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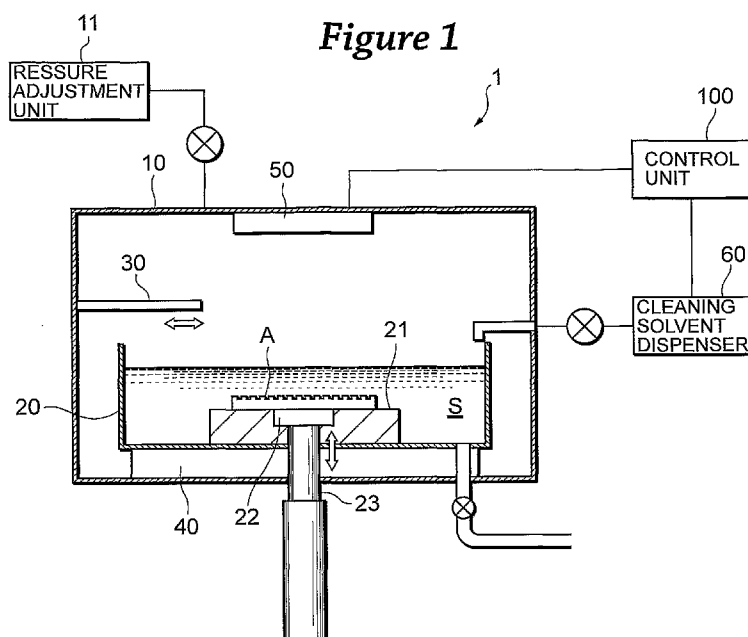
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(54) Title: CLEANING APPARATUS AND METHOD UTILIZING SUBLIMATION OF NANOFABRICATED PARTICLES



(57) Abstract: A cleaning apparatus comprises a container configured to hold an article to be cleaned, a cleaning solvent dispenser configured to supply a cleaning solvent to the container, an energy generator configured to provide thermal energy to an interior of the container; and a control device in communication with the energy generator and configured to select thermal energy sufficient to sublime the particles. The cleaning solvent comprises a solvent and nanofabricated particles dispersed therein. The control device controls the energy generator to provide thermal energy to the cleaning solvent in container in which the article is submerged in order to cause sublimation of the particles.

DESCRIPTION

TITLE

CLEANING APPARATUS AND METHOD UTILIZING SUBLIMATION OF NANOFABRICATED PARTICLES

BACKGROUND

[0001] Nanoimprint lithography has attracted growing attention in recent years as the integration of semiconductor devices increases or various devices become more miniaturized. The nanoimprint lithography provides a method of forming nanometer-sized patterns. Typically, in nanoimprint lithography, a template (mold), which has predetermined topological patterns, is pressed onto a silicon wafer on which an imprint resist is provided, thereby transferring the patterns in the imprint resist on the silicon wafer. By way of this, patterns can be transferred with a high accuracy of size control and with an excellent reproducibility of pattern designs.

[0002] Accordingly, even a very small contaminant adhering to the mold would cause the resulting pattern to undesirably contain the shape of the contaminant, which results in defects in the pattern. In order to improve the yield of semiconductor devices and ensure a high reliability thereof, molds need to be cleaned so as to be free from the adhesion of contaminants.

[0003] One of potential methods of cleaning molds would be ultrasonic cleaning. However, in ultrasonic cleaning, generated ultrasonic cavitation itself as well as vibration of removed contaminant particles might damage the surface of a mold having nanofabricated patterns. Another potential method would be a method of removing contaminant particles by dissolving the contaminant particles with an

acid or alkali solution. However this method requires the selection of a solution that does not react with an object to be cleaned, and thus such a method is not widely applicable.

BRIEF DESCRIPTION OF DRAWINGS

- [0004] Figure 1 is a schematic illustration of an example of a cleaning apparatus arranged in accordance with the present disclosure.
- [0005] Figure 2 is a schematic illustration of an example of a cleaning solvent dispenser of the cleaning apparatus arranged in accordance with the present disclosure.
- [0006] Figure 3 is an exemplary phase graph of carbon dioxide.
- [0007] Figure 4 is a flowchart explaining an example of a cleaning method arranged in accordance with the present disclosure.
- [0008] Figures 5A and 5B are schematic illustrations explaining cleaning action in a cleaning method arranged in accordance with the present disclosure.
- [0009] Figures 6A-6D are partial cross-sectional views of an article as explained in Figures 5A and 5B.
- [0010] Figure 7 is a schematic illustration of another example of a cleaning apparatus arranged in accordance with the present disclosure.
- [0011] Figure 8 is a schematic illustration explaining profile information of an article detected by a detection device arranged in accordance with the present disclosure.
- [0012] Figure 9 is a schematic illustration of another example of a cleaning apparatus arranged in accordance with the present disclosure.
- [0013] Figures 10A-10D are schematic illustrations explaining cleaning action in a cleaning method arranged in accordance with the present disclosure.

DETAILED DESCRIPTION

[0014] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings. The drawings are intended to be explanatory and may not be drawn to scale. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one of ordinary skill in the art that the present disclosure may be practiced without these specific details. In other instances, well-known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

[0015] Figure 1 is a schematic illustration of an example of a cleaning apparatus arranged in accordance with the present disclosure. As shown in Figure 1, a cleaning apparatus 1 comprises a chamber 10, a container 20, a conveying arm 30, a temperature maintaining device 40, an energy generator 50, and a cleaning solvent dispenser 60. Further, the cleaning apparatus 1 comprises a control unit 100 configured to control various electronically-driven devices arranged in the cleaning apparatus 1.

[0016] The chamber 10 is configured to adjust and maintain its internal pressure at a predetermined level. In an example, the internal pressure of the chamber 10 may be at the atmospheric pressure (*i.e.*, 1 atm). In another example, the internal pressure of the chamber 10 may be at a vacuum pressure of about 0.06 atm or lower. The internal pressure of the chamber 10 may be adjusted and maintained in accordance with a sublimation point of particles dispersed in a solvent, as will be explained later. The internal pressure of the chamber 10 may be adjusted and maintained by a pressure adjustment unit 11.

[0017] The container 20 is configured to hold a cleaning solvent S in a continuous liquid medium. The cleaning solvent S comprises a solvent with nanometer-sized

particles dispersed therein. Thus, the cleaning solvent S may refer to as a sol or colloid. In the present disclosure, the cleaning solvent S comprises liquid butane serving as a solvent and nanometer-sized particles of carbon dioxide in a solid phase (*i.e.*, nanoparticulated dry ice) which are dispersed therein. The container 20 includes a stage 21 on which an article A to be cleaned, such as a semiconductor wafer, an MEMS device, or a template, is placed. The article A may have nanofabricated patterns on a surface thereof. The stage 21 may be configured to include a movable chuck 22 for chucking the article A. The movable chuck 22 is configured to move up and down with its extensible shaft 23.

[0018] The conveying arm 30 is configured to convey the article A from/to the inside of the chamber 10. The article A which has been conveyed to a predetermined position in the chamber 10 by the conveying arm 30 is picked up and placed on the stage 21 by the movable chuck 22. A surface to be cleaned of the article A may be directed upward in order that the particles dispersed in the solvent are easily introduced into the structure of nanofabricated patterns on the surface of the article A.

