

METHOD FOR PARALLEL OPERATION OF REACTORS THAT GENERATE MOISTURE

Technical Field

[0001] The present invention relates to a method for the parallel operation of moisture-generating reactors that is used in, for example, semiconductor manufacturing facilities, or chemical manufacturing facilities, and that enables each moisture generating reactor to perform a stable parallel operation in a predetermined amount of moisture generation merely by inserting orifices, each of which has an appropriate opening diameter, into the source-gas supply lines of the moisture generating reactors, respectively, that perform a parallel operation without using a special apparatus that divides the flow of source gas and supplies the gas.

Background Art

[0002] For example, in silicon-dioxide-film adhesion processing according to a moisture oxidation method used by semiconductor manufacturing facilities, a high-purity water supply is required, and, in usual cases, the necessary high-purity moisture is supplied by a moisture generating reactor as shown in, for example, FIG. 8.

[0003] More specifically, this moisture generating reactor is structured so that, as disclosed by International Publication No. WO97/28085 and by Japanese Patent No. 3639469, a reactor body 1 having a space 4 thereinside is formed by assembling an inlet-side reactor body member 2 and an outlet-side reactor body

member 3 together so as to face each other, and the reactor body 1 is provided with a source gas inlet 5, a moisture gas outlet 6, a reflector 7, and a reflector 8, and, furthermore, a platinum coating film 9 is formed on an inner surface of the outlet-side reactor body member 3.

[0004] When moisture is generated, mixed gas G consisting of oxygen O_2 and hydrogen H_2 is first supplied from the source gas inlet 5 into the space 4, and is then stirred by the reflectors 7 and 8 while oxygen O_2 and hydrogen H_2 are activated by the catalytic action of the platinum coating film 9. Thereafter, activated oxygen O_2 and hydrogen H_2 are allowed to instantaneously react with each other in a non-combustion state below a temperature of 450°C , thus generating water. The resulting water is discharged from the moisture gas outlet 6 out of the reactor body 1 in the form of moisture gas W.

[0005] In spite of the fact that the moisture generating reactor structure, as shown in FIG. 8, is very small (for example, about 114mm in outer diameter and about 35mm in thickness), the moisture generating reactor can continuously generate moisture gas W of about 2SLM (which is a moisture gas quantity calculated in a standard state at a temperature of 0°C and at 1 atmosphere of pressure) by the catalytic reaction performed below a temperature of 400°C . Thus, the moisture generating reactor structure shown in FIG. 8 has an excellent, practicable effect.

[0006] However, in the moisture generating reactor shown in FIG. 8, if the supply of the source gas G is increased in amount so as to increase the amount of moisture generation, a rise in temperature of the outlet-side reactor body member 3 becomes steep, and the temperature of the internal space of the reactor body 1 will rise and approach the explosive temperature of the source gas G, which is H_2 - O_2 mixed gas, and, as a result, an extremely dangerous state will be reached. Additionally, if the supply of the source gas G is

increased in amount, the rate of reaction between hydrogen H_2 and oxygen O_2 will fall, and oxygen O_2 and hydrogen H_2 will enter into, and mix with, moisture gas GW without allowing oxygen O_2 and/or hydrogen H_2 to react with each other, and, as a result, various disadvantages will occur on the process side where the moisture gas W is used. Additionally, if the temperature of the reactor body 1 rises, the platinum coating film 9 formed on the inner wall surface of the outlet-side reactor body member 3 will peel and fall off, and, as a result, a significant deterioration in catalytic action will result.

[0007] On the other hand, in order to avoid the occurrence of the disadvantages mentioned above, a moisture generating reactor structured to advance heat dissipation from the reactor body 1 has been developed by providing cooling fins 10 and 11 on the outer wall surface of the inlet-side reactor body member 2 and on the outer wall surface of the outlet-side reactor body member, respectively, as shown in FIG. 9. In FIG. 9, reference numeral 12 designates an electric heater that is used to raise the temperature of the moisture generating reactor 1 to nearly $300^{\circ}C$ when the moisture generating reactor 1 is started.

[0008] However, a problem resides in the fact that the disposition of the cooling fins 10 and 11 leads to a great increase in outside dimensions of the moisture generating reactor 1, and, if the amount of moisture generation is made, for example, 1.3 times as great as the conventional amount of moisture generation, the volume of the reactor 1 must be tripled, and hence it is impossible to meet the requirement of reducing the moisture generating reactor 1 in size. A possible method for increasing the amount of moisture generation, without using the cooling fins 10 and 11, is to increase the outside dimensions of the reactor body 1. However, if the area in which the platinum coating film 9 is formed exceeds a predetermined area, unevenness will occur in the

temperature distribution on the inner surface of the outlet-side reactor body member 3 when moisture is generated, and, as a result, the platinum coating film 9 may readily peel off. Therefore, another problem resides in the fact that, if the inner diameter of the reactor body 1 is made, for example, twice or more as large as the conventional one, the frequency of occurrence of peeling off of the platinum coating film 9 will rise steeply, as is well known, and the requirement of increasing the amount of moisture generation cannot be satisfactorily met.

