

LIQUID FOR CIRCULATING COOLING OF SEMICONDUCTOR ETCHING EQUIPMENT

TECHNICAL FIELD

[1] The present disclosure relates to the technical field of cooling media, and in particular to a liquid for circulating cooling of semiconductor etching equipment, and further to a method for screening liquid for circulating cooling of semiconductor etching equipment.

BACKGROUND

[2] During the dry etching process of semiconductors, when plasma etches the wafer, a large amount of heat will be generated on the wafer. In order to prevent deformation and cracking of semiconductor materials due to temperature rise during the process, temperature control is required. In environments with high vacuum, plasma, and halogens, etc., an electrostatic chuck is often used to effectively clamp the wafer, so the temperature of the electrostatic chuck needs to be controlled. Usually, the electrostatic chuck is mainly cooled to maintain a constant temperature so that the wafer on the electrostatic chuck also maintains a constant temperature, thereby improving the stability of the process.

[3] At present, the cooling of the electrostatic chuck requires auxiliary external liquid for cooling. The cooling liquid is transported from the refrigeration equipment to the etching equipment through a pipeline, and then the electrostatic chuck inside the equipment is cooled through the circulation pipeline inside the etching equipment. In this application scenario, the liquid will directly contact the charged part of the electrostatic chuck. If the electrical properties of the liquid cannot meet the requirements, it is easy to cause electrical breakdown inside the machine, seriously affecting its use. The commonly used cooling liquids in related technologies are fluorine-containing cooling liquids or organosilicon cooling liquids. Fluorine-containing cooling liquids have low boiling points and are easy to evaporate, which is harmful to the environment and personnel. Although the commonly used organosilicon cooling liquids have good high-temperature resistance, there is a problem that heat exchange performance and electrical properties cannot be taken into account at the same time. Therefore, it is necessary to conduct in-depth research on cooling

liquids to meet the needs of semiconductor etching equipment.

SUMMARY

[4] The present disclosure is based on the inventor's discovery and understanding of the following facts and problems: in semiconductor etching equipment, since the cooling liquid will directly contact the charged part of the electrostatic chuck, this puts higher requirements on the electrical properties of the cooling liquid. However, the current cooling liquid cannot effectively take into account heat exchange efficiency, fluidity, electrical properties and environmental protection requirements.

[5] The present disclosure aims to solve at least one of the technical problems in the related art to a certain extent. Therefore, the present disclosure provides a liquid for circulating cooling of semiconductor etching equipment, which includes at least one organosilicon compound. The chemical formula of the organosilicon compound is $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$, wherein,

[6] R_1 , R_2 , R_3 , and R_4 are each independently selected from alkyl or alkoxy groups, and $2 \leq n \leq 5$;

[7] and the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid satisfy the following relationship: $28 \leq 3 \log \rho_r \cdot \epsilon_r (\mu / \rho_g) \leq 32$.

[8] In the present disclosure, the dynamic viscosity μ and density ρ_g refer to the dynamic viscosity μ and density ρ_g of the cooling liquid measured at 25°C.

[9] Optionally, $2 \leq n \leq 4$.

[10] Optionally, $29 \leq 3 \log \rho_r \cdot \epsilon_r (\mu / \rho_g) \leq 31.5$.

[11] Optionally, the number of carbon atoms of R_1 , R_2 , R_3 or R_4 is 1-6.

[12] Optionally, R_2 and/or R_3 are methyl.

[13] Optionally, R_1 , R_2 , and R_3 are methyl, R_4 is not methyl, and n is 2 or 3.

[14] The present disclosure further provides an application of the liquid for circulating cooling of semiconductor etching equipment in semiconductor equipment.

[15] Optionally, the circulating cooling liquid is used to cool electrostatic chucks.

