ETCHING METHOD FOR INSULATING FILM

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ABSTRACT

A mixed gas containing at least a first fluorocarbon gas having C=F 4 and a C/F ratio of 0.625 or higher, a second fluorocarbon gas having F 4 and a C/F ratio of 0.5 or lower, an Ar gas, and an O 2 gas is used as an etching gas to etch an insulating film formed of a silicon oxide film or the like. This can improve an etching rate and a resist mask selection ratio, and in addition, prevent the formation of a contact hole in a bowing shape even when a high-aspect-ratio contact hole is formed.
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<th>FIRST FLUOROCARBON GAS</th>
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**FIG. 4**
FIG. 5A

FIG. 5B
FIG. 9
FIG. 10
ETCHING METHOD FOR INSULATING FILM

TECHNICAL FIELD

[0001] The present invention relates to an insulating film etching method, and more particularly to that suitable for use in etching for a high-aspect-ratio contact hole.

BACKGROUND ART

[0002] With the recent progress of high density design of semiconductor integrated circuits, the aspect ratio of contact holes is becoming higher, and a C$_3$F$_6$/Ar/O$_2$ etching gas has been in use for forming such contact holes.

[0003] With the C$_3$F$_6$/Ar/O$_2$ etching gas, however, there has been not only a problem of low throughput due to a low etching rate but also a problem of the occurrence of a bowing (sake bottle) shape due to a low resist mask selection ratio.

DISCLOSURE OF THE INVENTION

[0004] It is an object of the present invention to provide an insulating film etching method capable of not only increasing an etching rate and a resist mask selection ratio but also restraining the occurrence of a bowing shape.

[0005] In order to overcome the above-described problems, according to an aspect of the present invention, provides an insulating film etching method in which a mixed gas containing at least a first fluorocarbon gas having C$\equiv$4 and a C/F ratio of 0.625 or higher, a second fluorocarbon gas having F=4 and a C/F ratio of 0.5 or lower, an Ar gas, and an O$_2$ gas is used as an etching gas, the method characterized in that a ratio between flow rates of the first fluorocarbon gas and the second fluorocarbon gas (the flow rate of the first fluorocarbon gas/the flow rate of the second fluorocarbon gas) is 0.50 or higher, and a C/F ratio of the mixed gas as a whole is 0.52 or higher.

[0006] Owing to the use of the mixture of the first fluorocarbon gas in which the C content is higher, that is, having a high C/F ratio, and the second fluorocarbon gas in which the F content is lower, that is, having a low C/F ratio, the first fluorocarbon gas can contribute to the increase in the resist mask selection ratio, and the second fluorocarbon gas can contribute to the restraint of the occurrence of the bowing shape and the increase in the etching rate, and as a result, the etching rate and the resist mask selection ratio can be both increased.

[0007] According to another aspect of the present invention, it is characterized in that the first fluorocarbon gas is a C$_3$F$_6$ gas or a C$_4$F$_8$ gas having C$\equiv$4 and a C/F ratio of 0.625 or higher.

[0008] According to still another aspect of the present invention, it is characterized in that the second fluorocarbon gas is one selected from a CF$_4$ gas, a C$_2$F$_6$ gas, a C$_3$F$_8$ gas, and a C$_4$F$_{10}$ gas.

[0009] This allows the etching rate to be increased while the occurrence of the bowing shape is restrained, which enables efficient formation of high-aspect-ratio contact holes.

[0010] Here, when a C/F ratio of the second fluorocarbon gas is made higher (in other words, the second fluorocarbon gas is changed as CF$_4$→C$_2$F$_6$→C$_3$F$_8$→C$_4$F$_{10}$), an etching species (mainly, a CF$_2$ radical) can be produced efficiently, which can further improve the etching rate.

[0011] According to yet another aspect of the present invention, it is characterized in that the mixed gas further contains a hydrofluorocarbon gas. Here, the hydrofluorocarbon gas is preferably a CH$_2$F$_2$ gas.

[0012] This makes it possible to further increase the resist mask selection ratio while giving little influence to the bowing shape and etching rate.

[0013] According to yet another aspect of the present invention, it is characterized in that the insulating film is a silicon oxide film. Further, according to yet another aspect of the present invention, it is characterized in that, when the silicon oxide film is etched, a silicon nitride film is exposed to an upper layer or a lower layer. It is further characterized in that the silicon oxide film is thus etched in a self-alignment contact forming step.