[0009] Therefore, when employing the above-described type of conventional equipment for supplying moisture gas W, a plurality of moisture generating reactors may be connected in parallel with each other. Then, the flow rate of mixed gas G supplied to each moisture generating reactor is controlled by use of a highly accurate apparatus (i.e., a mixed-gas-flow-dividing-and-supplying apparatus) that divides the flow of the mixed gas G and that supplies the gas to each moisture generating reactor in order to meet the requirement of increasing the amount of moisture generation (i.e., the amount of moisture that needs to be supplied).

[0010] However, still another problem resides in the fact that the disposition of the highly accurate apparatus for dividing the flow of the mixed gas G, and supplying the gas, brings about not only a steep rise in the amount of equipment employed, but also brings about the need for a large space for the installation of the equipment, and furthermore, it increases costs for the maintenance, or the like, of the mixed-gas-flow-dividing-and-supplying apparatus.

[0011] Patent Literature 1: International Publication No. WO97/28085

Patent Literature 2: Japanese Patent No. 3639469

Disclosure of the Invention

Problems to be Solved by the Invention

[0012] The present invention has been made to solve the above-mentioned problems occurring in equipment for supplying high-purity moisture used by a conventional moisture generating reactor. Specifically, the present invention has been made to solve (i) the problem of given constraints on meeting the requirement of increasing the amount of to-be-supplied moisture by increasing the moisture generating reactor in size (or in volume) because there is a limit to the enlargement of the moisture generating reactor from the viewpoint of structural factors, such as the durability of the platinum coating catalyst film, and (ii) the problem of the steep rise in equipment costs and in management costs, and in the need for a large installation space for the mixed-gas-flow-dividing-and-supplying apparatus, which are problems caused when the need to increase the amount of to-be-supplied moisture is met by employing the-mixed-gas-flow-dividing-and-supplying apparatus that divides the flow of mixed gas G and that supplies the gas, and by supplying the mixed gas G to a plurality of moisture generating reactors performing a parallel operation. It is therefore a main object of the present invention to provide a method for the parallel operation of moisture generating reactors that is capable of supplying a predetermined amount of mixed gas G to each moisture generating reactor performing a parallel operation by employing a simple mechanism at low cost, which is accurate and capable of easily meeting the need to increase the amount of moisture generation by attaching orifices, each of which has a predetermined inner diameter to mixed-gas supply lines, respectively. Thus, another object of the present invention is to supply mixed gas to the moisture generating reactors performing a parallel operation without requiring a structurally complex apparatus for dividing the flow of mixed gas G and that

supplies the gas in amounts required.

Means for Solving the Problems

[0013] The invention of claim 1 has a basic constitution of the invention in which an orifice is disposed on a mixed-gas inlet side of each of a plurality of moisture generating reactors; an end on an inlet side of each orifice is connected to a mixed gas supply line in parallel; and mixed gas consisting of hydrogen and oxygen is allowed to branch off and is supplied to each of the moisture generating reactors through each of the orifices.

[0014] The invention of claim 2 has a basic constitution of the invention in which orifices are disposed on mixed-gas inlet sides of a plurality of moisture generating reactors, respectively; an end on an inlet side of each of the orifices is connected to a mixed-gas supply line in parallel; mixed gas consisting of hydrogen and oxygen is allowed to branch off and is supplied to each of the moisture generating reactors through each of the orifices; ends on moisture-gas outlet sides of the moisture generating reactors are connected in parallel with each other; and moisture generated by each of the moisture generating reactors is supplied to an apparatus using the moisture along a moisture supply line.

[0015] The invention according to claim 3 is as set forth in claim 2, in which the apparatus using the moisture is a process chamber for use under pressure that is approximately atmospheric pressure.

[0016] The invention according to claim 4 is as set forth in claim 2, in which the apparatus using the moisture is a process chamber for use under a pressure of 1 to 700 Torr, and the moisture supply line along which moisture generated from the moisture generating reactors is supplied is provided with a depressurizing orifice.

[0017] The invention according to claim 5 is as set forth in claim 1 or claim 2, in

which the number of the moisture generating reactors connected in parallel with each other is two; the orifices disposed on the mixed-gas inlet sides of the moisture generating reactors are equal in opening diameter to each other; and mixed gases that are substantially equal in amount to each other are supplied from the mixed-gas supply lines to the moisture generating reactors, respectively.

[0018] The invention according to claim 6 is as set forth in claim 5, in which a rated amount of moisture generation of each of the moisture generating reactors is 5SLM to 10SLM, and the opening diameter of the orifice disposed on the mixed-gas inlet side is 0.8 to 0.6mm ϕ .

[0019] The invention according to claim 7 is as set forth in claim 6, in which an internal pressure of the moisture generating reactor has a pressure value of 200 Torr or more.

