

DESCRIPTION

CLEANING AGENT FOR SILICON WAFER

TECHNICAL FIELD

[0001] The present invention relates to a technique of cleaning a silicon
5 substrate (a wafer) in production of semiconductor devices, the purpose of
which being production yield improvements of devices having such a circuit
pattern as to be particularly fine and particularly high in aspect ratio.

BACKGROUND OF THE INVENTION

[0002] Semiconductor devices for use in networks or digital household
10 electric appliances are being further desired to be sophisticated,
multifunctional, and low in power consumption. Accordingly, the trend toward
micro-patterning for circuits has been developed, with which micro-sizing of
particles has advanced to cause reduction in production yield. As a result of
this, a cleaning process for the purpose of removing the micro-sized particles is
15 frequently used. As a result of this, 30-40% of the whole of the semiconductor
fabrication process is occupied with the cleaning process.

[0003] On the other hand, in cleaning conventionally performed with a
mixed ammonia cleaning agent, damages to the wafer due to its basicity are
getting serious with the trend toward micro-patterning for circuits. Therefore,
20 alternation with a dilute hydrofluoric acid-based cleaning agent is taking
place.

[0004] With this, problems about the damages to the wafer due to cleaning
have been solved; however, problems due to an aspect ratio increased with the
trend toward micro-processing in the semiconductor devices have become
25 obvious. In other words, a phenomenon where the pattern collapses when a
gas-liquid interface passes through the pattern is brought about after cleaning
or rinsing to largely reduce the yield, which has become a significant problem.

[0005] The pattern collapse occurs at the time of drawing the wafer out of a
cleaning liquid or a rinsing liquid. It is said that the reason thereof is that a
30 difference in height of residual liquid between a part of high aspect ratio and a
part of low aspect ratio causes a difference in capillary force which acts on the

pattern.

[0006] Accordingly, it is expected, by decreasing the capillary force, that the difference in capillary force due to the difference in height of residual liquid is reduced thereby resolving the pattern collapse. The magnitude of the capillary force is the absolute value of P obtained by the equation as represented below. It is expected from this equation that the capillary force can be reduced if decreasing γ or $\cos\theta$.

[0007] $P=2 \times \gamma \times \cos\theta/S$ (γ : Surface tension, θ : Contact angle, S : Pattern width).

[0008] In Patent Document 1, a technique of replacing water serving as a cleaning agent with 2-propanol before the gas-liquid interface passes through the pattern is disclosed as a method of decreasing γ to suppress the pattern collapse. This method is effective for preventing the pattern collapse; however, a solvent having small γ such as 2-propanol and the like is also small in normal contact angle, which results in the trend to increase $\cos\theta$. It is therefore said that there are limitations to adaptable patterns, for example, an aspect ratio of not higher than 5.

[0009] Additionally, in Patent Document 2, a technique directed to a resist pattern is disclosed as a method for decreasing $\cos\theta$ to suppress the pattern collapse. This method is a method of setting a contact angle to around 90° to bring $\cos\theta$ close to 0 so as to reduce the capillary force to the limit thereby suppressing the pattern collapse.

[0010] However, the thus disclosed technique cannot be applied to the present object, because: it is directed to the resist pattern or for reforming a resist itself; and a final removal together with the resist is possible so as not to need the assumption about a method of removing a treatment agent after drying.

[0011] Additionally, the use of a critical fluid, the use of liquid nitrogen or the like are proposed as the method of preventing the pattern collapse of the semiconductor devices. However, any of these needs a treatment in a closed system or a batch in contrast to the conventional cleaning processes and

therefore involves issues in view of cost such as throughput, though effective to some extent.

REFERENCES ABOUT PRIOR ART

5 Patent Publication

[0012] Patent Publication 1: Japanese Patent Application Publication No. 2008-198958

Patent Publication 2: Japanese Patent Application Publication No. 5-299336

10 SUMMARY OF THE INVENTION

[0013] In production of semiconductor devices, a surface of a silicon wafer is made a surface having a finely uneven pattern. An object of the present invention is to provide a silicon wafer cleaning agent for improving a cleaning process which tends to induce a pattern collapse, in a method of producing the
15 silicon wafer having at its surface a finely uneven pattern.

[0014] A cleaning agent for a silicon wafer having a finely uneven pattern at its surface, according to the present invention comprises: a water-based cleaning liquid; and a water-repellent cleaning liquid for providing at least a recessed portion of the uneven pattern with water repellency during a cleaning
20 process. The water-repellent cleaning liquid comprises a mixture of a water-repellent compound and an organic solvent. The water-repellent compound has a hydrophobic group and a reactive moiety chemically bondable to Si element in the silicon wafer. The organic solvent contains at least an alcoholic solvent.

25 [0015] In the cleaning agent of the present invention, each cleaning liquid is mutually independently used, and at least two or more kinds of the cleaning liquids are used.

[0016] Additionally, in the present invention, water repellency means to decrease a surface energy of a surface of an article thereby reducing an
30 interaction between water or other liquid and the surface of the article (an interface), such as hydrogen bond, intermolecular forces and the like. The

effect of reducing an interaction against water is particularly exhibited; however, the effect of reducing an interaction against a mixture liquid of water and liquid other than water or against a liquid other than water is also exhibited. With the reduction of the interaction, it is possible to increase a
5 contact angle of the liquid to the surface of the article.

[0017] In cleaning the silicon wafer in which an uneven pattern is formed, the water-based cleaning liquid contained in the silicon wafer cleaning agent of the present invention is provided to recessed portions of the surface of the silicon wafer upon making the surface of the silicon wafer a surface having a
10 finely uneven pattern. Additionally, the water-based cleaning liquid may be provided to the silicon wafer through providing the water-repellent cleaning liquid to the silicon wafer. Furthermore, the water-repellent cleaning liquid and the water-based cleaning liquid may be provided to the surface of the silicon wafer while substituting a cleaning liquid different from the cleaning
15 liquids under a condition where the different cleaning liquid is retained in the recessed portions of the surface of the silicon wafer.

[0018] The cleaning agent for the silicon wafer of the present invention is comprised of two or more cleaning liquids and is used while substituting a cleaning liquid retained in the recessed portion with another cleaning liquid.
20 The cleaning agent is finally removed from the surface of the silicon wafer.

[0019] While the surface of the silicon wafer is cleaned by the cleaning agent for the silicon wafer of the present invention, the recessed portion of the surface of the silicon wafer is to temporarily retain the water-repellent cleaning liquid. With this retention, the recessed portion is brought into a
25 surface condition provided with water repellency by the water-repellent compound. The surface condition provided with water repellency of the present invention may not be necessarily continuously established and may not be necessarily uniformly established; however, it is preferable to establish it continuously and uniformly since more excellent water repellency is obtained
30 thereby.

[0020] In the present invention, the water-repellent compound has a

reactive moiety chemically bondable to Si element in the silicon wafer, and a hydrophobic group. With this, the surface of the silicon wafer can keep the surface condition provided with water repellency until the cleaning agent is removed from the recessed portion. Since the surface of the recessed portion is under the condition provided with water repellency when the cleaning liquid is removed or dried, the capillary force is so reduced that the pattern collapse becomes hard to occur. If the capillary force of the surface of the recessed portion on the assumption that water is retained in the recessed portion of the surface of the silicon wafer provided with water repellency is not larger than 2.1 MN/m², the capillary force is so small as not to cause the pattern collapse and therefore preferable. Additionally, the surface condition provided with water repellency can be removed by at least one treatment selected from irradiation with light, heating of the silicon wafer, and exposing the silicon wafer to ozone.

[0021] Additionally, in the water-repellent cleaning liquid, the water-repellent compound having a reactive moiety chemically bondable to Si element in the silicon wafer and a hydrophobic group and the alcoholic solvent are mixed and contained. With this, the surface of the recessed portion can readily reach the surface condition sufficiently provided with water repellency, in a short time.

[0022] In the water-repellent cleaning liquid, a water-repellent compound of less than 0.1 mass% relative to the total quantity of 100 mass% of the water-repellent cleaning liquid makes the surface of the recessed portion hard to reach the surface condition sufficiently provided with water repellency. Meanwhile, a water-repellent compound exceeding 99.9 mass% lessens the effect of alcohol (with which water repellency can be sufficiently imparted to the surface of the recessed portion in a short time).

BRIEF EXPLANATION OF THE DRAWINGS

[0023] [Fig. 1] A schematic plan view of a silicon wafer 1 of which surface is made a surface having a finely uneven pattern 2.

[Fig. 2] A view showing a part of a-a' cross section of Fig. 1.

[Fig. 3] A schematic view showing a condition where a cleaning liquid 8 is retained in a recessed portion 4 in a cleaning process.

[Fig. 4] A schematic view showing a condition where a water-based cleaning liquid is retained in the recessed portion 4 which is under a surface condition provided with water repellency.

DETAILED DESCRIPTION

[0024] A silicon wafer cleaning agent of the present invention exhibits an excellent pattern collapse-preventability. When using the cleaning agent, therefore, a cleaning process in a production method for a silicon wafer having a finely uneven pattern at its surface is improved without reducing throughput. With this, the productivity of the production method for the silicon wafer having the finely uneven pattern at its surface, which is conducted by using the silicon wafer cleaning agent of the present invention, is increased.

[0025] The silicon wafer cleaning agent of the present invention is adaptable to uneven patterns having aspect ratios expected to be raised increasingly, for example, an aspect ratio of not less than 7, and therefore allows cost reduction in producing more sophisticated semiconductor devices. In addition to this, the agent is adaptable without considerably modifying conventional apparatuses, which results in being one applicable in production of various kinds of semiconductor devices.

[0026] A cleaning method for a silicon wafer having a finely uneven pattern at its surface, using the silicon wafer cleaning agent of the present invention, preferably includes:

a step of making a surface of a silicon wafer a surface having a finely uneven pattern, followed by providing a water-based cleaning liquid to the surface and retaining the water-based cleaning liquid in recessed portions;

a step of substituting the water-based cleaning liquid retained in the recessed portions with a cleaning liquid A which is different from the water-based cleaning liquid;

a step of retaining a water-repellent cleaning liquid in the recessed portions in order to impart water repellency to surfaces of the recessed portions

of the uneven pattern; and

a step of removing the cleaning agent.

