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Specification

Etching Method

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Technical Field

The present invention relates to an etching method.

Background Art

To keep pace with the great improvements made with respect to the degree of integration of semiconductor devices in recent years, miniaturization of various elements formed on semiconductor substrates has become one of the crucial technical requirements. In order to meet this requirement, the distances between the individual gates (electrodes) formed on a semiconductor substrate must be reduced. If contact holes are formed between the gates, the contact holes, too, must be miniaturized. However, as the distances between the gates become increasing small, the difficulty in forming ever smaller contact holes at accurate positions increases, due to the limits of the alignment performance of the stepper and the like. Accordingly, a self-aligning contact technology, whereby self-aligned contact holes are formed within the minute space between individual gates by forming a protective film (base) constituted of, for instance, an SiNx film (silicon nitride film) at the surfaces of the gates and thereby preventing the gates from becoming etched during the contact hole formation, has been proposed of late.

For the etching process implemented to form the contact holes and, more specifically, during the etching process implemented to form contact holes passing through the insulating film covering the individual gates and constituted of, for instance, an SiO_2 film (silicon oxide film) between the gates, a mixed gas constituted by adding CO to C_4F_8, for instance, is used as the processing gas. The processing

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gas constituted by adding CO to C_4F_8 provides advantages in that an almost vertical etching shape is achieved and in that the selection ratio of the SiO_2 film to the SiNx film (SiO_2 film etching rate /SiNx film etching rate) (hereafter referred to as the "selection ratio") is improved.

However, if C_4F_8, which is not readily degraded in the atmosphere, is directly released into the atmosphere without having been dissociated during the processing, it becomes a greenhouse effect inducing gas to hasten the process of global warming.

For instance, it has been reported that the life of C_4F_8 in the atmosphere is 3200 years (Climate Change 1995, the Current Status and Measures Taken with Respect to the PFC Problem At Semiconductor Mass Producing Plants), whereas the life of C_5F_8 in the atmosphere is only one year.

Disclosure of the Invention

An object of the present invention, which has been completed by addressing the problems of the prior art discussed above, is to provide a new and improved etching method that allows an etching process to be implemented using a gas that becomes degraded in a relatively short period of time when it is released into the atmosphere and does not induce the greenhouse effect while achieving vertical etching of an SiO_2 film and a selection ratio which are comparable to or better than those in the prior art.

In order to achieve the object described above, in the etching method according to the present invention, in which an SiO_2 film formed on a workpiece placed within an airtight processing chamber is etched by raising a processing gas induced into the processing chamber to plasma, the processing gas contains at least C_5F_8 and O_2, as disclosed in claim 1.

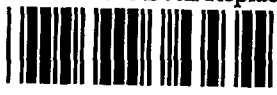
It has been confirmed that C_5F_8 constituting the processing gas according to the present invention becomes degraded in a relatively short period of time in the atmosphere compared to the CF gases that are used as processing gases in the prior art such as CF_4, C_2F_6 and C_4F_8. Thus, the use of C_5F_8, which does not induce the greenhouse effect even when it is directly released into the atmosphere, will contribute toward prevention of global warming.

In addition, since C_5F_8 is relatively rich in carbon compared to the CF gases such as CF_4, C_2F_6 and C_4F_8 mentioned above, a carbon-containing film that is to constitute a protective film can be formed with ease at the etching mask, at the shoulders of the etching mask pattern or at the inner side walls of the contact holes. However, if C_5F_8 alone or a mixed gas constituted of C_5F_8 and Ar is used for the etching process, the carbon-containing film remains at the bottoms of the contact holes to result in a so-called etch stop. Accordingly, the processing gas according to the present invention contains O_2 so that the quantity of carbon-containing film within the contact holes can be controlled through the O_2 to prevent the occurrence of an etch stop and to achieve control of the contact hole angle. As a result, compared to the prior art, which uses a gas containing C_4F_8 and CO for the etching process, the contact holes achieving an equal or higher degree of verticality can be formed.

Furthermore, forming an SiO_2 film over an SiNx film formed on the workpiece as disclosed in claim 2 prevents etching of the exposed surface of the SiNx film by the carbon-containing film covering the exposed surface to achieve an improvement in the selection ratio.

Also, by setting the flow rate ratio of C_5F_8 and O_2 within the range of $1 \leq (C_5F_8 \text{ flow rate}/O_2 \text{ flow rate}) \leq 1.5$ as disclosed in claim 3, a high selection ratio comparable to or better than the selection ratios

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achieved when using the processing gases in the prior art mentioned above is achieved.

Moreover, a nearly vertical etching shape can be obtained by, for instance, setting the flow rate ratio of C_5F_8 and O_2 within the range of $1.3 \leq (C_5F_8$ flow rate$/O_2$ flow rate$) \leq 1.625$, by setting the atmosphere pressure within the processing chamber to 45mTorr ~ 50mTorr, by setting the temperature of the stage on which the workpiece is mounted within the range of 20°C ~ 40°C or by adding an inert gas such as Ar to the processing gas, as disclosed in claims 4 ~ 8.

Brief Description of the Drawings

FIG. 1 is a schematic sectional view of an etching apparatus that may adopt the present invention;

FIG. 2 is a schematic sectional view in an enlargement, illustrating a wafer processed by using the etching apparatus shown in FIG. 1;

FIG. 3 schematically illustrates a wafer processed in embodiments of the present invention and in comparative examples from the prior art; and

FIG. 4 schematically illustrates the taper angle of the contact hole.

Best Mode for Carrying Out the Invention

The following is an explanation of the preferred embodiments of the etching method according to the present invention, given in reference to the attached drawings.

First, the structure of an etching apparatus in which the etching method according to the present invention may be adopted and is explained in reference to FIG. 1.