[0019] The temperature maintaining device 40 is disposed at, but not limited to, the bottom of the container 20. The temperature maintaining device 40 is configured to adjust and maintain the cleaning solvent S in the container 20 at a predetermined temperature. The cleaning solvent S may be adjusted and maintained at a temperature slightly below the sublimation point of the particles. For example, where the dispersing particles are dry ice whose sublimation point is about -78.5 degrees Celsius under a pressure of 1 atm, the cleaning solvent may be at a temperature of about -80 degrees Celsius, which is slightly below the sublimation point of the dry ice.

[0020] The energy generator 50 is configured to provide external energy (*e.g.*, thermal energy) to the particles dispersed in the solvent in the container 20. Power

of the energy generator 50 is selected by the control unit 100 such that the sublimation of the particles of dry ice can be induced. Since the cleaning solvent S is adjusted and maintained at the temperature slightly below the sublimation point of the particles as explained above, the energy generator 50 may allow the particles to sublime with relatively-low thermal energy. The energy generator 50 may provide the thermal energy continuously or periodically to cause the particles to sublime. In an example, the energy generator 50 may comprise a thermoelectric element or heater, or an electromagnetic radiation emitter. In another example, the energy generator 50 may comprise an infrared laser. It should be understood that carbon dioxide can absorb radiation in infrared radiation wavelengths. Thus, when using an infrared laser, materials that do not absorb infrared radiation may be selected as the solvent.

[0021] The cleaning solvent dispenser 60 is configured to supply the cleaning solvent S, which comprises the solvent with the nanometer-sized particles dispersed therein, into the container 20. In an example, the solvent is liquid butane, whereas the particles are carbon dioxide in a solid phase. Since carbon dioxide is nonpolar molecule, aggregation of the molecule hardly occurs. The cleaning solvent dispenser 60 may produce nanometer-sized ultrafine particles by crushing or milling coarse particles premixed in the solvent while being cooled. It should be noted that not all the particles have to be formed uniformly in a nanometer size, and it is only necessary that the cleaning solvent S contains a sufficient amount of particles that are sufficiently small to be introduced into the structure of the fine patterns on the surface of the article. In an example, Ultrafine grinder/SS5 produced by M Technique Co., Ltd. may be used. This product allows particles to be nanoparticulated by a high-speed shearing force in a boundary layer of fluid. Alternatively, High-Shear colloid mills produced by Bematex systems, Inc. may be used.

[0022] Figure 2 is a schematic illustration of an example of the cleaning solvent dispenser of the cleaning apparatus arranged in accordance with the present disclosure.

[0023] The cleaning solvent dispenser comprises an inlet port 61 from which an object to be processed is introduced and a crushing unit 62 operatively communicated with the inlet port 61. The crushing unit 62 includes two ring-shaped discs 63A and 63B arranged opposite to each other. A lower disc 63B rotates at a high speed of, for example, 50-100 m/sec, while an upper disc 63A is loaded with a back pressure on its back surface by means of a plurality of springs and an air pressure. Respective opposing surfaces of the upper and lower discs 63A and 63B are mirror-finished, so that the object which is being processed can be sealed therebetween when the rotation of the lower disc 63B stops. The lower disc 63B is provided with a spiral groove and provides a intensified pressure when rotating at a high speed, thereby generating force that extends a space between the pair of discs 63A and 63B. The particles premixed in the solvent introduced from the inlet port 61 are crushed into finer particles by these two discs 63A and 63B, and then discharged. In this way, the cleaning solvent dispenser 60 can produce dry ice particles having a size of 1-5 μm .

[0024] Substances that are capable of sublimating at a desired temperature may be used as the particles. Figure 3 is an example phase diagram of carbon dioxide. Phase diagrams for a wide array of materials are publicly available. At temperatures below -56.6 degrees Celsius and at pressures below 5.2 atm (the "triple point" for carbon dioxide), solid particles of carbon dioxide can sublime directly to a gaseous state when heated, without first transitioning through a liquid state. If the solid particles were to become a liquid, the carbon dioxide may diffuse away from the article, possibly before performing any cleaning of the article. As a result, it is expected that the cleaning performance of the carbon dioxide will be superior at temperatures and pressures below the triple point. The

phase diagram can also be used to obtain the sublimation temperature at a particular pressure. For example, at an ambient pressure of 1 atm, the sublimation temperature of carbon dioxide is -78.5 degrees Celsius. Cleaning performed at 1 atm pressure is expected to be superior at temperatures below this temperature, as the solid particles would sublimate directly to a gas as the temperature is increased past -78.5 degrees Celsius.

[0025] In another example, xenon in a solid phase may be used as the particles. The triple point of xenon is at a temperature of -122 degrees Celsius at a pressure of 1 atm. Xenon serving as the solvent may be easily introduced into the structure of patterns on the article as the density of xenon is relatively high (*i.e.*, 5.9 kg/m³). In another example, water in the solid phase (*i.e.*, ice) may be used as the particles. The triple point of water is at a temperature of 0.01 degrees Celsius at a pressure of 0.06 atm. An atmospheric pressure surrounding the solvent may be depressurized below a vapor pressure of the particles.

[0026] As is anticipated from the above, it is required that the solvent have a freezing point lower than the sublimation point of the particles and have a boiling point higher than the sublimation point. Saturated aliphatic hydrocarbons such as, among others, propane, butane, pentane, and hexane, may be used as the solvent. The freezing point and the boiling point of butane at a pressure of 1 atm are -135 degrees Celsius and -0.5 degrees Celsius, respectively. For example, such a solvent with the particles of dry ice may be maintained at a temperature of about -80 degrees Celsius at a pressure of about 1 atm.

[0027] Further, the particles of carbon dioxide can absorb mainly infrared radiation, as explained above. In other words, the infrared radiation can easily cause excitation of carbon dioxide due to its energy, and accordingly the phase of the particles transfers from the solid phase to the gas phase, along with the expansion energy generated when the particles are rapidly expanded. A primary absorption

wavelength of carbon dioxide is about $20\text{ }\mu\text{m}^{-1}$. In contrast, saturated aliphatic hydrocarbons have absorption wavelengths which are definitely different from that of carbon dioxide, and substantially do not absorb at the same wavelength as does carbon dioxide. Thus, the energy of the infrared radiation which applies to the cleaning solvent S can selectively raise the temperature of the particles of carbon dioxide.

[0028] Figure 4 is a flowchart explaining an example of a cleaning method arranged in accordance with the present disclosure. The cleaning method may be performed by the cleaning apparatus 1 under control of the control unit 100.

[0029] Referring to Figure 4, the control unit 100 of the cleaning apparatus 1 controls the conveying arm 30 and the movable chuck 22 to place the article A to be cleaned on the stage 21 in the container 20. Specifically, the conveying arm 30 conveys the article A to a predetermined position in the chamber 10, and then the chuck 22 picks up the article A and moves vertically down to the stage 21 (block 410). The control unit 100 then controls the cleaning solvent dispenser 60 to provide the solvent with the nanometer-sized particles dispersed therein in the container 20 (block 420). It should be understood that the solvent with the particles dispersed therein may be provided in the container 20 first, and thereafter the article A may be placed on the stage 21 in the solvent in the container 20.

