Description

Title of Invention: ETCHING METHOD AND PLASMA PROCESSING SYSTEM

Technical Field

[0001]

Exemplary embodiments of the present disclosure relate to an etching method and a plasma processing system.

Background Art

[0002]

Patent Literature 1 discloses a technique related to an etching method in which a shape after etching is an anisotropic shape and the etching method is selective to a silicon oxide film.

Citation List

Patent Literature

[0003]

Patent Literature 1: Japanese Patent Application Laid-Open No. 7-029875

Summary of Invention

Technical Problem

[0004]

The present disclosure provides a technique for improving etching processability.

Solution to Problem

[0005]

In one exemplary embodiment of the present disclosure, there is

provided an etching method including: (a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film; (b) etching the etching target film with plasma generated from a first processing gas including Cl_2 gas; and (c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

Advantageous Effect of Invention

[0006]

According to one exemplary embodiment of the present disclosure, it is possible to provide a technique for improving etching processability.

Brief Description of Drawings

[0007]

[Figure 1] Figure 1 is a diagram illustrating a configuration example of a plasma processing system.

[Figure 2] Figure 2 is a diagram illustrating a configuration example of an inductively coupled plasma processing apparatus.

[Figure 3] Figure 3 is a flowchart illustrating an example of the present etching method.

[Figure 4] Figure 4 is a diagram illustrating an example of a cross-sectional structure of a substrate W prepared in a step ST1.

[Figure 5] Figure 5 is a diagram illustrating an example of a cross-sectional

structure of the substrate W after a step ST2 is executed.

[Figure 6] Figure 6 is a diagram illustrating an example of a cross-sectional structure of the substrate W after a step ST3 is executed.

[Figure 7] Figure 7 is a flowchart illustrating another example of the present etching method.

[Figure 8] Figure 8 is a diagram illustrating a measurement example of a footing width and a bottom angle in the cross-sectional structure of the substrate W after the step ST2 is executed.

Description of Embodiments

[0008]

Hereinafter each embodiment of the present disclosure will be described.

[0009]

In one exemplary embodiment, there is provided an etching method including: (a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film; (b) etching the etching target film with plasma generated from a first processing gas including Cl_2 gas; and (c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[0010]

In one exemplary embodiment, the (b) includes forming a recess in the

etching target film, a footing being formed at a bottom portion of the recess, and the (c) includes removing at least a part of the footing.

[0011]

In one exemplary embodiment, the first processing gas does not include HCl gas or includes HCl gas at a flow rate lower than a flow rate of the HCl gas in the second processing gas.

[0012]

In one exemplary embodiment, the second processing gas does not include Cl_2 gas or includes Cl_2 gas at a flow rate lower than a flow rate of the Cl_2 gas in the first processing gas.

[0013]

In one exemplary embodiment, the (c) includes further etching, in a horizontal direction, a recess formed in the etching target film by the etching of the (b).

[0014]

In one exemplary embodiment, a width of a bottom portion of the recess at an end of the (c) is larger than a width of a bottom portion of the recess at an end of the (b).

[0015]

In one exemplary embodiment, in the (c), an etching amount of a bottom portion of the recess in the horizontal direction is larger than an etching amount of a portion other than the bottom portion of the recess in the horizontal direction.

[0016]

In one exemplary embodiment, switching from the (b) to the (c) is performed after at least a part of the underlying film is exposed or immediately before at least a part of the underlying film is exposed.

[0017]

In one exemplary embodiment, the (b) and the (c) are alternately repeated.

[0018]

In one exemplary embodiment, the (b) and the (c) are simultaneously executed.

[0019]

In one exemplary embodiment, at least one of the first processing gas and the second processing gas further includes an oxygen-containing gas.

[0020]

In one exemplary embodiment, the oxygen-containing gas includes at least one gas selected from the group consisting of O_2, CO, CO_2, SO_2, and COS.

[0021]

In one exemplary embodiment, a temperature of the substrate or the substrate support in the (c) is higher than a temperature of the substrate or the substrate support in the (b).

[0022]

In one exemplary embodiment, in the (b) and the (c), a bias signal is supplied to the substrate support, and a level of the bias signal in the (c) is higher than a level of the bias signal in the (b).

[0023]

In one exemplary embodiment, at least one of the first processing gas and the second processing gas further includes a noble gas.

[0024]

In one exemplary embodiment, the noble gas includes at least one selected from the group consisting of Ar and He.

[0025]

In one exemplary embodiment, at least one of the first processing gas and the second processing gas further includes at least one selected from the group consisting of a bromine-containing gas and a fluorine-containing gas.

[0026]

In one exemplary embodiment, there is provided an etching method including: (a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film; (b) etching the etching target film with plasma generated from a first processing gas including a chlorine-containing gas other than HCl gas; and (c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[0027]

In one exemplary embodiment, there is provided an etching method including: (a) preparing a substrate on a substrate support, the substrate

including an underlying film and an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, the etching target film including a recess, a footing being formed at a bottom portion of the recess; and (b) removing at least a part of the footing with plasma generated from a processing gas including HCl gas.

[0028]

In one exemplary embodiment, there is provided a plasma processing system including: a chamber; a substrate support provided in the chamber; a gas supply configured to supply a first processing gas and a second processing gas into the chamber; a plasma generator configured to generate plasma in the chamber; and a controller, in which the controller is configured to use the gas supply and the plasma generator to execute control including: (a) control of preparing a substrate on the substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film; (b) control of etching the etching target film with plasma generated from the first processing gas including Cl_2 gas; and (c) control of further etching the etching target film with plasma generated from the second processing gas including HCl gas.

[0029]

Each embodiment of the present disclosure will be described in detail

below with reference to the drawings. Furthermore, identical or similar elements in each drawing are denoted by the same reference numeral, and redundant explanations are omitted. Unless otherwise specified, positional relationships of up, down, left, right, and the like will be explained based on positional relationships illustrated in the drawings. The dimensional ratios illustrated in the drawings do not represent actual ratios, and actual ratios are not limited to those illustrated.

[0030] <Example of Plasma Processing System>

Figure 1 is a diagram illustrating a configuration example of a plasma processing system. In one embodiment, the plasma processing system includes a plasma processing apparatus 1 and a controller 2. The plasma processing system is one example of a substrate processing system and the plasma processing apparatus 1 is one example of a substrate processing apparatus. The plasma processing apparatus 1 includes a plasma processing chamber 10, a substrate support 11 and a plasma generator 12. The plasma processing chamber 10 has a plasma processing space. Further, the plasma processing chamber 10 has at least one gas supply port for supplying at least one processing gas into the plasma processing space, and at least one gas exhaust port for exhausting the gas from the plasma processing space. The gas supply port is connected to the gas supply 20, which will be described below, and the gas exhaust port is connected to the exhaust system 40, which will be described below. The substrate support 11 is placed in the plasma processing space and has a substrate support surface for supporting a substrate.