[0014] According to yet another aspect of the present invention, provides an insulating film etching method in which a mixed gas containing at least a first fluorocarbon gas having C$\equiv$4 and a C/F ratio of 0.625 or higher, a second fluorocarbon gas having F$\equiv$4 and a C/F ratio of 0.5 or lower, an Ar gas, and an O$_2$ gas is used as an etching gas, the method characterized in that a temperature of a substrate on which the insulating film is formed is 80°C to 120°C.

[0015] Setting the substrate temperature within the above temperature range allows the etching rate, resist mask selection ratio, bowing ratio, bottom diameter ratio, and silicon nitride film selection ratio to be maintained at appropriate values.

BRIEF DESCRIPTION OF DRAWINGS

[0016] FIG. 1 is a sectional view showing the schematic configuration of an etching apparatus according to an embodiment of the present invention.

[0017] FIG. 2A and FIG. 2B are sectional views showing the structure of an etching sample according to an example of the present invention, FIG. 2A showing the state before etching and FIG. 2B showing the state after etching.

[0018] FIG. 3 is a chart showing etching characteristics according to an example of the present invention when the kind and flow rate ratio of fluorocarbon are defined as parameters.

[0019] FIG. 4 is a chart showing the calculation result of the C/F ratio of each etching gas as a whole according to an example of the present invention.

[0020] FIG. 5A and FIG. 5B are charts showing the correlation between an addition amount of CF$_3$ and etching characteristics according to an example of the present invention, FIG. 5A showing an etching rate and a resist mask selection ratio and FIG. 5B showing a bowing ratio and a bottom diameter ratio.

[0021] FIG. 6A and FIG. 6B are charts showing the correlation between an addition amount of C$_3$F$_8$ and etching characteristics according to an example of the present invention, FIG. 6A showing an etching rate and a resist mask selection ratio and FIG. 6B showing a bowing ratio and a bottom diameter ratio.
FIG. 7A and FIG. 7B are charts showing the correlation between an addition amount of $C_4F_8$ and etching characteristics according to an example of the present invention, FIG. 7A showing an etching rate and a resist mask selection ratio and FIG. 7B showing a bowing ratio and a bottom diameter ratio.

FIG. 8 is a sectional view showing the structure of an etching sample according to an example of the present invention.

FIG. 9 is a chart showing the correlation between an addition amount of $CF_4$ and etching characteristics according to an example of the present invention.

FIG. 10 is a chart showing temperature dependency of etching characteristics according to an example of the present invention.

BEST MODE FOR IMPLEMENTING THE INVENTION

Hereinafter, an etching method according to an embodiment of the present invention will be explained with reference to the drawings.

FIG. 1 is a sectional view showing the schematic configuration of an etching apparatus according to an embodiment of the present invention. This embodiment shows a case of etching through the use of a $C_4F_8/CF_4/Ar/O_2$ mixed gas in which a first fluorocarbon gas is $C_4F_8$, having a straight-chain molecular structure and a second fluorocarbon gas is $CF_4$.

In FIG. 1, an upper electrode 2 and a susceptor 3 are provided in a processing chamber 1. This susceptor 3 also serves as a lower electrode. The upper electrode 2 has gas ejecting ports 2a through which an etching gas is introduced into the processing chamber 1.

The abovementioned susceptor 3 is supported on a susceptor supporting table 4, and the susceptor supporting table 4 is held in the processing chamber 1 via an insulating board 5. Radio-frequency power supplies 13, 11 are connected to the upper electrode 2 and the susceptor 3 respectively so that the etching gas introduced into the processing chamber 1 is plasma-treated.

The susceptor supporting table 4 has a refrigerant chamber 10 provided therein, and a refrigerant such as liquid nitrogen circulates inside the refrigerant chamber 10 through a refrigerant supply pipe 10a and a refrigerant discharge pipe 10b. Then, a cooling energy generated therefrom is transmitted to a wafer W via the susceptor supporting table 4 and the susceptor 3 so that the wafer W can be cooled.

