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SPECIFICATION

Title of the Invention

ETCHING METHOD

Background of the Invention

The present invention relates to an etching method for etching a semiconductor substrate and more particularly to an etching method for controlling the processing shape of a wiring material used for LSIs and the like and specifically suitable for controlling a processing shape on the side surface of multi-layered or single-layered Al wiring.

Al wiring of LSIs mostly employs a three-layered structure comprising a TiN cap layer/an Al-Cu alloy/a TiN barrier layer. Dry etching with a BCl_3/Cl_2 gas has been widely employed for patterning this wiring. Since the etching rate of the Al-Cu alloy is higher than that of TiN in BCl_3/Cl_2 type etching, there have developed problems arising from the occurrence of not only side etching 305 on an Al-Cu alloy layer 303 but also notches 306 in the Al-Cu alloy layer 303 immediately below the TiN cap layer 304 as shown in Fig. 4 illustrating the sectional shape of conventional multi-layered Al wiring. In Fig. 3, reference numeral 302 denotes a TiN barrier layer; 301, an insulating film; and 300, a semiconductor substrate. In order to accomplish an excellent processing shape, the Al wiring has to be etched while the formation of a side wall protective film is being controlled. As described in, for example, "Journal of Vacuum Science & Technology, Vol. A10, No. 4, pp. 1232-1237", reduction of the notches 306 and anisotropic processing of the Al-Cu alloy layer 303 are attained by adding N2 to the BCl_3/Cl_2 gas so as to cope with the aforementioned problem. The side wall protective film by this means contains BN compounds resulting from the reaction of B from BCl_3 with N of the TiN layer, and the side wall protective film is more effective in controlling the shape than the conventional BCl_3/Cl_2 etching.

In cases where aluminum and aluminum alloy are subjected to plasma etching under reduced pressure, there is a technique of preventing the resist from being damaged, as also described in Japanese Patent Laid-Open No. 169140/1985, by applying a high-frequency electric power of 13.56 MHz to one electrode on the wafer mounting side out of a pair of electrodes, and adding a BCl_3+Cl_2 gas to a CH_4 gas so as to attain anisotropic etching at high speed with low electric power.

The above-described method of adding N_2 to the

BCl_3/Cl_2 etching gas is effective in reducing the notches 306 as the side wall protective film containing the BN compound is formed with a good efficiency. However, the side wall protective film containing the BN compound still involves a problem that because it has chemically strong bonds, it is not easily removable through the ashing step and the solution treatment carried out in succession to the etching step. Since the formation/deposition reaction of the BN compound occurs on the inner wall of the etching chamber, foreign matter tends to be produced in the etching apparatus and this may also be problematical when this method is applied to the mass-production of LSIs. Therefore, means for forming such a side wall protective film in place of the BN compound, which is strong and firm and easily removed after etching, becomes necessary.

In the case of plasma etching, the photoresist mask is also removed by the plasma and the photoresist thus removed sticks to the side to be etched, thus functioning as a side wall protective film. When a photoresist area is relatively smaller than an etching area like ASICs or logic circuits in recent years, for example, 30% or less smaller than the wafer area; in other words, when the area of an etching portion is 70% or greater, the absolute quantity of photoresist to be removed by the plasma is also small at the time of etching and the side wall protective film functions poorly, which makes it necessary to form a side wall protective film positively and separately.

Incidentally, the process described in Japanese Patent Laid-Open No. 169140/1985 is intended only to attain anisotropic etching at high speed with low electric power and to suppress damage to resist; however, the patent application above discloses nothing about the function of a side wall protective film.

Summary of the Invention

An object of the present invention is to provide an etching method for ensuring that in the case of a sample having an etching portion whose area is greater than a resist mask area, a desired etching shape is made obtainable.

Another object of the present invention is to provide an etching method for forming a side wall protective film, of which shape is easy to control at the time of etching, and which is readily removable after etching.

The object above can be accomplished by etching not only a sample patterned with a resist mask whose

area is 30% or less by the use of a processing gas which is ionized by supplying organic matter thereto but also a wafer whose etching area is 70% of or greater than the wafer area and which has an Al wiring film by a plasma to which organic matter is added.

The other object is accomplished by subjecting a side wall protective film formed of organic matter to the etching process, and in an etching method for etching multi-layered or single-layered Al wiring formed on a semiconductor substrate, by an arrangement in which a processing gas for etching is a mixed gas containing at least a gas selected from the group consisting of BCl_3, Cl_2, $CHC\ell_3$ or another CxHyClz (where each of x, y and z is 0-8), CxHyBrz (where each of x, y and z is 0-8) gases and at least a gas selected from the group consisting of Ar, Xe and Kr gases.