[0031]

The plasma generator 12 is configured to generate plasma from at least one processing gas supplied into the plasma processing space. Plasma generated in the plasma processing space may be Capacitively Coupled Plasma (CCP), Inductively Coupled Plasma (ICP), Electron-Cyclotron-resonance (ECR) plasma, Helicon Wave Plasma (HWP), Surface Wave Plasma (SWP), or the like. Furthermore, various types of plasma generators, including an Alternating Current (AC) plasma generator and a Direct Current (DC) plasma generator, may be used. In one embodiment, an AC signal (AC power) used in the AC plasma generator has a frequency in the range of 100 kHz to 10 GHz. Accordingly, the AC signal includes a Radio Frequency (RF) signal and a microwave signal. In one embodiment, the RF signal has a frequency in the range of 100 kHz to 150 MHz.

[0032]

The controller 2 processes computer-executable instructions that cause the plasma processing apparatus 1 to execute various steps described in the present disclosure. The controller 2 may be configured to control each element of the plasma processing apparatus 1 to execute the various steps described herein. In one embodiment, a part or all of the controller 2 may be included in the plasma processing apparatus 1. The controller 2 may include, for example, a computer 2a. The computer 2a may include, for example, a processor (central processing unit (CPU)) 2a1, a storage 2a2, and a communication interface 2a3. The processor 2a1 may be configured to read a program from the storage 2a2 and perform various control operations

by executing the read program. This program may be stored in the storage 2a2 in advance, or may be acquired via a medium when needed. The acquired program is stored in the storage 2a2 and read from the storage 2a2 and executed by the processor 2a1. The medium may be various storage media readable by the computer 2a, or may be a communication line connected to the communication interface 2a3. The storage 2a2 may include Random Access Memory (RAM), Read Only Memory (ROM), Hard Disk Drive (HDD), Solid State Drive (SSD), or a combination thereof. The communication interface 2a3 may communicate with the plasma processing apparatus 1 via a communication line such as a Local Area Network (LAN).

[0033]

The following describes a configuration example of an inductively coupled plasma processing apparatus as an example of a plasma processing apparatus 1. Figure 2 is a diagram illustrating the configuration example of the inductively coupled plasma processing apparatus. The inductively coupled plasma processing apparatus 1 includes a plasma processing chamber 10, a gas supply 20, a power source 30, and an exhaust system 40. The plasma processing chamber 10 includes a dielectric window 101. Furthermore, the plasma processing apparatus 1 includes a substrate support 11, a gas introduction unit, and an antenna 14. The substrate support 11 is placed in the plasma processing chamber 10. The antenna 14 is placed on or above the plasma processing chamber 10 (that is, on or above the dielectric window 101). The plasma processing chamber 10 has a plasma processing space 10s defined by the dielectric window 101, a side wall 102 of

the plasma processing chamber 10, and the substrate support 11. The plasma processing chamber 10 is grounded.

[0034]

The substrate support 11 includes a main body 111 and a ring assembly 112. The main body 111 has a central region 111a for supporting the substrate W and an annular region 111b for supporting the ring assembly 112. A wafer is an example of the substrate W. The annular region 111b of the main body 111 surrounds the central region 111a of the main body 111 in a plan view. The substrate W is placed on the central region 111a of the main body 111 and the ring assembly 112 is placed on the annular region 111b of the main body 111 to surround the substrate W on the central region 111a of the main body 111. Accordingly, the central region 111a is also referred to as a substrate support surface for supporting the substrate W, and the annular region 111b is also referred to as a ring support surface for supporting the ring assembly 112.

[0035]

In one embodiment, the main body 111 includes a base 1110 and an electrostatic chuck 1111. The base 1110 includes a conductive member. The conductive member of the base 1110 may function as a bias electrode. The electrostatic chuck 1111 is placed on the base 1110. The electrostatic chuck 1111 includes a ceramic member 1111a and an electrostatic electrode 1111b placed in the ceramic member 1111a. The ceramic member 1111a has a central region 111a. In one embodiment, the ceramic member 1111a also has an annular region 111b. Other members that surround the

electrostatic chuck 1111, such as an annular electrostatic chuck and an annular insulating member, may have the annular region 111b. In this case, the ring assembly 112 may be placed on the annular electrostatic chuck or the annular insulating member, or may be placed on both the electrostatic chuck 1111 and the annular insulating member. In addition, an RF or DC electrode may be placed in the ceramic member 1111a, and in this case, the RF or DC electrode functions as a bias electrode. Both the conductive member of the base 1110 and the RF or DC electrode may function as two bias electrodes.

[0036]

The ring assembly 112 includes one or more annular members. In one embodiment, the one or more annular members include one or more edge rings and at least one cover ring. The edge ring is formed of a conductive material or an insulating material, and the cover ring is formed of an insulating material.

[0037]

Further, the substrate support 11 may include a temperature control module configured to adjust at least one of the electrostatic chuck 1111, the ring assembly 112, and the substrate to a target temperature. The temperature control module may include a heater, a heat transfer medium, a flow path 1110a, or a combination thereof. A heat transfer fluid, such as brine or gas, flows through the flow path 1110a. In one embodiment, the flow path 1110a is formed in the base 1110, and one or more heaters are placed in the ceramic member 1111a of the electrostatic chuck 1111. Further, the substrate support 11 may include a heat transfer gas supply configured to

supply the heat transfer gas between a back surface of the substrate W and the central region 111a.

[0038]

The gas introduction unit is configured to introduce at least one processing gas from the gas supply 20 into the plasma processing space 10s. In one embodiment, the gas introduction unit includes a center gas injector (CGI) 13. The center gas injector 13 is placed above the substrate support 11 and is attached to a central opening formed in the dielectric window 101. The center gas injector 13 has at least one gas supply port 13a, at least one gas flow path 13b, and at least one gas introduction port 13c. The processing gas supplied to the gas supply port 13a passes through the gas flow path 13b and is introduced into the plasma processing space 10s from the gas introduction port 13c. In addition to or instead of the center gas injector 13, the gas introduction unit may also include one or more side gas injectors (SGIs) attached to one or more openings formed in the side wall 102.

[0039]

The gas supply 20 may include at least one gas source 21 and at least one flow rate controller 22. In one embodiment, the gas supply 20 is configured to supply at least one processing gas from the respective corresponding gas sources 21 to the gas introduction unit via the respective corresponding flow rate controllers 22. Each flow rate controller 22 may include, for example, a mass flow controller or a pressure-controlled flow rate controller. Further, the gas supply 20 may include at least one flow rate modulation device that modulates or pulses a flow rate of at least one

processing gas.