An electrostatic chuck 6 is provided on the susceptor 3. The electrostatic chuck 6 is so structured that a conductive layer 7 is sandwiched between polyimide films 8a and 8b. A DC high-voltage power supply 12 is connected to the conductive layer 7, and when a DC high voltage is applied to the conductive layer 7, a Coulomb force acts on the wafer W so that the wafer W can be fixed on the susceptor 3.

Further, a gas passage 9 through which a He gas is introduced is provided in the susceptor 3 and the electrostatic chuck 6. The He gas is supplied to the rear face side of the wafer W via this gas passage 9 so that the wafer W mounted on the susceptor 3 can be cooled. The gas passage 9 is connected to a He gas supply source 18 via an open/close valve 18a and a flow control valve 18b so that the pressure of the He gas on the rear face of the wafer W can be controlled.

A gas supply pipe 1a and an exhaust pipe 1b are connected to the processing chamber 1. The gas supply pipe 1a is connected to a $C_4F_8$ gas supply source 14, a $CF_4$ gas supply source 15, an Ar gas supply source 16, and an $O_2$ gas supply source 17 via open/close valves 14a to 17a and flow control valves 14b to 17b.

The exhaust pipe 1b is connected to a vacuum pump and the inside of the processing chamber 1 is exhausted with this vacuum pump so that the pressure of the processing chamber 1 can be adjusted.

When an insulating film is to be etched, the wafer W on which the insulating film is formed is mounted on the susceptor 3 and fixed by the electrostatic chuck 6.

Next, while the processing chamber 1 is exhausted to adjust the inner pressure of the processing chamber 1, the open/close valves 14a to 17a are opened to introduce a $C_4F_8$ gas, a $CF_4$ gas, an Ar gas, and an $O_2$ gas into the processing chamber 1.

The ratio among the flow rates of the $C_4F_8$ gas, the $CF_4$ gas, the Ar gas, and the $O_2$ gas is adjustable by the flow control valves 14b to 17b, the ratio between the flow rates of the $C_4F_8$ gas and the $CF_4$ gas (the flow rate of the $CF_4$ gas/the flow rate of the $C_4F_8$ gas) is preferably 0.5 or higher in order to ensure a resist mask selection ratio.

Next, an RF power (60 MHz) from the radio-frequency power supply 13 is applied to the upper electrode 2 and an RF power (2 MHz) from the radio-frequency power supply 12 is applied to the susceptor 3, thereby plasma-treating the etching gas to etch the insulating film. At this time, in order to cool the wafer W efficiently, the open/close valve 18a is opened to supply the He gas to the rear face side of the wafer W through the gas passage 9. The temperature for cooling the wafer W is controllable by the adjustment of the pressure of the He gas through the use of the flow control valve 18b. Preferable etching conditions are such that the RF powers to the upper electrode 2 and the susceptor 3 are about 140 W to about 2100 W, the inner pressure of the processing chamber 1 is about 1.33 Pa to about 9.31 Pa (about 10 mTorr to about 70 mTorr), the temperature of the susceptor 3 is about −20°C to about 20°C, and the temperature of the wafer W is about 80°C to about 120°C.

The $C_4F_8$ gas in which the number of C (carbon atoms) in a molecule is large promotes the deposition of carbon polymers while supplying a large amount of etching species such as a CF radical ($CF_4^+$, $CF_3^+$, and $CF_2^+$), and consequently, it can increase a resist selection ratio while increasing an etching rate, but it is likely to cause a bowing shape to occur.

The reason why the $C_4F_8$ gas is likely to cause the bowing to occur is that, since a large amount of the carbon polymers deposits near an entrance of a contact hole, the deposition does not easily occur, on the other hand, in a lower side of this deposition portion, resulting in the progress of etching of a contact hole sidewall in this portion.
Therefore, when CF₄ having a large number of F (fluorine atoms) in a molecule and having a low C/F ratio is added in the CₓFₓ gas that is likely to cause the bowing shape to occur, the deposition of the carbon polymers at the entrance of the contact hole can be restrained, which will end up with the prevention of occurrence of the bowing shape.