[0030] The control unit 100 then controls the energy generator 50 to apply external energy to the particles dispersed in the solvent to cause the particles to sublime (block 430). The energy may be applied continuously or intermittently for a predetermined period of time. Such an operation causes the temperatures of the solvent and particles to rise rapidly and thus creates numerous nanobubbles, and the pressure, flow and buoyancy of the bubbles remove contamination on the surface of the article A. After the nanobubble creation process, the control unit

100 controls the chuck 22 and the conveying arm 30 to carry the article A out of the chamber 10 (block 440).

[0031] Figures 5A and 5B, and Figures 6A-6D are schematic illustrations explaining cleaning action in the cleaning method performed by the cleaning apparatus 1 arranged in accordance with the present disclosure.

[0032] As shown in Figure 5, the article A to be cleaned is placed on the stage 21, being submerged in the cleaning solvent S in the container 20. As explained above, the cleaning solvent S comprises liquid butane serving as a solvent with nanometer-sized particles P of dry ice dispersed therein, the cleaning solvent S being maintained at a temperature of about -80 degrees Celsius. In this state, thermal energy is applied to the article A, as shown in Figure 5B.

[0033] Specifically, Figure 6A illustrates a partial cross-sectional view of the structure of a certain pattern of the article A. Contamination or an unwanted material C adheres to the groove-like structure on the surface of the article A. Since the density of dry ice is higher than that of liquid butane, some of the nanometer-sized particles may be introduced into the groove-like structure.

[0034] When external energy is applied to the article A, the temperature of the particles rises and the sublimation of the particles occurs (Figure 6B). Accordingly, since the phase of the particles transfers from the solid phase to the gas phase, the volume thereof rapidly expands, and the expansion energy at this time removes the contamination adhering to the article A (Figure 6C). The removed contamination is guided out of the groove by the buoyancy of the bubbles (Figure 6D).

[0035] Figure 7 is a schematic illustration of another example of a cleaning apparatus 1 arranged in accordance with the present disclosure. In Figure 6, the cleaning apparatus 1 is shown as including an inspection apparatus 70.

[0036] The inspection apparatus 70 comprises a detection device 71 for detecting contamination on a surface of the article A. The detection device 71 scans the surface of the article A, which has been divided into regions in a grid for contamination detection, and detects contamination, if any, for each region. The result of the contamination detection by the detection device 71 is represented as profile information and transmitted to the control unit 100.

[0037] Figure 8 is a schematic illustration explaining the profile information of the article A detected by the detection device 71 arranged in accordance with the present disclosure.

[0038] As shown in Figure 8, the profile information represents the presence/absence of contamination in each region into which the surface of the article A has been geometrically divided. In other words, the profile information represents the position of contamination on the surface of the article A. In this example, the profile information indicates that contamination is present in three regions on the surface of the article A.

[0039] The control unit 100 controls the energy generator 50 based on the profile information transmitted from the inspection apparatus 70. Specifically, the control unit 100 controls the energy generator 50 so as to selectively apply thermal energy to the regions where the contamination has been detected. With such an operation, time and energy required for cleaning can be reduced.

[0040] Figure 9 is a schematic illustration of another example of a cleaning apparatus arranged in accordance with the present disclosure. In the example of Figure 9, a cleaning apparatus 1' is shown as including a flow generator 80 configured to generate a liquid flow of the cleaning solvent S toward the article A in the container 20. The cleaning apparatus 1' allows the particles in a solid phase to sublime by collision energy of the particles colliding against the surface on the article A.

[0041] Specifically, the flow generator 80 may comprise an agitator blade 81 and a motor 82 configured to rotate the agitator blade 81. The motor 82 may be driven by the control unit 100. The speed of the liquid flow generated by the agitator blade 81 may be selected so as to produce the collision energy sufficient to sublime the particles. The article A may be placed in the container 20 such that a surface to be cleaned of the article can effectively receive the liquid flow of the cleaning solvent. In view of this, a conveying arm 30' shown in Figure 8 may comprise, but not limited to, a robot arm including joints allowing rotational motion and linear displacement.

[0042] Figures 10A-10D are schematic illustrations explaining cleaning action in the cleaning method performed by the cleaning apparatus 1' arranged in accordance with the present disclosure.

[0043] In Figure 10A, contamination or an unwanted material C adheres to the groove-like structure on the surface of the article A. When the cleaning solvent S is agitated, a liquid flow of the cleaning solvent S is generated. Some of the particles are guided by the liquid flow toward the article A, collide against the surface of the article A, and the temperature of these particles rise due to the collision energy, which causes the particles to sublime (Figure 10B). Accordingly, since the phase of the particles transfer from the solid phase to the gas phase, the volume thereof expands rapidly, and the expansion energy removes the contamination adhering to the article A (Figure 10C). Then, the removed contamination is guided out of the groove by the buoyancy of the bubbles (Figure 10D)

[0044] The technique in the present disclosure can be used for cleaning devices having nanostructures, such as semiconductor devices, MEMS devices and nanoimprint templates. In addition, this technique can be used in combination

with conventional cleaning methods that use acid and alkali solutions as well as organic solvents.

[0045] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

CLAIMS

1. A cleaning apparatus comprising:
 - a container configured to hold an article to be cleaned;
 - a cleaning solvent dispenser configured to supply a solvent with particles dispersed therein to the container;
 - an energy generator configured to provide thermal energy to an interior of the container; and
 - a control device in communication with the energy generator, and configured to select thermal energy sufficient to sublime the particles.
2. The cleaning apparatus according to claim 1, wherein the particles comprise a substance that has a sublimation point.
3. The cleaning apparatus according to claim 2, wherein the particles comprise carbon dioxide or xenon in a solid phase.
4. The cleaning apparatus according to claim 2, wherein the cleaning solvent dispenser is configured to provide the solvent at a temperature lower than the sublimation point of the particles.
5. The cleaning apparatus according to claim 4, wherein the solvent has a freezing point lower than the sublimation point of the particles and has a boiling point higher than the sublimation point of the particles.
6. The cleaning apparatus according to claim 5, wherein the solvent is saturated aliphatic hydrocarbon.
7. The cleaning apparatus according to claim 6, wherein the solvent is at least one selected from the group consisting of propane, butane, pentane, and hexane.

8. The cleaning apparatus according to claim 4, further comprising a temperature maintaining unit configured to maintain the temperature of the solvent in the container.
9. The cleaning apparatus according to claim 8, wherein the temperature maintaining unit is attached to the container.
10. The cleaning apparatus according to claim 9, wherein the temperature maintaining unit includes a cooling device.
11. The cleaning apparatus according to claim 1, further comprising a stage configured to support the article thereon such that a surface to be cleaned of the article is directed substantially upward.
12. The cleaning apparatus according to claim 4, further comprising:
 - a chamber configured to accommodate the container, wherein the chamber is configured to maintain a predetermined pressure; and
 - a temperature maintaining unit configured to maintain the temperature in the chamber.
13. The cleaning apparatus according to claim 12, further comprising a pressure adjustment device configured to depressurize an interior atmosphere of the chamber below a vapor pressure of the particles.
14. The cleaning apparatus according to claim 1, wherein the cleaning solvent dispenser is configured to provide the particles in a solid phase.
15. The cleaning apparatus according to claim 14, wherein the cleaning solvent dispenser is configured to provide the particles by crushing particles that are pre-mixed in the solvent.
16. The cleaning apparatus according to claim 1, wherein the energy generator includes a thermoelectric element.