[16] The present disclosure further provides a method for screening of liquid for circulating cooling of semiconductor etching equipment, including the following steps:

[17] a. determining the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid to be selected, wherein the circulating cooling liquid to be selected includes at least one organosilicon compound, and the chemical formula of the organosilicon compound is $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$, wherein R_1 , R_2 , R_3 , and R_4 are each independently selected from alkyl or alkoxy groups, and $2 \leq n \leq 5$;

[18] b. calculating the value of $3 \log \rho_r - \epsilon_r (\mu / \rho_g)$; and

[19] c. when the circulating cooling liquid to be selected satisfies $28 \leq 3 \log \rho_r - \epsilon_r (\mu / \rho_g) \leq 32$, using the circulating cooling liquid as the cooling liquid for semiconductor equipment.

[20] Optionally, the number of carbon atoms of R_1 , R_2 , R_3 or R_4 is 1-6.

[21] According to the liquid for circulating cooling of semiconductor etching equipment provided by the present disclosure, an organosilicon compound with a chemical formula of $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$ is used as a cooling liquid. The organosilicon compound has a high boiling point and good thermal stability, is not easy to evaporate, and is friendly and safe to the environment and workers. The inventors have found through experiments that when the circulating cooling liquid of the present disclosure satisfies $28 \leq 3 \log \rho_r - \epsilon_r (\mu / \rho_g) \leq 32$, the cooling liquid not only has good heat exchange performance, but also can meet the requirements for the electrical properties of the cooling liquid in semiconductor equipment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[22] The embodiments of the present disclosure are described in detail below. The embodiments are exemplary and intended to explain the present disclosure, and should not be construed as limiting the present disclosure.

[23] The embodiments of the present disclosure provide a liquid for circulating cooling of semiconductor etching equipment, including at least one organosilicon compound, the chemical formula of the organosilicon compound is $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$, wherein,

[24] R_1 , R_2 , R_3 , and R_4 are each independently selected from alkyl or alkoxy groups, and $2 \leq n \leq 5$;

[25] and the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and

density ρ_g of the circulating cooling liquid satisfy the following relationship:
 $28 \leq 3 \log \rho_r - \epsilon_r (\mu / \rho_g) \leq 32$.

[26] For the liquid for circulating cooling of semiconductor etching equipment in embodiments of the present disclosure, an organosilicon compound with a chemical formula of $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$ is used as the cooling liquid. The organosilicon compound has a high boiling point and good thermal stability, is not easy to evaporate, and is friendly and safe to the environment and workers. It is found through experiments that when the circulating cooling liquid of the present disclosure satisfies $28 \leq 3 \log \rho_r - \epsilon_r (\mu / \rho_g) \leq 32$, the cooling liquid not only has good heat exchange performance, but also can meet the requirements on the electrical properties of the cooling liquid in semiconductor equipment.

[27] In $3 \log \rho_r - \epsilon_r (\mu / \rho_g)$, the μ / ρ_g term is related to the heat exchange efficiency of the cooling liquid on the machine. The larger the μ / ρ_g value, the worse the fluidity of the cooling liquid and the lower the heat exchange efficiency. In practical applications, a smaller μ / ρ_g value is desirable. The ϵ_r and $\log \rho_r$ terms are closely related to the electrical properties of the cooling liquid. The larger the relative dielectric constant ϵ_r , the stronger the ability of the cooling liquid to store charge, which can easily cause deviations in the electric field distribution of the electrostatic chuck during machine operation, affecting the etching effect. Therefore, in practical applications, the relative dielectric constant ϵ_r tends to be as small as possible. The smaller the volume resistivity ρ_r , the better the charge conduction performance. The cooling liquid is prone to breakdown of the overall charged parts of the machine during the circulation process. However, if the volume resistivity ρ_r is too large, static electricity accumulation phenomenon is likely to occur during the flow process, which will also cause electrical breakdown phenomenon inside the machine. When $3 \log \rho_r - \epsilon_r (\mu / \rho_g)$ is too low, the fluidity of the cooling liquid is poor and the heat exchange efficiency is relatively low. When $3 \log \rho_r - \epsilon_r (\mu / \rho_g)$ is too high, static electricity accumulation phenomenon is likely to occur in the cooling liquid, which can easily cause electrical breakdown inside the machine. Therefore, the present disclosure achieves an effective balance between heat exchange performance and electrical properties by making the circulating cooling liquid satisfy $28 \leq 3 \log \rho_r - \epsilon_r (\mu / \rho_g) \leq 32$.