The reason why the deposition of the carbon polymers increases the resist selection ratio is that, on an etched surface of the oxide film, oxygen contained in the oxide film is sputtered out to contribute to the decomposition of the carbon polymers while, on a resist surface, the carbon polymers are not easily removed even by ion bombardment or the like. Moreover, since the CF₄ gas promotes etching while restraining the deposition of the carbon polymers, the etching rate can be increased. Especially, the mixture of the CF₄ gas in the CₓFₓ gas makes it possible to restrain the deposition of the carbon polymers while supplying a large amount of the etching species. Consequently, even when a contact hole having an aspect ratio of 10 or higher is to be formed, the lack of etching in the hole is also prevented to allow the efficient formation of the contact hole having the high aspect ratio of 10 or higher.

Incidentally, the insulating film may be, for example, a PSG film, a BSG film, a BPSG film, an AsSG film, an AsPSG film, or alike besides a SiO₂ film. Though the case when the CₓFₓ/CₓFₓ/Ar/O₂ gas is used is explained in the above-described embodiment, a CₓFₓ gas or a CₓFₓ gas having a cyclic molecular structure may be used instead of the CₓFₓ gas having the straight-chain molecular structure. Further, a CₓFₓ gas, a CₓFₓ gas, or a CₓFₓ gas may be used instead of the CₓFₓ gas.

Moreover, though the method of mixing two series of the fluorocarbon gases of different kinds and an Ar/O₂ gas is explained in the above-described embodiment, three series or more of fluorocarbon gases of different kinds may be used. A hydrofluorocarbon gas such as a CH₂F₂ gas or a CH₃F gas containing hydrogen in a molecular structure thereof may be further added. When the CH₃F gas or the like is added, hydrogen contained in the CH₂F₂ gas captures fluorine to increase the C/F ratio of the etching gas, which enables further increase in the resist selection ratio.

Further, though the explanation in the above-described embodiment is given on the etching method using an RIE apparatus that is a type of an apparatus that applies a radio-frequency voltage both to the upper electrode and the lower electrode, this method may be also applied to a magnetron RIE apparatus, an ECR (electron cyclotron resonance) plasma etching apparatus, a HEP (helicon excited plasma) etching apparatus, an ICP (inductively coupled plasma) etching apparatus, a TCP (transfer coupled plasma) etching apparatus, and so on. Hereinafter examples of the present invention will be explained with reference to experimental data.

FIG. 2A is a sectional view showing the structure of an etching sample according to an example of the present invention. In FIG. 2A, a silicon oxide film 22 (thermal oxide film) is formed on a silicon substrate 21, and a photoresist film 23 having opening portions 24 formed therein is formed on the silicon oxide film 22. Here, a film thickness Θ of the silicon oxide film 22 is 2 μm, a film thickness Θ of the photoresist film 23 is 600 nm, and a diameter Φ of the opening portion 24 is 0.15 μm. The sample shown in FIG. 2A is used and is subjected to etching ET through the use of the etching apparatus shown in FIG. 1.

FIG. 2B is a sectional view showing a bowing shape after the etching. In FIG. 2B, a contact hole having a bowing shape is formed in the silicon oxide film 22 after the sample shown in FIG. 2A is subjected to the etching ET.

A bowing ratio representing the degree of the bowing is defined as a bowing diameter Gc/a top diameter Te. This bowing ratio is most preferably 1, and preferably falls within a range from 0.95 to 1.05 (within ±5%). Note that the bowing diameter Gc is a diameter of a portion of the contact hole 25 having the largest bulge, and the top diameter Te is a diameter of a top portion of the contact hole 25.

A bottom diameter Gc is a diameter of a bottom of the contact hole 25. A bottom diameter ratio defined as the bottom diameter Gc/the top diameter Te is most preferably 1. In the case of a hole having a small diameter and a large depth, however, the bottom diameter ratio becomes low. In general, when the top diameter is about 0.15 μm and the depth of the hole is 2 μm to 3 μm, 30% overetching is performed so that the bottom diameter ratio is about 70%.

A resist mask selection ratio in this example is equal to a value obtained by dividing an etching rate of the silicon oxide film 22 by an etching rate of the photoresist film 23 in a flat portion. The higher resist mask selection ratio is the better, and it is preferably 5.0 or higher.