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A processing chamber 102 of an etching apparatus 100 is formed within an airtight conductive processing container 104. In addition, a magnet 106 capable of generating a rotating magnetic field in the plasma area formed within the processing chamber 102 surrounds the processing container 104. Inside the processing chamber 102, an upper electrode 108 constituting the ceiling of the processing chamber 102 and a lower electrode 110 facing opposite the upper electrode 108 and constituting a susceptor are formed.

An electrostatic chuck 112, to which a high-voltage DC source 114 is connected is provided on the lower electrode 110. A workpiece such as a semiconductor wafer (hereafter referred to as a "wafer") W can be a vacuum-held onto the mounting surface on the electrostatic chuck 112. In addition, an elevator mechanism (not shown) is connected to the lower electrode 110 via an elevator shaft 116 to allow the lower electrode 110 to move freely along the vertical direction. A focus ring 118 constituted of an insulating material is provided to cover the side surface of the lower electrode 110. A baffle plate 120 having a plurality of through holes formed therein is attached to the side surface of the focus ring 118. The baffle plate 120 is constituted of a conductive material and is grounded via a conductive bellows 121 and the processing container 104. The lower electrode 110 is also connected with a high-frequency source 124 capable of outputting a specific level of high-frequency power for plasma generation via a matching device 122.

The upper electrode 108 having formed therein numerous through holes 108a communicating between the space inside the processing chamber 102 and a gas supply source 126 achieves a showerhead structure. By assuming this structure, the processing gas in this embodiment, e.g., a mixed gas constituted of C_5F_8, O_2 and Ar is discharged evenly via the through holes 108a along the direction

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in which the wafer W extends inside the processing chamber 102 from the gas supply source 126.

In addition, the atmosphere inside the processing chamber 102 is discharged from a discharge pipe 128 via the baffle plate 120. The atmosphere pressure inside the processing chamber 102 is set as appropriate by adjusting the quantity of the processing gas described above supplied into the processing chamber 102 and the quantity of the atmosphere within the processing chamber 102 that is discharged from the processing chamber 102.

Next, a method of forming contact holes in the minute space between the individual gates formed on the wafer W by implementing an etching process on the wafer W with the etching apparatus 100 described above is explained.

First, in reference to FIG. 2, the wafer W to be processed is explained. Gates 202 are formed via an SiO_2 film 201 on an Si (silicon) substrate 200 constituting the wafer W, and an SiNx film 206 is formed to cover the gates 202. The SiNx film 206 prevents the gates 202 from becoming etched during the formation of contact holes 210 which is to be detailed later so that self-aligned contact holes 210 are formed between the gates 202. In addition, a silicon type oxide film constituting an insulating film, e.g., an SiO_2 film 208, is formed on the SiNx film 206. It is to be noted that an insulating film constituted of BPSG (silicate glass constituted of boron and phosphorous), PSG (silicate glass constituted of phosphorus), TEOS (tetra-ethoxy orthosilane), Th-OX (thermal oxide) or SOG (spin on glass), may be formed instead of the SiO_2 film 208.

Next, the process implemented to form the contact holes 210 between the gates 202 at the wafer W mentioned above is explained in reference to FIGS. 1 and 2.

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First, after mounting the wafer W on the lower electrode 110 with its temperature maintained at 20°C ~ 40°C, the processing gas in the embodiment, e.g., a mixed gas constituted of C_5F_8, O_2 and Ar is induced into the processing chamber 102 and vacuum drawing is implemented to sustain the atmosphere inside the processing chamber 102 at a specific level of reduced pressure, e.g., in a range of 45mTorr ~ 50mTorr. During this process, the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.625 and, more desirably, within the range of $1.3 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.5. In addition, a rotating magnetic field of 100 Gauss ~ 200 Gauss is generated in the plasma area inside the processing chamber 102 by rotating the magnet 106. Next, when specific process conditions are achieved, a specific level of high-frequency power, e.g., 1500 W, with a specific frequency of, for instance, 13.56 MHz is applied from the high-frequency source 124 to the lower electrode 110 to cause a glow discharge to occur between the lower electrode 110 and the upper electrode 108. This dissociates the processing gas in the embodiment supplied into the processing chamber 102 to excite the plasma.

Since the processing gas in the embodiment is a mixed gas constituted of C_5F_8, O_2 and Ar, an atmosphere that is rich in carbon can be created inside the processing chamber 102 without having to add a carbon gas such as CO, and a carbon-containing film that is to constitute a protective film can be formed reliably at the inner wall surfaces of the contact holes 210. As a result, the CF (fluorocarbon) type radicals which are the etching seed, are not allowed to reach the SiNx film 206 readily. Thus, the SiNx film 206 is protected to improve the selection ratio. In addition, the contact holes 210 achieving the desired uniform shape are formed in the minute space between the

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gates 202. It is to be noted that a photoresist film 212, which is to be used as an etching mask, is formed on the SiO_2 film 208 in the figure.

Embodiments

Next, embodiments of the etching method according to the present invention are explained. It is to be noted that since the embodiments below were all implemented by employing the etching apparatus 100 in the embodiment described above with specific conditions such as the composition of the processing gas and the gas flow rates varied as explained below to form the contact holes 210 between the gates 202 formed at the wafer W, the same reference numbers are assigned to components having roughly identical functions and structural features to preclude the necessity for repeated explanation thereof.

(A) Contact hole taper angle

First, in reference to Table 1, the taper angle of the contact holes 210 is explained. It is to be noted that the term "taper angle" refers to the angle (theta) formed by a side surface of the SiO_2 film 208 inside a contact hole 210 and the upper surface of the SiNx film 206 shown in FIG. 3(c) and FIG. 4 when the SiO_2 film 208 is etched by using the photoresist film 212 having a specific pattern formed therein as a mask, as illustrated in FIG. 3(a) presenting a view of the area over which the contact hole 210 is formed, FIG. 3(b) presenting a sectional view through a plane along line A-A in FIG. 3(a) and FIG. 3(c) presenting a sectional view through a plane along line B-B in FIG. 3(a).