[0040]

The power source 30 includes an RF power source 31 coupled to the plasma processing chamber 10 via at least one impedance matching circuit. The RF power source 31 is configured to supply at least one RF signal (RF power) such as a source RF signal and a bias RF signal to at least one bias electrode and the antenna 14. As a result, plasma is formed from at least one processing gas supplied into the plasma processing space 10s. Accordingly, the RF power source 31 may function as at least a part of the plasma generator 12. Further, by supplying a bias RF signal to the at least one bias electrode, a bias potential is generated in the substrate W, making it possible to draw ions in the formed plasma into the substrate W.

[0041]

In one embodiment, the RF power source 31 includes a first RF generator 31a and a second RF generator 31b. The first RF generator 31a is configured to be coupled to the antenna 14 via at least one impedance matching circuit and to generate a source RF signal (source RF power) for plasma generation. In one embodiment, the source RF signal has a frequency in the range of 10 MHz to 150 MHz. In one embodiment, the first RF generator 31a may be configured to generate multiple source RF signals having different frequencies. The generated one or more source RF signals are supplied to the antenna 14.

[0042]

The second RF generator 31b is configured to be coupled to at least

one bias electrode via at least one impedance matching circuit to generate the bias RF signal (bias RF power). A frequency of the bias RF signal may be the same as or different from a frequency of the source RF signal. In one embodiment, the bias RF signal has a lower frequency than the frequency of the source RF signal. In one embodiment, the bias RF signal has a frequency in the range of 100 kHz to 60 MHz. In one embodiment, the second RF generator 31b may be configured to generate multiple bias RF signals having different frequencies. The generated one or more bias RF signals are supplied to at least one bias electrode. Further, in various embodiments, at least one of the source RF signal and the bias RF signal may be pulsed.

[0043]

Further, the power source 30 may include a DC power source 32 coupled to the plasma processing chamber 10. The DC power source 32 includes a bias DC generator 32a. In one embodiment, the bias DC generator 32a is configured to be connected to at least one bias electrode to generate a bias DC signal. The generated bias DC signal is applied to at least one bias electrode.

[0044]

In various embodiments, the bias DC signal may be pulsed. In this case, a sequence of voltage pulses is applied to at least one bias electrode based on the DC. The voltage pulse may have a pulse waveform of a rectangle, a trapezoid, a triangle or a combination thereof. In one embodiment, a waveform generator for generating a sequence of voltage

pulses from the DC signal is connected between the bias DC generator 32a and at least one bias electrode. Accordingly, the bias DC generator 32a and the waveform generator constitute a voltage pulse generator. The voltage pulse may have a positive polarity or a negative polarity. Further, the sequence of the voltage pulses may include one or more positive voltage pulses and one or more negative voltage pulses in one cycle. The bias DC generator 32a may be provided in addition to the RF power source 31, or may be provided instead of the second RF generator 31b.

[0045]

The antenna 14 includes one or more coils. In one embodiment, the antenna 14 may include an outer coil and an inner coil coaxially placed. In this case, the RF power source 31 may be connected to both the outer coil and the inner coil, or may be connected to either the outer coil or the inner coil. In the former case, the same RF generator may be connected to both the outer coil and the inner coil, or separate RF generators may be connected to the outer coil and the inner coil separately.

[0046]

The exhaust system 40 may be connected, for example, to a gas exhaust port 10e provided at a bottom portion of the plasma processing chamber 10. The exhaust system 40 may include a pressure adjusting valve and a vacuum pump. The pressure in the plasma processing space 10s is adjusted by the pressure adjusting valve. The vacuum pump may include a turbo molecular pump, a dry pump, or a combination thereof.

[0047] <Example of Etching Method>

Figure 3 is a flowchart illustrating an etching method (hereinafter, also referred to as a "present etching method") according to an exemplary embodiment. The present etching method includes a step ST1 of preparing a substrate, a step ST2 of performing first etching, and a step ST3 of performing second etching. Each step may be executed using any one of the plasma processing systems (see Figures 1 and 2) described above, or may be executed using two or more of the plasma processing systems. For example, the present etching method may be executed by the plasma processing system illustrated in Figure 1. Hereinafter, a case where the controller 2 controls each unit of the plasma processing apparatus 1 to execute the present etching method on the substrate W will be described as an example.

[0048] (Step ST1: Preparation of Substrate)

In the step ST1, the substrate W is prepared on the substrate support 11. The substrate W includes an etching target film EF and a mask MK disposed on the etching target film EF. The mask MK includes at least one opening OP that exposes the etching target film EF. The substrate W may be used for manufacturing a semiconductor device. The semiconductor device includes, for example, a memory device such as a DRAM and a 3D-NAND flash memory, and a logic device.

[0049]

Figure 4 is a diagram illustrating an example of a cross-sectional structure of the substrate W prepared in the step ST1. As illustrated in Figure 4, the substrate W may be configured by stacking the etching target

film EF and the mask MK on any underlying film UF in this order.

[0050]

The underlying film UF is, in an example, a silicon wafer, or an organic film, a dielectric film, a metal film, a semiconductor film, or the like formed on the silicon wafer. As an example, the dielectric film may include SiN or the like. As an example, the metal film may include TiN, TaN, W, WSi, WC, or the like. The underlying film UF may be configured by stacking multiple films.

[0051]

The etching target film EF may include, for example, at least one selected from the group consisting of silicon, germanium, and a metal. The etching target film may be, for example, a silicon-containing film, a germanium-containing film, or a metal-containing film. The silicon-containing film includes, for example, a spin-on-glass (SOG) film, an Si-containing anti-reflective film (SiARC), a silicon oxide film, a silicon nitride film, a silicon oxynitride film, a silicon carbide film, a silicon carbonitride film, a polycrystalline silicon film, an amorphous silicon film, and the like. In one embodiment, the silicon-containing film may include at least one element selected from the group consisting of H, P, N, and B. The germanium-containing film includes, for example, a germanium film or a silicon germanium film. The metal-containing film includes, for example, a film including at least one selected from the group consisting of tungsten, hafnium, tin, and titanium. As an example, the etching target film EF may be a conductive film. The etching target film EF and the underlying film UF constituting the substrate W may be formed by a CVD method, an atomic layer deposition method

(hereinafter referred to as the "ALD method"), a spin coating method, or the like, respectively. The etching target film EF and the underlying film UF may be flat films, respectively, or may be films having irregularities.