Etching according to a conventional example was performed in order to compare the result of the etching according to an example of the present invention with that of the conventional example. The conventional etching was performed under such conditions that a CₓFₓ/Ar/O₂ mixed gas was used under the flow rate ratio of 15/380/19 sccm. The settings were such that the RF power of the upper electrode 2 was 2170 W, the RF power of the lower electrode 3 was 1550 W, the pressure was 2.00 Pa (15 mTorr), the He pressure on the rear face of the wafer W was 2000 Pa (15 Torr) at the center and 3330 Pa (25 Torr) at an edge, the top temperature was 60°C, the wall temperature was 50°C, and the bottom temperature was 20°C. The etching time was set to 30% underetching condition when the etching rate and the resist selection ratio were to be obtained, and was set to 4 minutes and 48 seconds that corresponds to 30% overetching when a sectional shape was to be evaluated. The spaced interval between the electrodes was 25 mm.

In this case, a sectional shape having a bowing shape was obtained, where, at the center, middle, and edge of the wafer W, the etching rates were 560 nm/min, 558 nm/min, and 504 nm/min respectively, the resist mask selection ratios on a facet face were 4.9, 5.4, and 5.0 respectively, the bowing ratios were 1.02, 1.06, and 1.03 respectively, the bottom diameters Gc were 107 nm, 108 nm, and 95 nm respectively, and the bottom diameter ratios were 71.3%, 72.0%, and 63.3% respectively.

Meanwhile, as conditions of etching of this example, a CₓFₓ/CFₓ/Ar/O₂ mixed gas containing CFₓ as a first fluorocarbon gas and CFₓ as a second fluorocarbon gas was used under the flow rate ratio of 25/10/500/26 sccm. The settings were such that the RF power of the upper electrode 2 was 1800 W, the RF power of the lower electrode 3 was...
In this case, the sectional shape without any bowing shape was obtained, where, at the center, middle and edge of the wafer W, the etching rates were 588 nm/min, 606 nm/min, and 622 nm/min respectively, the resist mask selection ratios on the facet face were 5.7, 5.3, and 5.5 respectively, the bowing ratios were 1.00, 1.00, and 1.00 respectively, the bottom diameters Be were 99 nm, 93 nm, and 109 nm respectively, and the bottom diameter ratios were 66.0%, 62.0%, and 72.7% respectively.

Thus, etching using the CF₆/CF₄/Ar/O₂ mixed gas instead of the CF₆/Ar/O₂ mixed gas realized the control of the bowing ratio within ±5% and the increase in the etching rate to about 1.12 times and the resist selection ratio to about 1.08 times.

Further, etching was performed using a CF₆/CF₄/Ar/O₂ mixed gas in which CF₆ was used as the second fluorocarbon gas, in place of the CF₆/CF₄/Ar/O₂ mixed gas. All the etching conditions were set to the same as those in the above-described example except that the etching time corresponding to 30% overetching when the sectional shape was to be evaluated was set to 4 minutes and 32 seconds.

In this case, at the center, middle and edge of the wafer W, the etching rates were 608 nm/min, 636 nm/min, and 686 nm/min respectively, the resist mask selection ratios on the facet face were 6.2, 5.9, and 6.0 respectively, the bowing ratios were 0.98, 0.99, and 1.00 respectively, the bottom diameters Be were 105 nm, 99 nm, and 99 nm respectively, and the bottom diameter ratios were 70.0%, 66.0%, and 66.0% respectively.

Thus, etching using the CF₆/CF₄/Ar/O₂ mixed gas instead of the CF₆/CF₄/Ar/O₂ mixed gas also realized the control of the bowing ratio within ±5% and the increase in the etching rate to about 1.19 times and the resist selection ratio to 1.18 times.

Further, etching was performed using a CF₆/CF₄/Ar/O₂ mixed gas in which CF₆ was used as the first fluorocarbon gas, in place of the CF₆/CF₄/Ar/O₂ mixed gas. A sample constituted of a silicon base and a BPSG film with a 3 nm thickness formed thereon was used. A diameter of a hole formed by the etching was 0.25 μm.

Etching conditions were such that the flow rate ratio was 25/15:500/25 sccm, the RF power of the upper electrode was 1750 W, the RF power of the lower electrode was 1800 W, the pressure was 2.66 Pa (20 mTorr), the He pressure on the rear face of the wafer W was 665 Pa (5 Torr) at the center and 3330 Pa (25 Torr) at the edge, the top temperature was 60°C, the wall temperature was 60°C, the bottom temperature was 50°C, and the etching time was the time corresponding to 30% overetching.