[0020] The invention according to claim 8 is as set forth in claim 1 or claim 2, in which the moisture generating reactor is structured so that the moisture generating reactor has an internal space by combining an inlet-side reactor body member and an outlet-side reactor body member together so as to face each other; the inlet-side reactor body member is provided with a mixed-gas inlet, whereas the outlet-side reactor body member is provided with a moisture-gas outlet; a platinum coating film is disposed on an inner wall surface of the outlet-side reactor body member; a reflector is disposed in the internal space; and moisture is generated by allowing the hydrogen gas and the oxygen gas of the mixed gas to react with each other by catalytic action of the platinum coating film under a non-combustion state inside the internal space.

Effects of the Invention

[0021] In accordance with the present invention, mixed gas, which is a source gas used to generate moisture, can be allowed to branch off with extreme accuracy by using a flow-dividing structure having a simple construction in which an orifice having a predetermined opening diameter is only disposed on the mixed-gas inlet side of each of the moisture generating reactors connected in parallel with each other, and a large amount of high-purity water can be supplied using a non-combustion type moisture generating reactor that employs a conventional platinum coating catalyst. In other words, according to the present invention, a large amount of high-purity water can be supplied safely, and at lower cost, by using a conventional non-combustion type moisture generating reactor without using a mixed-gas-flow-dividing apparatus that is high in cost, and complex in structure, and without having to enlarge the equipment to supply the large amount of high-purity water.

Brief Description of the Drawings

[0022]

FIG. 1 is a system diagram that shows the parallel operation of moisture generating reactors in accordance with a first embodiment of the present invention.

FIG. 2 is a system diagram that shows the parallel operation of moisture generating reactors in accordance with a second embodiment of the present invention.

FIG. 3 is a system diagram in which N_2 gas is supplied instead of mixed gas G, and wherein the state of each divided flow toward each moisture-generating reactor is measured.

FIG. 4 shows graphs, each exhibiting arithmetic values of Table 3, in which (a) shows the relationship of the divided-flow error to the flow rate (MFM_1),

(b) shows the relationship of the divided-flow error to the orifice upstream-side pressure P_2 , (c) shows the relationship between the orifice upstream-side pressure P_2 and the calculated pressure, and (d) shows the relationship between the orifice upstream-side pressure P_2 and the relative divided-flow error (%) of the flow rate.

FIG. 5 is a system diagram wherein 17SLM moisture gas is supplied from two moisture generating reactors to a chamber CH under normal pressure.

FIG. 6 is a system diagram showing a moisture supply state created by actual parallel operation using two moisture generating reactors (whose rating is 5SLM).

FIG. 7 is a graph showing one example of test results obtained with respect to the system diagram according to FIG. 6.

FIG. 8 is a sectional view showing an example of a conventional moisture generating reactor.

FIG. 9 is a sectional view showing an example of a conventional moisture generating reactor provided with cooling fins.

Description of Symbols

[0023]

H₂: Hydrogen gas

O₂: Oxygen gas

N₂: Nitrogen gas

M: Gas mixer that mixes H₂ and O₂

G: Mixed gas (Source gas)

WG₁, WG₂: Moisture generating reactors

OR₁, OR₂, OR₃: Orifices

S: H₂ gas sensor

F: Filter

CH: Process chamber

P₁, P_{w1}, P_{w2}, P_c: Pressure gauges

W₁, W₂, W: Moisture (Moisture gas) lines

L₁, L₂, L₃, L₄: Tube lines

MFC₁, MFM₁, MFM₂: Mass flowmeters

HTC₁ - HTC₄: Temperature controllers

RG₁ - RG₄: Pressure regulators

V₁ - V₄: Valves

FA₁, FA₂: Cooling fans

HTM₁, HTM₂: Temperature monitors

1: Reactor body

2: Inlet-side reactor body member

3: Outlet-side reactor body member

4: Internal space of the reactor body

5: Mixed-gas inlet (Source-gas inlet)

6: Moisture-gas outlet

7, 8: Reflectors

9: Platinum coating film

10, 11: Cooling fins

Best Mode for Carrying Out the Invention

[0024] Embodiments of the present invention will be hereinafter described with reference to the drawings. FIG. 1 shows a first embodiment of the present invention, and depicts an example in which moisture W is supplied to a process chamber CH under normal pressure by use of two moisture generating reactors WG₁ and WG₂.

[0025] In FIG. 1, H₂ designates hydrogen gas, O₂ designates oxygen gas, N₂ designates nitrogen gas, M designates a gas mixer that mixes H₂ and O₂, G designates mixed gas, WG₁ and WG₂ designate moisture generating reactors, OR₁ and OR₂ designate orifices, S designates a H₂ sensor, F designates a filter, CH designates a process chamber, P₁, Pw₁, Pw₂, and Pc designate pressure gauges, W₁, W₂, and W designate moisture, and L₁, L₂, L₃, and L₄ designate tube lines.