Brief Description of the Drawings

Figure 1 is a sectional view of a sample of an embodiment of the present invention.

Figure 2 is a schematic diagram of an etching apparatus of the embodiment of the present invention.

Figure 3 is a sectional view of an example of a semiconductor device produced by applying the present invention thereto.

Figure 4 is a sectional shape of conventional Al wiring.

Detailed Description of the Preferred Embodiments

According to the present invention, the etching chamber of a single-wafer etching apparatus is subjected to O_2 plasma cleaning so as to remove organic matter and then a mixed gas containing BCl_3, Cl_2, CH_4 and Ar as well as an organic resist film mask is used to form multi-layered Al wiring by plasma etching while the temperature of the wall surface of the chamber is being controlled so that the temperature remains in the predetermined range of 80 to 250°C. The mass flow rate ratios of the gases are such that BCl_3, CH_4 and Ar are 5-50, 1-20, 50-500 for Cl_2: 100, respectively. The O_2 plasma cleaning may be conducted for a continuous processing of a plurality of wafers or for a single-wafer processing. Since the organic components dissociated from CH_4 form a side wall protective film with a good efficiency, the occurrence of side etching and notches is suppressed, so that the etching of multi-layered Al wiring with an excellent processing shape is made possible. Moreover, the sputtering effect based on the addition of Ar leads to good controlling of the

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thickness of the side wall protective film, thus further improving the controllability of the processing shape. The side wall protective film formed in the above system is easily removable through the after-treatment. In addition, the maintainability of the etching apparatus is not affected by the addition of CH_4. When etching with the addition of an organic gas such as CH_4 and the like is applied to mass-production, change of processing shape with time usually occurs. However, the application of the present invention to mass production is made possible by effecting the removal of organic matter in the chamber by periodic O_2 cleaning and controlling the temperature of the wall surface of the chamber so as to improve the stability and reproducibility of the etching atmosphere.

An embodiment of the present invention will be described with reference to Fig. 1 showing a sectional view of a sample and Fig. 2 showing a schematic view of an etching apparatus. First, a sample is put into a sample exchange chamber of an etching apparatus. As shown in Fig. 1(a), the sample has an insulating film 101, a TiN barrier layer 102, an Al-Cu alloy layer 103 and a TiN cap layer 104, these layers being formed successively on a semiconductor substrate 100 in the aforementioned order; further, a resist film 105 having a desired pattern is formed on the TiN cap layer 104. In the etching apparatus, microwaves generated by a magnetron 200 are transmitted through a waveguide 201 and an introduction window 202 into an etching chamber 203, as shown in Fig. 2, wherein microwaves undergo electron-cyclotron resonance with the magnetic field generated by a magnetic field control coil 204 and a high density plasma is produced. A radio frequency power source 206 is connected to a sample holder 205, and an RF bias can be applied independently. An O_2 cleaning process is carried out so as to remove organic matter inside the etching chamber 203 before the sample is put into the etching chamber. The cleaning conditions are as follows: the O_2 flow rate is 100 sccm, the total gas pressure is 2Pa and the microwave output is 800 W.

After the temperature of the wall surface of the etching chamber 203 is so controlled as to be 100°C, the sample is transferred into the etching chamber, and the TiN cap layer 104, the Al-Cu alloy layer 103 and the TiN barrier layer 102 are serially etched with the resist film 105 as a pattern mask. The main etching conditions at this time in the case of (1) were as follows: the gas flow rates of BCl_3, Cl_2, and CH_4 were 20 sccm, 80 sccm,

and 4 sccm, respectively, the total gas pressure was 2Pa, the microwave output was 800 W, the RF power was 60 W and the substrate temperature was 40°C. The result obtained is shown in Fig. 1(b). The main etching conditions in the case of (2) were follows: the gas flow rates of BCl_3, Cl_2, CH_4 and Ar were 20 sccm, 80 sccm, 4 sccm and 96 sccm, respectively and the total gas pressure was 3Pa. The result obtained is shown in Fig. 1(c). In this case, the other etching conditions were the same as those shown in Fig. 1(b). Moreover, control of the gas flow rates was respectively effected under mass flow control by the use of a flow rate controller 207a-207d. Incidentally, even after the etching of the TiN barrier layer 102 judged by a plasma emission monitor was completed, over-etching was continued successively for 15 seconds.