In this case, the average of etching rates at the center, middle, and edge of the wafer W was 680.5 nm/min.

At the center, middle, and edge of the wafer W, amounts of a remaining film of the resist mask on the facet face were 184 nm, 158 nm, and 86 nm respectively (the initial film thickness was about 500 nm), the bowing ratios were 1.00, 1.00, and 1.00 respectively, and the bottom diameter ratios were 0.59, 0.59, and 0.59 respectively.

Meanwhile, as a comparison example, etching using a CF₆/Ar/O₂ mixed gas was performed under the same conditions as those in the above-described case except that CF₆ was removed from the gas used above. As a result, the average etching rate was 561.1 nm/min, and at the center, middle, and edge of the wafer W, amounts of the remaining film of the resist mask on the facet face were 91 nm, 112 nm, and 33 nm respectively (the initial film thickness was about 800 nm), the bowing ratios were 1.15, 1.10, and 1.05 respectively, and the bottom diameter ratios were 0.77, 0.67, and 0.62 respectively.

Thus, when the CF₆/CF₄/Ar/O₂ mixed gas in which CF₆ is used as the first fluorocarbon gas is used, though the bottom diameter ratio was slightly worsened, the favorable bowing ratio of 1.00 was obtained and the increase in the etching rate to about 1.20 times was realized compared with that of the comparison example. Further, from the fact that the remaining amount of the resist mask was large compared with that in the comparison example, it is seen that the resist mask selection ratio was also increased.

In FIG. 3 is a chart showing etching characteristics according to an example of the present invention when the kind and the flow rate ratio of fluorocarbon are defined as parameters. Processing conditions were the same as those in the aforesaid example, and overetching was 30%. In FIG. 3, a first fluorocarbon gas having a high C/F ratio is shown by CF₆ and a second fluorocarbon gas having a low C/F ratio is shown by CF₄. The curves A1, A2, the curves B1, B2, the curves C1, C2, and the curves D1, D2 show the cases when CF₆ =CF₄, CF₆ =CF₄, CF₆ =CF₄, and CF₆ =CF₄ respectively.

In FIG. 3, as the ratio of the flow rate of the CF₆ gas to that of the CF₄ gas (the flow rate of the CF₆ gas/the flow rate of the CF₄ gas) becomes higher with the fixed total gas flow rate (35 sccm), the resist mask selection ratio is increased and the etching rate is also increased. It can be reasoned that this is because the increase in etching species due to the increase in the C/F ratio as the whole gas and the deposition of carbon polymers contribute to the increase in the etching rate and the increase in the resist mask selection ratio.

On the other hand, when the flow rate of the CF₆ gas is increased under the same flow rate (25 sccm) of the CF₆ gas, the etching rate is increased but the resist mask selection ratio is lowered. It can be reasoned that this is because the increase in the flow rate of the CF₆ gas causes the decrease in the C/F ratio as the whole gas, resulting in the decrease in the deposition of carbon polymers. Therefore, the ratio of the flow rate of the CF₆ gas to that of the CF₄ gas (the flow rate of the CF₆ gas/the flow rate of the CF₄ gas) is preferably 0.5 or higher, more preferably 1 or higher in view of the resist mask selection ratio. In view of the etching rate, the flow rate of the CF₆ gas is preferably 20 sccm or higher.

FIG. 4 is a table showing the calculation result of the C/F ratio of each etching gas as a whole according to an example of the present invention.
It is seen from FIG. 4 that the C/F ratio of the etching gas as a whole is 0.5 or higher when the ratio of the flow rate of the C2F6 gas to that of the C2F4 gas is 1 or higher. In FIG. 3, the cases where the C/F ratio is 0.5 or higher are shown by the circles. As shown in FIG. 3, the C/F ratio of the whole etching gas in which two kinds of fluorocarbon gases are mixed is preferably 0.5 or higher in order to increase the resist mask selection ratio.

Further, when the C2F4 is changed as CF4→C2F6→C3F8→C4F8, the etching rate can be increased while the resist mask selection ratio is maintained substantially constant. It can be reasoned that this is because the deposition of the carbon polymers does not have significant influence since the C/F ratio (x/y) in C2F4, in which the etching species are increased due to the increase in the number (x) of C in C2F4, is maintained at 0.5 or lower. Therefore, the number (x) of C in C2F4 is preferably larger in view of the etching rate.