[0026] The two moisture generating reactors WG₁ and WG₂ used herein are the same in structure, and are made of stainless steel. Each of the moisture generating reactors WG₁ and WG₂ is about 180mmφ in outer diameter, and is about 37mm in thickness. A platinum coating film is formed on the inner wall surface of an outlet-side reactor body member of the reactor. Although the two moisture generating reactors, each having the same structure, are connected together in parallel in this embodiment of the invention, more than two moisture generating reactors, for example, three to five moisture generating reactors may be connected together in parallel in accordance with the present invention.

[0027] Each of the orifices OR₁ and OR₂ is formed by boring a predetermined orifice hole (e.g., a circular hole) in a thin stainless steel plate having an outer diameter of about 12mmφ and a thickness of 0.2 to 1.0mm, and each orifice is replaceably inserted in an orifice inserter (not shown in the drawings). In this embodiment of the invention, the orifices OR₁ and OR₂, each of which has an

orifice hole of 0.5 to 1.0mm ϕ , are used as described later.

[0028] Each of the tube lines L_1 to L_4 is formed of a stainless steel tube having an inner diameter of 4.3mm ϕ and an outer diameter of 6.35mm ϕ , and the process chamber CH that consumes generated moisture W is used to perform various semiconductor processings under normal pressure (i.e., 760 Torr).

[0029] With reference to FIG. 1, mixed gas G supplied from the gas mixer M passes through the mixed gas supply line L_1 and through the orifices OR_1 and OR_2 (0.6mm ϕ or 0.7mm ϕ), and is supplied to the moisture generating reactors WG_1 and WG_2 . Moistures W_1 and W_2 generated by the reactors WG_1 and WG_2 , respectively, are supplied to the normal-pressure chamber CH through the moisture supply line L_4 . In order to allow mixed gas G to smoothly branch off and be supplied to the two reactors, the relationship $P_1 > P_W > P_C$ is required to be established among pressures P_1 , P_W , and P_C . Additionally, pressure P_C is made smaller (e.g., about 0.02 to 0.03 MPa) than pressure P_W due to pressure loss in the tube lines L_3 and L_4 .

[0030] Table 1, presented below, shows one example of provisional calculations of the upstream-side pressure P_1 corresponding to the orifices OR_1 and OR_2 when the mixture ratio of H_2 and O_2 , and the moisture-supply flow rate (sccm) to the process chamber CH under normal pressure (760 Torr), are changed under the condition that the opening diameter of each of the orifices OR_1 and OR_2 is 0.6 or 0.7mm ϕ . Under these conditions, the estimated value of the pressure can be determined. Equations (2) and (3), provided below, are used as the pressure computing equation in accordance with the present invention, and the length of the tube line, which is formed of a stainless steel tube having an inner diameter of 4mm ϕ , is 600mm to 800mm. In Table 1, the amount of supply moisture per reactor is shown.

[0031]

[Table 1]

Examination of upstream orifice diameters 0.6 and 0.7											
Calculation of sound velocity							Calculation of subsonic velocity		Examination of upstream necessary pressure		
	H ₂ (sccm)	O ₂ (sccm)	N ₂ (sccm)	H ₂ O (sccm)	Excess O ₂ (sccm)	Total Flow Rate (sccm)	Orifice (mm)	Pressure (Torr abs)	Necessary differential pressure (Torr)	Calculation of sound velocity (MPa G)	Calculation of subsonic velocity (MPa G)
	5000	4000	0	5000	1500	9000	0.6	2174.305	1555.389	0.189	0.207
	5000	3500	0	5000	1000	8500	0.6	1986.777	1298.662	0.164	0.173
	5000	3000	0	5000	500	8000	0.6	1796.626	1061.973	0.138	0.142
	4500	4500	0	4500	2250	9000	0.6	2289.427	1724.453	0.204	0.230
	4500	2700	0	4500	450	7200	0.6	1616.963	860.198	0.114	0.115
	5000	3000	0	5000	500	8000	0.7	1319.970	573.226	0.075	0.076
	4000	2400	0	4000	400	6400	0.7	1055.976	366.865	0.039	0.049
	3000	1800	0	3000	300	4800	0.7	791.982	206.361	0.004	0.028

[0032] FIG. 2 shows a second embodiment of the present invention, and depicts an example in which generated moisture W is supplied from the two moisture generating reactors WG_1 and WG_2 to the process chamber CH, which is used in a depressurized state of 1 to 100 Torr. In accordance with FIG. 2, OR_3 designates an orifice disposed on the downstream side of the filter F, and is provided to depressurize generated moisture W supplied to the chamber CH.

