ooze.

Although the embodiments of the present disclosure have been described in detail above, the present disclosure is not limited to the above embodiments, and various design changes can be made within the spirit and scope of the present disclosure recited in the claims.

For example, although the example of continuously interrupting the suction passage during film formation has been described in the above first and second embodiments, the present disclosure is not limited thereto, and the suction passage may be interrupted intermittently during film formation. This can remove a gas such as hydrogen, for example, if generated between the porous film and the substrate during film formation.

In addition, although the film forming apparatus including the gas-liquid separator in the suction unit has been described in the above first and second embodiments, as long as a fluid mixture of the sucked electrolytic solution and gas can be separated in the collection tank, for example, the gas-liquid separator may be omitted, and the collection tank may be coupled to the suction passage via the suction device.

What is claimed is:

**1**. A film forming method for forming a metal film from metal ions contained in an electrolytic solution on a surface of a substrate by depositing metal on the surface of the substrate by electroplating or electroless plating, the film forming method comprising at least:

placing the substrate on a mount base;

while sucking a gas between the substrate and a porous film from a suction port of a suction passage formed on the mount base, the suction passage connecting a suction pump to the suction port, moving the porous film toward the substrate and bringing the porous film into contact with the surface of the substrate;

stopping suction from the suction pump in the suction passage in a state where the porous film is in contact with the surface of the substrate; and

in a state where suction in the suction passage is stopped, allowing the electrolytic solution to pass through the porous film while the porous film is pressed against the substrate with a fluid pressure of the electrolytic solution and depositing the metal from the metal ions contained in the passed electrolytic solution on the surface of the substrate, thereby forming the metal film on the surface of the substrate.

**2**. The film forming method for forming a metal film according to claim **1**, wherein:

allowing the suction passage to be communicated to atmosphere after the forming the metal film; and

separating the porous film from the substrate after the suction passage is communicated to the atmosphere.

**3**. The film forming method for forming a metal film according to claim **1**, wherein in the bringing the porous film into contact with the surface of the substrate, separating, from the gas, the electrolytic solution having been sucked into the suction passage together with the gas during suction of the gas.

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