Incidentally, when C2F6→C2F4, the deposition of the carbon polymers is promoted due to the large number (x) of C. Therefore, when a contact hole having an aspect ratio of 10 or higher is formed in a SiO2 film, the lack of etching of the hole occurs. However, since the lack of etching of the hole can be prevented when the contact hole is formed in a low-melting film such as a PSG film, a BSG film, a BPSG film, an AsSi film, an AsPSi film, and an AsBSi film, the mixed gas in which C2F6→C2F4 is especially suitable for etching these low-melting films.

FIGS. 5A and 5B show the study results for C2F6→C2F4. FIGS. 6A and 6B show the study results for C2F4→C2F6 and FIGS. 7A and 7B show the study results for C2F6→C2F4. In these drawings, FIG. 5A, FIG. 6A, and FIG. 7A show the changes in the etching rate and the resist mask selection ratio in the flat portion, and FIG. 5B, FIG. 6B, and FIG. 7B show the changes in the etching rate and the bottom diameter ratio. Etching conditions are such that the flow rate ratio of C2F6/C2F4/Ar/O2 is 35/0 to 35/700/36 sccm, the RF power of the upper electrode 2 is 2200 W, the RF power of the lower electrode 3 is 1800 W, the pressure is 2.66 Pa (20 mTorr), the He pressure on the rear face of the wafer W is 665 Pa (5 Torr) at the center and 3330 Pa (25 Torr) at the edge, the top temperature is 60°C, the wall temperature is 60°C, and the bottom temperature is 10°C.

The etching time was set to a 30% underetching condition when the etching rate and the resist selection ratio were to be obtained, and set to the time corresponding to 30% overetching when the sectional shape was to be evaluated.

As shown in these drawings, the addition of CF4, C2F6, or C2F4 increases the etching rate, and also improves the etching ratio and the bottom diameter ratio. On the other hand, the resist mask selection ratio, though increased by the addition of CF4, C2F6, or C2F4, tends to become gradually lower when the addition amount is further increased. Therefore, the addition amount of CF4, C2F6, or C2F4 preferably falls within the range demarcated by the vertical bold line in each drawing (left side of the bold line), where the C/F ratio=0.5 or higher.

Incidentally, in an etching step in which a contact hole (self-alignment contact) is formed by a so-called self-alignment technique, when a silicon oxide film is etched and so on are etched via a resist mask 31 to form a contact hole 34 reaching a silicon substrate 33, a silicon nitride film (SiN film) 36 formed around a gate electrode 35 formed on a lower layer is sometimes exposed, as shown in FIG. 8.

In the step in which the silicon nitride film is thus exposed, it is necessary in etching for forming the contact hole that the selection ratio of the silicon oxide film relative to the silicon nitride film (silicon nitride film selection ratio) is made high. FIG. 9 shows the result of measuring the changes in the etching rate, the resist mask selection ratio (facet portion), the silicon nitride film selection ratio (SiN selection ratio) of a silicon oxide film (BPSG film) in accordance with the difference in an addition amount of CF4.

Etching conditions are such that the flow rate ratio of C2F6/CF4/Ar/O2 is 16/0 to 10/8000/16 sccm, the RF power of the upper electrode 2 is 1530 W, the RF power of the lower electrode 3 is 1350 W, the pressure is 3.39 Pa (30 mTorr), the He pressure on the rear face of the wafer W is 665 Pa (5 Torr) at the center and 3330 Pa (10 Torr) at the edge, the top temperature is 40°C, the wall temperature is 60°C, and the bottom temperature is 50°C. The etching time is 90 seconds in the case of measuring the etching rate and the resist mask selection ratio, and is the time corresponding to 100% overetching in the case of measuring the silicon nitride film selection ratio. Incidentally, the thickness of the silicon oxide film is 1400 nm and the diameter of a contact hole is 400 nm.

As shown in the drawing, the addition of CF4 increases the etching rate and the SiN selection ratio. However, when the addition amount of CF4 is increased, the resist mask selection ratio tends to be lowered. Therefore, in the example shown in this drawing, it is preferable that the addition amount of CF4 is about 10 sccm or smaller, which, in terms of the C/F ratio, falls within the range demarcated by the bold line in the drawing, where the C/F ratio=0.54 or higher (left side of the bold line).