[0033] In this embodiment of the present invention, in order to allow mixed gas G to smoothly branch off and be supplied to the reactors so that a predetermined amount of generated moisture W_1 and W_2 are supplied from the moisture generating reactors WG_1 and WG_2 , respectively, in the same way as in the first embodiment shown in FIG. 1, each of the moisture generating reactors WG_1 and WG_2 is required to have a pressure of 200 Torr to 900 Torr. The reason is that, if the internal pressure of each of the moisture generating reactors WG_1 and WG_2 becomes below 200 Torr, the explosion limit temperature (i.e., explosive temperature) of H_2 gas will be lowered to a temperature of about 350°C to 400°C.

[0034] Table 2 shows an example of arithmetic values of the internal pressure P_w , and so forth, for the moisture generating reactors WG_1 and WG_2 when the opening diameter of the depressurizing orifice OR_3 is 0.8mm ϕ and 1.0mm ϕ , and the pressure computing equation, etc., used herein are the same as used in obtaining values shown in Table 1 above.

[0035]

[Table 2]

Examination of orifice diameters 0.8 and 1.0 (for depressurizing)										Inflow gas to Pc
Amount of gas introduced per reactor WVG					Total of two reactors	Calculation of sound velocity				
H ₂ (sccm)	O ₂ (sccm)	N ₂ (sccm)	H ₂ O (sccm)	Excess O ₂ (sccm)	Total downstream flow rate (sccm)	Orifice (mm)	WVG Pressure (Torr abs)	Specific gravity	Cv value	Flow rate m ³ /Hr
5000	3500	0	5000	1000	12000	1.0	849.831	0.350575	0.036941	0.72
5000	3000	0	5000	500	11000	1.0	758.423	0.332288	0.036941	0.66
4000	3000	0	4000	1000	10000	1.0	716.274	0.358621	0.036941	0.6
4000	2400	0	4000	400	8800	1.0	606.738	0.332288	0.036941	0.528
3500	2400	0	3500	650	8300	1.0	585.765	0.348151	0.036941	0.498
5000	3000	0	5000	500	11000	0.8	1185.036	0.332288	0.023642	0.66
4000	2400	0	4000	400	8800	0.8	948.029	0.332288	0.023642	0.528
3500	2000	0	3500	250	7500	0.8	800.833	0.326437	0.023642	0.45
3000	1800	0	3000	300	6600	0.8	711.022	0.332288	0.023642	0.396

[0036] Table 3 shows one example of the arithmetic operation of pressure values on the upstream side of the orifices OR₁ and OR₂, under the condition that the opening diameter of each of the upstream-side orifices OR₁ and OR₂ is

0.7mm ϕ , when the mixing conditions, etc., of mixed gas G are the same as in Table 2. From this data, the outline or curve of the pressure values P_1 on the upstream side of the orifices OR₁ and OR₂ can be determined.

[0037] [Table 3]

Examination of orifice diameters 0.8 and 1.0 (for depressurizing)					Examination of upstream-side (flow-dividing) orifice (An increase in pressure from necessary pressure of the depressurizing orifice)				
Amount of gas introduced per reactor									
H ₂ (sccm)	O ₂ (sccm)	N ₂ (sccm)	H ₂ O (sccm)	ExcessO ₂ (sccm)	Total Flow rate (sccm)	Orifice (mm)	Increase in pressure (Torr)	Upstream pressure (Torr abs)	Pressure (MPa G)
5000	3500	0	5000	1000	8500	0.7	1460	2309.504	0.221023
5000	3000	0	5000	500	8000	0.7	1320	2078.393	0.188568
4000	3000	0	4000	1000	7000	0.7	1223	1939.289	0.169034
4000	2400	0	4000	400	6400	0.7	1056	1662.714	0.130194
3500	2400	0	3500	650	5900	0.7	1008	1593.657	0.120497
5000	3000	0	5000	500	8000	0.7	1320	2505.006	0.248477
4000	2400	0	4000	400	6400	0.7	1056	2004.005	0.178122
3500	2000	0	3500	250	5500	0.7	896	1696.562	0.134948
3000	1800	0	3000	300	4800	0.7	792	1503.004	0.107766

[0038] FIG. 3 shows a flow circuit in which the state of divided flows of N_2 gas has been examined when N_2 gas is supplied, instead of a mixed gas G, in the parallel operation of the moisture generating reactors in the first embodiment shown in FIG. 1. In FIG. 3, MFC_1 , MFM_1 , and MFM_2 designate mass flowmeters, respectively.

[0039] In the flow circuit shown in FIG. 3, the measured value of MFM_1 and the measured value of MFM_2 are proportionate directly to the inflow of mixed gas G into the moisture generating reactors WG_1 and WG_2 , respectively; hence, the amounts of moisture generated in the moisture generating reactors WG_1 and WG_2 can be determined from the measured values of the mass flowmeters MFM_1 and MFM_2 .

[0040] Table 4, below, shows arithmetic values of a divided-flow error and a pressure error obtained from each measured value when the opening diameter of each of the orifices OR_1 and OR_2 , of FIG. 3, is set at 0.7 mm ϕ , 0.6 mm ϕ , and 0.5 mm ϕ .