[0027] Furthermore, after the step of retaining the water-repellent cleaning liquid in the recessed portions, the water-repellent cleaning liquid retained in the recessed portions may be substituted with a cleaning liquid B which is different from the water-repellent cleaning liquid. Additionally, it is more preferable to take a step of retaining a water-based cleaning liquid comprised of a water-based solution in the recessed portions through the substitution with the different cleaning liquid B.

10 [0028] Additionally, the step of removing the cleaning agent includes:

a step of drying thereby removing the cleaning liquid retained in the recessed portions from the recessed portions; and

a step of conducting at least one treatment selected from irradiating the surface of the silicon wafer with light, heating the silicon wafer, and exposing the silicon wafer to ozone.

15 [0029] Additionally, in the step of removing the cleaning agent, between the step of drying thereby removing the cleaning liquid retained in the recessed portions from the recessed portions and the step of conducting at least one treatment selected from irradiating the surface of the silicon wafer with light, heating the silicon wafer, and exposing the silicon wafer to ozone, there may be taken: a step of providing the cleaning liquid B to the recessed portions and then removing the cleaning liquid B by drying; or a step of retaining the water-based cleaning liquid comprised of the water-based solution in the recessed portions after providing the cleaning liquid B, followed by removing the water-based cleaning liquid by drying.

25 [0030] The water-repellent cleaning liquid is a liquid comprised of: the water-repellent compound from 0.1 to 99.9 mass%, preferably from 0.2 to 75 mass%, much more preferably 0.3 to 50 mass% relative to the total quantity of 100 mass% of the water-repellent cleaning liquid; and an organic solvent including at least an alcohol solvent. With a 0.1 to 99.9 mass% content of the water-repellent compound, the surfaces of the recessed portions can readily

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obtain the surface condition uniformly provided with water repellency, in a short time.

[0031] The water-repellent cleaning liquid contains at least an alcoholic solvent. With the presence of the alcoholic solvent, a reaction between the water-repellent compound and Si element in the silicon wafer is accelerated, so that the surfaces of the recessed portions can readily obtain the surface condition sufficiently provided with water repellency, in a short time.

[0032] Examples of the alcoholic solvent are: alcohol comprised of alkyl group and one hydroxyl group, such as methanol, ethanol, 1-propanol, 2-propanol, 1-butanol, 2-butanol, tert-butanol, iso-butanol, 1-pentanol, 1-hexanol, 1-heptanol, 1-octanol and the like; and polyhydric alcohol and derivatives of these, such as ethylene glycol, glycerine, 1,2-propanediol, 1,3-propanediol, 1,2-butanediol, 1,3-butanediol, diethylene glycol monoethyl ether, ethylene glycol monomethyl ether, ethylene glycol monoethyl ether, ethylene glycol monobutyl ether, propylene glycol monomethyl ether, propylene glycol monoethyl ether and the like.

[0033] Additionally, the alcoholic solvent is preferably an alcohol comprised of alkyl group and one hydroxyl group. In this case, the surfaces of the recessed portions can readily obtain the surface condition sufficiently provided with water repellency, in a short time. Furthermore, among alcohols comprised of alkyl group and one hydroxyl group, primary alcohol and secondary alcohol are particularly preferable.

[0034] Additionally, the alcoholic solvent preferably has a carbon number of not larger than 10, particularly preferably has a carbon number of not larger than 6. Furthermore, the alcoholic solvent may be either a single one or a mixture of two or more alcoholic solvents.

[0035] It is preferable to set the alcoholic solvent from 0.1 to 10000 mass%, particularly from 0.5 to 5000 mass% relative to the total quantity of 100 mass% of the water-repellent compound because the surfaces of the recessed portions can readily obtain the surface condition sufficiently provided with water repellency in a short time.

[0036] Additionally, the water-repellent cleaning liquid may contain other organic solvents than the alcoholic solvent. Since the water-repellent compound is reactive with protic solvents, it is particularly preferable to use an aprotic solvent as the organic solvents other than the alcoholic solvent because water repellency can be readily exhibited in a short time. Incidentally, the aprotic solvent includes both aprotic polar solvents and aprotic nonpolar solvents. Examples of such an aprotic solvent are hydrocarbons, esters, ethers, ketones, halogen element-containing solvents, sulfoxide-based solvents, derivatives of polyhydric alcohol having no hydroxyl group, and nitrogen element-containing solvents having no N-H bond. Examples of hydrocarbons are toluene, benzene, xylene, hexane, heptane, octane and the like. Examples of esters are ethyl acetate, propyl acetate, butyl acetate, ethyl acetoacetate and the like. Examples of ethers are diethyl ether, dipropyl ether, dibutyl ether, tetrahydrofuran, dioxane and the like. Examples of ketones are acetone, acetylacetone, methyl ethyl ketone, methyl propyl ketone, methyl butyl ketone, cyclohexanone, isophorone and the like. Examples of the halogen element-containing solvent are: perfluorocarbons such as perfluorooctane, perfluorononane, perfluorocyclopentane, perfluorocyclohexane, hexafluorobenzene and the like; hydrofluorocarbons such as 1,1,1,3,3-pentafluorobutane, octafluorocyclopentane, 2,3-dihydrodecafluoropentane, ZEORORA-H (produced by ZEON CORPORATION) and the like; hydrofluoroethers such as methyl perfluoroisobutyl ether, methyl perfluorobutyl ether, ethyl perfluorobutyl ether, ethyl perfluoroisobutyl ether, ASAHIKLIN AE-3000 (produced by Asahi Glass Co., Ltd.), Novec HFE-7100, Novec HFE-7200, Novec 7300, Novec 7600 (any of these are produced by 3M Limited) and the like; chlorocarbons such as tetrachloromethane and the like; hydrochlorocarbons such as chloroform and the like; chlorofluorocarbons such as dichlorodifluoromethane and the like; hydrochlorofluorocarbons such as 1,1-dichloro-2,2,3,3,3-pentafluoropropane, 1,3-dichloro-1,1,2,2,3-pentafluoropropane, 1-chloro-3,3,3-trifluoropropene, 1,2-dichloro-3,3,3-trifluoropropene and the like; perfluoroethers;

perfluoropolyethers; and the like. Examples of the sulfoxide-based solvents are dimethyl sulfoxide and the like. Examples of the derivatives of polyhydric alcohol having no hydroxyl group are diethylene glycol monoethyl ether acetate, ethylene glycol monomethyl ether acetate, ethylene glycol monobutyl ether acetate, propylene glycol monomethyl ether acetate, propylene glycol monoethyl ether acetate, diethylene glycol dimethyl ether, diethylene glycol ethylmethyl ether, ethylene glycol diethyl ether, ethylene glycol dimethyl ether and the like. Examples of the nitrogen element-containing solvents having no N-H bond are *N,N*-dimethylformamide, *N,N*-dimethylacetamide, *N*-methyl-2-pyrrolidone, triethylamine, pyridine and the like.

[0037] Additionally, it is preferable to use an unflammable one as the organic solvent other than the alcoholic solvent since the water-repellent cleaning liquid becomes unflammable or increases in flash point to reduce the risk of the water-repellent cleaning liquid. Most of the halogen element-containing solvents are unflammable. Such a halogen element-containing unflammable solvent can be preferably used as an unflammable organic solvent.

[0038] In this case, the organic solvent other than the alcoholic solvent is preferably from 2 to 95000 times, more preferably from 4 to 50000 times the alcoholic solvent, in mass ratio.

[0039] In a case of providing the water-repellent cleaning liquid to the wafer while rotating the wafer and in a case where the organic solvent has a low boiling point, the water-repellent cleaning liquid tends to dry up before so spreading over the wafer as to wet the same. Additionally, in a case where the boiling point is high, the viscosity tends to increase. Therefore, it is preferable to use an organic solvent having a boiling point of from 70 to 220 °C. When taking the cost or compatibility with other cleaning liquids (a facility for substitution) into account, 1-propanol and 2-propanol are preferable as an alcohol, diethylene glycol monoethyl ether acetate, ethylene glycol monomethyl ether acetate, propylene glycol monomethyl ether acetate, propylene glycol monoethyl ether acetate, diethylene glycol dimethyl ether, diethylene glycol ethylmethyl ether, ethylene glycol diethyl ether, ethylene glycol dimethyl ether

and cyclohexanone are preferable as the organic solvent other than the alcoholic solvent.

[0040] In a pattern forming step in which the surface of the silicon wafer is made a surface having a finely uneven pattern, a resist is applied to the surface of the wafer first of all. Thereafter, the resist is exposed through a resist mask, followed by conducting an etching removal on the exposed resist or an unexposed resist, thereby producing a resist having a desired uneven pattern. Additionally, the resist having the uneven pattern can be obtained also by pushing a mold having a pattern onto a resist. Then, etching is conducted on the wafer. At this time, recessed portions of a resist pattern are etched selectively. Finally, the resist is stripped off thereby obtaining a silicon wafer having a finely uneven pattern.

[0041] Incidentally, the silicon wafer also includes those on which surface a silicon oxide film such as native oxide film, a thermal oxide film, a gas-phase synthesized film (a CVD film, etc.) and the like is formed or those in which at least a part of its uneven pattern is to be silicon oxide when forming the uneven pattern. Additionally, silicon and silicon nitride are also usable because these are naturally oxidized to form a silicon oxide film on its surface when an outermost surface of them is brought into contact with water or air.

[0042] Additionally, also against a wafer comprised of two or more components including silicon and/or silicon oxide, it is possible to provide its surface of silicon and/or silicon oxide with water repellency. The wafer comprised of two or more components includes those on which surface a silicon film and/or a silicon oxide film such as a native oxide film, a thermal oxide film, a gas-phase synthesized film (a CVD film, etc.) and the like is formed or those in which at least a part of its uneven pattern is to be silicon and/or silicon oxide when forming the uneven pattern.