[0052]

The mask MK is formed on the etching target film EF and includes at least one opening OP. The mask MK may include at least one selected from a silicon-containing film, a carbon-containing film, and a metal-containing film. As an example, the silicon-containing film may be a silicon oxide film, a silicon nitride film, a silicon carbonitride film, a polycrystalline silicon film, or a carbon-containing silicon film. As an example, the silicon oxide film may be tetraethoxysilane (TEOS). The silicon-containing film may be doped with an element such as phosphorus, boron, or nitrogen. When the etching target film EF is the silicon-containing film, the mask MK is a silicon-containing film different from the etching target film EF. As an example, the carbon-containing film may be a spin-on carbon (SOC) film, an amorphous carbon (ACL) film, a photoresist film, a tungsten carbide film, or a boron carbide film. As an example, the metal-containing film may be a film including at least one metal selected from the group consisting of tungsten, molybdenum, ruthenium, titanium, tin, and aluminum. In one embodiment, the mask MK may be a single-layer mask consisting of one layer or may be a multilayer mask consisting of two or more layers. When the mask MK is the multilayer mask, the mask MK may include a silicon nitride film and a silicon oxide film, and the silicon oxide film may be formed to be thicker than the silicon nitride film. As an example, the mask MK may be a multilayer mask including a SiN

film and a TEOS film in this order. In one embodiment, the mask MK may be a photoresist. In one embodiment, the mask MK may be a photoresist exposed by extreme ultra violet (hereinafter referred to as "EUV") light. As an example, the metal-containing resist may be exposed by EUV. In one embodiment, the mask MK may be a chemically amplified resist (hereinafter referred to as the "CAR"). As an example, the CAR may be exposed by EUV.

[0053]

The opening OP may have any shape in a plan view of the substrate W, that is, when the substrate W is viewed in a direction from top to bottom in Figure 4. The shape may be, for example, a circle, an ellipse, a rectangle, a line, or a shape in which one or more of these are combined. The mask MK may have multiple side walls, and the multiple side walls may define multiple openings OP. The multiple openings OP may each have a linear shape and may be arranged at regular intervals to form a line and space pattern. In addition, the multiple openings OP may each have a hole shape and may form an array pattern. In one embodiment, a dimension of the opening OP may be 100 nm or less, 50 nm or less, or 30 nm or less. In one embodiment, the opening OP may be formed by lithography. As an example, the opening OP may be formed by exposing and developing a photoresist formed on the etching target film EF. When an EUV resist is used as the photoresist, the exposure may be EUV exposure using an EUV exposure apparatus. In addition, the development may be dry development or wet development.

[0054]

In the step ST1, the substrate W may be prepared in the plasma processing chamber 10 (hereinafter also referred to as the "chamber 10"). In one embodiment, the substrate W is transported into the chamber 10 by a transport arm, placed on the substrate support 11 by a lifter, and adsorbed and held by suction on the substrate support 11, for example, as illustrated in Figure 2.

[0055] (Step ST2: First Etching)

In the step ST2, the etching target film EF is etched. In the step ST2, the etching target film EF is etched with plasma generated from the first processing gas via the mask MK. The first processing gas includes a chlorine-containing gas. In one embodiment, the chlorine-containing gas may include Cl_2 gas, HCl gas, $CHCl_3$, and the like. In one embodiment, the first processing gas may be the Cl_2 gas. In one embodiment, the first processing gas does not include the HCl gas. In one embodiment, the first processing gas includes the chlorine-containing gas other than the HCl gas. The step ST2 includes supplying the first processing gas to the chamber 10 and generating plasma from the first processing gas.

[0056]

In the step ST2, the first processing gas is supplied into the chamber 10. The first processing gas may be, for example, supplied into the chamber 10 from the gas supply 20 via the gas introduction port 13c of the center gas injector 13. In one embodiment, the first processing gas may include at least one selected from the group consisting of an oxygen-containing gas, a bromine-containing gas, a fluorine-containing gas, and a noble gas. As an

example, the oxygen-containing gas may include at least one gas selected from the group consisting of O_2, CO, CO_2, SO_2, and COS. As an example, the noble gas may include at least one selected from the group consisting of Ar and He. As an example, the bromine-containing gas may include HBr. As an example, the fluorine-containing gas may include a CHF-based gas such as CHF_3 gas, CH_2F_2 gas, CH_3F gas, $C_3H_2F_4$ gas, $C_4H_2F_6$ gas, C_2HF_5 gas, $C_2H_2F_4$ gas, $C_2H_3F_3$ gas, $C_2H_4F_2$ gas, C_3HF_7 gas, $C_3H_2F_2$ gas, $C_3H_2F_6$ gas, $C_3H_3F_5$ gas, $C_4H_5F_5$ gas, $C_4H_2F_8$ gas, $C_5H_2F_6$ gas, $C_5H_2F_{10}$ gas, and $C_5H_3F_7$ gas. A pressure in the chamber 10 may be adjusted to a set pressure. The set pressure may be 15 mTorr or more and 200 mTorr or less.

[0057]

Next, plasma is generated from the first processing gas in the chamber 10. In one embodiment, the source RF signal is supplied to the antenna 14, and as a result, an RF electric field is generated between the antenna 14 and the substrate support 11, and plasma is generated from the processing gas in the plasma processing space 10s. At this time, a bias signal may be supplied to the substrate support 11. The bias signal may be the bias RF signal supplied from the RF power source 31 or the bias DC signal supplied from the DC power source 32. In this case, a bias potential is generated between plasma and the substrate W. Active species such as ions and radicals in plasma are attracted to the substrate W, and the etching target film EF is etched by the active species. In one embodiment, the bias signal may have an electric power of 300 W or more and 1500 W or less, and may have an electric power of 300 W or more and 900 W or less.

[0058]

Figure 5 is a diagram illustrating an example of a cross-sectional structure of the substrate W after the step ST2 is executed. In the step ST2, the mask MK functions as a mask. That is, a portion of the etching target film EF exposed to the opening OP is selectively etched by the active species in plasma. As a result, as illustrated in Figure 5, a recess RC is formed. In the step ST2, the first processing gas includes a chlorine-containing gas, so that a retained edge (footing F) tends to be generated in the vicinity of a bottom portion BT of the recess RC while a decrease of an etching rate tends to be suppressed. The footing F is a portion that extends from a sidewall of the etching target film EF in a horizontal direction in the vicinity of the bottom portion BT of the recess RC. The footing F is also referred to as a foot portion, a residue, or the like in the present technical field. The footing F defines a width (width in the horizontal direction (left-right direction on a paper surface in Figure 5)) of the recess RC in the vicinity of the bottom portion BT of the recess RC. The width (width CD of the recess RC) given by the footing F tends to gradually decrease from the vicinity of the bottom portion BT of the recess RC toward the bottom portion BT, and the footing F gives a width CD1 at the bottom portion BT of the recess RC. In the present etching method, the footing F tends to be decreased (the width CD1 is increased) by executing the step ST3 described below. As described above, in the present etching method, a shape of the recess RC in which the footing F is decreased without impairing the etching rate may be obtained. The decrease of the footing F may be evaluated based on a method described in examples

described below. In one embodiment, when the chlorine-containing gas includes Cl_2 gas, the occurrence of the footing tends to be apparent while the decrease of the etching rate is suppressed, and thus the effect of decreasing the footing by executing the step ST3 may also be apparent. When the chlorine-containing gas includes Cl_2 gas, from the viewpoint described above, a flow rate of the Cl_2 gas in the chlorine-containing gas may be larger than a flow rate of each of the other chlorine-containing gases. As an example, when the chlorine-containing gas includes Cl_2 gas and HCl gas, a flow rate of the Cl_2 gas in the chlorine-containing gas may be larger than a flow rate of the HCl gas.