[28] In some embodiments, the number of carbon atoms of R_1 , R_2 , R_3 or R_4 is 1-6.

[29] In a specific embodiment, the number of carbon atoms of R₁, R₂, R₃ or R₄ can be 1, 2, 3, 4, 5, or 6.

[30] In a preferred embodiment, the number of carbon atoms of R₁, R₂, R₃ or R₄ is 1-3.

[31] In the embodiments of the present disclosure, the number of carbon atoms in the groups R₁, R₂, R₃ or R₄ in the organosilicon compound is limited to 6 or less, so that the cooling liquid can obtain better heat exchange performance and electrical properties. If the number of carbon atoms is too large, although the dielectric constant of the cooling liquid will be reduced, which is beneficial to improving the electrical properties of the cooling liquid, the excessive number of carbon atoms will make the branched chains of the organosilicon compound too long, resulting in a decrease in the density of the substance, , causing the value of $3\log\rho_r-\epsilon_r(\mu/\rho_g)$ of the cooling liquid to exceed the control range of the embodiments of the present disclosure, which is not conducive to improving the heat transfer performance of the cooling liquid.

[32] In a specific embodiment, n in the chemical formula (R₁)₃Si-[OSiR₂R₃]_n-OSi(R₄)₃ is 2, 3, 4, or 5.

[33] In a preferred embodiment, $2\leq n\leq 4$.

[34] In embodiments of the present disclosure, the value n of the repeating unit [OSiR₂R₃] is preferably selected, which is conducive to maintaining excellent heat exchange performance while having excellent electrical properties. If the value of n is too small, that is, the degree of polymerization is too low, the flash point of the organosilicon compound is too low, posing a safety risk; if the value of n is too large, that is, the degree of polymerization is too high, the viscosity of the cooling liquid will increase significantly, and the density will increase, resulting in poor fluidity of the cooling liquid, which is not conducive to maintaining good heat exchange performance of the cooling liquid.

[35] In a specific embodiment, $3\log\rho_r-\epsilon_r(\mu/\rho_g)$ is 28, 28.5, 29, 29.5, 30, 30.5, 31, 31.5, or 32.

[36] In a preferred embodiment, $29\leq 3\log\rho_r-\epsilon_r(\mu/\rho_g)\leq 31.5$.

[37] In the embodiments of the present disclosure, the value of $3\log\rho_r-\epsilon_r(\mu/\rho_g)$ is preferably selected, which is conducive to making the cooling liquid obtain better heat exchange performance and electrical properties. When used for cooling semiconductor equipment, the electrostatic chuck maintains excellent temperature stability and improves

the etching effect.

[38] In a preferred embodiment, the R_2 and/or R_3 are methyl groups.

[39] In a preferred embodiment, the R_1 , R_2 , and R_3 are methyl groups, the R_4 is not methyl, and n is 2 or 3.

[40] The organosilicon compound with the chemical formula $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$ in embodiments of the present disclosure can be prepared by the method of the prior art. For example, alkoxysilane is used as a raw material to prepare the organosilicon compound by hydrolysis condensation reaction under acid catalyst conditions.

[41] The embodiments of the present disclosure further provide an application of the liquid for circulating cooling of semiconductor etching equipment in semiconductor equipment.

[42] In some embodiments, the liquid for circulating cooling is used to cool electrostatic chucks.