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Table 1

(Table 1)

embodiment	processing gas flow rates (sccm)			C_5F_8 / O_2 flow rate ratio	atmosphere pressure inside processing chamber (mTorr)	power (kW)	lower electrode temperature (°C)	contact hole taper angle (°)
	C_5F_8	O_2	A_r					
1	6.5	4	400	1.625	50	1.5	40	86.9
2	6	4	400	1.5	50	1.5	40	87.5
3	6.5	5	400	1.3	50	1.5	40	87.9
4	6.5	4	400	1.625	50	1.4	40	87.2
5	6.5	4	400	1.625	50	1.6	40	87.4
6	6.5	4	400	1.625	45	1.5	40	87.0
7	6.5	4	400	1.625	50	1.5	20	86.4
8	3.25	2	200	1.625	50	1.5	40	87.1
9	9.75	6	600	1.625	50	1.5	40	87.5
comparison example 1	18 (C_4F_8)	300 (CO)	380	-	40	1.5	40	86.3

The results presented in Table 1 were achieved by forming contact holes 210 at the SiO_2 film 208 under various etching conditions corresponding to embodiment 1 ~ embodiment 9 and comparison example 1 listed in Table 1.

Now, the difference between the shapes of the contact holes 210 formed through etching processes implemented using processing gasses constituted of C_5F_8, O_2 and Ar as described above and the shape of a contact hole resulting from an etching process implemented using the processing gas constituted of C_4F_8, CO and Ar in the prior art is explained by using a relational expression;

$$c = a - (2b/\tan \text{theta}) \ldots (1),$$

which expresses the relationship that the taper angle (theta) has with "a" representing the diameter of the upper portion of the contact hole 210 (hereafter referred to as the "etching diameter"), "b" representing the depth (height) of the contact hole 210 (hereafter referred to as the "etching film thickness") and "c" representing the diameter of the lower portion of the contact hole 210 (hereafter referred to as the "contact diameter") in FIG. 4.

Assuming that the etching process is implemented through ultra-fine machining with the etching diameter (a) at 0.25μm and the etching film thickness (b) at 1.5μm, the contact diameter "c" for the comparison example 1 is calculated to be 0.056μm and the average contact diameter for embodiment 1 ~ embodiment 9 is calculated to be 0.103μm by substituting the taper angle (theta) in expression (1) above, with 86.3° for comparison example 1 with the average 87.2° for embodiment 1 ~ embodiment 9 respectively. Using these results, the area ratio of the average bottom area of the contact hole 210 among the embodiments and the area of the contact hole 210 in the comparison example is calculated to be;

$$(0.103/0.056)^2 = 3.38.$$

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Thus, only by changing the taper angle (theta) by as little as 0.9°, the area at the bottom of the contact hole 210 increases by as much as 3.38 times the bottom area in the prior art, to greatly contribute to a reduction in the contact resistance.

In addition, by setting the flow rate ratio of C_5F_8 and O_2 within the range of $1.3 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.625, setting the atmosphere pressure within the processing chamber 102 to 45 mTorr ~ 50mTorr and setting the temperature of the lower electrode 110 within the range of 20°C ~ 40°C as indicated in Table 1, the taper angle (theta) is increased compared to that achieved by using the processing gas in the prior art.

(B) Selection ratio

Next, the selection ratio is explained in reference to Table 2.

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(Table 2)

Table 2

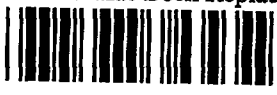
embodiment	processing gas flow rates (sccm)			C_5F_8 / O_2 flow rate ratio	atmosphere pressure inside processing chamber (mTorr)	power (kW)	lower electrode temperature (°C)	SiO_2 film / SiNx film selection ratio
	C_5F_8	O_2	A_r					
10	6	4	380	1.5	40	1.5	40	16.8
11	6	4	500	1.5	40	1.5	40	16.8
12	6	4	600	1.5	40	1.5	40	14.7
13	3	2	190	1.5	40	1.5	40	10.8
14	6	4	380	1.5	30	1.5	40	13.1
15	6	6	500	1	40	1.5	40	13.3
comparison example 2	18 (C_4F_8)	300 (CO)	380	-	40	1.5	40	11.2

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The results presented in Table 2 were achieved by forming contact holes 210 at the SiO_2 film 208 under various etching conditions corresponding to embodiment 10 ~ embodiment 15 and comparison example 2 listed in Table 2. By performing the etching process using a processing gas containing C_5F_8 and O_2 with a flow rate ratio of C_5F_8 and O_2 set within the range of $1 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.5 as indicated in the table, a selection ratio that is comparable to or better than that achieved in the etching process implemented by using the processing gas of the prior art constituted of C_4F_8, CO and Ar is achieved.

It is to be noted that the results presented in Table 3 were achieved in embodiment 16 ~ embodiment 19 implemented by using processing gasses constituted of C_5F_8, CO and Ar.

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(Table 3)

Table 3

embodiment	processing gas flow rates (sccm)			atmosphere pressure inside processing chamber (mTorr)	power (kW)	lower electrode temperature (°C)	SiO_2 film / SiNx film selection ratio
	C_5F_8	CO	A_r				
16	6	300	380	40	1.5	40	9.6
17	9	300	380	40	1.5	40	23.1
18	6	150	380	40	1.5	40	11.4
19	6	150	600	40	1.5	40	12.0

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While the invention has been particularly shown and described with respect to preferred embodiments thereof by referring to the attached drawings, the present invention is not limited to these examples and it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit, scope and teaching of the invention.