[0043] After making the surface of the silicon wafer a surface having a finely uneven pattern, cleaning of the surface is conducted in the use of the water-based cleaning liquid, followed by removing the water-based cleaning liquid by drying or the like. If the recessed portions have a small width and

projected portions have a large aspect ratio, a pattern collapse is to easily occur. The uneven pattern is defined as shown in Fig. 1 and Fig. 2. Fig. 1 is a schematic plan view of a silicon wafer 1 whose surface is made a surface having a finely uneven pattern. Fig. 2 shows a part of an a-a' cross section in
5 Fig. 1. A width 5 of recessed portions is defined by an interval between a projected portion 3 and a projected portion 3, as shown in Fig. 2. The aspect ratio of projected portions is expressed by dividing a height 6 of the projected portions by a width 7 of the recessed portions. The pattern collapse in the cleaning process is to easily occur when the recessed portions have a width of
10 not more than 70 nm, particularly not more than 45 nm and when the aspect ratio is not less than 4, particularly not less than 6.

[0044] In the preferable embodiment of the present invention, the surface of the silicon wafer is made a surface having a finely uneven pattern, followed by providing the water-based cleaning liquid to the surface to retain the
15 water-based cleaning liquid in the recessed portions. Then, the water-based cleaning liquid retained in the recessed portions is substituted with the cleaning liquid A which is different from the water-based cleaning liquid. Preferable examples of the different cleaning liquid A are the water-repellent cleaning liquid specified by the present invention, water, organic solvents, a
20 mixture of these, these to which at least one kind of acid, alkali and surfactants is added, and the like. Particularly, if taking damages and cleanliness of the pattern into account, the particularly preferable are the water-repellent cleaning liquid specified by the present invention, water, organic solvents and a mixture of these. Additionally, in the case of using other
25 than the water-repellent cleaning liquid as the different cleaning liquid A, it is preferable to substitute the different cleaning liquid A with the water-repellent cleaning liquid under a condition where the different cleaning liquid A is retained in the recessed portions 4.

[0045] Additionally, examples of the organic solvents, which is one of the
30 preferable examples of the different cleaning liquid A, include hydrocarbons, esters, ethers, ketones, halogen element-containing solvents, sulfoxide-based solvents,

alcohols, derivatives of polyhydric alcohol, nitrogen element-containing solvents and the like.

[0046] Examples of hydrocarbons are toluene, benzene, xylene, hexane, heptane, octane and the like. Examples of esters are ethyl acetate, propyl acetate, butyl acetate, ethyl acetoacetate and the like. Examples of ethers are diethyl ether, dipropyl ether, dibutyl ether, tetrahydrofuran, dioxane and the like. Examples of ketones are acetone, acetylacetone, methyl ethyl ketone, methyl propyl ketone, methyl butyl ketone, cyclohexanone, isophorone and the like. Examples of the halogen element-containing solvent are: perfluorocarbons such as perfluorooctane, perfluorononane, perfluorocyclopentane, perfluorocyclohexane, hexafluorobenzene and the like; hydrofluorocarbons such as 1,1,1,3,3-pentafluorobutane, octafluorocyclopentane, 2,3-dihydrodecafluoropentane, ZEORORA-H (produced by ZEON CORPORATION) and the like; hydrofluoroethers such as methyl perfluoroisobutyl ether, methyl perfluorobutyl ether, ethyl perfluorobutyl ether, ethyl perfluoroisobutyl ether, ASAHIKLIN AE-3000 (produced by Asahi Glass Co., Ltd.), Novec HFE-7100, Novec HFE-7200, Novec 7300, Novec 7600 (any of these are produced by 3M Limited) and the like; chlorocarbons such as tetrachloromethane and the like; hydrochlorocarbons such as chloroform and the like; chlorofluorocarbons such as dichlorodifluoromethane and the like; hydrochlorofluorocarbons such as 1,1-dichloro-2,2,3,3,3-pentafluoropropane, 1,3-dichloro-1,1,2,2,3-pentafluoropropane, 1-chloro-3,3,3-trifluoropropene, 1,2-dichloro-3,3,3-trifluoropropene and the like; perfluoroethers; perfluoropolyethers; and the like. Examples of the sulfoxide-based solvents are dimethyl sulfoxide and the like. Examples of the alcohols are methanol, ethanol, propanol, butanol, ethylene glycol, 1,3-propanediol and the like. Examples of the derivatives of polyhydric alcohol are diethylene glycol monoethyl ether, ethylene glycol monomethyl ether, ethylene glycol monobutyl ether, propylene glycol monomethyl ether, propylene glycol monoethyl ether, diethylene glycol monoethyl ether acetate, ethylene glycol monomethyl ether acetate, ethylene glycol monobutyl ether acetate, propylene glycol monomethyl

ether acetate, propylene glycol monoethyl ether acetate, diethylene glycol dimethyl ether, diethylene glycol ethylmethyl ether, ethylene glycol diethyl ether, ethylene glycol dimethyl ether and the like. Examples of the nitrogen element-containing solvents are formamide, *N,N*-dimethylformamide, *N,N*-dimethylacetamide, *N*-methyl-2-pyrrolidone, diethylamine, triethylamine, pyridine and the like.

[0047] Fig. 3 is a schematic view showing a condition where a cleaning liquid 8 is retained in the recessed portions 4 in the cleaning process. A silicon wafer of the schematic view of Fig.3 shows a part of the a-a' cross section in Fig. 1. At the time of the cleaning process, the water-repellent cleaning liquid is provided onto a silicon wafer 1 in which an uneven pattern 2 is formed. At this time, the water-repellent cleaning liquid is brought into a condition retained at least in the recessed portions 4 as shown in Fig. 3, thereby imparting water repellency to the recessed portions 4.

[0048] In a case of providing the water-based cleaning liquid through the substitution with the cleaning liquid different from the cleaning liquid and through a condition where the water-repellent cleaning liquid is temporarily retained in the recessed portions 4, the water-repellent cleaning liquid retained in the recessed portions 4 is substituted with the cleaning liquid B which is different from the water-repellent cleaning liquid. Examples of the different cleaning liquid B are: a water-based cleaning liquid comprised of a water-based solution; an organic solvent; a mixture of the water-based cleaning liquid and the organic solvent; these in which at least one kind of acid, alkali and surfactants are mixed; and the like. Particularly, if taking damages and cleanliness of the pattern into account, the water-based cleaning liquid, the organic solvent or the mixture of the water-based cleaning liquid and the organic solvent are preferable. Additionally, when using other than the water-based cleaning liquid as the different cleaning liquid B, it is preferable to substitute the cleaning liquid with the water-based cleaning liquid under a condition where a cleaning liquid other than the water-based cleaning liquid is retained in the recessed portions 4.

[0049] Additionally, an example of the organic solvent, which is one preferable example of the different cleaning liquid B, is hydrocarbons, esters, ethers, ketones, halogen element-containing solvents, sulfoxide-based solvents, alcohols, derivatives of polyhydric alcohol, nitrogen element-containing solvents, and the like.

[0050] Examples of hydrocarbons are toluene, benzene, xylene, hexane, heptane, octane and the like. Examples of esters are ethyl acetate, propyl acetate, butyl acetate, ethyl acetoacetate and the like. Examples of ethers are diethyl ether, dipropyl ether, dibutyl ether, tetrahydrofuran, dioxane and the like. Examples of ketones are acetone, acetylacetone, methyl ethyl ketone, methyl propyl ketone, methyl butyl ketone, cyclohexanone, isophorone and the like. Examples of the halogen element-containing solvent are: perfluorocarbons such as perfluorooctane, perfluorononane, perfluorocyclopentane, perfluorocyclohexane, hexafluorobenzene and the like; hydrofluorocarbons such as 1,1,1,3,3-pentafluorobutane, octafluorocyclopentane, 2,3-dihydrodecafluoropentane, ZEORORA-H (produced by ZEON CORPORATION) and the like; hydrofluoroethers such as methyl perfluoroisobutyl ether, methyl perfluorobutyl ether, ethyl perfluorobutyl ether, ethyl perfluoroisobutyl ether, ASAHIKLIN AE-3000 (produced by Asahi Glass Co., Ltd.), Novec HFE-7100, Novec HFE-7200, Novec 7300, Novec 7600 (any of these are produced by 3M Limited) and the like; chlorocarbons such as tetrachloromethane and the like; hydrochlorocarbons such as chloroform and the like; chlorofluorocarbons such as dichlorodifluoromethane and the like; hydrochlorofluorocarbons such as 1,1-dichloro-2,2,3,3,3-pentafluoropropane, 1,3-dichloro-1,1,2,2,3-pentafluoropropane, 1-chloro-3,3,3-trifluoropropene, 1,2-dichloro-3,3,3-trifluoropropene and the like; perfluoroethers; perfluoropolyethers; and the like. Examples of the sulfoxide-based solvents are dimethyl sulfoxide and the like. Examples of the alcohols are methanol, ethanol, propanol, butanol, ethylene glycol, 1,3-propanediol and the like. Examples of the derivatives of polyhydric alcohol are diethylene glycol monoethyl ether, ethylene glycol monomethyl ether, ethylene glycol monobutyl

ether, propylene glycol monomethyl ether, propylene glycol monoethyl ether, diethylene glycol monoethyl ether acetate, ethylene glycol monomethyl ether acetate, ethylene glycol monobutyl ether acetate, propylene glycol monomethyl ether acetate, propylene glycol monoethyl ether acetate, diethylene glycol dimethyl ether, diethylene glycol ethylmethyl ether, ethylene glycol diethyl ether, ethylene glycol dimethyl ether and the like. Examples of the nitrogen element-containing solvents are formamide, *N,N*-dimethylformamide, *N,N*-dimethylacetamide, *N*-methyl-2-pyrrolidone, diethylamine, triethylamine, pyridine and the like.

10 [0051] Examples of the water-based cleaning liquid are water or water obtained by mixing at least one kind of an organic solvent, acid and alkali, which include water as a primary component (for example, 50 mass% or more water content). If taking the cleanliness into account, it is particularly preferable to use water as the water-based cleaning liquid.

15 [0052] A schematic view of a case in which the water-based cleaning liquid is retained in the recessed portions 4 provided with water repellency by the water-repellent compound is shown in Fig. 4. A silicon wafer of the schematic view of Fig. 4 shows a part of the a-a' cross section in Fig. 1. The surfaces of the recessed portions 4 are brought into a surface condition 10 provided with water repellency by the water-repellent compound. Then, with a unit chemically bondable to Si element, the surface condition 10 provided with water repellency is kept on the surface of the silicon wafer even when the water-based cleaning liquid 9 is removed from the recessed portions 4.