[43] The embodiments of the present disclosure further provide a method for screening of liquid for circulating cooling of semiconductor etching equipment, including the following steps:

[44] a. determining the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid to be selected, wherein the circulating cooling liquid to be selected includes at least one organosilicon compound, and the chemical formula of the organosilicon compound is $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$, wherein R_1 , R_2 , R_3 , and R_4 are each independently selected from alkyl or alkoxy groups, and $2 \leq n \leq 5$;

[45] b. calculating the value of $3\log\rho_r-\epsilon_r(\mu/\rho_g)$; and

[46] c. when the circulating cooling liquid to be selected satisfies $28 \leq 3\log\rho_r-\epsilon_r(\mu/\rho_g) \leq 32$, using the circulating cooling liquid as the cooling liquid for semiconductor etching equipment.

[47] In some embodiments, the number of carbon atoms of R_1 , R_2 , R_3 or R_4 is 1-6.

[48] The method for screening of liquid for circulating cooling of semiconductor etching equipment of the embodiments of the present disclosure can quickly determine whether the circulating cooling liquid to be selected is suitable for semiconductor equipment by measuring the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid and calculating the value of $3\log\rho_r-\epsilon_r(\mu/\rho_g)$, and

provides a fast and effective screening method for selecting a suitable liquid for circulating cooling of semiconductor equipment. When the cooling liquid satisfies $28 \leq 3 \log \rho_r \cdot \epsilon_r (\mu / \rho_g) \leq 32$, the circulating cooling liquid not only has good fluidity to meet the requirements of heat exchange performance, but also can meet the requirements of semiconductor equipment for the electrical properties of the circulating cooling liquid, is not prone to static electricity accumulation, and can avoid electrical breakdown inside the machine.

[49] The present disclosure is described below with reference to specific embodiments. It should be noted that these embodiments are merely illustrative and do not limit the present disclosure in any way.

[50] Example 1

[51] The liquid for circulating cooling of semiconductor etching equipment of this example included an organosilicon compound with the chemical formula $(\text{CH}_3)_3\text{Si}-[\text{OSiCH}_3\text{CH}_3]_3-\text{OSi}(\text{CH}_3)_3$.

[52] After air in a flask was replaced with nitrogen gas, 516 g of ethoxysilane was added, and then 3.4 g of sulfuric acid was added dropwise at room temperature. The temperature was raised to 70°C and the mixture was stirred for reaction for 5 h. After removing the acid, rotary evaporation was carried out at 115°C for 3 h to obtain the product $(\text{CH}_3)_3\text{Si}-[\text{OSiCH}_3\text{CH}_3]_3-\text{OSi}(\text{CH}_3)_3$.

[53] The relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the liquid for circulating cooling of this embodiment were tested, and the test results are shown in Table 1.

[54] After calculation, $3 \log \rho_r \cdot \epsilon_r (\mu / \rho_g) = 29.52$.

[55] Examples 2-10

[56] Examples 2-10 were used to illustrate the liquid for circulating cooling disclosed in the present disclosure, and included most of the operating steps in the Example 1, and the difference was that the groups and n values in the chemical formula $(\text{R}_1)_3\text{Si}-[\text{OSiR}_2\text{R}_3]_n-\text{OSi}(\text{R}_4)_3$ of the organosilicon compound were different:

[57] R_1 , R_2 , R_3 , R_4 , n and the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid used in the Example 2-10 were shown in Table 1.

[58] Comparative Examples 1-6

[59] Comparative Examples 1-6 were used to illustrate the liquid for circulating cooling disclosed in the present disclosure, and included most of the operating steps in the Example 1, and the difference was that the groups and n values in the chemical formula $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$ of the organosilicon compound were different:

[60] R_1 , R_2 , R_3 , R_4 , n and the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid used in the Comparative Example 1-6 were shown in Table 1.

[61] Performance Tests

[62] The following performance tests were conducted on the above-mentioned liquid for circulating cooling of semiconductor etching equipment:

[63] (1) electrostatic evaluation: a magnetic pump was used to circulate the cooling liquid, with a flow rate of 4 L/min, a pipe material of PFA, and a pipe diameter of 10 mm. After circulating for 5 min, an electrostatic meter was used to test at a pipe diameter of 2.5 cm and the reading of the electrostatic meter was recorded. It was determined as acceptable (“OK”) if the reading was below 0.5 kV.