According to the present invention, in which an etching process is implemented by using a gas containing C_5F_8 that is degraded in a relatively short period of time in the atmosphere, a contribution is made toward the prevention of global warming since C_5F_8 does not induce the greenhouse effect even when it is directly released into the atmosphere without becoming degraded during the process. In addition, since O_2 is added to the processing gas, an etch stop is prevented, and an etching shape that is almost vertical is attained. Furthermore, the process can be implemented at a high selection ratio.

Industrial Applicability

The present invention may be adopted in an etching method, and, more specifically, in an etching method in which an SiO_2 film is formed at a workpiece placed within an airtight processing chamber by raising a processing gas induced into the processing chamber to plasma.

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What is claimed is;

1. An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said processing gas contains at least C_5F_8 and O_2.

2. An etching method according to claim 1, wherein;

said SiO_2 film is formed on an SiNx film formed at said workpiece.

3. An etching method according to claim 2, wherein;

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1 \leq$ (flow rate of said C_5F_8/flow rate of said O_2) ≤ 1.5.

4. An etching method according to claim 1, wherein;

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1.3 \leq$ (flow rate of said C_5F_8/flow rate of said O_2) ≤ 1.625.

5. An etching method according to claim 1, wherein;

the atmosphere pressure within said processing chamber is set to 45mTorr ~ 50mTorr.

6. An etching method according to claim 1, wherein;

the temperature of the stage on which said workpiece is mounted is set within the range of 20°C ~ 40°C.

7. An etching method according to claim 1, wherein;

said processing gas further contains an inert gas.

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8. An etching method according to claim 7, wherein;
said inert gas is Ar.

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Abstract

A processing gas constituted of C_5F_8, O_2 and Ar achieving a flow rate ratio of $1 \leq C_5F_8$ flow rate/O_2 flow rate ≤ 1.625 is supplied into a processing chamber 102 of an etching apparatus 100 and the atmosphere pressure is set within a range of 45mTorr ~ 50mTorr. High-frequency power is applied to a lower electrode 110 sustained within a temperature range of 20°C ~ 40°C on which a wafer W is mounted to raise the processing gas to plasma, and using the plasma, a contact hole 210 is formed at an SiO_2 film 208 on an SiNx film 206 formed at the wafer W. The use of C_5F_8 and O_2 makes it possible to form a contact hole 210 achieving near-perfect verticality at the SiO_2 film 208 and also improves the selection ratio of the SiO2 film 208 relative to the SiNx film 206. C_5F_8, which becomes decomposed over a short period of time when released into the atmosphere, does not induce the greenhouse effect.

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DISCLOSURE OF THE INVENTION

An object of the present invention, which has been completed by addressing the problems of the prior art discussed above, is to provide a new and improved etching method that allows an etching process to be implemented using a gas that becomes degraded in a relatively short period of time when it is released into the atmosphere and does not induce the greenhouse effect while achieving vertical etching of an SiO_2 film and a selection ratio which are comparable to or better than those in the prior art.

In order to achieve the object described above, in the etching method in a first aspect of the present invention, in which an SiO_2 film formed at a workpiece placed within an airtight processing chamber is etched by raising a processing gas induced into the processing chamber to plasma, the processing gas contains at least C_5F_8 and O_2, and the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq$ (C_5F_8 flow rate/ O_2 flow rate) ≤ 1.5, as disclosed in claim 1.

It has been confirmed that C_5F_8 constituting the processing gas according to the present invention becomes degraded in a relatively short period of time in the atmosphere compared to the CF gasses that are used as processing gases in the prior art such as CF_4, C_2F_6 and C_4F_8. Thus, the use of C_5F_8, which does not induce the greenhouse effect even when it is directly released into the atmosphere, will contribute toward prevention of global warming.

In addition, since C_5F_8 is relatively rich in carbon compared to the CF gases such as CF_4, C_2F_6 and C_4F_8 mentioned above, a carbon-containing film that is to constitute a protective film can be formed with ease at the etching mask, at the

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shoulders of the etching mask pattern or at the inner side walls of the contact holes. However, if C_5F_8 alone or a mixed gas constituted of C_5F_8 and Ar is used for the etching process, the carbon-containing film remains at the bottoms of the contact holes to result in a so-called etch stop. Accordingly, the processing gas according to the present invention contains O_2 so that the quantity of carbon-containing film within the contact holes can be controlled through the O_2 to prevent the occurrence of an etch stop and to achieve control of the contact hole angle. As a result, compared to the prior art, which uses a gas containing C_4F_8 and CO for the etching process, the contact holes achieving an equal or higher degree of verticality can be formed.

Furthermore, since the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq (C_5F_8$ flow rate $/O_2$ flow rate$) \leq 1.5$, a high selection ratio comparable to or better than the selection ratio achieved by using the processing gas in the prior art is realized.

In a second aspect of the present invention there is provided, an etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into the processing chamber to plasma, the processing gas contains, at least, C_5F_8 and O_2 and the flow rate ratio of C_5F_8 and O_2 is set within the range of $1.3 \leq (C_5F_8$ flow rate $/O_2$ flow rate$) \leq 1.625$, as disclosed in claim 2.

In addition, by setting the atmosphere pressure inside the processing chamber to 45mTorr ~ 50mTorr, setting the temperature of the stage on which the workpiece is mounted within the range of 20°C ~ 40°C or adding an inert gas such as Ar into the processing gas as disclosed in claims 3 ~ 6, for instance, a nearly vertical etching shape is achieved.

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In a third aspect of the present invention, an etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into the processing chamber to plasma, in which the SiO_2 film is formed on an SiNx film formed at the workpiece and the processing gas contains, at least, C_5F_8 and O_2 is provided, as disclosed in claim 7.

When the SiO_2 film is formed on an SiNx film formed at the workpiece as in the third aspect of invention, the carbon-containing film covers the exposed surface of the SiNx film to protect it from being etched, thereby improving the selection ratio.