[0041]

[Table 4]

Orifice (mm)	Upstream pressure ① (MPa G)	MFM ₁ ② (SLM)	MFM ₂ ③ (SLM)	Divided-flow error ② and ③ %	Mean value ② and ③ (SLM)	Calculation value ④	Pressure error ①-④ (MPa)
0.8	0.011	1.15	1.13	1.74%	1.14	0.0014	0.0096
0.8	0.020	2.69	2.67	0.74%	2.68	0.0077	0.0123
0.8	0.046	5.19	5.17	0.39%	5.18	0.0288	0.0172
0.8	0.088	7.63	7.68	-0.66%	7.655	0.0630	0.025
0.8	0.136	10.13	10.15	-0.20%	10.14	0.110	0.026
0.7	0.011	1.14	1.13	0.88%	1.135	0.0024	0.0086
0.7	0.014	1.66	1.64	1.20%	1.65	0.005	0.0090
0.7	0.017	2.16	2.17	-0.46%	2.165	0.0086	0.0084
0.7	0.023	2.69	2.65	1.49%	2.67	0.0131	0.0089
0.7	0.027	3.17	3.18	-0.32%	3.175	0.0185	0.0085
0.7	0.034	3.69	3.67	0.54%	3.68	0.0248	0.0092
0.7	0.04	4.2	4.18	0.48%	4.19	0.0322	0.0078
0.7	0.048	4.69	4.68	0.21%	4.685	0.0402	0.0078
0.7	0.057	5.17	5.18	-0.19%	5.175	0.0491	0.0079
0.6	0.036	2.74	2.61	4.74%	2.675	0.0243	0.0117
0.6	0.045	3.24	3.11	4.01%	3.175	0.0342	0.0108
0.6	0.061	3.75	3.61	3.73%	3.68	0.046	0.0150
0.6	0.111	5.30	5.06	4.53%	5.18	0.0911	0.0199
0.6	0.186	7.41	7.16	3.37%	7.285	0.169	0.0170
0.6	0.193	7.52	7.27	3.32%	7.395	0.173	0.020
0.6	0.201	7.79	7.52	3.47%	7.655	0.183	0.018
0.6	0.210	7.99	7.72	3.38%	7.855	0.19	0.020
0.6	0.224	8.33	8.03	3.60%	8.18	0.202	0.022
0.6	0.238	8.74	8.43	3.55%	8.585	0.217	0.021
0.6	0.258	9.28	8.95	3.56%	9.115	0.237	0.021
0.6	0.304	10.44	10.06	3.64%	10.25	0.279	0.025
0.5	0.011	0.61	0.63	-3.28%	0.62	0.0037	0.0073
0.5	0.017	1.12	1.15	-2.68%	1.135	0.0125	0.0045
0.5	0.028	1.64	1.66	-1.22%	1.65	0.0264	0.0016
0.5	0.043	2.16	2.17	-0.46%	2.165	0.0454	-0.0024
0.5	0.062	2.67	2.68	-0.37%	2.675	0.0694	-0.0074
0.5	0.088	3.18	3.17	0.31%	3.175	0.0977	-0.0097
0.5	0.111	3.71	3.66	1.35%	3.685	0.130	-0.019
0.5	0.134	4.20	4.18	0.48%	4.19	0.161	-0.027
0.5	0.162	4.70	4.67	0.64%	4.685	0.192	-0.03
0.5	0.189	5.19	5.16	0.58%	5.175	0.215	-0.026

[0042] Figures (a), (b), (c), and (d) of FIG. 4 are graphs of the arithmetic values compiled in Table 3. FIG. 4(a) shows the relationship of the divided-flow error to the flow rate (MFM₁), FIG. 4(b) shows the relationship of the divided-flow error to the orifice upstream-side pressure P₂, FIG. 4(c) shows the relationship between the orifice upstream-side pressure P₂ and the calculated pressure, and FIG. 4(d) shows the relationship between the orifice upstream-side pressure P₂

and the relative divided-flow error % of the flow rate.

[0043] As is apparent from Table 4 and figures (a), (b), (c), and (d) of FIG. 4, the divided-flow error (FIG. 4(a)) stays below about 5 %, and the variation $(MFM_1 - MFM_2 / MFC_1)$ also stays below 3%. Therefore, the divided flows created by the orifices OR_1 and OR_2 can be used without, from a practical standpoint, causing any problems, and it is understood that mixed gas G can be allowed to branch off and be supplied to the moisture generating reactors GW_1 and GW_2 by using an extremely simple flow-dividing device.

Embodiment 1

[0044] FIG. 5 is a system diagram wherein 17SLM moisture gas W is supplied to the chamber CH, which operates under normal pressure (760 Torr), using the two moisture generating reactors WG_1 and WG_2 . Table 5, below, shows orifice upstream-side pressures calculated from the flow rate Q and from the sectional area S on the assumption that a critical condition is established between the upper and lower streams of the orifices OR_1 and OR_2 , shown in the system diagram of FIG. 5.