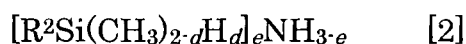
25 [0053] When the recessed portions of the surface of the silicon wafer provided with water repellency by the water-repellent cleaning liquid or the surfaces of the recessed portions 4 as shown in Fig. 4 are brought into the surface condition 10 provided with water repellency by the water-repellent compound, the capillary force on the assumption that water is retained in the recessed portions is preferably not greater than 2.1 MN/m^2 . A capillary force of not greater than 2.1 MN/m^2 makes the pattern collapse difficult to occur, and
30 therefore preferable. Additionally, a smaller capillary force makes the pattern

collapse further difficult to occur, so that the capillary force is particularly preferably not greater than 1.5 MN/m^2 , much more preferably not greater than 1.0 MN/m^2 . Furthermore, it is ideal to put the capillary force close to 0.0 MN/m^2 as much as possible by adjusting the contact angle to the cleaning liquid to be around 90° .

[0054] Moreover, in the water-repellent compound in the water-repellent cleaning liquid which compound has a reactive moiety chemically bondable to Si element in the silicon wafer and a hydrophobic group, the reactive moiety is exemplified by those who can react with silanol group (Si-OH group). Examples thereof are: halogen group such as chloro group, bromo group and the like; Si-N bond with isocyanate group, amino group, dialkylamino group, isothiocyanate group, azide group, acetamide group, silazane, $\text{-N(CH}_3\text{)COCH}_3$, $\text{-N(CH}_3\text{)COCF}_3$, imidazole ring, oxazolidinone ring, morpholine ring or the like; Si-O-C bond with alkoxy group, acetoxy group, trifluoroacetoxy group, $\text{-OC(CH}_3\text{)=CHCOCH}_3$, $\text{-OC(CH}_3\text{)=N-Si(CH}_3\text{)}_3$, $\text{-OC(CF}_3\text{)=N-Si(CH}_3\text{)}_3$, $\text{-CO-NH-Si(CH}_3\text{)}_3$ or the like; Si-O-S bond with alkylsulfonate group, perfluoroalkylsulfonate group or the like; nitrile group; and the like. Additionally, examples of the hydrophobic group are a monovalent organic group having hydrocarbon group and a monovalent organic group having C-F bond. Such a water-repellent compound is to swiftly react at its reactive moiety with silanol group of a silicon oxide layer of the uneven pattern of the silicon wafer so as to be chemically bonded to Si element in the silicon wafer through siloxane bond. With this, it becomes possible to coat the surface of the wafer with hydrophobic groups, thereby allowing reducing the capillary force of the surfaces of the recessed portions of the wafer in a short time.

[0055] Furthermore, it is preferable in the water-repellent cleaning liquid that the water-repellent compound having the reactive moiety chemically bondable to Si element in the silicon wafer and the hydrophobic group is comprised of at least one selected from the group consisting of the following general formulas [1] and [2].





Here, R^1 mutually independently is a monovalent organic group having hydrocarbon group with a carbon number of from 1 to 18 or a monovalent organic group having fluoroalkyl chain with a carbon number of from 1 to 8. R^2 mutually independently is a monovalent organic group having hydrocarbon group with a carbon number of from 1 to 18 or a monovalent organic group having fluoroalkyl chain with a carbon number of from 1 to 8. Additionally, X mutually independently represents at least one group selected from the group consisting of halogen group, alkoxy group, acetoxy group, trifluoroacetoxy group, $-OC(CH_3)=CHCOCH_3$, $-OC(CH_3)=N-Si(CH_3)_3$, $-OC(CF_3)=N-Si(CH_3)_3$, $-CO-NH-Si(CH_3)_3$, alkylsulfonate group, perfluoroalkylsulfonate group, nitrile group and a monovalent organic group whose element to be bonded to Si element is nitrogen. a is an integer of from 1 to 3. Each of b and c is an integer of from 0 to 2. The total of a , b and c is from 1 to 3. Furthermore, d is an integer of from 0 to 2. e is an integer of from 1 to 3.

[0057] Additionally, it is particularly preferable that each of R^1 of the general formula [1] and R^2 of the general formula [2] is C_mH_{2m+1} ($m=1-18$) or $C_nF_{2n+1}CH_2CH_2$ ($n=1-8$).

[0058] Examples of a usable water-repellent compound represented by the general formula [1] are: alkylchlorosilane such as $C_{18}H_{37}SiCl_3$, $C_{10}H_{21}SiCl_3$, $C_6H_{13}SiCl_3$, $C_3H_7SiCl_3$, CH_3SiCl_3 , $C_{18}H_{37}Si(CH_3)Cl_2$, $C_{10}H_{21}Si(CH_3)Cl_2$, $C_6H_{13}Si(CH_3)Cl_2$, $C_3H_7Si(CH_3)Cl_2$, $(CH_3)_2SiCl_2$, $C_{18}H_{37}Si(CH_3)_2Cl$, $C_{10}H_{21}Si(CH_3)_2Cl$, $C_6H_{13}Si(CH_3)_2Cl$, $C_3H_7Si(CH_3)_2Cl$, $(CH_3)_3SiCl$, $(CH_3)_2SiHCl$ and the like; fluoroalkylchlorosilane such as $C_8F_{17}CH_2CH_2SiCl_3$, $C_6F_{13}CH_2CH_2SiCl_3$, $C_4F_9CH_2CH_2SiCl_3$, $CF_3CH_2CH_2SiCl_3$, $C_8F_{17}CH_2CH_2Si(CH_3)Cl_2$, $C_6F_{13}CH_2CH_2Si(CH_3)Cl_2$, $C_4F_9CH_2CH_2Si(CH_3)Cl_2$, $CF_3CH_2CH_2Si(CH_3)Cl_2$, $C_8F_{17}CH_2CH_2Si(CH_3)_2Cl$, $C_6F_{13}CH_2CH_2Si(CH_3)_2Cl$, $C_4F_9CH_2CH_2Si(CH_3)_2Cl$, $CF_3CH_2CH_2Si(CH_3)_2Cl$, $CF_3CH_2CH_2Si(CH_3)HCl$ and the like; or a water-repellent compound in which chloro group of the chlorosilane is substituted with halogen group other than chloro group, such as bromo group, isocyanate group, alkoxy group, acetoxy group, trifluoroacetoxy

group, $-\text{OC}(\text{CH}_3)=\text{CHCOCH}_3$, $-\text{OC}(\text{CH}_3)=\text{N}\cdot\text{Si}(\text{CH}_3)_3$, $-\text{OC}(\text{CF}_3)=\text{N}\cdot\text{Si}(\text{CH}_3)_3$,
 $-\text{CO}\cdot\text{NH}\cdot\text{Si}(\text{CH}_3)_3$, alkylsulfonate group, perfluoroalkylsulfonate group, nitrile
 group, $-\text{NH}_2$, $-\text{N}(\text{CH}_3)_2$, $-\text{N}(\text{C}_2\text{H}_5)_2$, $-\text{NHCOCH}_3$, $-\text{N}_3$, $-\text{N}=\text{C}=\text{S}$, $-\text{N}(\text{CH}_3)\text{COCH}_3$,
 $-\text{N}(\text{CH}_3)\text{COCF}_3$, $-\text{N}=\text{C}(\text{CH}_3)\text{OSi}(\text{CH}_3)_3$, $-\text{N}=\text{C}(\text{CF}_3)\text{OSi}(\text{CH}_3)_3$,
 5 $-\text{NHCO}\cdot\text{OSi}(\text{CH}_3)_3$, $-\text{NHCO}\cdot\text{NH}\cdot\text{Si}(\text{CH}_3)_3$, imidazole ring, oxazolidinone ring,
 morpholine ring or the like.

[0059] Additionally, when the water-repellent compound has two or more
 reactive moieties, the water-repellent compound tends to coagulate, so that the
 surface condition uniformly provided with water-repellency becomes hard to be
 10 obtained. As a result of this, in a process of irradiating the surface of the silicon
 wafer with light or a process of heating the silicon wafer, it becomes necessary
 to spare an additional time for light irradiation or heating in order to remove a
 region formed due to the coagulation of the water-repellent compound.
 Therefore, “4-*a-b-c*”, which represents the number of the reactive moiety, is
 15 preferably 1.

[0060] Examples of usable water-repellent compound represented by the
 general formula [2] are $(\text{CH}_3)_3\text{SiNHSi}(\text{CH}_3)_3$, $\text{C}_2\text{H}_5\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{C}_2\text{H}_5$,
 $\text{C}_3\text{H}_7\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{C}_3\text{H}_7$, $\text{C}_6\text{H}_{13}\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{C}_6\text{H}_{13}$,
 $\text{C}_6\text{H}_5\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{C}_6\text{H}_5$, $\{(\text{CH}_3)_3\text{Si}\}_3\text{N}$, $\{\text{C}_2\text{H}_5\text{Si}(\text{CH}_3)_2\}_3\text{N}$,
 20 $(\text{CH}_3)_2\text{HSiNHSi}(\text{CH}_3)_2\text{H}$, $\text{CF}_3\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{CH}_2\text{CH}_2\text{CF}_3$,
 $\text{C}_4\text{F}_9\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{CH}_2\text{CH}_2\text{C}_4\text{F}_9$,
 $\text{C}_6\text{F}_{13}\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{CH}_2\text{CH}_2\text{C}_6\text{F}_{13}$,
 $\text{C}_8\text{F}_{17}\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\text{NHSi}(\text{CH}_3)_2\text{CH}_2\text{CH}_2\text{C}_8\text{F}_{17}$, $\{\text{CF}_3\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\}_3\text{N}$, and
 the like. Particularly, disilazane represented by the general formula [2] where
 25 *e* is 2 is preferable.

[0061] Among the above-mentioned examples of the water-repellent
 compound, the particularly preferable is chlorosilane in which X in the general
 formula [1] is chloro group from the viewpoint of attainability to the surface
 condition where the surfaces of the recessed portions are sufficiently provided
 30 with water-repellency in a short time.