[0059]

In one embodiment, a temperature of the substrate support 11 may be adjusted to a set temperature by the temperature control module while the step ST2 is executed. The set temperature while the step ST2 is executed may be, for example, a temperature of -30°C or higher and 120°C or lower. In one embodiment, the set temperature while the step ST2 is executed may be higher than 120°C. In one example, adjusting or maintaining the temperature of the substrate support 11 includes adjusting or maintaining a temperature of the heat transfer fluid flowing through the flow path 1110a to the set temperature or a temperature different from the set temperature. In one example, adjusting or maintaining the temperature of the substrate support 11 includes controlling a pressure of the heat transfer gas (for example, He) between the electrostatic chuck 1111 and the back surface of the substrate W. Timing at which the heat transfer fluid begins to flow in the

flow path 1110a may be before, after, or at the same time as the time at which the substrate W is placed on the substrate support 11. In addition, in the present etching method, the temperature of the substrate support 11 may be adjusted to the set temperature before the step ST2 or before the step ST1. That is, the substrate W may be prepared on the substrate support 11 after the temperature of the substrate support 11 is adjusted to the set temperature. In one embodiment, instead of controlling the substrate support 11 to the set temperature, the substrate W may be controlled to the set temperature. Controlling the temperature of the substrate W to the set temperature includes setting the temperature of the substrate support 11, the temperature of the heat transfer fluid flowing through the flow path 1110a, and/or the temperature of the heater to the set temperature, or to a temperature different from the set temperature. In the present etching method, the temperature of the substrate support 11 or the substrate W may be changed in each of the step ST1, the step ST2, and the step ST3. In the subsequent steps of the present etching method, the temperature of the substrate support 11 may be maintained at the set temperature adjusted in the step ST1, the step ST2, or the step ST3 described below.

[0060]

In one embodiment, in the process of forming the recess RC, the bottom portion BT of the recess may reach the underlying film UF, so that at least a part of the underlying film UF may be exposed to the opening OP. The step ST2 may be ended after at least a part of the underlying film UF is exposed or before (for example, immediately before) at least a part of the

underlying film UF is exposed. That is, in the step ST2, switching to the step ST3 described below may be performed after at least a part of the underlying film UF is exposed or before (for example, immediately before) at least a part of the underlying film UF is exposed. In addition, the step ST2 may be ended by satisfying a given stop condition. The stop condition may be, for example, an etching time or a depth of the recess RC. An operation at the end of the etching may be the stop of the supply of the source RF signal, the bias RF signal, the bias DC signal, and the first processing gas.

[0061]

In one embodiment, after the end of the step ST2 and before the execution of the step ST3, a step ST2A of exposing the substrate W to the oxygen-containing gas or plasma generated from the oxygen-containing gas may be further included. The oxygen-containing gas in the step ST2A may include O_2 gas. When the step ST2A is executed, a protective film may be formed on at least a part of surfaces of the etching target film EF and the mask MK. In addition, after the end of the step ST2A and before the execution of the step ST3, a step ST2B of exposing the substrate W to plasma generated from the fluorine-containing gas may be further included. The fluorine-containing gas in the step ST2B may include CF_4 gas. When the step ST2B is executed, the protective film in the region at the bottom portion BT may be selectively removed from the vicinity of the bottom portion BT of the recess RC, and the protective film in a region excluding the region may be maintained. When the protective film is formed, bowing tends to be suppressed. As a result, a shape abnormality of the recess RC on the

etching target film EF may be suppressed.

[0062] (Step ST3: Second Etching)

In the step ST3, the etching target film EF is further etched. In the step ST3, the etching target film EF is further etched with plasma generated from a second processing gas via the mask MK. The second processing gas includes HCl gas. In one embodiment, the second processing gas may be HCl gas. In one embodiment, the second processing gas may include Cl_2 gas, $CHCl_3$, and the like. In one embodiment, the second processing gas does not include Cl_2 gas. The step ST3 includes supplying the second processing gas to the chamber 10 and generating plasma from the second processing gas.

[0063]

In the step ST3, the second processing gas is supplied into the chamber 10. The second processing gas may be supplied, for example, into the chamber 10 from the gas supply 20 via the gas introduction port 13c of the center gas injector 13. In one embodiment, the second processing gas may include at least one selected from the group consisting of an oxygen-containing gas, a bromine-containing gas, a fluorine-containing gas, and a noble gas. As an example, the oxygen-containing gas may include at least one gas selected from the group consisting of O_2, CO, CO_2, SO_2, and COS. As an example, the noble gas may include at least one selected from the group consisting of Ar and He. As an example, the bromine-containing gas may include HBr. As an example, the fluorine-containing gas may include a CHF-based gas such as CHF_3 gas, CH_2F_2 gas, CH_3F gas, $C_3H_2F_4$ gas, $C_4H_2F_6$

gas, C_2HF_5 gas, $C_2H_2F_4$ gas, $C_2H_3F_3$ gas, $C_2H_4F_2$ gas, C_3HF_7 gas, $C_3H_2F_2$ gas, $C_3H_2F_6$ gas, $C_3H_3F_5$ gas, $C_4H_5F_5$ gas, $C_4H_2F_8$ gas, $C_5H_2F_6$ gas, $C_5H_2F_{10}$ gas, and $C_5H_3F_7$ gas. The pressure in the chamber 10 may be adjusted to a set pressure. The set pressure may be 15 mTorr or more and 200 mTorr or less.

[0064]

Next, plasma is generated from the second processing gas in the chamber 10. In one embodiment, the source RF signal is supplied to the antenna 14, and as a result, the RF electric field is generated between the antenna 14 and the substrate support 11, and plasma is generated from the processing gas in the plasma processing space 10s. At this time, the bias signal may be supplied to the substrate support 11. The bias signal may be the bias RF signal supplied from the RF power source 31 or the bias DC signal supplied from the DC power source 32. In this case, the bias potential is generated between plasma and the substrate W. Active species such as ions and radicals in plasma are attracted to the substrate W, and the etching target film EF is etched by the active species. In one embodiment, when the bias signal is supplied to the substrate support 11 in the step ST2 and the step ST3, a level of the bias signal in the step ST3 may be higher than a level of the bias signal in the step ST2. As an example, when the bias RF signal is used as the bias signal, an electric power W3 of the bias RF signal in the step ST3 may be higher than an electric power W2 of the bias RF signal in the step ST2. In one embodiment, the bias RF signal may have an electric power of 300 W or more and 1500 W or less, and may have an electric power of 300 W or more and 900 W or less.