17. The cleaning apparatus according to claim 1, wherein the energy generator includes an infrared laser.
18. The cleaning apparatus according to claim 17, wherein the particles comprise carbon dioxide in a solid phase, and wherein the solvent is at least one selected from the group consisting of propane, butane, pentane, and hexane.
19. The cleaning apparatus according to claim 1, wherein the energy generator includes an electromagnetic radiation emitter.
20. The cleaning apparatus according to claim 1, further comprising a detection device configured to detect at least one region that includes unwanted materials on the article, wherein the energy generator selectively provides the thermal energy to the at least one region detected by the detection device.
21. A cleaning apparatus comprising:
 - a container configured to hold an article to be cleaned;
 - a cleaning solvent dispenser configured to supply a solvent with particles dispersed therein to the container; and
 - a flow generator configured to generate a flow of the solvent to the article in the container.
22. The cleaning apparatus according to claim 21, wherein the flow generator includes an agitator configured to agitate the solvent in the container.
23. The cleaning apparatus according to claim 21, wherein the particles comprise a substance that has a sublimation point.
24. The cleaning apparatus according to claim 22, wherein the cleaning solvent dispenser is configured to supply the solvent at a temperature lower than the sublimation point of the particles to the container.

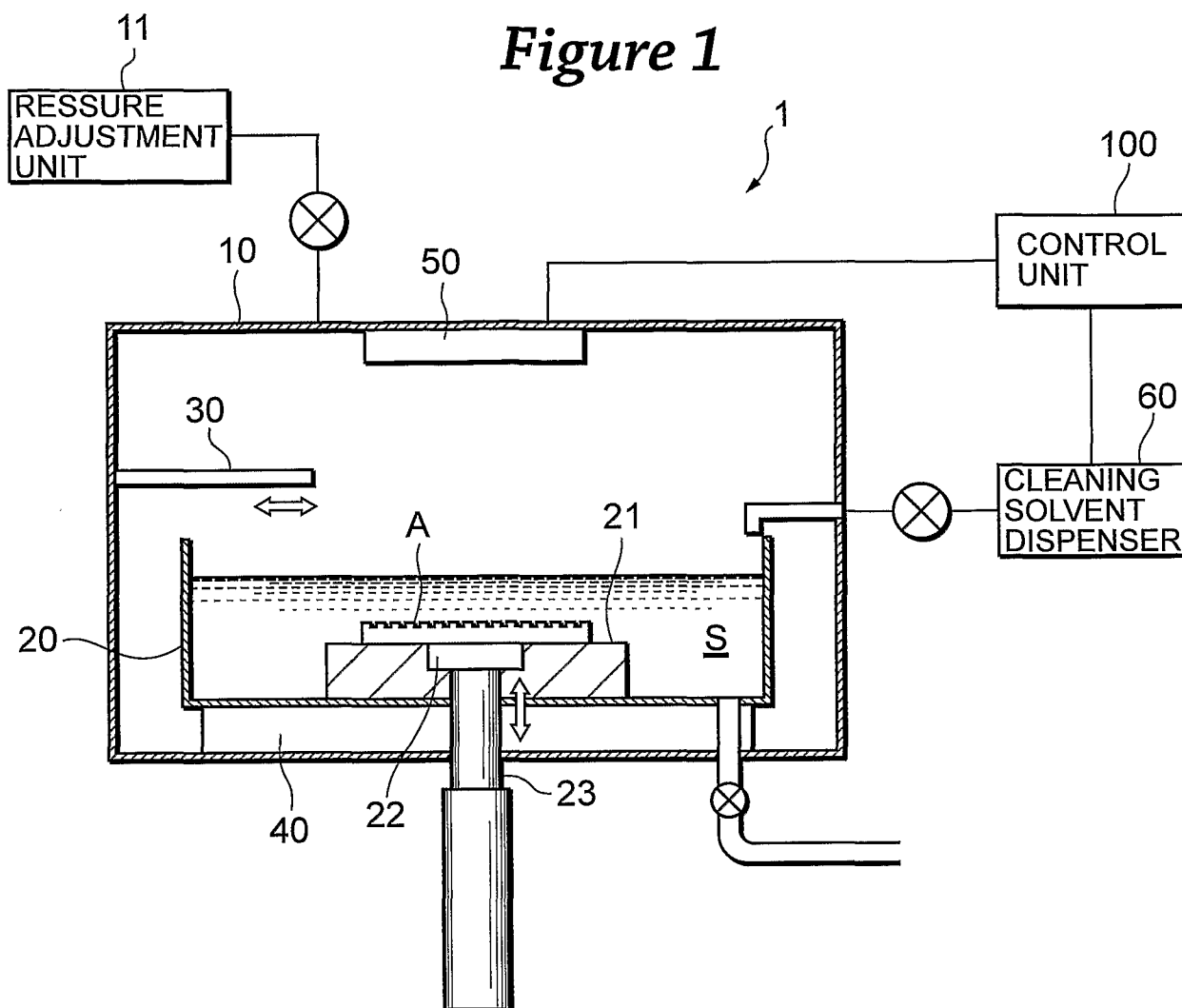
25. The cleaning apparatus according to claim 23, further comprising:
an energy generator configured to provide thermal energy to an interior of the container; and
a control device in communication with the energy generator and configured to select thermal energy sufficient to sublime the particles.
26. The cleaning apparatus according to claim 23, wherein the energy generator heats the article a) at a temperature that is higher than the temperature of the solvent and b) at a temperature about equal to or higher than, the sublimation point of the particles.
27. A cleaning method using vaporization of solid-phase particles, the method comprising:
providing an article to be cleaned of unwanted materials, and a solvent with particles dispersed therein at a temperature below a sublimation point of the particles; and
applying thermal energy to the particles sufficient to sublime the particles, and thereby to cause unwanted materials on the article to be removed.
28. The cleaning method according to claim 27, wherein the particles comprise carbon dioxide or xenon in a solid phase.
29. The cleaning method according to claim 27, wherein the solvent has a freezing point lower than the sublimation point of the particles and has a boiling point higher than the sublimation point of the particles.
30. The cleaning method according to claim 29, wherein the solvent is a saturated aliphatic hydrocarbon.
31. The cleaning method according to claim 30, wherein the solvent is at least one selected from the group consisting of propane, butane, pentane, and hexane.