[0062] Additionally, if water is present in the water-repellent cleaning liquid,

the reactive moiety of the water-repellent compound is hydrolyzed to be silanol group (Si-OH). The reactive moiety is reactive with this silanol group. As a result, water-repellent compounds are bonded to each other to be a dimer. The dimer is low in reactivity with silanol group in the silicon oxide layer of the silicon wafer, so that the time required providing the surface of the silicon wafer with water repellency is increased. As the solvent for the water-repellent cleaning liquid, therefore, other than water, i.e. the above-mentioned organic solvent containing at least the alcoholic solvent is used.

[0063] Incidentally, the water-repellent cleaning liquid allows the presence of a small quantity of water in the solvent. However, when a large quantity of water is contained in the solvent, the water-repellent compound is hydrolyzed by the water content thereby sometimes decreasing in reactivity. It is therefore preferable to make the water content in the solvent low. The water content is preferably smaller than 3 times, more preferably 1 time, much more preferably smaller than 0.5 time the water-repellent compound in mole ratio, when mixed with the water-repellent compound.

[0064] Additionally, in order to accelerate the reaction between the water-repellent compound and the wafer surface, a catalyst may be added to the water-repellent cleaning liquid. The preferably used as such a catalyst are: acids containing no water such as trifluoroacetic acid, trifluoroacetic anhydride, pentafluoropropionic acid, pentafluoropropionic anhydride, trifluoromethanesulfonic acid, trifluoromethanesulfonic anhydride, sulfuric acid, hydrogen chloride and the like; bases such as ammonia, alkylamine, dialkylamine and the like; salts such as ammonium sulfide, potassium acetate, methylhydroxyamine hydrochloride; a metallic complex or a metallic salt of tin, aluminum, titanium or the like; chlorosilane; trimethylsilyltrifluoroacetate; trimethylsilyltrifluoromethanesulfonate. Particularly, if taking a catalytic effect and cleanliness into account, the preferable are the acids containing no water such as trifluoroacetic acid, trifluoroacetic anhydride, trifluoromethanesulfonic acid, trifluoromethanesulfonic anhydride, sulfuric acid, hydrogen chloride and the like; chlorosilane;

trimethylsilyltrifluoroacetate; and trimethylsilyltrifluoromethanesulfonate.

[0065] The addition amount of the catalyst is preferably from 0.001 to 5 mass% relative to the total quantity of 100 mass% of the water-repellent compound. A small addition amount reduces the catalytic effect so as not to be preferable. Meanwhile, an excessively large amount raises a concern that the catalyst erodes the surface of the wafer or is left on the wafer as an impurity rather than improves the catalytic effect. Therefore, the addition amount of the catalyst is particularly preferably from 0.005 to 3 mass%.

[0066] Furthermore, when the temperature of the water-repellent cleaning liquid is high, the surfaces of the recessed portions can readily attain the surface condition provided with water repellency in a shorter time. The temperature at which the surface condition uniformly provided with water repellency is readily brought about is preferably maintained at 0 to 160 °C, particularly preferably at 10 to 120 °C. It is preferable to maintain the temperature of the water-repellent cleaning liquid at the temperature even when the water-repellent cleaning liquid is retained in the recessed portions 4.

[0067] Thereafter, a step of removing the cleaning liquid retained in the recessed portions 4 provided with water repellency by the water-repellent compound and then removing the cleaning agent is conducted. It is preferable that this step includes:

- a step of removing the cleaning liquid retained in the recessed portions from the recessed portions by drying; and

- a step of conducting at least one treatment selected from irradiating the surface of the silicon wafer with light, heating the silicon wafer, and exposing the silicon wafer to ozone.

[0068] It is preferable that the cleaning liquid retained in the recessed portions is the water-based cleaning liquid, when removing the cleaning liquid from the recessed portions. In this case, it is preferable to conduct a step of retaining the water-based cleaning liquid comprised of the water-based solution in the recessed portions through the substitution between the water-repellent cleaning liquid retained in the recessed portions and the

cleaning liquid B which is different from the water-repellent cleaning liquid, after a step of retaining the water-repellent cleaning liquid in the recessed portions. Incidentally, the cleaning liquid retained in the recessed portions when the cleaning liquid is removed from the recessed portions may be either
5 of the water-repellent cleaning liquid and the different cleaning liquid B.

[0069] In the step of removing the cleaning liquid from the recessed portions, the cleaning liquid is removed by drying. The drying is preferably conducted by a conventional drying method such as spin drying, IPA (2-propanol) steam drying, Marangoni drying, heating drying, warm air drying, vacuum drying
10 and the like.

[0070] In the step of conducting at least one treatment selected from irradiating the surface of the silicon wafer with light, heating the silicon wafer, and exposing the silicon wafer to ozone, the surface condition 10 under which the surface of the silicon wafer is provided with water repellency is removed.

15 [0071] In the case where the surface condition 10 provided with water repellency is removed by light irradiation, it is effective to cleave Si-C bond, C-C bond and C-F bond in the surface condition 10 provided with water repellency by the water-repellent compound. In order to achieve this, it is preferable to conduct an irradiation with ultraviolet rays having wavelengths
20 of 350-450nm, 340 nm and shorter than 240 nm (corresponding to bond energies of them, i.e., 58-80 kcal/mol, 83 kcal/mol and 116 kcal/mol). As the light source therefor, there is used a metal halide lamp, a low-pressure mercury lamp, a high-pressure mercury lamp, an excimer lamp, a carbon arc or the like. The intensity of the ultraviolet irradiation is preferably not less
25 than 100 mW/cm², particularly preferably not less than 200 mW/cm², for example, as a measurement value by the illuminance meter (an intensity strength meter UM-10 produced by Konica Minolta Sensing, Inc., Light-Receptor UM-360 [Peak sensitivity wavelength : 365 nm, measured wavelength range : 310 to 400 nm]). Incidentally, an irradiation intensity less
30 than 100 mW/cm² takes a long time to remove the surface condition 10 provided with water repellency. Additionally, the low-pressure mercury lamp

allows an irradiation with ultraviolet rays of shorter wavelengths, so as to be preferably used because the surface condition 10 provided with water repellency can be removed in a short time even if the intensity is low.

[0072] Additionally, in the case of removing the surface condition 10 provided with water repellency by light irradiation, it is particularly preferable to generate ozone in parallel with decomposing components of the surface condition 10 provided with water repellency by ultraviolet rays and then to induce oxidation-volatilization of the components of the surface condition 10 provided with water repellency by the ozone, since a treating time is to be saved thereby. As the light source therefor, the low-pressure mercury lamp or the excimer lamp is used. Additionally, the silicon wafer may be heated while being irradiated with light.

[0073] In the case of heating the silicon wafer, heating of the silicon wafer is conducted at 400 to 700 °C, preferably at 500 to 700 °C. It is preferable to keep the heating time from 1 to 60 min, preferably from 10 to 30 min. Additionally, this step may be conducted in combination with ozone exposure, plasma irradiation, corona discharge or the like. Additionally, the light irradiation may be conducted while heating the silicon wafer.

[0074] In the case of exposing the silicon wafer to ozone, it is preferable to provide ozone generated by ultraviolet irradiation using the low-pressure mercury lamp, low-temperature discharge using high voltage or the like, to the surface of the silicon wafer. The silicon wafer may be irradiated with light or may be heated while being exposed to ozone.

[0075] In the step of removing the surface condition 10 of the surface of the silicon wafer which condition is provided with water repellency, the surface condition 10 can be efficiently removed by combining the above-mentioned light irradiation treatment, the heating treatment or the ozone-exposure treatment therewith. Additionally, this step may be combined with plasma irradiation, corona discharge or the like.

30 EXAMPLES

[0076] To make a silicon wafer have a surface with a finely uneven pattern

and to substitute a cleaning liquid retained in recessed portions with another cleaning liquid are already-established techniques, as discussed in conventionally known literatures and the like. In the present invention, therefore, evaluations of a water-repellent cleaning liquid were mainly performed. Additionally, a pattern collapse greatly depends on the contact angle of the cleaning liquid to the surface of the silicon wafer or the contact angle of liquid drop and on the surface tension of the cleaning liquid, as clearly represented by the equation discussed in the background technique and the like

$$P=2 \times \gamma \times \cos\theta / S \quad (\gamma: \text{Surface tension, } \theta: \text{Contact angle, } S: \text{Pattern width}).$$

In a case of a cleaning liquid retained in recessed portions 4 of an uneven pattern 2, the contact angle of liquid drop and the capillary force of surfaces of the recessed portions which force can be regarded as an equivalent of the pattern collapse are in correlation with each other, so that the capillary force may be derived from the equation and the evaluation of the contact angle of liquid drop under the surface condition 10 provided with water repellency. Incidentally, in Examples, a representative of a water-based cleaning liquid, i.e., water was used.

[0077] However, in a case where the silicon wafer has a finely uneven pattern at its surface, the pattern is significantly fine. Therefore it is not possible to exactly evaluate the water repellency of a water repellency-provided surface condition 10 itself.

[0078] Evaluation of the contact angle of waterdrop for evaluating the water repellency is conducted by dropping several microliters of waterdrop on a surface of a sample (substrate) and then by measuring an angle formed between the waterdrop and the substrate surface, as discussed in JIS R 3257 (Testing method of wettability of glass substrate surface). However, in the case of the silicon wafer having a pattern, the contact angle is enormously large. This is because Wenzel's effect or Cassie's effect is caused. That is because an apparent contact angle of the waterdrop is increased under the influence of a

surface shape (roughness) of the substrate upon the contact angle.

[0079] In view of this, in the present invention, evaluations are performed by providing the water-repellent cleaning liquid to a silicon wafer having a smooth surface so as to impart a surface condition provided with
5 water-repellency therewith and then regarding the surface condition as a water repellency-provided surface condition 10 of a silicon wafer 1 at which surface an uneven pattern 2 is formed.

[0080] Details will be discussed below. Hereinafter, there will be discussed: an evaluation method for a silicon wafer provided with a water-repellent
10 cleaning liquid; preparation of the water-repellent cleaning liquid; and evaluation results after providing the water-repellent cleaning liquid to the silicon wafer.

[0081] [Evaluation Method for Silicon Wafer to which Water-Repellent Cleaning Liquid is provided]

15 As an evaluation method for the silicon wafer provided with the water-repellent cleaning liquid, the following evaluations (1) to (4) were performed.