In the case of (1), it is found from Fig. 1(b) that the sectional shape of the sample is such that the side wall protective film is formed and its etching shape is controllable. In this case, the side wall protective film is formed of the organic components C, CH contained in the plasma due to the CH_4 gas and the components become equal to those of the resist mask formed of organic matters. Therefore, the side wall protective film is removable by the same process as resist ashing. In this case, the sectional shape is forwardly tapered (i.e., tapered in a sectional shape expanding downward as shown in Fig. 1(b)) because the side wall protective film is too thick owning to the CH_4 gas. In other words, the organic components C, CH contained in the plasma adhere as a side wall protective film and expand in the tapered form at the time of etching owning to the excessive organic components.

The thickness of the side wall protective film can be controlled by changing the quantity of CH_4, and vertical etching is possible by optimizing the quantity. This processing is effectively usable when, for example, the area of an etching portion is greater than that of a patterned resist mask as in the case of an ASIC or a logic circuit and particularly when the area ratio of the resist mask to the etching portion is 3 : 7. More specifically, part of the resist mask is also etched by sputtering because of the action of ions within the plasma at the time of plasma etching when the area of the resist mask is 30% or greater, for example, when it is 40%, and part of the resist thus etched by sputtering adheres to the etched wall surface and functions as a side wall protective film to some extent. When the area of the resist mask is 30% or less, however, the quantity

of resist to be etched by sputtering is small and consequently the resist hardly functions as a side wall protective film. In the case of a sample in which the area of its resist mask is small, a side wall protective film can be effectively formed by supplying into the plasma the organic components C, CH equal to those contained in the resist mask formed using the CH_4 gas.

Since the vertical etching can be carried out by minimizing the side wall protective film, further, a wiring film of a multilayer structure of a fine pattern having a line width of 0.5 μm or less; a pattern width of 0.5 μm or less and a depth of 0.5 μm or greater can be etched as shown in Fig. 3(a). Thus, a semiconductor device which is structured as shown in Fig. 3(b) can be manufactured by forming an insulating film on the portion etched into a fine pattern.

In the case of (2), further, an Ar gas is added to the process in the case (1) as shown in Fig. 1(c) and the vertical etching is carried out. More specifically, it is considered that the side surface of each of the TiN cap layer 104, the Al-Cu alloy layer 103 and the TiN barrier layer 102 is processed vertically because the thickness of the side wall protective film is controlled by the sputtering property of Ar ions during the etching operation when the Ar gas is added. Even in this case, the etching side surface is covered with by-products of etching, that is, a side wall protective film 106 formed of organic matter such as C, CH and the like. Therefore, the side wall protective film 106 can easily be removed by, for example, the resist ashing simultaneously with the removal of the resist mask through post-processing after the etching process.

According to the process in the case of (2), the addition of the Ar gas makes the control of the thickness of the side wall protective film easier than in the case of (1). In other words, the quantity of CH_4 gas is small from the beginning in the case of (1) and the quantity is difficult to adjust. In the case of (2), on the other hand, an optimum flow rate can readily be determined in agreement with the etching shape as the quantity of Ar gas is large, whereby a desired etching shape is easily obtainable. Thus, the process in the case of (2) is suitable for use in etching a sample with a small resist mask, for example, a resist mask of small area (30% or less of the wafer area), a thin resist mask (1 μm or thinner), a resist mask which has so large a resist selection ratio that the resist is hardly removed.

In this embodiment of the present invention, it is possible to form a multi-layered Al wiring of good shape

by etching without forming notches in the Al-Cu alloy layer 103 right below the TiN cap layer 104. Further, the resist film 105 and the side wall protective film 106 are made easily removable in the post etching process. Moreover, the change of the processing shape hardly occurs even when 25 samples are continuously etched following the O_2 cleaning process. In other words, the present invention can provide an etching method suitable for mass fabrication of the multi-layered Al wiring without change in the processing shape with time by carrying out periodically the O_2 cleaning process and besides the maintainability of the apparatus remains unaffected. Although the effect of an ordinary continuous processing of one lot of 25 samples has been confirmed, the continuous processing of more than 25 samples can be made by optimizing various conditions. Needless to say, the present invention is effective in continuously processing samples of not greater than 25 sheets, for example, 1, 5 or 10 sheets.

Although the temperature of the inner wall of the etching chamber of this embodiment of the present invention is so controlled as to be 100°C, the similar effect is obtainable at any temperature within the range of 80 to 250°C by properly adjusting the $BCl_3/Cl_2/CH_4/Ar$ flow rate ratios. The guideline for the suitable mass to flow rate ratio are 50 to 50 for BCl_3, 1 to 20 for CH_4 and 50 to 500 for Ar with respect to 100 for Cl_2. In this embodiment described above, the CH_4 and Ar gases are added to BCl_3/Cl_2. Similar effects may be expected by using a mixed gas containing at least one of CxHyClz (where each of x, y and z is 0-8) and CxHyBrz (where each of x, y and z is 0-8) and at least one of Ar, Xe and Kr; however, it has been found out from the experiment results that the addition of the CH_4 and Ar gases is effective.