[0065]

Figure 6 is a diagram illustrating an example of a cross-sectional structure of the substrate W after the step ST3 is executed. In the step ST3, the mask MK functions as a mask, and a portion of the etching target film EF exposed to the opening OP is selectively etched by the active species in plasma, so that the shape of the recess RC formed by the step ST2 is changed. In the step ST3, since the second processing gas includes HCl gas, the footing F in the recess RC formed in the step ST2 tends to be decreased. This is considered to be because, in the etching process, hydrogen ions derived from the HCl gas change at least a part of a bonding state of silicon in the etching target film EF (for example, change from Si-Si bond to Si-H bond), and thus the footing F tends to be decreased. The action mechanism in the present etching method is not intended to limit to the above content, and the footing F in the recess RC formed in the step ST2 tends to be decreased as long as the step ST3 is executed. As described above, the step ST3 may include further etching the recess RC formed on the etching target film EF by the step ST2 in the horizontal direction (left-right direction on a paper surface in Figure 6). As a result of the decrease of the footing F, a width CD2 of the bottom portion BT of the recess RC (width of the bottom portion BT of the recess RC at the end of the step ST3) tends to be larger than the width CD1 (width of the bottom portion BT of the recess RC at the end of the step ST2). As described above, in the present etching method, since the shape of the recess RC in which the footing F is decreased by the step ST3 may be obtained after the decrease in the etching rate is

suppressed by the step ST2, the etching processability may be improved. In addition to the above, in the present etching method, an etching amount of the bottom portion of the recess RC in the horizontal direction tends to be larger than an etching amount of a portion other than the bottom portion of the recess RC, that is, bowing tends to be suppressed. In one embodiment, when the second processing gas includes Cl_2 gas, the flow rate of the Cl_2 gas in the second processing gas may be smaller than the flow rate of the HCl gas. In addition, when the second processing gas includes Cl_2 gas, the flow rate of the Cl_2 gas in the second processing gas may be smaller than the flow rate of the Cl_2 gas in the first processing gas. In one embodiment, when the first processing gas includes HCl gas, the flow rate of the HCl gas in the first processing gas may be smaller than the flow rate of the HCl gas in the second processing gas.

[0066]

The recess RC after the step ST3 has a region DF corresponding to a region in which the footing F is decreased. In one embodiment, as illustrated in Figure 6, the region DF may be a region formed by completely removing the footing F. In one embodiment, the region DF may be a region formed by removing at least a part of the footing F.

[0067]

In one embodiment, the temperature of the substrate support 11 may be adjusted to a set temperature by the temperature control module while the step ST3 is executed. The set temperature while the step ST3 is executed may be, for example, a temperature of -30°C or higher and 120°C or lower.

In one embodiment, the set temperature while the step ST3 is executed may be higher than 120°C. In one example, adjusting or maintaining the temperature of the substrate support 11 includes adjusting or maintaining the temperature of the heat transfer fluid flowing through the flow path 1110a to the set temperature or a temperature different from the set temperature. In one example, adjusting or maintaining the temperature of the substrate support 11 includes controlling the pressure of the heat transfer gas (for example, He) between the electrostatic chuck 1111 and the back surface of the substrate W. In one embodiment, instead of controlling the substrate support 11 to the set temperature, the substrate W may be controlled to the set temperature. Controlling the temperature of the substrate W to the set temperature includes setting the temperature of the substrate support 11, the temperature of the heat transfer fluid flowing through the flow path 1110a, and/or the temperature of the heater to the set temperature, or to a temperature different from the set temperature. In one embodiment, a temperature T3 of the substrate W or the substrate support 11 in the step ST3 may be higher than a temperature T2 of the substrate W or the substrate support 11 in the step ST2.

[0068]

In one embodiment, the step ST1, the step ST2, and the step ST3 may be executed in the same chamber. In one embodiment, the step ST2 and the step ST3 may be executed in different chambers. In one embodiment, the step ST2 and the step ST3 may be alternately repeated. In one embodiment, the step ST2 and the step ST3 may be simultaneously executed.

[0069] (Modification Example 1)

As a modification example of the present etching method, an example in which the chlorine-containing gas includes Cl_2 gas and HCl gas, and the flow rate of the HCl gas in the chlorine-containing gas is larger than the flow rate of the Cl_2 gas in the step ST2 will be described. In addition to the above, a step ST1, a step ST2, and a step ST3 of the present modification example may be executed in the same manner as the step ST1, the step ST2, and the step ST3 of the present etching method. Even after the step ST2 of the present modification example is executed, the footing F as illustrated in the example of Figure 5 may occur in the vicinity of the bottom portion BT of the recess RC. In this case as well, the footing F may be decreased by executing the step ST3 of the present modification example as illustrated in the example of Figure 6.

[0070]

The first processing gas in the step ST2 of the present modification example may include an oxygen-containing gas. In addition, the second processing gas in the step ST3 of the present modification example may include the oxygen-containing gas. In the present modification example, when the first processing gas and/or the second processing gas includes the oxygen-containing gas, a decrease in a selectivity may be suppressed.

[0071]

In the present modification example, the temperature T3 of the substrate W or the substrate support 11 in the step ST3 may be higher than the temperature T2 of the substrate W or the substrate support 11 in the step

ST2. As an example, the temperature T2 may be -30°C or higher and 30°C or lower, and the temperature T3 may be -30°C or higher and 120°C or lower. When the temperature is controlled in this manner, the decrease of the footing F may be promoted.

[0072]

In the present modification example, the electric power W3 of the bias signal in the step ST3 may be higher than the electric power W2 of the bias signal in the step ST2. As an example, the electric power W2 may be 300 W or more and 900 W or less, and the electric power W3 may be 300 W or more and 1500 W or less. When the electric power is controlled in this manner, the decrease of the footing F may be promoted.

[0073] (Modification Example 2)

Figure 7 is a flowchart illustrating another example of the present etching method. As illustrated in Figure 7, the etching method of Modification Example 2 includes a step ST21 of preparing a substrate and a step ST22 of performing etching.

[0074] (Step ST21: Preparation of Substrate)

In the step ST21, the substrate W is prepared. In one embodiment, the step ST21 may be executed in the same manner as the step ST1 and the step ST2 described in the present etching method. The substrate W prepared in the step ST21 includes the underlying film UF and the etching target film EF on the underlying film UF. In the substrate W prepared in the step ST21, the etching target film EF includes the recess RC. In the substrate W prepared in the step ST21, the footing F is formed at the bottom

portion of the recess RC. The substrate W prepared in the step ST21 may have the same configuration as the substrate W prepared by the step ST2 described in the present etching method. For example, a cross-sectional structure of the substrate W prepared in the step ST21 may be the same as the cross-sectional structure of the substrate W illustrated in Figure 5.