[0082] (1) Evaluation of Contact Angle under Surface Condition provided with Water Repellency by Water-Repellent Cleaning Liquid

20 Pure water of about 2 microliters was dropped on a wafer surface provided with water repellency, followed by measuring an angle (contact angle) formed between the waterdrop and the wafer surface by a contact angle meter (produced by Kyowa Interface Science Co., Ltd.: CA-X Model). At this time, a water repellency-provided surface condition having a contact angle within a
25 range of from 50 to 120° was determined as an acceptable one (indicated in Tables with "A"). Meanwhile, an unacceptable one is indicated with "B".

[0083] (2) Evaluation of Capillary Force

The capillary force (the absolute value of P) was obtained by calculating P by using the following equation.

30 [0084] $P=2 \times \gamma \times \cos\theta/S$

[0085] Here, γ represents a surface tension, θ represents a contact angle,

and S represents a pattern width. Incidentally, in a pattern having a line width of 45 nm and an aspect ratio of 6, the pattern tends to collapse in a case where the cleaning liquid used when the wafer passes through an gas-liquid interface is water, while being difficult to collapse in a case of 2-propanol. In a case where the pattern width is 45 nm and the wafer surface is silicon oxide, when the cleaning liquid is 2-propanol (Surface tension: 22 mN/m, Contact angle to silicon oxide: 1°), the capillary force is 0.98 MN/m². On the other hand, in a case of water having the largest surface tension among liquids other than mercury (Surface tension: 72 mN/m, Contact angle to silicon oxide: 2.5°), the capillary force is 3.2 MN/m². In view of this, the objective was set to the midpoint, i.e., 2.1 MN/m². A capillary force of not greater than 2.1 MN/m², at the time of retaining water, was determined as an acceptable one (indicated in Tables with "A"). Meanwhile, an unacceptable one is indicated with "B".

[0086] (3) Removability for Surface Condition Provided with Water Repellency by Water-Repellent Cleaning Liquid

Under the following conditions, the sample was irradiated with UV rays from a metal halide lamp for 2 hours. Those having a contact angle to waterdrop of not larger than 30° after the irradiation were determined as acceptable ones (indicated in Tables with "A"). Meanwhile, an unacceptable one is indicated with "B".

[0087] • Lamp: M015-L312 produced by EYE GRAPHICS CO., LTD.
(Intensity: 1.5 kW)

• Illuminance: 128 mW/cm² as a measurement value under the following conditions

• Measuring Apparatus: Ultraviolet Intensity Meter (UM-10 produced by Konica Minolta Sensing, Inc.)

• Light-Receptor: UM-360

(Light-Receptive Wavelength : 310-400 nm, Peak Wavelength: 365 nm)

• Measuring Mode: Irradiance Measurement

[0088] (4) Evaluation of Surface Smoothness of Silicon Wafer after removing Water Repellency-Provided Surface Condition

The surface was observed by atomic force microscope (produced by Seiko Instruments Inc.: SPI3700, 2.5 micrometer square scan), thereby obtaining the centerline average surface roughness: Ra (nm). Incidentally, Ra is a three-dimensionally enlarged one obtained by applying the centerline average roughness defined by JIS B 0601 to a measured surface and is calculated as "an average value of absolute values of difference from standard surface to designated surface" from the following equation. If the wafer has an Ra value of not higher than 1 nm after removing the water repellency-provided surface condition, the wafer surface was considered not to be eroded and not to have a residue of the water-repellent cleaning liquid thereon, so as to be determined as an acceptable one (indicated in Tables with "A"). Meanwhile, an unacceptable one is indicated with "B".

$$[0089] \quad Ra = \frac{1}{S_0} \int_{Y_T}^{Y_B} \int_{X_L}^{X_R} |F(X,Y) - Z_0| dXdY$$

Here, X_L and X_R and Y_B and Y_T represent a measuring range in the X coordinate and the Y coordinate, respectively. S_0 is an area on the assumption that a measured surface is ideally flat, and is a value obtained by $(X_R - X_L) \times (Y_B - Y_T)$. Additionally, $F(X,Y)$ represents the height at a measured point (X,Y). Z_0 represents the average height within the measured surface.

[0090] [Example 1]

(1) Preparation of Water-Repellent Cleaning Liquid

3 g of trimethylchlorosilane $[(CH_3)_3SiCl]$ serving as a water-repellent compound and a mixture of 5 g of 2-propanol (iPA) serving as an alcoholic solvent and 92 g of toluene serving as an organic solvent other than the alcoholic solvent were mixed and stirred for 5 min, thereby obtaining a water-repellent cleaning liquid having a concentration of the water-repellent compound (hereinafter referred to as "a water-repellent compound concentration") of 3 mass% relative to the total quantity of the water-repellent cleaning liquid and a concentration of the alcoholic solvent (hereinafter referred to as "an alcohol concentration") of 5 mass% relative to the total

quantity of the water-repellent cleaning liquid.

[0091] (2) Cleaning of Silicon Wafer

A smooth silicon wafer having a thermal oxide film (a silicon wafer having on its surface a thermal oxide film layer of 1 micrometer thickness) was
5 immersed in 1 mass% hydrofluoric acid aqueous solution for 2 min, followed by being immersed in pure water for 1 min and then in acetone for 1 min.

[0092] (3) Surface Treatment of Silicon Wafer Surface with Water-Repellent Cleaning Liquid

The silicon wafer was immersed in the water-repellent cleaning
10 liquid prepared in the "(1) Preparation of Water-Repellent Cleaning Liquid" at 20 °C for 10 min. Thereafter, the silicon wafer was immersed in iPA for 1 min, followed by being immersed in pure water serving as a water-based cleaning liquid for 1 min. Finally, the silicon wafer was drawn out of the pure water and then an air was sprayed thereon, thereby removing the pure water from the
15 surface.

[0093] As a result of evaluating the obtained wafer in a manner discussed in the [Evaluation Method for Silicon Wafer to which Water-Repellent Cleaning Liquid is provided], one which had an initial contact angle of smaller than 10° before a surface treatment changed to have a contact angle of 70° after the
20 surface treatment as shown in Table 1, thereby exhibiting a water repellency-providing effect. Additionally, as a result of calculating the capillary force at the time where water was retained by using the equation discussed in the above-mentioned "Evaluation of Capillary Force", the capillary force was 1.1 MN/m² and therefore the capillary force was small. Additionally, the
25 contact angle after UV irradiation was smaller than 10°, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after
30 UV irradiation.

[0094]

[Table 1]

	Water-repellent cleaning liquid						Treatment before surface treatment with water-repellent cleaning liquid	Immersion		Treatment after surface treatment with water-repellent cleaning liquid				Evaluation results				
	Water-repellent compound	Water-repellent compound concentration [mass%]	Organic solvent			Solvent used for cleaning after rinsing with water	Temperature [°C]	Time [min]	Drying	Cleaning with solvent	Cleaning with water	Drying	Initial contact angle [°]	Contact angle after surface treatment [°]	Capillary force [mN/m²] <calculated value>	Removability of water-repellent surface condition (contact angle [°])	Surface smoothness (Ra [nm])	
			Alcoholic solvent	Alcohol concentration [mass%]	Organic solvent other than alcoholic solvent													
Example 1	(CH ₃) ₂ SiCl	3	IPA	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 2	(CH ₃) ₂ SiCl	1	IPA	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (66)	A (1.3)	A (<10)	A (<0.5)	
Example 3	(CH ₃) ₂ SiCl	3	IPA	10	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (68)	A (1.2)	A (<10)	A (<0.5)	
Example 4	(CH ₃) ₂ SiCl	3	nPA	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 5	(CH ₃) ₂ SiCl	3	Ethanol	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 6	(CH ₃) ₂ SiCl	3	1-Butanol	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 7	(CH ₃) ₂ SiCl	3	1-Hexanol	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 8	(CH ₃) ₂ SiCl	3	IPA	5	AE3000	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)	
Example 9	(CH ₃) ₂ SiCl	3	IPA	5	HFE-7100	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (76)	A (0.8)	A (<10)	A (<0.5)	
Example 10	(CH ₃) ₂ SiCl	3	IPA	5	OTFP	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)	
Example 11	(CH ₃) ₂ SiCl	3	IPA	5	DOTFP	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)	
Example 12	OF ₃ CH ₂ CH ₂ Si(CH ₃) ₂ Cl	3	IPA	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (66)	A (1.3)	A (<10)	A (<0.5)	
Example 13	OF ₃ (CF ₂) ₂ CH ₂ CH ₂ Si(CH ₃) ₂ Cl	3	IPA	5	Toluene	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 14	(CH ₃) ₂ SiCl	3	IPA	5	Toluene	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)	
Example 15	(CH ₃) ₂ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)	
Example 16	(CH ₃) ₂ SiCl	3	IPA	5	OTFP	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)	
Example 17	(CH ₃) ₂ SiCl	3	nPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (80)	A (0.6)	A (<10)	A (<0.5)	
Example 18	(CH ₃) ₂ SiCl	3	nPA	5	OTFP	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (78)	A (0.7)	A (<10)	A (<0.5)	
Example 19	(CH ₃) ₂ SiCl	5	nPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (82)	A (0.4)	A (<10)	A (<0.5)	
Example 20	(CH ₃) ₂ SiCl	10	nPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (82)	A (0.4)	A (<10)	A (<0.5)	
Example 21	(CH ₃) ₂ SiCl	50	nPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (84)	A (0.3)	A (<10)	A (<0.5)	
Example 22	(CH ₃) ₂ SiCl	5	nPA	95	-	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (74)	A (0.8)	A (<10)	A (<0.5)	
Example 23	(CH ₃) ₂ SiCl	10	nPA	80	-	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (78)	A (0.7)	A (<10)	A (<0.5)	
Example 24	(CH ₃) ₂ SiCl	50	nPA	50	-	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (80)	A (0.6)	A (<10)	A (<0.5)	
Example 25	(CH ₃) ₂ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Not performed	Not performed	Not performed	Not performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)	

[0095] [Example 2]

The manner was all the same as Example 1 with the exception that the water-repellent compound concentration was set to 1 mass%. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 66° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.3 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10°, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0096] [Example 3]

The manner was all the same as Example 1 with the exception that the alcohol concentration was set to 10 mass%. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 68° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.2 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10°, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0097] [Example 4]

The manner was all the same as Example 1 with the exception that 1-propanol (nPA) was used as the alcoholic solvent. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 70° and therefore the water repellency-providing effect was exhibited. Additionally, the

capillary force at the time where water was retained was 1.1 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0098] [Example 5]

10 The manner was all the same as Example 1 with the exception that ethanol was used as the alcoholic solvent. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 70° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.1 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

20 [0099] [Example 6]

The manner was all the same as Example 1 with the exception that 1-butanol was used as the alcoholic solvent. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 70° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.1 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the

water-repellent cleaning liquid did not remain after UV irradiation.