[0045] Formula (1) is the operational expression of the flow rate Q.

[Formula 1]

$$Q = \frac{SP_H}{\sqrt{T_H}} \cdot C' \cdot (F.F.) \cdot \cdot \cdot \cdot (1)$$

In this equation, Formula 1, Q is a flow rate of gas, S is an orifice sectional area, T_H is a temperature of gas, P_H is upstream pressure, C is the constant 187021, and C' is a correction ($C \times 0.82$) calculated from an actual flow rate.

[0046]

[Table 5]

Orifice	Sectional area S	Stream above orifice		Stream below orifice
mm	mm ²	kPa abs	Torr	Torr
0.65	0.332	202.6	1519.5	759.8
0.6	0.283	237.7	1783.4	891.7
0.55	0.238	282.9	2122.3	1061.2
0.5	0.196	342.4	2568.0	1284.0
0.45	0.159	422.7	3170.4	1585.2
0.4	0.126	534.9	4012.6	2006.3

Embodiment 2

[0047] In the same system diagrammed as that of FIG. 5, pressure P_1 and pressure P_2 on the upstream side (i.e., tube upstream side) and on the downstream side (i.e., above the orifices OR_1 and OR_2) of the mass flowmeter MFC have been respectively calculated when mixed gas G consisting of H_2 and O_2 , corresponding to moisture generation of 17SLM, is allowed to flow. Formulas (2) and (3) are operational expressions therefor.

[0048]

[Formula 2]

$$Q = C(P_1 - P_2) \cdot \cdot \cdot \cdot (2)$$

[Formula 3]

$$C = \frac{\pi}{8\eta} \frac{a^4}{l} \left(\frac{p_1 + p_2}{2} \right) \cdot \cdot \cdot \cdot (3)$$

In the equations of Formulas (2) and (3), Q is a flow rate of gas, P_1 is upstream pressure, P_2 is downstream pressure, a is an orifice radius, and η is a viscosity coefficient of the gas. When a tube pressure loss (H_2/O_2) is calculated, the viscosity coefficient of mixed gas G cannot be calculated and, hence, a calculation is performed both for H_2 and for O_2 as shown in Table 6 (the viscosity coefficient η of H_2 is $0.88 \times 10^{-5} \text{Pa} \cdot \text{sec}$, and the viscosity coefficient ζ of O_2 is $1.75 \times 10^{-5} \text{Pa} \cdot \text{sec}$).

[0049]

[Table 6]

Orifice	Sectional area S	Stream above orifice		Stream below orifice	Upper stream (H ₂) through tube		Upper stream (O ₂) through tube	
mm	mm ²	kPa abs	Torr	Torr	kPa abs	Torr	kPa abs	Torr
0.8	0.503	133.7	1003.3	501.6	187.4	1406	240.2	1801
0.75	0.442	152.2	1141.3	570.7	201.0	1508	250.9	1882
0.7	0.385	174.7	1310.2	655.1	218.5	1639	265.1	1989
0.65	0.353	190.7	1430.2	715.1	231.5	1737	275.9	2070
0.66	0.342	196.5	1473.8	736.9	236.3	1773	280.0	2100

Embodiment 3

[0050] FIG. 6 is a system diagram showing parallel operation of two moisture generating reactors WG₁ and WG₂ performed according to the present invention. In FIG. 6, RG₁ to RG₄ designate pressure regulators, V₁ to V₄ designate valves, FA₁ and FA₂ designate cooling fans, HTC₁, HTC₂, HTC₃, and HTC₄ designate temperature controllers, and HTM₁ and HTM₂ designate temperature monitors. The outlet side of each of the moisture generating reactors WG₁ and WG₂ opens toward the atmosphere.

[0051] The temperature controllers HTC₁ and HTC₄ are used to keep the temperature of the moisture generating reactors WG₁ and WG₂ at 350°C, and the cooling fans FA₁ and FA₂ are controllably operated, if necessary. The temperature controllers HTC₂ and HTC₃ are used to keep the temperature of the tube lines at 140°C. Each of the orifices OR₁ and OR₂ is an orifice whose opening diameter is 0.7mmφ, and each of the moisture generating reactors WG₁ and WG₂ is a 5SLM type reactor having an outer diameter of 180mmφ.

[0052] According to the system diagram of FIG. 6, mixed gas G (H₂=6SLM to 10SLM, O₂=7SLM) flows from the gas mixer M to each of the moisture generating reactors WG₁ and WG₂ through the orifices OR₁ and OR₂, and supply pressures P_H and P_O of O₂ gas and H₂ gas, respectively, the concentration of unreacted H₂, and a change in temperature caused when moisture was generated, were measured. The amount of moisture to be

generated was set between 6SLM and 10SLM in each of the moisture generating reactors.

[0053] Table 7 shows moisture generation test results corresponding to operation of the system shown in FIG. 6. FIG. 7 is a graph outlining the test results.