Furthermore, it is desirable to set the flow rate ratio of C_5F_8 and O_2 within the range of $1 \leq (C_5F_8$ flow rate $/O_2$ flow rate) ≤ 1.5 or $1.3 \leq (C_5F_8$ flow rate$/O_2$ flow rate) ≤ 1.625, to set the atmosphere pressure within the processing chamber to 45mTorr ~ 50mTorr, to set the temperature of the stage on which the workpiece is mounted in the range of 20°C ~ 40°C or to add an inert gas such as Ar to the processing gas, as in the inventions disclosed in claims 8 ~ 13.

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What is claimed is;

1. (amended)

An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said processing gas contains at least C_5F_8 and O_2; and

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1 \leq$ (flow rate of said C_5F_8 /flow rate of said O_2) ≤ 1.5.

2. (amended)

An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said processing gas contains at least C_5F_8 and O_2; and

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1.3 \leq$ (flow rate of said C_5F_8 /flow rate of said O_2) ≤ 1.625.

3. (amended)

An etching method according to claim 1or 2, wherein;

the atmosphere pressure within said processing chamber is set to 45mTorr ~ 50mTorr.

4. (amended)

An etching method according to claim 1 or 2, wherein;

the temperature of a stage on which said workpiece is mounted is set within the range of 20°C ~ 40°C.

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5. (amended)

An etching method according to claim 1 or 2, wherein;

said processing gas further contains an inert gas.

6. (amended)

An etching method according to claim 5, wherein;

said inert gas is Ar.

7. (amended)

An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said SiO_2 film is formed on an SiNx film formed at said workpiece; and

said processing gas contains at least C_5F_8 and O_2.

8. (amended)

An etching method according to claim 7, wherein;

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1 \leq$ (flow rate of said C_5F_8 /flow rate of said O_2) ≤ 1.5.

9. (added)

An etching method according to claim 7, wherein;

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1.3 \leq$ (flow rate of said C_5F_8 /flow rate of said O_2) ≤ 1.625.

10. (added)

An etching method according to claim 7, wherein;

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the atmosphere pressure within said processing chamber is set to 45mTorr ~ 50mTorr.

11. (added)

An etching method according to claim 7, wherein;

the temperature of a stage on which said workpiece is mounted is set within the range of 20°C ~ 40°C.

12. (added)

An etching method according to claim 7, wherein;

said processing gas further contains an inert gas.

13. (added)

An etching method according to claim 12, wherein;

said inert gas is Ar.

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Specification

Etching Method

Technical Field

The present invention relates to an etching method.

Background Art

To keep pace with the great improvements made with respect to the degree of integration of semiconductor devices in recent years, miniaturization of various elements formed on semiconductor substrates has become one of the crucial technical requirements. In order to meet this requirement, the distances between the individual gates (electrodes) formed on a semiconductor substrate must be reduced. If contact holes are formed between the gates, the contact holes, too, must be miniaturized. However, as the distances between the gates become increasing small, the difficulty in forming ever smaller contact holes at accurate positions increases, due to the limits of the alignment performance of the stepper and the like. Accordingly, a self-aligning contact technology, whereby self-aligned contact holes are formed within the minute space between individual gates by forming a protective film (base) constituted of, for instance, an SiNx film (silicon nitride film) at the surfaces of the gates and thereby preventing the gates from becoming etched during the contact hole formation, has been proposed of late.

For the etching process implemented to form the contact holes and, more specifically, during the etching process implemented to form contact holes passing through the insulating film covering the individual gates and constituted of, for instance, an SiO_2 film (silicon oxide film) between the gates, a mixed gas constituted by adding CO to C_4F_8, for instance, is used as the processing gas. The processing

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gas constituted by adding CO to C_4F_8 provides advantages in that an almost vertical etching shape is achieved and in that the selection ratio of the SiO_2 film to the SiNx film (SiO_2 film etching rate /SiNx film etching rate) (hereafter referred to as the "selection ratio") is improved.

However, if C_4F_8, which is not readily degraded in the atmosphere, is directly released into the atmosphere without having been dissociated during the processing, it becomes a greenhouse effect inducing gas to hasten the process of global warming.

For instance, it has been reported that the life of C_4F_8 in the atmosphere is 3200 years (Climate Change 1995, the Current Status and Measures Taken with Respect to the PFC Problem At Semiconductor Mass Producing Plants), whereas the life of C_5F_8 in the atmosphere is only one year.

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DISCLOSURE OF THE INVENTION

An object of the present invention, which has been completed by addressing the problems of the prior art discussed above, is to provide a new and improved etching method that allows an etching process to be implemented using a gas that becomes degraded in a relatively short period of time when it is released into the atmosphere and does not induce the greenhouse effect while achieving vertical etching of an SiO_2 film and a selection ratio which are comparable to or better than those in the prior art.

In order to achieve the object described above, in the etching method in a first aspect of the present invention, in which an SiO_2 film formed at a workpiece placed within an airtight processing chamber is etched by raising a processing gas induced into the processing chamber to plasma, the processing gas contains at least C_5F_8 and O_2, and the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq$ (C_5F_8 flow rate/ O_2 flow rate) ≤ 1.5.

It has been confirmed that C_5F_8 constituting the processing gas according to the present invention becomes degraded in a relatively short period of time in the atmosphere compared to the CF gasses that are used as processing gases in the prior art such as CF_4, C_2F_6 and C_4F_8. Thus, the use of C_5F_8, which does not induce the greenhouse effect even when it is directly released into the atmosphere, will contribute toward prevention of global warming.