[0100] [Example 7]

The manner was all the same as Example 1 with the exception that 1-hexanol was used as the alcoholic solvent. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 70 ° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.1 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10 °, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0101] [Example 8]

The manner was all the same as Example 1 with the exception that a fluorine-based solvent (ASAHIKLIN AE3000 produced by Asahi Glass Co., Ltd.: Hydrofluoroether) was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 72 ° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10 °, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0102] [Example 9]

The manner was all the same as Example 1 with the exception that a fluorine-based solvent (Novec HFE-7100 produced by 3M Limited:

Hydrofluoroether) was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 76° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.8 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0103] [Example 10]

The manner was all the same as Example 1 with the exception that 1-chloro-3,3,3-trifluoropropene (CTFP) was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0104] [Example 11]

The manner was all the same as Example 1 with the exception that 1,2-dichloro-3,3,3-trifluoropropene (DCTFP) was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface

treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

10 [0105] [Example 12]

The manner was all the same as Example 1 with the exception that trifluoropropyldimethylchlorosilane $[\text{CF}_3\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\text{Cl}]$ was used as the water-repellent compound. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 66° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.3 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0106] [Example 13]

The manner was all the same as Example 1 with the exception that nonafluorohexyldimethylchlorosilane $[\text{CF}_3(\text{CF}_2)\text{CH}_2\text{CH}_2\text{Si}(\text{CH}_3)_2\text{Cl}]$ was used as the water-repellent compound. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 70° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.1 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface

condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

5 [0107] [Example 14]

The manner was all the same as Example 1 with the exception that the silicon wafer was immersed in hydrofluoric acid aqueous solution for 2 min, followed by being immersed in pure water for 1 min and then in iPA for 1 min, in “(2) Cleaning of Silicon Wafer”. As shown in the evaluation result of Table 1,
10 the contact angle after the surface treatment was 70 ° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.1 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10 °, so that removal of the water repellency-provided surface
15 condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0108] [Example 15]

20 The manner was all the same as Example 14 with the exception that HFE-7100 was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 74 ° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary
25 force at the time where water was retained was 0.9 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10 °, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the
30 wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0109] [Example 16]

The manner was all the same as Example 14 with the exception that CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0110] [Example 17]

The manner was all the same as Example 15 with the exception that 1-propanol (nPA) was used as the alcoholic solvent. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 80° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.6 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0111] [Example 18]

The manner was all the same as Example 17 with the exception that CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 78° and therefore the water

repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.7 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10°, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0112] [Example 19]

10 The manner was all the same as Example 17 with the exception that the water-repellent compound concentration was set to 5 mass%. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 82° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.4
15 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10°, so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that
20 the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0113] [Example 20]

The manner was all the same as Example 17 with the exception that the water-repellent compound concentration was set to 10 mass%. As shown in
25 the evaluation result of Table 1, the contact angle after the surface treatment was 82° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.4 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10°, so that removal of the water
30 repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it

was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0114] [Example 21]

5 The manner was all the same as Example 17 with the exception that the water-repellent compound concentration was set to 50 mass%. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 84° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.3
10 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that
15 the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0115] [Example 22]

 The manner was all the same as Example 19 with the exception that 1-propanol (nPA) was singly used as the organic solvent in the water-repellent
20 cleaning liquid. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 74° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was
25 smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

30 [0116] [Example 23]

 The manner was all the same as Example 22 with the exception that

the water-repellent compound concentration was set to 10 mass%. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 78° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.7 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0117] [Example 24]

The manner was all the same as Example 22 with the exception that the water-repellent compound concentration was set to 50 mass%. As shown in the evaluation result of Table 1, the contact angle after the surface treatment was 80° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.6 MN/m² and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0118] [Example 25]

The manner was all the same as Example 15 with the exception that, in “(3) Surface Treatment of Silicon Wafer Surface with Water-Repellent Cleaning Liquid”, the silicon wafer was immersed in pure water for 1 min after being immersed in the water-repellent cleaning liquid, followed by spraying air on the silicon wafer finally drawn out of the pure water to obtain a wafer with the water repellency-provided surface condition. As shown in the evaluation

result of Table 1, the contact angle after the surface treatment was 74° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV
5 irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV
10 irradiation.

[0119] [Example 26]

The manner was all the same as Example 25 with the exception that CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2,
15 the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface
20 condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0120]

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[Table 2]

	Water-repellent cleaning liquid				Treatment before surface treatment with water-repellent cleaning liquid	Immersion		Treatment after surface treatment with water-repellent cleaning liquid				Evaluation results					
	Water-repellent compound	Water-repellent compound concentration [mass%]	Organic solvent			Solvent used for cleaning after rinsing with water	Temperature [° C]	Time [min]	Drying	Cleaning with solvent	Cleaning with water	Drying	Initial contact angle [°]	Contact angle after surface treatment [°]	Capillary force [mN/m ² <calculated value>]	Removability of water-repellent surface condition (contact angle [°])	Surface smoothness (Ra [nm])
			Alcoholic solvent	Alcohol concentration [mass%]													
Example 26	(CH ₃) ₃ SiCl	3	IPA	5	GTFP	IPA	20	10	Not performed	Not performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 27	(CH ₃) ₃ SiCl	3	IPA	5	DOTFP	IPA	20	10	Not performed	Not performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 28	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Performed	Performed	Performed	Performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)
Example 29	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Performed	Performed	Not performed	Not performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 30	(CH ₃) ₃ SiCl	3	IPA	5	GTFP	IPA	20	10	Performed	Performed	Not performed	Not performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 31	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Performed	Not performed	Performed	Performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)
Example 32	(CH ₃) ₃ SiCl	3	IPA	5	GTFP	IPA	20	10	Performed	Not performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 33	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Performed	Not performed	Not performed	Not performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)
Example 34	(CH ₃) ₃ SiCl	3	IPA	5	GTFP	IPA	20	10	Performed	Not performed	Not performed	Not performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 35	(CH ₃) ₃ SiCl	3	IPA	5	DOTFP	IPA	20	10	Performed	Not performed	Not performed	Not performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 36	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Not performed	Not performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)
Example 37	(CH ₃) ₃ SiCl	3	IPA	5	GTFP	IPA	20	10	Not performed	Performed	Not performed	Not performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 38	(CH ₃) ₃ SiCl	3	IPA	5	DOTFP	IPA	20	10	Not performed	Performed	Not performed	Not performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 39	(CH ₃) ₃ SiCl	3	IPA	5	Toluene	IPA, Toluene	20	10	Not performed	Performed	Performed	Performed	<10	A (70)	A (1.1)	A (<10)	A (<0.5)
Example 40	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	IPA, HFE-7100	20	10	Not performed	Performed	Performed	Performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)
Example 41	(CH ₃) ₃ SiCl	3	IPA	5	HFE-7100	None	20	10	Not performed	Performed	Performed	Performed	<10	A (74)	A (0.9)	A (<10)	A (<0.5)
Example 42	(CH ₃) ₃ SiCl	3	IPA	5	GTFP	None	20	10	Not performed	Performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 43	(CH ₃) ₃ SiCl	3	IPA	5	DOTFP	None	20	10	Not performed	Performed	Performed	Performed	<10	A (72)	A (1.0)	A (<10)	A (<0.5)
Example 44	C ₂ H ₅ Si(CH ₃) ₂ Cl	3	IPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (78)	A (0.7)	A (<10)	A (<0.5)
Example 45	C ₃ H ₇ Si(CH ₃) ₂ Cl	3	IPA	5	HFE-7100	IPA	20	10	Not performed	Performed	Performed	Performed	<10	A (82)	A (0.5)	A (<10)	A (<0.5)
Comparative Example 1	Not treated	-	-	-	-	Acetone	-	-	Not performed	Performed	Performed	Performed	<10	B (3)	B (3.2)	-	A (<0.5)
Comparative Example 2	Hydrolysate of (CH ₃) ₃ SiCl	3	IPA	84.6	-	Acetone	20	10	Not performed	Performed	Performed	Performed	<10	B (14)	B (3.1)	-	-

[0121] [Example 27]

The manner was all the same as Example 25 with the exception that DCTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0122] [Example 28]

The manner was all the same as Example 15 with the exception that, in “(3) Surface Treatment of Silicon Wafer Surface with Water-Repellent Cleaning Liquid”, the silicon wafer was immersed in the water-repellent cleaning liquid, followed by spraying air thereon to remove the water-repellent cleaning liquid from the surface and that the silicon wafer was thereafter immersed in iPA for 1 min and then in pure water for 1 min and finally drawn out of the pure water, followed by spraying air thereon to remove the pure water from the surface to obtain a wafer with the water repellency-provided surface condition. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 74° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the

water-repellent cleaning liquid did not remain after UV irradiation.

[0123] [Example 29]

The manner was all the same as Example 15 with the exception that, in “(3) Surface Treatment of Silicon Wafer Surface with Water-Repellent
5 Cleaning Liquid”, the silicon wafer was immersed in the water-repellent cleaning liquid, followed by spraying air thereon to remove the water-repellent cleaning liquid from the surface and that the silicon wafer was thereafter immersed in iPA for 1 min and finally drawn out of iPA, followed by spraying
10 air thereon to remove iPA from the surface to obtain a wafer with the water repellency-provided surface condition. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation
15 was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

20 [0124] [Example 30]

The manner was all the same as Example 29 with the exception that CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water
25 repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV
30 irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the

water-repellent cleaning liquid did not remain after UV irradiation.