[64] (2) heat exchange efficiency: an ATS ENT-30 machine was used for refrigeration running test, combined with a 6 kW heat load for verification. If the liquid could achieve normal temperature control under 20 LPM and 20°C conditions, i.e., the temperature fluctuation was less than $\pm 1^\circ\text{C}$ during operation (with an operation duration required to be longer than 1 h), and there was no temperature control failure and no continuous rise of the liquid temperature, then the heat exchange efficiency was determined as acceptable (“OK”), and the smaller the temperature fluctuation, the better the heat exchange efficiency.

[65] Table 1

	R_1	R_2	R_3	R_4	n	$\epsilon_r/\text{Dimensionless}$	$\rho_r/\Omega\cdot\text{cm}$	μ/cP @25°C	$\rho_g/\text{g}\cdot\text{mL}$ @25°C	$3\log\rho_r$ - $\epsilon_r(\mu/\rho_g)$
Example 1	-CH ₃	-CH ₃	-CH ₃	-CH ₃	3	2.21	10^{13}	4.00	0.9324	29.52
Example 2	-CH ₃	-CH ₃	-CH ₃	-CH ₃	2	2.21	10^{13}	3.20	0.9233	31.34
Example 3	-CH ₃	-CH ₃	-CH ₃	-CH ₃	5	2.20	10^{13}	4.70	0.9417	28.02
Example 4	-CH ₃	-CH ₃	-CH ₃	-CH ₃	4	2.20	10^{13}	4.30	0.9297	28.82
Example 5	-CH ₃	-C ₂ H ₅	-CH ₃	-CH ₃	2	2.19	10^{13}	3.30	0.9142	31.09
Example 6	-CH ₃	-CH ₃	-CH ₃	-C ₄ H ₉	2	2.18	10^{13}	3.40	0.9189	30.93

Example 7	-CH ₃	-CH ₃	-CH ₃	-C ₆ H ₁₃	2	2.17	10 ¹³	3.60	0.9007	30.33
Example 8	-CH ₃	-CH ₃	-CH ₃	-OCH ₃	2	2.24	10 ¹³	2.91	0.9300	31.99
Example 9	-CH ₃	-CH ₃	-CH ₃	-OC ₂ H ₅	2	2.23	10 ¹³	3.90	0.9244	29.59
Example 10	-CH ₃	-CH ₃	-CH ₃	-OC ₆ H ₁₃	2	2.22	10 ¹³	3.80	0.9048	29.68
Comparative Example 1	-CH ₃	-CH ₃	-CH ₃	-CH ₃	6	2.52	10 ¹³	6.10	0.9612	23.01
Comparative Example 2	-CH ₃	-CF ₃	-CF ₃	-CH ₃	3	3.97	10 ¹²	5.10	0.9347	14.34
Comparative Example 3	-CH ₃	-C ₆ H ₁₃	-C ₆ H ₁₃	-CH ₃	4	2.13	10 ¹⁴	4.30	0.9321	32.17
Comparative Example 4	-CH ₃	-CH ₃	-CH ₃	-CH ₃	1	2.22	10 ¹³	2.81	0.9041	32.10
Comparative Example 5	-CH ₃	-CH ₃	-C ₄ H ₉	-CH ₃	3	2.20	10 ¹³	4.70	0.9277	27.85
Comparative Example 6	-CH ₃	-CH ₃	-C ₇ H ₁₅	-CH ₃	2	2.16	10 ¹³	4.60	0.8923	27.86

[66] The performance test results of the liquid for circulating cooling of semiconductor etching equipment of Examples 1-10 and Comparative Examples 1-6 were shown in Table 2.