[0054] [Table 7]

H ₂ (SLM)	O ₂ (SLM)	H ₂ O (SLM)	HTC ₁ -R ₁ Temperature Max. (°C)	HTM ₁ -R ₁ Temperature Max. (°C)	HTC ₄ -R ₂ Temperature Max. (°C)	HTM ₂ -R ₂ Temperature Max. (°C)	Unreacted H ₂ Concentration Max. (Vol%)	P _H (MPaG)	P _O (MPaG)
6	7	6	357	362	358	347	0.08	0.091	0.089
7	7	6	350	350	351	357	0.08	0.094	0.093
8	7	6	353	353	353	360	0.08	0.099	0.097
9	7	6	366	364	360	364	0.08	0.102	0.100
10	7	6	359	366	366	367	0.08	0.105	0.103

[0055] As is apparent from FIG. 7 and Table 7, it is understood that mixed gases G, each of which is equal in amount, flow into the moisture reactors WG₁ and WG₂, respectively, by flow division, and the two moisture reactors cause an

equal rise in temperature by substantially the same moisture generation reaction. Additionally, it is understood from FIG. 7 and Table 7 that the concentration of unreacted H_2 is also kept stably at a low value by operation of the two moisture generation reactors in parallel.

Industrial Applicability

[0056] The present invention can be applied not only to semiconductor manufacturing facilities, and to chemical manufacturing facilities, but also to high-purity water supply facilities, or the like, in the food processing industry or the pharmaceutical industry.

CLAIMS

1. A method for parallel operation of moisture generating reactors, comprising the steps of: providing a plurality of moisture generating reactors, wherein an orifice is disposed on a mixed-gas inlet side of each moisture generating reactor of the plurality of moisture generating reactors, and wherein an inlet side of each orifice is connected to a mixed gas supply line in parallel; and providing a mixed gas consisting of hydrogen and oxygen, and allowing the mixed gas to branch off through each of the orifices so that the mixed gas is supplied to each reactor of the plurality of moisture generating reactors.
2. A method for parallel operation of moisture generating reactors, comprising the steps of: providing a plurality of moisture generating reactors, wherein an orifice is disposed on a mixed-gas inlet side of each moisture generating reactor of the plurality of moisture generating reactors, and an inlet side of each orifice is connected to a mixed-gas supply line in parallel; providing a mixed gas consisting of hydrogen and oxygen, and allowing the mixed gas to branch off through each of the orifices so that the mixed gas is supplied to each reactor of the plurality of moisture generating reactors; and supplying moisture generated by each reactor of the plurality of moisture generating reactors along a moisture supply line to an apparatus that uses the moisture, wherein each reactor has an end on a moisture gas outlet side, and the ends of the reactors are connected in parallel to each other.
3. The method for parallel operation of moisture generating reactors according to claim 2, wherein the apparatus that uses the moisture is a process chamber, and the method further comprises the step of: operating the process

chamber under pressure that is approximately atmospheric pressure.

4. The method for parallel operation of moisture generating reactors according to claim 2, wherein the apparatus that uses the moisture is a process chamber, and the method further comprises the step of: operating the process chamber under a pressure of 1 to 700 Torr, wherein the moisture supply line that supplies moisture generated from the moisture generating reactors is provided with a depressurizing orifice.

5. The method for parallel operation of moisture generating reactors according to claim 1 or claim 2, wherein the number of the moisture generating reactors connected in parallel with each other is two, and each orifice of the orifices disposed on the mixed-gas inlet side of the plurality of moisture generating reactors is equal in opening diameter to each other, and the method further comprises the step of: supplying the mixed gas so that mixed gas substantially equal in amount to each other is supplied from the mixed-gas supply line to each of the reactors of the plurality of moisture generating reactors.

6. The method for parallel operation of moisture generating reactors according to claim 5, wherein a rated amount of moisture generation of each reactor of the plurality of moisture generating reactors is 5SLM to 10SLM, and an opening diameter of each orifice disposed on the mixed-gas inlet side is 0.8 to 0.6mm ϕ .

7. The method for parallel operation of moisture generating reactors according to claim 6, wherein an internal pressure of each moisture generating reactor has a pressure value of 200 Torr or more.

8. The method for parallel operation of moisture generating reactors according to claim 1 or claim 2, wherein each moisture generating reactor has an internal space formed by combining an inlet-side reactor body member and an outlet-side reactor body member together so as to face each other, wherein the inlet-side reactor body member is provided with a mixed-gas inlet and the outlet-side reactor body member is provided with a moisture-gas outlet, and a platinum coating film is disposed on an inner wall surface of the outlet-side reactor body member, and a reflector is disposed in the internal space, and the method further comprises the step of: generating moisture by allowing the hydrogen gas and the oxygen gas of the mixed gas to react with each other by catalytic action of the platinum coating films of the plurality of moisture generating reactors under a non-combustion state inside the internal spaces of the plurality of moisture generating reactors.