[0125] [Example 31]

The manner was all the same as Example 15 with the exception that, in “(3) Surface Treatment of Silicon Wafer Surface with Water-Repellent
5 Cleaning Liquid”, the silicon wafer was immersed in the water-repellent cleaning liquid, followed by spraying air thereon to remove the water-repellent cleaning liquid from the surface and that the silicon wafer was thereafter immersed in pure water for 1 min and finally drawn out of the pure water, followed by spraying air thereon to remove the pure water from the surface to
10 obtain a wafer with the water repellency-provided surface condition. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 74° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small.
15 Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not
20 remain after UV irradiation.

[0126] [Example 32]

The manner was all the same as Example 31 with the exception that CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2,
25 the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface
30 condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the

wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0127] [Example 33]

The manner was all the same as Example 15 with the exception that,
5 in “(3) Surface Treatment of Silicon Wafer Surface with Water-Repellent Cleaning Liquid”, the silicon wafer was drawn out of the water-repellent cleaning liquid, followed by spraying air thereon to obtain a wafer with the water repellency-provided surface condition. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 74° and therefore
10 the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV
15 irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0128] [Example 34]

The manner was all the same as Example 33 with the exception that
20 CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary
25 force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the
30 water-repellent cleaning liquid did not remain after UV irradiation.

[0129] [Example 35]

The manner was all the same as Example 33 with the exception that DCTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water
5 repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV
10 irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0130] [Example 36]

The manner was all the same as Example 15 with the exception that,
15 in “(3) Surface Treatment of Silicon Wafer Surface with Water-Repellent Cleaning Liquid”, the silicon wafer was immersed in iPA for 1 min after being immersed in the water-repellent cleaning liquid and finally drawn out of iPA, followed by spraying air thereon to remove iPA from the surface to obtain a wafer with the water repellency-provided surface condition. As shown in the
20 evaluation result of Table 2, the contact angle after the surface treatment was 74° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water
25 repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

30 [0131] [Example 37]

The manner was all the same as Example 36 with the exception that

CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0132] [Example 38]

The manner was all the same as Example 36 with the exception that DCTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0133] [Example 39]

The manner was all the same as Example 1 with the exception that the silicon wafer was immersed in pure water for 1 min and then in iPA for 1 min after being immersed in hydrofluoric acid aqueous solution for 2 min, followed by being immersed in toluene for 1 min, in “(2) Cleaning of Silicon Wafer”. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 70° and therefore the water repellency-providing effect

was exhibited. Additionally, the capillary force at the time where water was retained was 1.1 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved.

5 Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0134] [Example 40]

10 The manner was all the same as Example 15 with the exception that the silicon wafer was immersed in pure water for 1 min and then in iPA for 1 min after being immersed in hydrofluoric acid aqueous solution for 2 min, followed by being immersed in HFE-7100 for 1 min, in “(2) Cleaning of Silicon Wafer”. As shown in the evaluation result of Table 2, the contact angle after the

15 surface treatment was 74° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved.

20 Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0135] [Example 41]

25 The manner was all the same as Example 15 with the exception that the silicon wafer was immersed in pure water for 1 min after being immersed in hydrofluoric acid aqueous solution for 2 min, in “(2) Cleaning of Silicon Wafer”. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 74° and therefore the water repellency-providing effect

30 was exhibited. Additionally, the capillary force at the time where water was retained was 0.9 MN/m^2 and therefore the capillary force was small.

Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0136] [Example 42]

The manner was all the same as Example 41 with the exception that CTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0137] [Example 43]

The manner was all the same as Example 41 with the exception that DCTFP was used as the organic solvent other than the alcoholic solvent in the water-repellent cleaning liquid. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 72° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 1.0 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm, with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the

water-repellent cleaning liquid did not remain after UV irradiation.

[0138] [Example 44]

The manner was all the same as Example 15 with the exception that ethyldimethylchlorosilane $[\text{C}_2\text{H}_5\text{Si}(\text{CH}_3)_2\text{Cl}]$ was used as the water-repellent compound. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 78° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.7 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

15 [0139] [Example 45]

The manner was all the same as Example 15 with the exception that propyldimethylchlorosilane $[\text{C}_3\text{H}_7\text{Si}(\text{CH}_3)_2\text{Cl}]$ was used as the water-repellent compound. As shown in the evaluation result of Table 2, the contact angle after the surface treatment was 82° and therefore the water repellency-providing effect was exhibited. Additionally, the capillary force at the time where water was retained was 0.5 MN/m^2 and therefore the capillary force was small. Additionally, the contact angle after UV irradiation was smaller than 10° , so that removal of the water repellency-provided surface condition was achieved. Furthermore, the Ra value of the wafer after UV irradiation was smaller than 0.5 nm , with which it was confirmed that the wafer was not eroded at the time of cleaning and that the residue of the water-repellent cleaning liquid did not remain after UV irradiation.

[0140] [Comparative Example 1]

The manner was the same as Example 1 with the exception that the water-repellent cleaning liquid was not provided to the silicon wafer. In other words, in this Comparative Example, a wafer which is not under the water

repellency-provided surface condition was evaluated. As shown in the evaluation result of Table 2, the contact angle of the wafer was 3° , which is small. Additionally, the capillary force at the time where water was retained was 3.2 MN/m^2 , which is large.

5 [0141] [Comparative Example 2]

The manner was the same as Example 1 with the exception that 3.0g of trimethylchlorosilane and 94.6 g of iPA were mixed, and 2.4 g of 0.1N nitric acid aqueous solution (pH 1) was added thereto, followed by stirring at room temperature for about 24 hours thereby obtaining a water-repellent cleaning
 10 liquid. In other words, this Comparative Example used a water-repellent cleaning liquid containing a water-repellent compound in which a reactive moiety was hydrolyzed. As shown in the evaluation result of Table 2, the contact angle of the wafer was 14° , which is small. Additionally, the capillary force at the time where water was retained was 3.1 MN/m^2 , which is large.

15 EXPLANATION OF REFERENCE NUMERALS

- | | | |
|--------|----|---|
| [0142] | 1 | Silicon wafer |
| | 2 | Finely uneven pattern that the silicon wafer has at its surface |
| | 3 | Projected portions of the pattern |
| | 4 | Recessed portions of the pattern |
| 20 | 5 | Width of the recessed portions |
| | 6 | Height of the projected portions |
| | 7 | Width of the projected portions |
| | 8 | Cleaning liquid retained in the recessed portions 4 |
| | 9 | Water-based cleaning liquid retained in the recessed portions 4 |
| 25 | 10 | Surface condition provided with water repellency by a water-repellent compound. |

CLAIMS

[Claim 1] A cleaning agent for a silicon wafer having a finely uneven pattern at its surface, comprising:

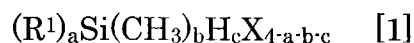
a water-based cleaning liquid having a water content of 50 mass % or more; and

a water-repellent cleaning liquid for providing at least a recessed portion of the uneven pattern with water repellency during a cleaning process,

the water-repellent cleaning liquid comprising a mixture of a water-repellent compound and an organic solvent, the water-repellent compound having a hydrophobic group and a reactive moiety chemically bondable to Si element in the silicon wafer, the organic solvent containing at least an alcoholic solvent.

[Claim 2] The cleaning agent for a silicon wafer according to claim 1, wherein the alcoholic solvent is at least one selected from the group consisting of alcohols with a carbon number of not greater than 10.

[Claim 3] The cleaning agent for a silicon wafer according to claim 1 or 2, wherein the water-repellent compound comprises at least one selected from the group consisting of the following general formulas [1] and [2].



where, R^1 mutually independently represents one of a monovalent organic group having hydrocarbon group with a carbon number of from 1 to 18 and a monovalent organic group having fluoroalkyl chain with a carbon number of from 1 to 8; R^2 mutually independently represents one of a monovalent organic group having hydrocarbon group with a carbon number of from 1 to 18 and a monovalent organic group having fluoroalkyl chain with a carbon number of from 1 to 8; X mutually independently represents at least one group selected from the group consisting of halogen group, alkoxy group, acetoxy group, trifluoroacetoxy group, $-OC(CH_3)=CHCOCH_3$, $-OC(CH_3)=N-Si(CH_3)_3$, $-OC(CF_3)=N-Si(CH_3)_3$, $-CO-NH-Si(CH_3)_3$, alkylsulfonate group,

perfluoroalkylsulfonate group, nitrile group and a monovalent organic group whose element to be bonded to Si element is nitrogen; a is an integer of from 1 to 3; each of b and c is an integer of from 0 to 2; the total of a, b and c is from 1 to 3; d is an integer of from 0 to 2; e is an integer of from 1 to 3.

[Claim 4] The cleaning agent for a silicon wafer according to claim 1 or 2, wherein the organic solvent comprises the alcoholic solvent and an aprotic solvent.

[Claim 5] The cleaning agent for a silicon wafer according to claim 1 or 2, wherein the organic solvent comprises the alcoholic solvent and a halogen element-containing unflammable solvent.

[Claim 6] The cleaning agent for a silicon wafer according to claim 1 or 2, wherein a surface of the recessed portion of the silicon wafer which surface is provided with water repellency by the water-repellent cleaning liquid has a capillary force of not larger than 2.1 MN/m^2 on the assumption that water is retained in the recessed portion of the surface of the silicon wafer.

[Claim 7] A water-repellent cleaning liquid for providing water repellency, during a cleaning process for a silicon wafer having at its surface a finely uneven pattern, at least to a recessed portion of the uneven pattern, comprising:

a water-repellent compound having a reactive moiety chemically bondable to Si element in the silicon wafer, and a hydrophobic group; and

an organic solvent containing at least an alcoholic solvent and mixed with the water-repellent compound,

wherein the water-repellent compound and the organic solvent are mixed.

[Claim 8] A cleaning method for a surface of a silicon wafer which method uses a cleaning agent for a silicon wafer according to claim 1, comprising:

a step of removing the cleaning agent from the surface of the silicon wafer, after removing the cleaning liquid from the surface of the silicon wafer.

[Claim 9] The cleaning method for a surface of a silicon wafer according to claim 8, comprising:

a step of conducting at least one treatment selected from the group consisting of irradiating the surface of the silicon wafer with light, heating the silicon wafer, and exposing the silicon wafer to ozone, after removing the cleaning liquid from the surface of the silicon wafer.