Although BCl_3/Cl_2 is used as the etching gas in this embodiment of the present invention, another chlorine gas such as $SiCl_4$ or CCl_4 may be used effectively.

Although the TiN/Al-Cu alloy layer/TiN multilayer film is etched in this embodiment of the present invention, the upper and lower films of the Al-Cu alloy layer may be a Ti/TiN film, a TiW film or a W film. Similar effects can be obtained in the case of an Al single-layered film (single-layered film of Al or Al alloy film) other than the multilayer film.

Although a description has been given of the use of an ECR type etching apparatus, another plasma etching apparatus such as an ICP (Inductively Coupled Plasma)

etching apparatus may be used produces similar effects.

The present invention has the effect that in the case of a sample having the etching portion whose area is greater than the resist mask area, a desired etching shape is made obtainable.

Moreover, the present invention has the effect of forming the side wall protective film, of which shape is easy to control at the time of etching, and which is readily removable after etching.

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What is claimed is

1. An etching method for etching a sample patterned with a resist mask whose area is 30% or less by the use of a processing gas which is ionized by supplying organic matter.

2. An etching method as claimed in claim 1, wherein said resist mask has a film thickness of 1 μm or less.

3. An etching method for etching a wafer whose etching area is 70% of or greater than the wafer area and which has an Al wiring film using a plasma to which organic matter is added.

4. An etching method as claimed in claim 3, wherein said organic contains at least C and H.

5. An etching method for etching multi-layered or single-layered Al wiring formed on a semiconductor substrate, characterized in that a processing gas for etching is a mixed gas containing at least one selected from the group consisting of BCl_3, Cl_2, $CHC\ell_3$ or other CxHyClz (where each of x, y and z is 0-8), CxHyBrz (where each of x, y and z is 0-8) gases and at least one selected from the group consisting of Ar, Xe and Kr gases.

6. An etching method for etching a wiring material as claimed in claim 5, wherein said multi-layered or single-layered Al wiring is etched using a plasma by controlling the temperature of the wall surface of the etching chamber so as to set the temperature within a predetermined range of 80 to 250°C and by using a mixed gas containing at least one selected from the group consisting of BCl_3, Cl_2 and $CHC\ell_3$ or another CxHyClz (where each of x, y and z is 0-8), CxHyBrz (where each of x, y and z is 0-8) gases and at least one selected from the group consisting of Ar, Xe and Kr gases.

7. An etching method for etching a wiring material as claimed in claim 5, wherein the mass flow rate ratio of BCl_3, Cl_2 and $CHC\ell_3$ or another CxHyClz (where each of x, y and z is 0-8) in said mixed gas is 5-50, 1-20 or 50-500 respectively for BCl_3 and $CHC\ell_3$ or another CxHyClz (where each of x, y and z is 0-8) or CxHyBrz (where each of x, y and z is 0-8) and Ar, Xe, Kr gas with Cl_2 being 100, and said multi-layered or single-layered Al wiring is etched by using an organic resist film as a mask.

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8. An etching method for etching a wiring material as claimed in either claim 5 or claim 6, wherein said multi-layered or single-layered Al wiring on a plurality of semiconductor substrates is continuously etched after the inside of said etching chamber for conducting etching is cleaned by discharge of a gas containing O_2.

9. An etching method for etching a wiring material as claimed in claim 5, wherein said multi-layered Al wiring is produced by forming an Al-Cu alloy layer and a barrier metal layer of any one of a TiN film, a TiW film, a W film and a Ti film.

10. A sample processing method comprising the steps of etching a sample having an Al wiring film and a resist mask patterned on said wiring film using a plasma of a mixed gas containing BCl_3, Cl_2, CH_4, Ar and removing a side wall protective film formed by said etching after the etching.

11. A sample processing method as claimed in claim 10, wherein the inside of an etching chamber in which said etching has been conducted is cleaned with an O_2 plasma.

12. A semiconductor device comprising an insulating film formed in an etching portion of a wiring film of multilayer structure having an Al wiring film which is etched into a shape having a line width of 0.5 μm or less; a pattern width of 0.5 μm or less and a depth of 0.3 μm or greater.

13. A semiconductor device as claimed in claim 12, wherein said wiring film of multilayer structure comprises an Al-Cu alloy film and a TiN film.

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