32. The cleaning method according to claim 27, further comprising placing the article such that a surface to be cleaned on the article is directed substantially upward.
33. The cleaning method according to claim 27, further comprising adjusting and maintaining the temperature in the container.
34. The cleaning method according to claim 27, further comprising depressurizing an atmosphere surrounding the solvent below a vapor pressure of the particles.
35. The cleaning method according to claim 27, further comprising producing the particles in a solid phase.
36. The cleaning method according to claim 35, wherein producing the particles in the solid phase includes pre-mixing particles in the solvent and crushing the coarse particles in the solvent.
37. The cleaning method according to claim 27, wherein applying the thermal energy includes irradiating infrared light.
38. The cleaning method according to claim 35, wherein the particles comprise carbon dioxide in a solid phase.
39. The cleaning method according to claim 38, wherein the solvent is at least one selected from the group consisting of propane, butane, pentane, and hexane.
40. The cleaning method according to claim 27, further comprising detecting at least one region that includes the unwanted materials on the article,
wherein applying the thermal energy selectively applies the thermal energy to the at least one region.
41. A cleaning method using vaporization of solid-phase particles, comprising:
providing a container configured to hold an article to be cleaned;

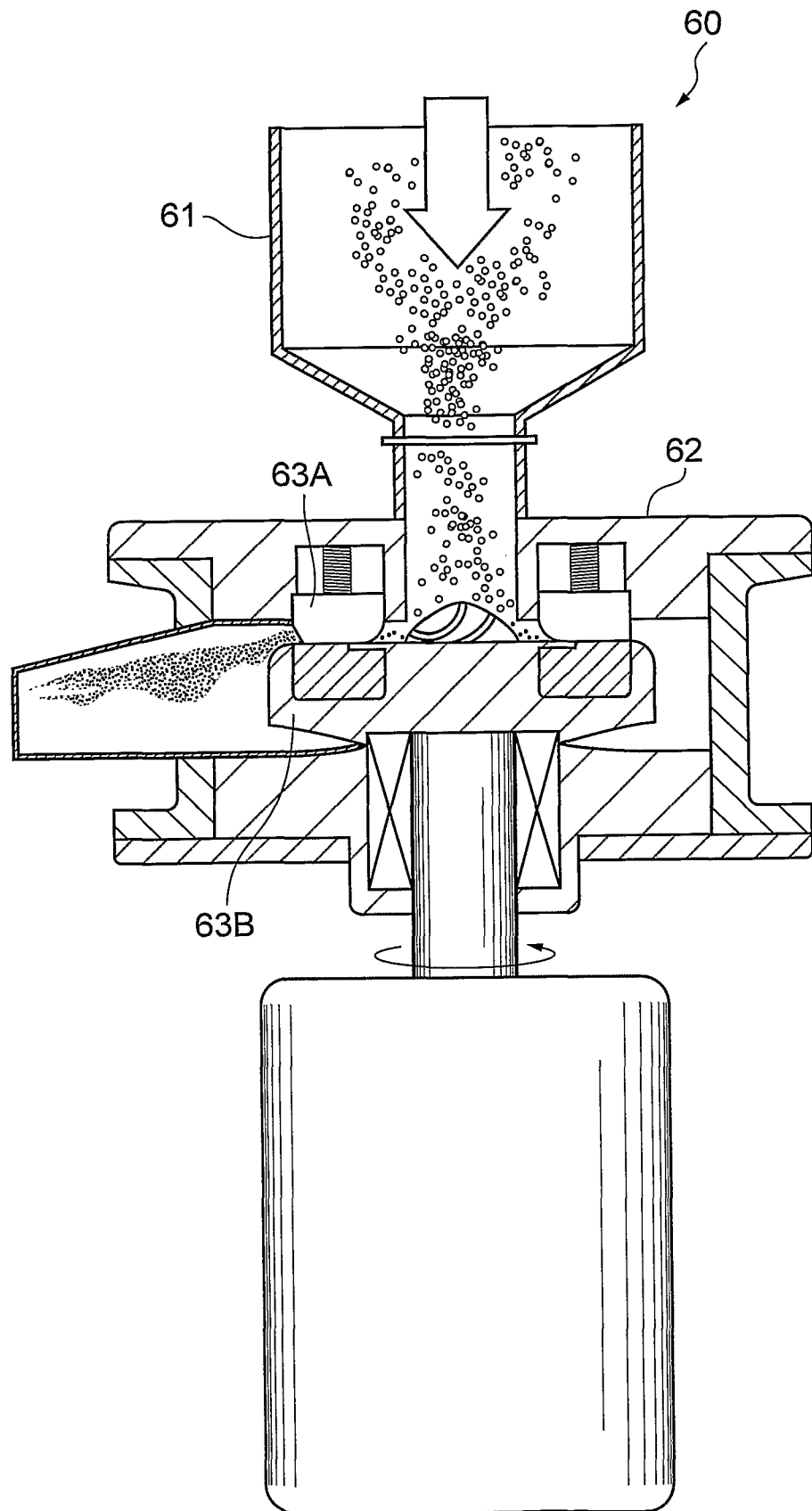
providing an article to be cleaned and a solvent with particles dispersed therein at a temperature below a sublimation point of the particles; and generating a flow of the solvent to the article to cause unwanted materials on the article to be removed.

42. The cleaning method according to claim 41, wherein generating the flow of the solvent includes agitating the solvent in the container.
43. The cleaning method according to claim 41, further comprising applying thermal energy to the particles sufficient to sublime the particles, and thereby to cause the unwanted materials on the article to be removed.
44. The cleaning method according to claim 41, wherein applying the thermal energy includes heating the article at a temperature that is higher than the temperature of the solvent and that is in the vicinity of, or higher than, the sublimation point of the particles.
45. A cleaning agent comprising a solvent with particles in a solid phase dispersed therein, wherein the particles comprise a substance that has a sublimation point.
46. The cleaning solvent according to claim 45, wherein the particles comprise carbon dioxide or xenon.
47. The cleaning solvent according to claim 45, wherein the solvent has a freezing point lower than the sublimation point of the particles and has a boiling point higher than the sublimation point of the particles.
48. The cleaning solvent according to claim 48, wherein the solvent is saturated aliphatic hydrocarbon.
49. The cleaning solvent according to claim 49, wherein the solvent is at least one selected from the group consisting of propane, butane, pentane, and hexane

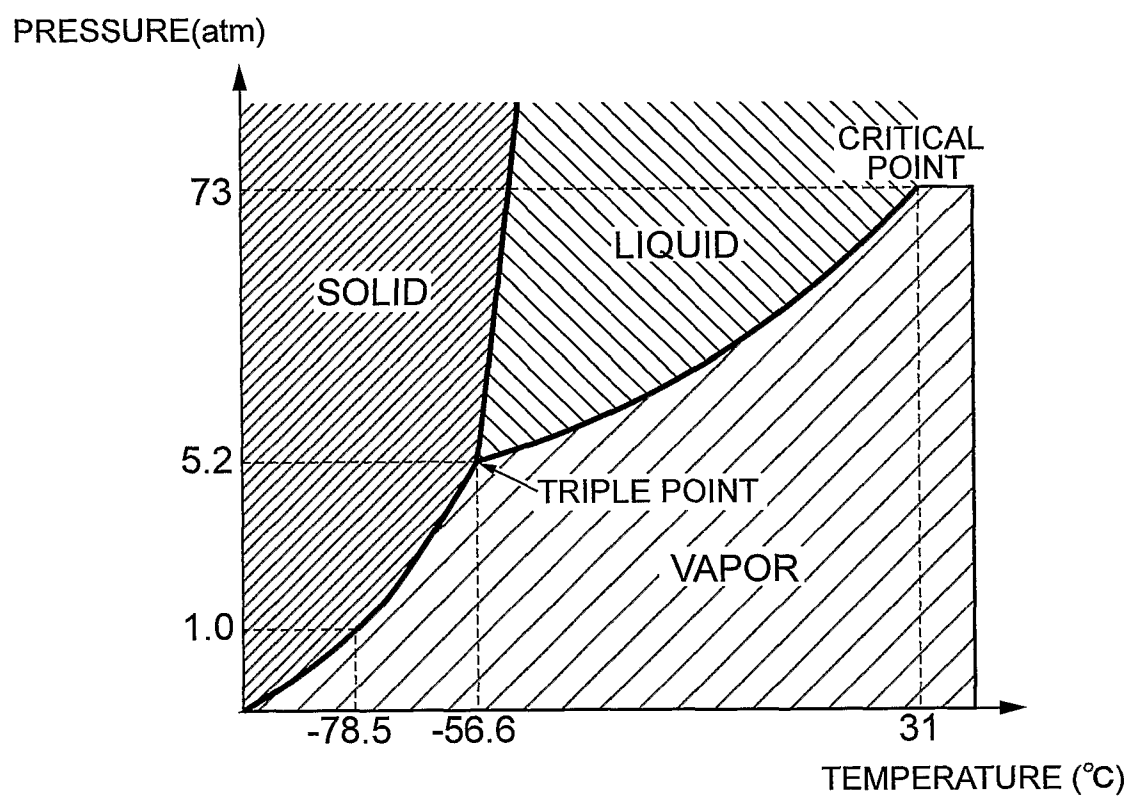
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Figure 1