Incidentally, when a silicon oxide film is etched in the structure in which a silicon nitride film is formed on the silicon oxide film, the same effects as in the above-described case can be also obtained.

FIG. 10 shows the result of measuring temperature dependency of the etching rate, the resist mask selection ratio (facet portion), the bowing ratio (bowing CD ratio), the bottom diameter ratio (bottom diameter CD ratio), and the silicon nitride film selection ratio of a silicon oxide film (P-SiO2 film).

Etching conditions were such that the flow rate ratio of C2F6/CF4/Ar/O2 mixed gas was 24/9/700/30 sccm (when the bottom temperature=20°C, 0°C (the wafer temperature=80°C, 100°C C.)), and was 30/11/830/36 sccm (when the bottom temperature=0°C, 20°C (wafer temperature=100°C, 120°C C.)).

Other etching conditions were set so that the RF power of the upper electrode 2 was 1800 W, the RF power of the lower electrode 3 was 2100 W, the pressure was 2.66 Pa (20 mTorr) to 3.33 Pa (25 mTorr), the He pressure on the rear face of the wafer W was 2000 Pa (15 Torr) at the center and 4660 Pa (35 Torr) at the edge, the top temperature was
60° C., the wall temperature was 50° C., and the bottom temperature was -20° C. to 20° C. (the wafer temperature was 80° C. to 120° C.). The etching time was 30% underetching in the case of obtaining the etching rate and the resist mask selection ratio of the silicon oxide film, and was the time corresponding to 20% overetching in other cases.

[0083] As is seen in this drawing, the etching rate, the resist mask selection ratio, the bowing ratio, the bottom diameter ratio, and the silicon nitride film selection ratio have temperature dependency.

[0084] The etching rate and the resist mask selection ratio are higher as the wafer temperature is lower, but the silicon nitride film selection ratio, the bowing ratio, and the bottom diameter ratio are better as the wafer temperature is higher. Therefore, it is seen that they are in a trade-off relation. When the wafer temperature exceeds 140° C. (the bottom temperature exceeds 40° C.), the resist is softened to be deformed, and consequently, the shape as the mask cannot be maintained. Therefore, the wafer temperature is preferably 80° C. to 120° C.

What is claimed is:

1. (amended) An insulating film etching method, wherein a mixed gas containing at least a first fluorocarbon gas having C≦4 and a C/F ratio of 0.625 or higher, a second fluorocarbon gas having F≦4 and a C/F ratio of 0.5 or lower, an Ar gas, and an O₂ gas is used as an etching gas, and wherein a ratio between flow rates of said first fluorocarbon gas and said second fluorocarbon gas (the flow rate of the first fluorocarbon gas/the flow rate of the second fluorocarbon gas) is 0.50 or higher, and a C/F ratio of said mixed gas as a whole is 0.52 or higher.

2. An insulating film etching method as set forth in claim 1, wherein said first fluorocarbon gas is a C₃F₈ gas or a C₄F₆ gas.

3. An insulating film etching method as set forth in claim 2, wherein said second fluorocarbon gas is one selected from a CₓF₄ gas, a CₓF₁₀ gas, a CₓF₁₈ gas, and a CₓF₆₈ gas.

4. (deleted)

5. An insulating film etching method as set forth in claim 1, wherein said mixed gas further contains a hydrofluorocarbon gas.

6. An insulating film etching method as set forth in claim 5, wherein said hydrofluorocarbon gas is a CH₃F₂ gas.

7. (deleted)

8. An insulating film etching method as set forth in claim 1, wherein said insulating film is a silicon oxide film.

9. An insulating film etching method as set forth in claim 8, wherein a silicon nitride film is exposed to an upper layer or a lower layer of said silicon oxide film.

10. An insulating film etching method as set forth in claim 9, wherein said silicon oxide film is etched in a self-alignment contact forming step.

11. (amended) An insulating film etching method, wherein a mixed gas containing at least a first fluorocarbon gas having C≦4 and a C/F ratio of 0.625 or higher, a second fluorocarbon gas having F≦4 and a C/F ratio of 0.5 or lower, an Ar gas, and an O₂ gas is used as an etching gas, and wherein a temperature of a substrate on which said insulating film is formed is 80° C. to 120° C.