In addition, since C_5F_8 is relatively rich in carbon compared to the CF gases such as CF_4, C_2F_6 and C_4F_8 mentioned above, a carbon-containing film that is to constitute a protective film can be formed with ease at the etching mask, at the

shoulders of the etching mask pattern or at the inner side walls of the contact holes. However, if C_5F_8 alone or a mixed gas constituted of C_5F_8 and Ar is used for the etching process, the carbon-containing film remains at the bottoms of the contact holes to result in a so-called etch stop. Accordingly, the processing gas according to the present invention contains O_2 so that the quantity of carbon-containing film within the contact holes can be controlled through the O_2 to prevent the occurrence of an etch stop and to achieve control of the contact hole angle. As a result, compared to the prior art, which uses a gas containing C_4F_8 and CO for the etching process, the contact holes achieving an equal or higher degree of verticality can be formed.

Furthermore, since the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq (C_5F_8$ flow rate $/O_2$ flow rate$) \leq 1.5$, a high selection ratio comparable to or better than the selection ratio achieved by using the processing gas in the prior art is realized.

In a second aspect of the present invention there is provided, an etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into the processing chamber to plasma, the processing gas contains, at least, C_5F_8 and O_2 and the flow rate ratio of C_5F_8 and O_2 is set within the range of $1.3 \leq (C_5F_8$ flow rate $/O_2$ flow rate$) \leq 1.625$.

In addition, by setting the atmosphere pressure inside the processing chamber to 45mTorr ~ 50mTorr, setting the temperature of the stage on which the workpiece is mounted within the range of 20°C ~ 40°C or adding an inert gas such as Ar into the processing gas,
a nearly vertical etching shape is achieved.

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In a third aspect of the present invention, an etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into the processing chamber to plasma, in which the SiO_2 film is formed on an SiNx film formed at the workpiece and the processing gas contains, at least, C_5F_8 and O_2 is provided, and wherein the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq$ (flow rate of C_5F_8/flow rate of O_2) ≤ 1.625.

When the SiO_2 film is formed on an SiNx film formed at the workpiece as in the third aspect of invention, the carbon-containing film covers the exposed surface of the SiNx film to protect it from being etched, thereby improving the selection ratio.

Furthermore, it is desirable to set the flow rate ratio of C_5F_8 and O_2 within the range of $1.3 \leq$ (C_5F_8 flow rate/O_2 flow rate) ≤ 1.5, to set the atmosphere pressure within the processing chamber to 45mTorr ~ 50 mTorr, to set the temperature of the stage on which the workpiece is mounted in the range of 20°C ~ 40°C or to add an inert gas such as Ar to the processing gas.

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Brief Description of the Drawings

FIG. 1 is a schematic sectional view of an etching apparatus that may adopt the present invention;

FIG. 2 is a schematic sectional view in an enlargement, illustrating a wafer processed by using the etching apparatus shown in FIG. 1;

FIG. 3 schematically illustrates a wafer processed in embodiments of the present invention and in comparative examples from the prior art; and

FIG. 4 schematically illustrates the taper angle of the contact hole.

Best Mode for Carrying Out the Invention

The following is an explanation of the preferred embodiments of the etching method according to the present invention, given in reference to the attached drawings.

First, the structure of an etching apparatus in which the etching method according to the present invention may be adopted and is explained in reference to FIG. 1.

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A processing chamber 102 of an etching apparatus 100 is formed within an airtight conductive processing container 104. In addition, a magnet 106 capable of generating a rotating magnetic field in the plasma area formed within the processing chamber 102 surrounds the processing container 104. Inside the processing chamber 102, an upper electrode 108 constituting the ceiling of the processing chamber 102 and a lower electrode 110 facing opposite the upper electrode 108 and constituting a susceptor are formed.

An electrostatic chuck 112, to which a high-voltage DC source 114 is connected is provided on the lower electrode 110. A workpiece such as a semiconductor wafer (hereafter referred to as a "wafer") W can be a vacuum-held onto the mounting surface on the electrostatic chuck 112. In addition, an elevator mechanism (not shown) is connected to the lower electrode 110 via an elevator shaft 116 to allow the lower electrode 110 to move freely along the vertical direction. A focus ring 118 constituted of an insulating material is provided to cover the side surface of the lower electrode 110. A baffle plate 120 having a plurality of through holes formed therein is attached to the side surface of the focus ring 118. The baffle plate 120 is constituted of a conductive material and is grounded via a conductive bellows 121 and the processing container 104. The lower electrode 110 is also connected with a high-frequency source 124 capable of outputting a specific level of high-frequency power for plasma generation via a matching device 122.

The upper electrode 108 having formed therein numerous through holes 108a communicating between the space inside the processing chamber 102 and a gas supply source 126 achieves a showerhead structure. By assuming this structure, the processing gas in this embodiment, e.g., a mixed gas constituted of C_5F_8, O_2 and Ar is discharged evenly via the through holes 108a along the direction

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in which the wafer W extends inside the processing chamber 102 from the gas supply source 126.

In addition, the atmosphere inside the processing chamber 102 is discharged from a discharge pipe 128 via the baffle plate 120. The atmosphere pressure inside the processing chamber 102 is set as appropriate by adjusting the quantity of the processing gas described above supplied into the processing chamber 102 and the quantity of the atmosphere within the processing chamber 102 that is discharged from the processing chamber 102.

Next, a method of forming contact holes in the minute space between the individual gates formed on the wafer W by implementing an etching process on the wafer W with the etching apparatus 100 described above is explained.

First, in reference to FIG. 2, the wafer W to be processed is explained. Gates 202 are formed via an SiO_2 film 201 on an Si (silicon) substrate 200 constituting the wafer W, and an SiNx film 206 is formed to cover the gates 202. The SiNx film 206 prevents the gates 202 from becoming etched during the formation of contact holes 210 which is to be detailed later so that self-aligned contact holes 210 are formed between the gates 202. In addition, a silicon type oxide film constituting an insulating film, e.g., an SiO_2 film 208, is formed on the SiNx film 206. It is to be noted that an insulating film constituted of BPSG (silicate glass constituted of boron and phosphorous), PSG (silicate glass constituted of phosphorus), TEOS (tetra-ethoxy orthosilane), Th-OX (thermal oxide) or SOG (spin on glass), may be formed instead of the SiO_2 film 208.