[67] Table 2

	Temperature control performance verification	Electrostatic test/kV	Judgement
Example 1	19.8-20.7°C	0.3	OK
Example 2	20.1-20.9°C	0.4	OK
Example 3	19.6-20.4°C	0.2	OK
Example 4	19.8-20.5°C	0.3	OK
Example 5	19.9-20.5°C	0.3	OK
Example 6	19.9-20.5°C	0.2	OK
Example 7	19.9-20.3°C	0.2	OK
Example 8	19.6-20.6°C	0.1	OK
Example 9	19.9-20.5°C	0.2	OK
Example 10	19.8-20.4°C	0.2	OK
Comparative Example 1	Continuous temperature rise	0.3	NG

Comparative Example 2	20.1-20.6°C	2.7	NG
Comparative Example 3	19.8-20.4°C	1.4	NG
Comparative Example 4	18.7-20.6°C	0.2	NG
Comparative Example 5	18.9-20.4°C	0.2	NG
Comparative Example 6	18.5-20.4°C	0.1	NG

[68] As shown in Table 1 and Table 2, the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the liquid for circulating cooling of semiconductor etching equipment of the Examples 1-10 all met the requirement of $28 \leq 3 \log \rho_r \epsilon_r (\mu / \rho_g) \leq 32$. After the electrostatic test, all values are less than 0.5 kV, and the heat exchange efficiency can be maintained at 20°C after a 6 kW heat load test. The temperature fluctuations are small (all within 1°C). These results show good heat exchange efficiency and electrical properties, and can meet the cooling requirements for electrostatic chucks in semiconductor equipment.

[69] However, the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid in Comparative Examples 1-6 can not meet the requirement of $28 \leq 3 \log \rho_r \epsilon_r (\mu / \rho_g) \leq 32$, and can not simultaneously meet the requirements of heat exchange efficiency and electrostatic test. In Comparative Example 1, the n value is too large, resulting in excessive viscosity of the cooling liquid, the fluidity is greatly reduced, causing a serious decrease in heat exchange efficiency. During the process, the liquid temperature continues to rise and temperature control fail. In Comparative Example 2, the R₂ and R₃ groups are CF₃, which cause a significant increase in the relative dielectric constant ϵ_r of the circulating cooling liquid. The voltage value after the electrostatic test is as high as 2.7 kV, which can not meet the requirements on the electrical properties of the cooling liquid for semiconductor equipment. In Comparative Example 3, although R₁, R₂, R₃, R₄ and n value in the organosilicon compound

$(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$ are all within the range of the embodiments of the present disclosure, but $3\log\rho_r\cdot\varepsilon_r(\mu/\rho_g)$ is greater than 32. Since the volume resistivity ρ_r of the circulating cooling liquid in Comparative Example 3 is too high, the cooling liquid is prone to static electricity accumulation during the flow process. The voltage value after the electrostatic test is as high as 1.4 kV, which cannot meet the requirements on the electrical properties of the cooling liquid for semiconductor equipment. In Comparative Example 4, the value of n is too small, and cannot meet the requirement of $28\leq 3\log\rho_r\cdot\varepsilon_r(\mu/\rho_g)\leq 32$ of the present disclosure. Although Comparative Example 4 can meet the requirements on the electrical properties of the cooling liquid for semiconductor equipment, the heat exchange performance is seriously reduced, and the temperature fluctuation is as high as 1.9°C. In Comparative Example 5, although R_1 , R_2 , R_3 , R_4 and n value in the organosilicon compound $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$ are all within the range of the embodiments of the present disclosure, $3\log\rho_r\cdot\varepsilon_r(\mu/\rho_g)$ is lower than the lower limit to be controlled in the embodiments of the present disclosure, and can only meet the requirements on the electrical properties of the cooling liquid for semiconductor equipment, and the heat exchange performance shows a significant decline, and the temperature fluctuation reaches 1.5°C, which cannot meet the requirements. In Comparative Example 6, the R_3 group is C_7H_{15} , the density of the cooling liquid is relatively low, and $3\log\rho_r\cdot\varepsilon_r(\mu/\rho_g)$ is 27.86, which exceeds the range to be controlled in the embodiments of the present disclosure. Although the electrical properties can meet the requirements, the heat exchange performance is greatly reduced, and the temperature fluctuation is as high as 1.9°C.