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Figure 2

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Figure 3

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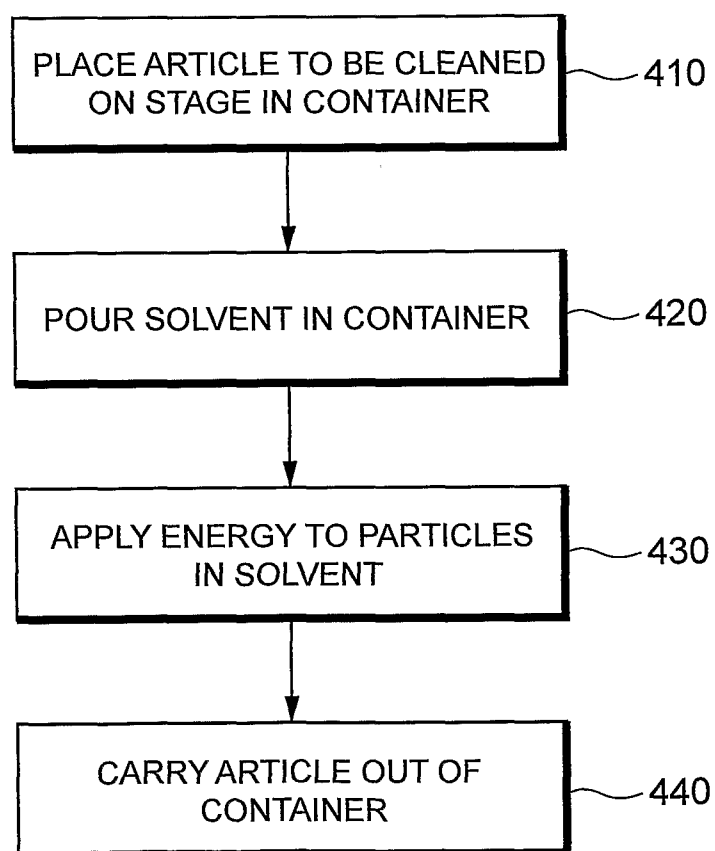
Figure 4