[0075] (Step ST22: Etching of Substrate)

In the step ST22, the substrate W is etched with plasma generated from a processing gas including HCl gas. The step ST22 may be executed in the same manner as the step ST3 described in the present etching method. In the etching method of Modification Example 2, at least a part of the footing F is removed by executing the step ST22. The substrate W after the step ST22 is executed may have the same configuration as the substrate W after the step ST3 described in the present etching method is executed. For example, a cross-sectional structure of the substrate W prepared in the step ST21 may be the same as the cross-sectional structure of the substrate W illustrated in Figure 5. As described above, according to the etching method of Modification Example 2, the footing F tends to be decreased, and the etching processability may be improved.

[0076] <Examples>

Next, an example in which a removal performance of the footing is evaluated based on the present etching method will be described. The present disclosure is not limited in any way by the following examples.

[0077] (Example 1)

An apparatus having the same configuration as the plasma processing

apparatus 1 illustrated in Figure 2 was prepared. A substrate was placed on the substrate support 11 of the apparatus. Such a substrate included the same configuration as the substrate W illustrated in Figure 4. As the underlying film UF, a TEOS film on a silicon base material was used. As the etching target film EF, an amorphous silicon film was used. As the mask MK, SiN and a TEOS film were used. That is, the substrate W included the TEOS film, the amorphous silicon film, SiN, and the TEOS film in this order. Multiple openings OP that expose the etching target film EF were formed in the mask MK. That is, the multiple openings OP were formed to constitute a line and space pattern.

[0078]

The etching was executed by applying the present etching method to the substrate W. That is, the first etching using the first processing gas and the second etching using the second processing gas were executed in this order. The first etching was ended immediately before the underlying film UF was exposed. As the first processing gas, Cl_2 gas and Ar gas were used. The second processing gas was the same as the first processing gas except that the Cl_2 gas in the first processing gas was changed to the HCl gas. The second etching was executed in the same manner as the first etching except that the first processing gas in the first etching was changed to the second processing gas and the processing time was set to 0.5 times the processing time of the first etching.

[0079] (Reference Example 1)

In Reference Example 1, the first processing gas was not changed to

the second processing gas in the second etching of Example 1. That is, in the second etching of Reference Example 1, the same gas as the first processing gas in Example 1 was used as the second processing gas. The substrate W was etched under the same conditions as in Example 1, except for the above-described change.

[0080] (Footing Width and Bottom Angle)

Figure 8 is a diagram illustrating a measurement example of a footing width and a bottom angle in the cross-sectional structure of the substrate W after the first etching is executed. As illustrated in Figure 8, a footing width Fw corresponds to a length of the footing F in the horizontal direction (left-right direction on a paper surface in Figure 8). A bottom angle θ corresponds to an angle (obtuse angle in the example of Figure 8) formed by the bottom portion BT of the recess RC and the footing F. A height h from the bottom portion BT of the recess RC as a reference when the bottom angle θ is measured may be, for example, 30 to 50 nm or may be 40 nm. In Example 1 and Reference Example 1, the removal performance of the footing was evaluated by measuring the footing width Fw and the bottom angle θ illustrated in Figure 8. That is, it was evaluated that the closer the footing width Fw measured in the cross-sectional structure of the substrate W after the second etching is executed is to 0 nm, the higher the removal performance of the footing is. In addition, it was evaluated that the closer the bottom angle θ is to 90°, that is, the closer a numerical value of a difference (θ - 90°) between the measured bottom angle θ and 90° is to 0°, the higher the removal performance of the footing is.

[0081]

As a result of the above measurement, in Reference Example 1, the footing width at the end of the second etching was 62% of the footing width at the end of the first etching. On the other hand, in Example 1, the footing width at the end of the second etching was 46% of the footing width at the end of the first etching. It can be said that the footing width Fw can be decreased in Example 1 as compared with Reference Example 1. Next, in Reference Example 1, a value obtained by subtracting 90° from the bottom angle at the end of the second etching was 34% of a value obtained by subtracting 90° from the bottom angle at the end of the first etching. On the other hand, in Example 1, a value obtained by subtracting 90° from the bottom angle at the end of the second etching was 14% of a value obtained by subtracting 90° from the bottom angle at the end of the first etching. It can be said that the bottom angle θ can be brought closer to 90° in Example 1 as compared with Reference Example 1. As described above, it can be said that the removal performance of the footing is excellent in Example 1 as compared with Reference Example 1.

[0082]

Embodiments of the present disclosure further include the following aspects.

[0083] (E1)

An etching method including:

(a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching

target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) etching the etching target film with plasma generated from a first processing gas including Cl_2 gas; and

(c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[0084] (E2)

The etching method according to E1,

in which the (b) includes forming a recess in the etching target film, a footing being formed at a bottom portion of the recess, and

the (c) includes removing at least a part of the footing.

[0085] (E3)

The etching method according to E1 or E2, in which the first processing gas does not include HCl gas or includes HCl gas at a flow rate lower than a flow rate of the HCl gas in the second processing gas.

[0086] (E4)

The etching method according to any one of E1 to E3, in which the second processing gas does not include Cl_2 gas or includes Cl_2 gas at a flow rate lower than a flow rate of the Cl_2 gas in the first processing gas.

[0087] (E5)

The etching method according to any one of E1 to E4, in which the (c) includes further etching, in a horizontal direction, a recess formed in the etching target film by the etching of the (b).

[0088] (E6)

The etching method according to E5, in which a width of a bottom portion of the recess at an end of the (c) is larger than a width of a bottom portion of the recess at an end of the (b).

[0089] (E7)

The etching method according to E5 or E6, in which, in the (c), an etching amount of a bottom portion of the recess in the horizontal direction is larger than an etching amount of a portion other than the bottom portion of the recess in the horizontal direction.

[0090] (E8)

The etching method according to any one of E1 to E7, in which, switching from the (b) to the (c) is performed after at least a part of the underlying film is exposed or immediately before at least a part of the underlying film is exposed.

[0091] (E9)

The etching method according to any one of E1 to E8, in which the (b) and the (c) are alternately repeated.

[0092] (E10)

The etching method according to any one of E1 to E8, in which the (b) and the (c) are simultaneously executed.

[0093] (E11)

The etching method according to any one of E1 to E10, in which at least one of the first processing gas and the second processing gas further includes an oxygen-containing gas.

[0094] (E12)

The etching method according to E11, in which the oxygen-containing gas includes at least one gas selected from the group consisting of O_2, CO, CO_2, SO_2, and COS.

[0095] (E13)

The etching method according to any one of E1 to E12, in which a temperature of the substrate or the substrate support in the (c) is higher than a temperature of the substrate or the substrate support in the (b).

[0096] (E14)

The etching method according to any one of E1 to E13, in which in the (b) and the (c), a bias signal is supplied to the substrate support, and

a level of the bias signal in the (c) is higher than a level of the bias signal in the (b).