[70] In the present disclosure, the terms “one embodiment,” “some embodiments,” “example,” “specific example,” or “some examples” etc., mean that the specific features, structures, materials or characteristics described in conjunction with the embodiment or example are included in at least one embodiment or example of the present disclosure. In this specification, the schematic representations of the above terms do not necessarily refer to the same embodiment or example. Moreover, the described specific features, structures, materials or characteristics may be combined in a suitable manner in any one or more embodiments or examples. In addition, those skilled in the art may integrate and combine the different embodiments or examples described in this specification and the features of the different embodiments or examples without conflicting with each other.

[71] Although the above embodiments have been shown and described, it is to be understood that the above embodiments are exemplary and should not be construed as limitations on the present disclosure. Changes, modifications, substitutions and variations of the above embodiments made by those of ordinary skill in the art are all within the scope of protection of the present disclosure.

CLAIMS

What is claimed is:

1. A liquid for circulating cooling of semiconductor etching equipment, wherein the liquid comprises at least one organosilicon compound, and the chemical formula of the organosilicon compound is $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$, in the formula,

R_1, R_2, R_3 , and R_4 are each independently selected from alkyl or alkoxy groups, and $2 \leq n \leq 5$;

and the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the liquid for circulating cooling satisfy the following relationship: $28 \leq 3 \log \rho_r \cdot \epsilon_r (\mu / \rho_g) \leq 32$.

2. The liquid for circulating cooling of semiconductor etching equipment of claim 1, wherein $2 \leq n \leq 4$.

3. The liquid for circulating cooling of semiconductor etching equipment of claim 1, wherein $29 \leq 3 \log \rho_r \cdot \epsilon_r (\mu / \rho_g) \leq 31.5$.

4. The liquid for circulating cooling of semiconductor etching equipment of claim 1, wherein the number of carbon atoms of the R_1 , the R_2 , the R_3 or the R_4 is 1-6.

5. The liquid for circulating cooling of semiconductor etching equipment of claim 1, wherein the R_2 and/or the R_3 are methyl.

6. The liquid for circulating cooling of semiconductor etching equipment of claim 5, wherein the R_1 , the R_2 , and the R_3 are methyl, the R_4 is not methyl, and n is 2 or 3.

7. Application of the liquid for circulating cooling of semiconductor etching equipment of any one of claims 1-6 in semiconductor equipment.

8. The application of claim 7, wherein the liquid for circulating cooling is used to cool electrostatic chucks.

9. A method for screening of liquid for circulating cooling of semiconductor etching equipment, comprising the following steps:

a. determining the relative dielectric constant ϵ_r , volume resistivity ρ_r , dynamic viscosity μ , and density ρ_g of the circulating cooling liquid to be selected, the circulating cooling liquid to be selected comprises at least one organosilicon compound, and the chemical formula of the organosilicon compound is $(R_1)_3Si-[OSiR_2R_3]_n-OSi(R_4)_3$, in the formula, R_1, R_2, R_3 , and R_4 are each independently selected from alkyl or alkoxy groups,

and $2 \leq n \leq 5$;

b. calculating the value of $3 \log_{r-\varepsilon_r}(\mu/\rho_g)$; and

c. when the circulating cooling liquid to be selected satisfies $28 \leq 3 \log_{r-\varepsilon_r}(\mu/\rho_g) \leq 32$, using the circulating cooling liquid as the liquid for circulating cooling of semiconductor equipment.

10. The method for screening circulating cooling liquid of claim 9, wherein the number of carbon atoms of the R_1 , the R_2 , the R_3 or the R_4 is 1-6.