Next, the process implemented to form the contact holes 210 between the gates 202 at the wafer W mentioned above is explained in reference to FIGS. 1 and 2.

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First, after mounting the wafer W on the lower electrode 110 with its temperature maintained at 20°C ~ 40°C, the processing gas in the embodiment, e.g., a mixed gas constituted of C_5F_8, O_2 and Ar is induced into the processing chamber 102 and vacuum drawing is implemented to sustain the atmosphere inside the processing chamber 102 at a specific level of reduced pressure, e.g., in a range of 45mTorr ~ 50mTorr. During this process, the flow rate ratio of C_5F_8 and O_2 is set within the range of $1 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.625 and, more desirably, within the range of $1.3 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.5. In addition, a rotating magnetic field of 100 Gauss ~ 200 Gauss is generated in the plasma area inside the processing chamber 102 by rotating the magnet 106. Next, when specific process conditions are achieved, a specific level of high-frequency power, e.g., 1500 W, with a specific frequency of, for instance, 13.56 MHz is applied from the high-frequency source 124 to the lower electrode 110 to cause a glow discharge to occur between the lower electrode 110 and the upper electrode 108. This dissociates the processing gas in the embodiment supplied into the processing chamber 102 to excite the plasma.

Since the processing gas in the embodiment is a mixed gas constituted of C_5F_8, O_2 and Ar, an atmosphere that is rich in carbon can be created inside the processing chamber 102 without having to add a carbon gas such as CO, and a carbon-containing film that is to constitute a protective film can be formed reliably at the inner wall surfaces of the contact holes 210. As a result, the CF (fluòrocarbon) type radicals which are the etching seed, are not allowed to reach the SiNx film 206 readily. Thus, the SiNx film 206 is protected to improve the selection ratio. In addition, the contact holes 210 achieving the desired uniform shape are formed in the minute space between the

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gates 202. It is to be noted that a photoresist film 212, which is to be used as an etching mask, is formed on the SiO_2 film 208 in the figure.

Embodiments

Next, embodiments of the etching method according to the present invention are explained. It is to be noted that since the embodiments below were all implemented by employing the etching apparatus 100 in the embodiment described above with specific conditions such as the composition of the processing gas and the gas flow rates varied as explained below to form the contact holes 210 between the gates 202 formed at the wafer W, the same reference numbers are assigned to components having roughly identical functions and structural features to preclude the necessity for repeated explanation thereof.

(A) Contact hole taper angle

First, in reference to Table 1, the taper angle of the contact holes 210 is explained. It is to be noted that the term "taper angle" refers to the angle (theta) formed by a side surface of the SiO_2 film 208 inside a contact hole 210 and the upper surface of the SiNx film 206 shown in FIG. 3(c) and FIG. 4 when the SiO_2 film 208 is etched by using the photoresist film 212 having a specific pattern formed therein as a mask, as illustrated in FIG. 3(a) presenting a view of the area over which the contact hole 210 is formed, FIG. 3(b) presenting a sectional view through a plane along line A-A in FIG. 3(a) and FIG. 3(c) presenting a sectional view through a plane along line B-B in FIG. 3(a).

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Table 1

embodiment	processing gas flow rates (sccm)			C_5F_8 / O_2 flow rate ratio	atmosphere pressure inside processing chamber (mTorr)	power (kW)	lower electrode temperature (°C)	contact hole taper angle (°)
	C_5F_8	O_2	A_r					
1	6.5	4	400	1.625	50	1.5	40	86.9
2	6	4	400	1.5	50	1.5	40	87.5
3	6.5	5	400	1.3	50	1.5	40	87.9
4	6.5	4	400	1.625	50	1.4	40	87.2
5	6.5	4	400	1.625	50	1.6	40	87.4
6	6.5	4	400	1.625	45	1.5	40	87.0
7	6.5	4	400	1.625	50	1.5	20	86.4
8	3.25	2	200	1.625	50	1.5	40	87.1
9	9.75	6	600	1.625	50	1.5	40	87.5
comparison example 1	18 (C_4F_8)	300 (CO)	380	-	40	1.5	40	86.3

(Table 1)

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The results presented in Table 1 were achieved by forming contact holes 210 at the SiO_2 film 208 under various etching conditions corresponding to embodiment 1 ~ embodiment 9 and comparison example 1 listed in Table 1.

Now, the difference between the shapes of the contact holes 210 formed through etching processes implemented using processing gasses constituted of C_5F_8, O_2 and Ar as described above and the shape of a contact hole resulting from an etching process implemented using the processing gas constituted of C_4F_8, CO and Ar in the prior art is explained by using a relational expression;

$c = a - (2b/\tan \text{theta})$... (1),

which expresses the relationship that the taper angle (theta) has with "a" representing the diameter of the upper portion of the contact hole 210 (hereafter referred to as the "etching diameter"), "b" representing the depth (height) of the contact hole 210 (hereafter referred to as the "etching film thickness") and "c" representing the diameter of the lower portion of the contact hole 210 (hereafter referred to as the "contact diameter") in FIG. 4.

Assuming that the etching process is implemented through ultra-fine machining with the etching diameter (a) at 0.25μm and the etching film thickness (b) at 1.5μm, the contact diameter "c" for the comparison example 1 is calculated to be 0.056μm and the average contact diameter for embodiment 1 ~ embodiment 9 is calculated to be 0.103μm by substituting the taper angle (theta) in expression (1) above, with 86.3° for comparison example 1 with the average 87.2° for embodiment 1 ~ embodiment 9 respectively. Using these results, the area ratio of the average bottom area of the contact hole 210 among the embodiments and the area of the contact hole 210 in the comparison example is calculated to be;

$(0.103/0.056)^2 = 3.38$.