Figure 5A

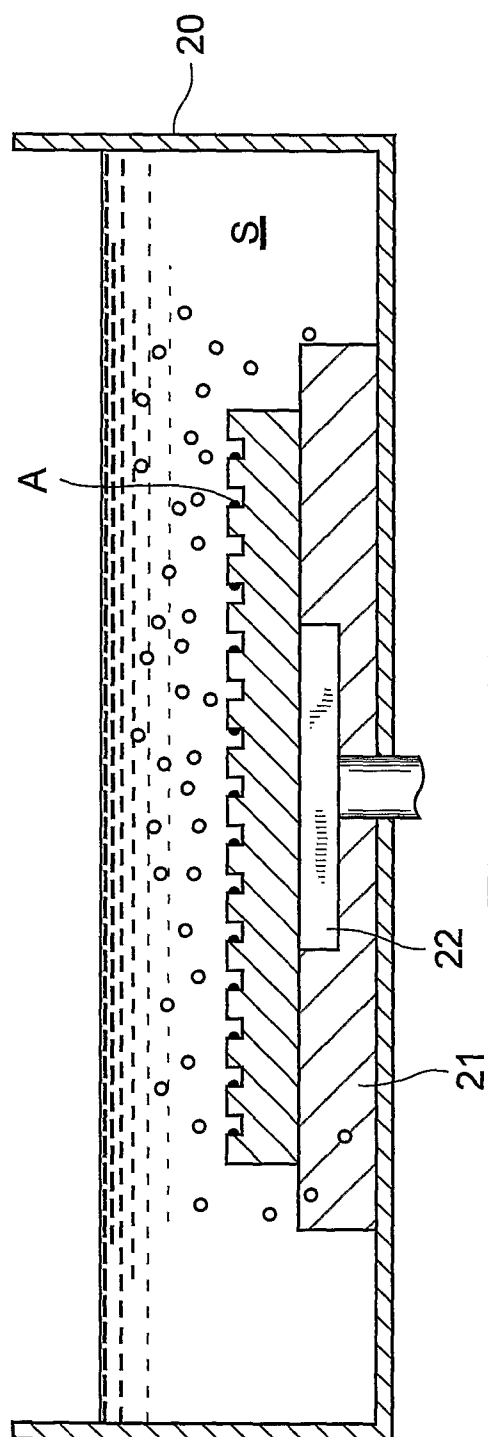


Figure 5B

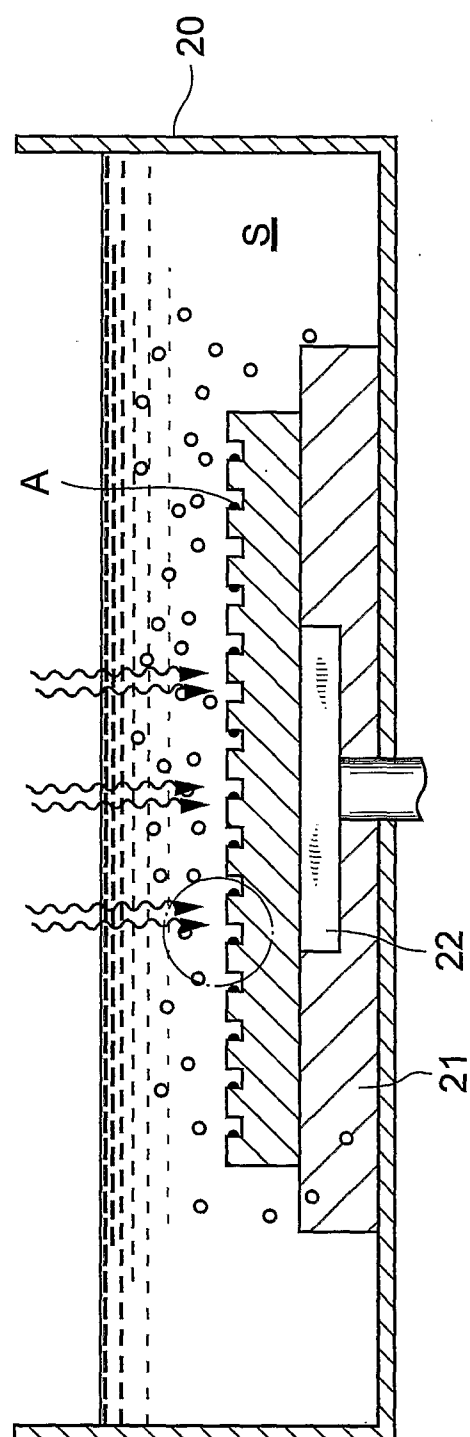


Figure 6A

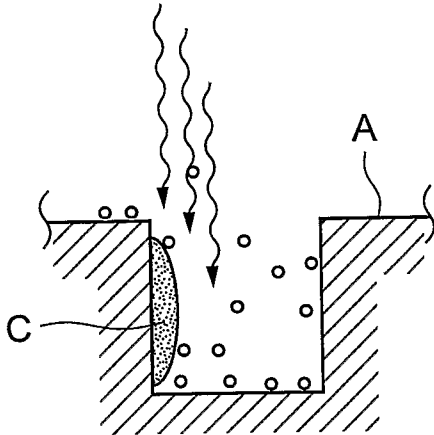


Figure 6B

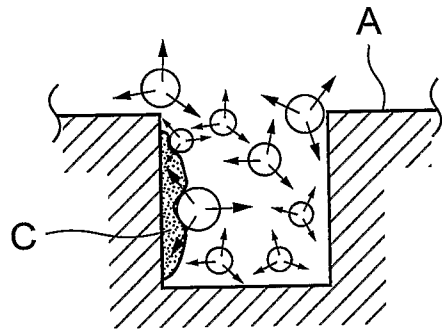


Figure 6C

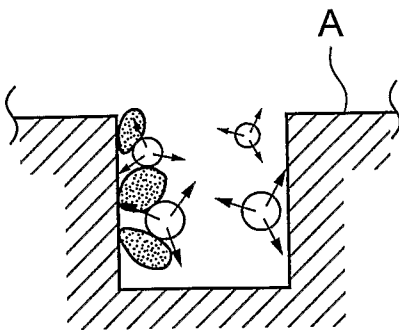


Figure 6D

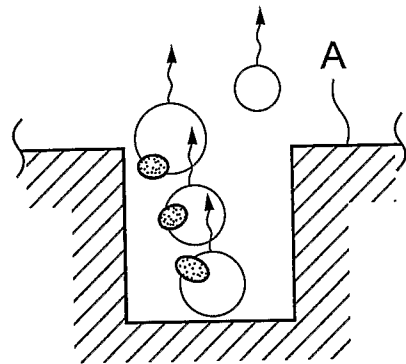
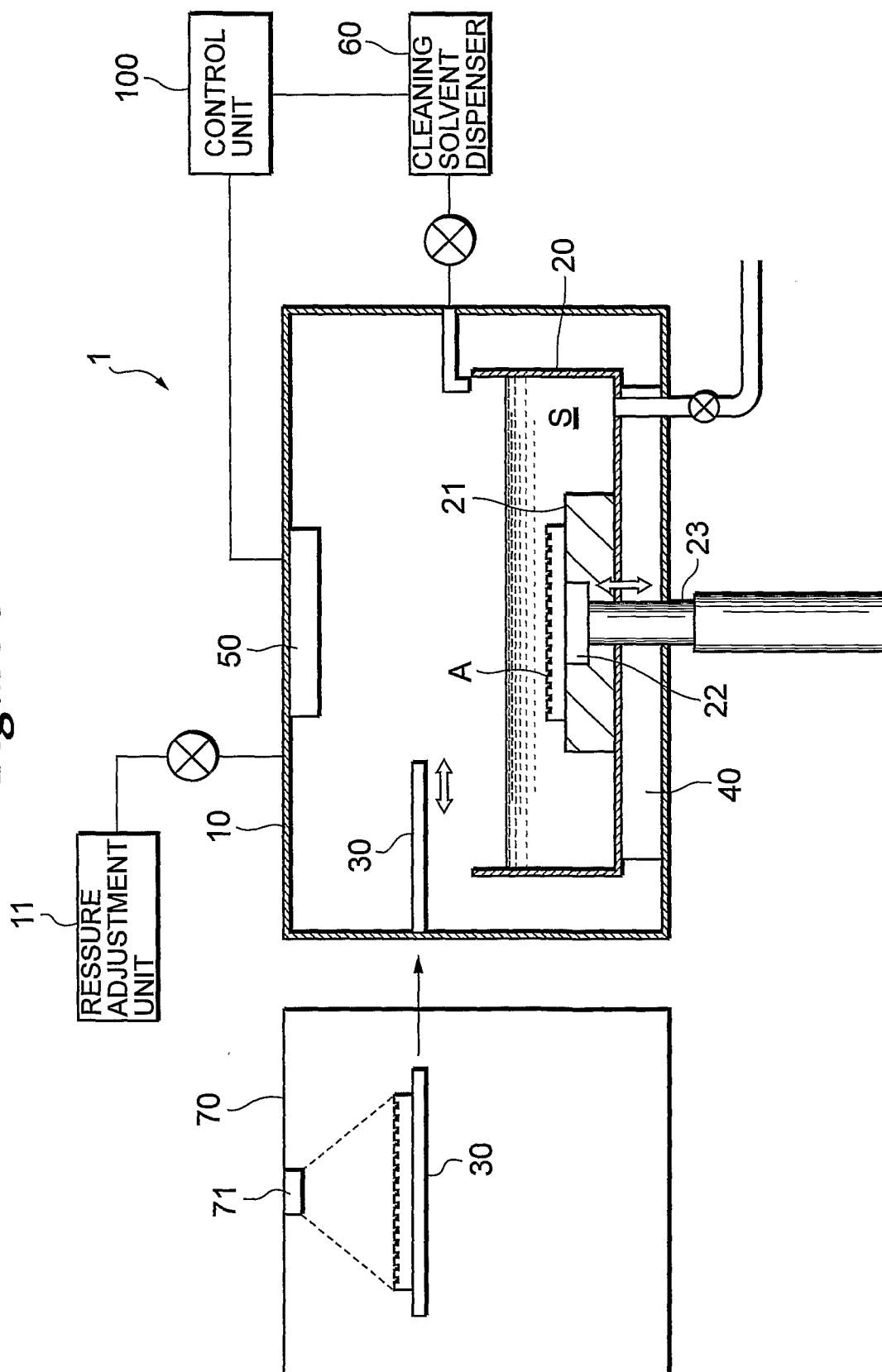


Figure 7



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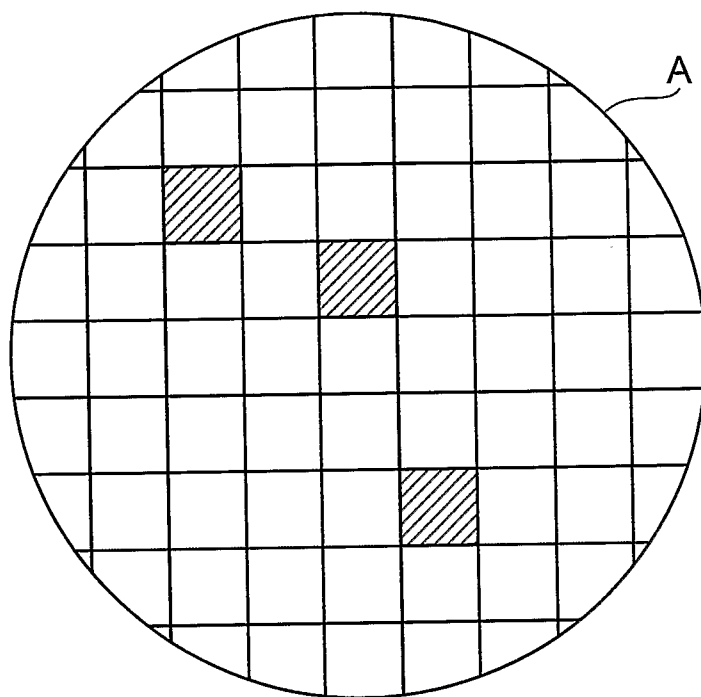
Figure 8