[0097] (E15)

The etching method according to any one of E1 to E14, in which at least one of the first processing gas and the second processing gas further includes a noble gas.

[0098] (E16)

The etching method according to E15, in which the noble gas includes at least one selected from the group consisting of Ar and He.

[0099] (E17)

The etching method according to any one of E1 to E16, in which at least one of the first processing gas and the second processing gas further includes at least one selected from the group consisting of a bromine-containing gas

and a fluorine-containing gas.

[0100] (E18)

An etching method including:

(a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) etching the etching target film with plasma generated from a first processing gas including a chlorine-containing gas other than HCl gas; and

(c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[0101] (E19)

An etching method including:

(a) preparing a substrate on a substrate support, the substrate including an underlying film and an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, the etching target film including a recess, a footing being formed at a bottom portion of the recess; and

(b) removing at least a part of the footing with plasma generated from a processing gas including HCl gas.

[0102] (E20)

A plasma processing system including:

a chamber;

a substrate support provided in the chamber;

a gas supply configured to supply a first processing gas and a second processing gas into the chamber;

a plasma generator configured to generate plasma in the chamber; and a controller,

in which the controller is configured to use the gas supply and the plasma generator to execute control including:

(a) control of preparing a substrate on the substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) control of etching the etching target film with plasma generated from the first processing gas including Cl_2 gas; and

(c) control of further etching the etching target film with plasma generated from the second processing gas including HCl gas.

[0103] (E21)

An etching method including:

(a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) etching the etching target film with plasma generated from a first processing gas including a chlorine-containing gas; and

(c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[0104] (E22)

A plasma processing system including:

a chamber;

a substrate support provided in the chamber; and

a controller,

in which the controller is configured to execute control including:

(a) control of preparing a substrate on the substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) control of etching the etching target film with plasma generated from a first processing gas including a chlorine-containing gas; and

(c) control of further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[0105]

Each of the embodiments described above is for illustrative purposes only and is not intended to limit the scope of the present disclosure. Each of the embodiments can be modified in various ways without departing from the

scope and spirit of the present disclosure. For example, some components from one embodiment can be added to other embodiments. Furthermore, some components in one embodiment can be replaced with corresponding components in another embodiment.

Reference Signs List

[0106]

1 ... plasma processing apparatus

2 ... controller

10 ... plasma processing chamber

11 ... substrate support

W ... substrate

UF ... underlying film

EF ... etching target film

MK ... mask

OP ... opening

RC ... recess

BT ... bottom portion of recess

CD1 ... width of bottom portion of recess at end of step ST2

CD2 ... width of bottom portion of recess at end of step ST3

F ... footing

Fw ... footing width

DF ... region in which footing F is decreased

Claims

[Claim 1] An etching method comprising:

(a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) etching the etching target film with plasma generated from a first processing gas including Cl_2 gas; and

(c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[Claim 2] The etching method according to Claim 1,

wherein the (b) includes forming a recess in the etching target film, a footing being formed at a bottom portion of the recess, and

the (c) includes removing at least a part of the footing.

[Claim 3] The etching method according to Claim 1, wherein the first processing gas does not include HCl gas or includes HCl gas at a flow rate lower than a flow rate of the HCl gas in the second processing gas.

[Claim 4] The etching method according to Claim 1, wherein the second processing gas does not include Cl_2 gas or includes Cl_2 gas at a flow rate lower than a flow rate of the Cl_2 gas in the first processing gas.

[Claim 5] The etching method according to Claim 1, wherein the (c) includes further etching, in a horizontal direction, a recess formed in the etching target film by the etching of the (b).

[Claim 6] The etching method according to Claim 5, wherein a width of a bottom portion of the recess at an end of the (c) is larger than a width of a bottom portion of the recess at an end of the (b).

[Claim 7] The etching method according to Claim 5, wherein, in the (c), an etching amount of a bottom portion of the recess in the horizontal direction is larger than an etching amount of a portion other than the bottom portion of the recess in the horizontal direction.

[Claim 8] The etching method according to any one of Claims 1 to 7, wherein, switching from the (b) to the (c) is performed after at least a part of the underlying film is exposed or immediately before at least a part of the underlying film is exposed.

[Claim 9] The etching method according to any one of Claims 1 to 7, wherein the (b) and the (c) are alternately repeated.

[Claim 10] The etching method according to any one of Claims 1 to 7, wherein the (b) and the (c) are simultaneously executed.

[Claim 11] The etching method according to any one of Claims 1 to 7, wherein at least one of the first processing gas and the second processing gas further includes an oxygen-containing gas.

[Claim 12] The etching method according to Claim 11, wherein the oxygen-containing gas includes at least one gas selected from the group consisting of O_2, CO, CO_2, SO_2, and COS.

[Claim 13] The etching method according to any one of Claims 1 to 7, wherein a temperature of the substrate or the substrate support in the (c) is higher than a temperature of the substrate or the substrate support in the (b).

[Claim 14] The etching method according to any one of Claims 1 to 7,

wherein in the (b) and the (c), a bias signal is supplied to the substrate support, and

a level of the bias signal in the (c) is higher than a level of the bias signal in the (b).

[Claim 15] The etching method according to any one of Claims 1 to 7, wherein at least one of the first processing gas and the second processing gas further includes a noble gas.

[Claim 16] The etching method according to Claim 15, wherein the noble gas

includes at least one selected from the group consisting of Ar and He.

[Claim 17] The etching method according to any one of Claims 1 to 7, wherein at least one of the first processing gas and the second processing gas further includes at least one selected from the group consisting of a bromine-containing gas and a fluorine-containing gas.

[Claim 18] An etching method comprising:

(a) preparing a substrate on a substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) etching the etching target film with plasma generated from a first processing gas including a chlorine-containing gas other than HCl gas; and

(c) further etching the etching target film with plasma generated from a second processing gas including HCl gas.

[Claim 19] An etching method comprising:

(a) preparing a substrate on a substrate support, the substrate including an underlying film and an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, the etching target film including a recess, a footing being formed at a bottom portion of the recess; and

(b) removing at least a part of the footing with plasma generated from a processing gas including HCl gas.

[Claim 20] A plasma processing system comprising:

a chamber;

a substrate support provided in the chamber;

a gas supply configured to supply a first processing gas and a second processing gas into the chamber;

a plasma generator configured to generate plasma in the chamber; and

a controller,

wherein the controller is configured to use the gas supply and the plasma generator to execute control including:

(a) control of preparing a substrate on the substrate support, the substrate including an underlying film, an etching target film on the underlying film, the etching target film including at least one selected from the group consisting of silicon, germanium, and a metal, and a mask on the etching target film, the mask including at least one opening that exposes the etching target film;

(b) control of etching the etching target film with plasma generated from the first processing gas including Cl_2 gas; and

(c) control of further etching the etching target film with plasma generated from the second processing gas including HCl gas.