Thus, only by changing the taper angle (theta) by as little as 0.9°, the area at the bottom of the contact hole 210 increases by as much as 3.38 times the bottom area in the prior art, to greatly contribute to a reduction in the contact resistance.

In addition, by setting the flow rate ratio of C_5F_8 and O_2 within the range of $1.3 \leq (C_5F_8$ flow rate/O_2 flow rate$) \leq 1.625$, setting the atmosphere pressure within the processing chamber 102 to 45 mTorr ~ 50mTorr and setting the temperature of the lower electrode 110 within the range of 20°C ~ 40°C as indicated in Table 1, the taper angle (theta) is increased compared to that achieved by using the processing gas in the prior art.

(B) Selection ratio

Next, the selection ratio is explained in reference to Table 2.

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Table 2

embodiment	processing gas flow rates (sccm)			C_5F_8 / O_2 flow rate ratio	atmosphere pressure inside processing chamber (mTorr)	power (kW)	lower electrode temperature (°C)	SiO_2 film / SiNx film selection ratio
	C_5F_8	O_2	A_r					
10	6	4	380	1.5	40	1.5	40	16.8
11	6	4	500	1.5	40	1.5	40	16.8
12	6	4	600	1.5	40	1.5	40	14.7
13	3	2	190	1.5	40	1.5	40	10.8
14	6	4	380	1.5	30	1.5	40	13.1
15	6	6	500	1	40	1.5	40	13.3
comparison example 2	18 (C_4F_8)	300 (CO)	380	-	40	1.5	40	11.2

(Table 2)

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The results presented in Table 2 were achieved by forming contact holes 210 at the SiO_2 film 208 under various etching conditions corresponding to embodiment 10 ~ embodiment 15 and comparison example 2 listed in Table 2. By performing the etching process using a processing gas containing C_5F_8 and O_2 with a flow rate ratio of C_5F_8 and O_2 set within the range of $1 \leq (C_5F_8$ flow rate/O_2 flow rate) ≤ 1.5 as indicated in the table, a selection ratio that is comparable to or better than that achieved in the etching process implemented by using the processing gas of the prior art constituted of C_4F_8, CO and Ar is achieved.

It is to be noted that the results presented in Table 3 were achieved in embodiment 16 ~ embodiment 19 implemented by using processing gasses constituted of C_5F_8, CO and Ar.

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(Table 3)

Table 3

embodiment	processing gas flow rates (sccm)			atmosphere pressure inside processing chamber (mTorr)	power (kW)	lower electrode temperature (°C)	SiO_2 film / SiNx film selection ratio
	C_5F_8	CO	A_r				
16	6	300	380	40	1.5	40	9.6
17	9	300	380	40	1.5	40	23.1
18	6	150	380	40	1.5	40	11.4
19	6	150	600	40	1.5	40	12.0

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While the invention has been particularly shown and described with respect to preferred embodiments thereof by referring to the attached drawings, the present invention is not limited to these examples and it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit, scope and teaching of the invention.

According to the present invention, in which an etching process is implemented by using a gas containing C_5F_8 that is degraded in a relatively short period of time in the atmosphere, a contribution is made toward the prevention of global warming since C_5F_8 does not induce the greenhouse effect even when it is directly released into the atmosphere without becoming degraded during the process. In addition, since O_2 is added to the processing gas, an etch stop is prevented, and an etching shape that is almost vertical is attained. Furthermore, the process can be implemented at a high selection ratio.

Industrial Applicability

The present invention may be adopted in an etching method, and, more specifically, in an etching method in which an SiO_2 film is formed at a workpiece placed within an airtight processing chamber by raising a processing gas induced into the processing chamber to plasma.

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What is claimed is;

1. An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said processing gas contains at least C_5F_8 and O_2; and

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1 \leq$ (flow rate of said C_5F_8/O_2) ≤ 1.5.

2. An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said processing gas contains at least C_5F_8 and O_2; and

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1.3 \leq$ (flow rate of said C_5F_8/flow rate of said O_2) ≤ 1.625.

3. An etching method according to claim 1 or 2, wherein;

the atmosphere pressure within said processing chamber is set to 45mTorr ~ 50mTorr.

4. An etching method according to claim 1 or 2, wherein;

the temperature of a stage on which said workpiece is mounted is set within the range of 20°C ~ 40°C.

5. An etching method according to claim 1 or 2, wherein;

said processing gas further contains an inert gas.

6. An etching method according to claim 5, wherein;

said inert gas is Ar.

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7. An etching method for etching an SiO_2 film formed at a workpiece placed inside an airtight processing chamber by raising a processing gas induced into said processing chamber to plasma, wherein;

said SiO_2 film is formed on an SiNx film formed at said workpiece; and

said processing gas contains at least C_5F_8 and O_2; and

wherein the flow rate of said C_5F_8 and said O_2 is set within the range of $1 \leq$ (flow rate of said C_5F_8/flow rate of said O_2) ≤ 1.625.

8. An etching method according to claim 7, wherein;

the flow rate ratio of said C_5F_8 and said O_2 is set within the range of $1.3 \leq$ (flow rate of said C_5F_8/flow rate of said O_2) ≤ 1.5.

9. An etching method according to claim 7, wherein;

the atmosphere pressure within said processing chamber is set to 45mTorr ~ 50mTorr.

10. An etching method according to claim 7, wherein;

the temperature of a stage on which said workpiece is mounted is set within the range of 20°C ~ 40°C.

11. An etching method according to claim 7, wherein;

said processing gas further contains an inert gas.

12. An etching method according to claim 11, wherein;

said inert gas is Ar.

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