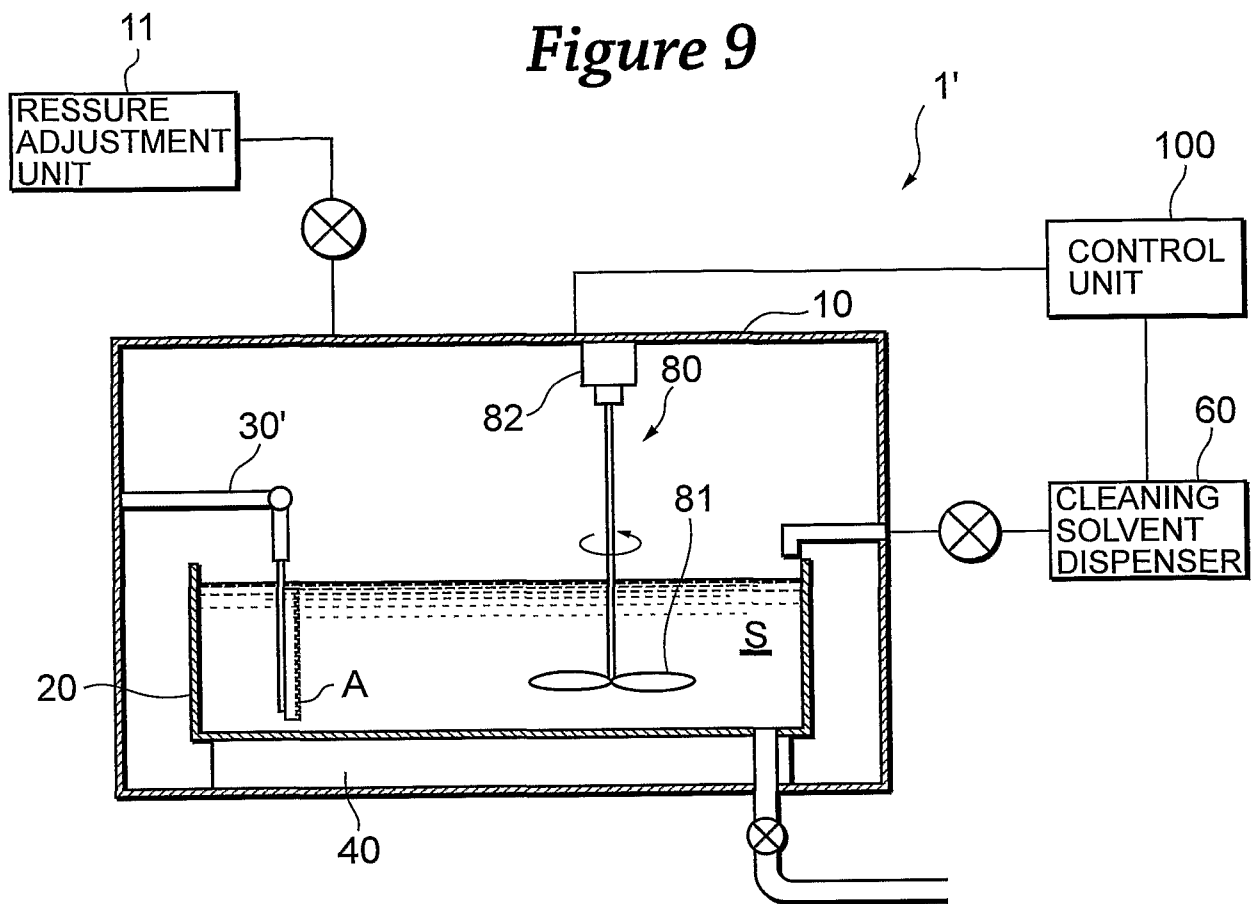
Figure 9

Figure 10A

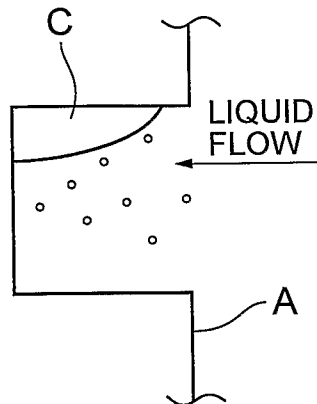


Figure 10B

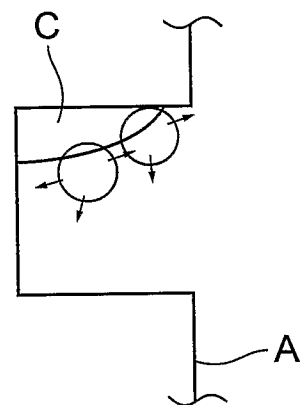


Figure 10C

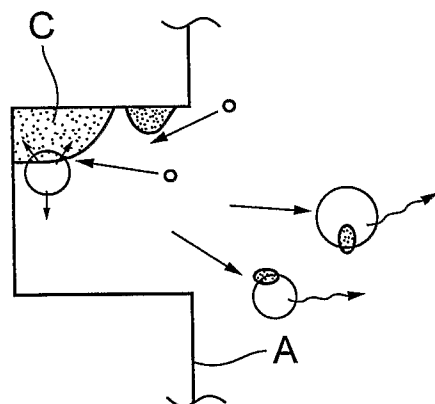
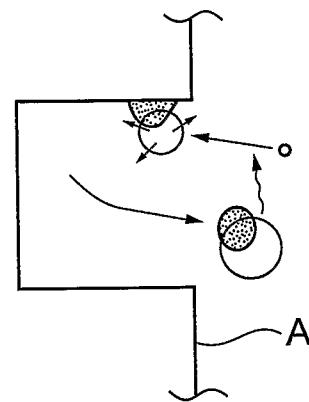


Figure 10D



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2010/070634

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H01L21/304 (2006.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H01L21/304

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2011
 Registered utility model specifications of Japan 1996-2011
 Published registered utility model applications of Japan 1994-2011

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2002-540939 A (STEAG MicroTech GmbH) 2002.12.03, whole document & US 6488779 B1 & EP 1169145 A & WO 2000/061306 A1 & DE 19916345 A & DE 50007622 D & AT 275004 T	1-4, 8-28, 32-38, 40-46 5-7, 29-31, 39, 47-49
Y A	JP 2002-329700 A (Sony Co., Ltd.) 2002.11.15, whole document (No Family)	1-4, 8-28, 32-38, 40-46 5-7, 29-31, 39, 47-49
Y	JP 2008-281332 A (OBAYASHI CORPORATION) 2008.11.20, whole document (No Family)	15
Y	JP 2003-303799 A (Sony Co., Ltd.) 2003.10.24, whole document (No Family)	20



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See patent family annex.

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“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

14.02.2011

Date of mailing of the international search report

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