[0005] Specifically, in the technique disclosed in Japanese Patent Laid-Open No. 2011-82560, the silicon oxide film is formed on the resist mask by an atomic layer deposition (ALD) method. More specifically, an organic silicon-containing source gas and activated oxygen species are alternately supplied into a processing container that accommodates a workpiece. As the source gas, aminosilane gas is used.

SUMMARY

[0005a] According to a first aspect of the present invention, there is provided A workpiece processing method including: a first process of generating plasma of a first gas containing a silicon halide gas in a processing container of a plasma processing apparatus that accommodates a workpiece including an etching target layer, an organic film formed on the etching target layer, a silicon-containing antireflective film formed on the organic film, and a first mask having a resist mask provided on the antireflective film, to form a reactive precursor; a second process of purging a space in the processing container; a third process of generating plasma of a second gas containing oxygen gas in the processing container to form a silicon oxide film including a first region, a second region, and a third region, and the first region extending above a top surface of the first mask and above the third region, and the second region extending between adjacent third regions and on a surface of the antireflective film, and the third region extending from the surface of the antireflective film to a bottom of the first region; and a fourth process of purging the space in the processing container, wherein a sequence including the first process to the fourth process is repeated, after executing the sequence including the first process to the fourth process, the method further comprises: removing the first region and the second region of the silicon oxide film by plasma of a third gas including a fluorocarbon gas in the processing container; etching the antireflective film by the plasma of the third

gas including the fluorocarbon gas in the processing container using a second mask including the first mask and the third region of the silicon oxide film; and etching the organic film by the plasma of the second gas including the oxygen gas in the processing container, and in the first process, the processing container is set to a high-pressure and low-power condition that a pressure therein is 13.33 Pa or more, a power of a high-frequency power source for plasma generation is 100 W or less, and no bias power for drawing ions is applied to a pedestal that supports the workpiece.

[0005b] According to a second aspect of the present invention, there is provided a workpiece processing method including: etching an antireflective film by plasma of a third gas including a fluorocarbon gas in a processing container of a plasma processing apparatus that accommodates a workpiece including an etching target layer, an organic film formed on the etching target layer, and the antireflective film formed on the organic film, and a first mask having a resist mask provided on the antireflective film organic film, to form a second mask; a first process of generating plasma of a first gas containing a silicon halide gas in the processing container to form a reactive precursor; a second process of purging a space in the processing container; a third process of generating plasma of a second gas containing oxygen gas in the processing container to form a silicon oxide film including a first region, a second region, and a third region, and the first region extending above a top surface of the first mask and above the third region, and the second region extending between adjacent third regions and on a surface of the organic film, and the third region formed on a side surface of the first mask and the second mask; and a fourth process of purging the space in the processing container; wherein a sequence including the first process to the fourth process is repeated, after executing the sequence including the first process to the fourth process, the method further comprises: removing the first region and the second region of the silicon oxide film by the plasma of the third gas including the fluorocarbon gas in the processing container; and etching the organic film by the plasma of the second gas including oxygen gas in the processing container using a third mask including the second mask and the third region of the silicon oxide film, and in the first process, the processing container is set to a high-pressure and low-power condition that a pressure therein is 13.33 Pa or more, a power of a high-frequency power source for plasma generation is 100 W or less, and no bias power for drawing ions is applied to a pedestal that supports the workpiece.

[0006] There is also disclosed a method of processing a workpiece including a mask. The processing method includes: a first process of generating plasma of a first gas containing a silicon halide gas in a processing container of a plasma processing apparatus that accommodates a workpiece having a mask, to form a reactive precursor; a second process of purging a space in the processing container; a third process of generating plasma of a second gas containing oxygen gas in the processing container to form a silicon oxide film; and a fourth process of purging the space in the processing container. A sequence including the first to fourth processes is repeated.

[0007] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a flowchart illustrating a workpiece processing method according to an exemplary embodiment.

[0009] FIG. 2 is a view illustrating an exemplary plasma processing apparatus.

What is claimed is:

1. A workpiece processing method including:

a first process of generating plasma of a first gas containing a silicon halide gas in a processing container of a plasma processing apparatus that accommodates a workpiece including an etching target layer, an organic film formed on the etching target layer, a silicon-containing antireflective film formed on the organic film, and a first mask having a resist mask provided on the antireflective film, to form a reactive precursor;

a second process of purging a space in the processing container;

a third process of generating plasma of a second gas containing oxygen gas in the processing container to form a silicon oxide film including a first region, a second region, and a third region, and the first region extending above a top surface of the first mask and above the third region, and the second region extending between adjacent third regions and on a surface of the antireflective film, and the third region extending from the surface of the antireflective film to a bottom of the first region; and

a fourth process of purging the space in the processing container,

wherein a sequence including the first process to the fourth process is repeated,

after executing the sequence including the first process to the fourth process, the method further comprises:

removing the first region and the second region of the silicon oxide film by plasma of a third gas including a fluorocarbon gas in the processing container;

etching the antireflective film by the plasma of the third gas including the fluorocarbon gas in the processing container using a second mask including the first mask and the third region of the silicon oxide film; and

etching the organic film by the plasma of the second gas including the oxygen gas in the processing container, and

in the first process, the processing container is set to a high-pressure and low-power condition that a pressure therein is 13.33 Pa or more, a power of a high-frequency power source for plasma generation is 100 W or less, and no bias power for drawing ions is applied to a pedestal that supports the workpiece.

2. The workpiece processing method of claim 1, wherein the silicon halide gas is $SiCl_4$ gas.

3. The workpiece processing method of claim 1, wherein the plasma processing apparatus is a capacitively coupled plasma processing apparatus, and

before executing the sequence including the first process to the fourth process, the method further comprises:

irradiating secondary electrons to the first mask by generating plasma in the processing container and applying a negative DC voltage to an upper electrode of the plasma processing apparatus.

4. A workpiece processing method including:

etching an antireflective film by plasma of a third gas including a fluorocarbon gas in a processing container of a plasma processing apparatus that accommodates a workpiece including an etching target layer, an organic film formed on the etching target layer, and the antireflective film formed on the organic film, and a first mask having a resist mask provided on the antireflective film organic film, to form a second mask;

a first process of generating plasma of a first gas containing a silicon halide gas in the processing container to form a reactive precursor;

a second process of purging a space in the processing container;

a third process of generating plasma of a second gas containing oxygen gas in the processing container to form a silicon oxide film including a first region, a second region, and a third region, and the first region extending above a top surface of the first mask and above the third region, and the second region extending between adjacent third regions and on a surface of the organic film, and the third region formed on a side surface of the first mask and the second mask; and

a fourth process of purging the space in the processing container;

wherein a sequence including the first process to the fourth process is repeated, after executing the sequence including the first process to the fourth process, the method further comprises:

removing the first region and the second region of the silicon oxide film by the plasma of the third gas including the fluorocarbon gas in the processing container; and

etching the organic film by the plasma of the second gas including oxygen gas in the processing container using a third mask including the second mask and the third region of the silicon oxide film, and

in the first process, the processing container is set to a high-pressure and low-power condition that a pressure therein is 13.33 Pa or more, a power of a high-frequency power source for plasma generation is 100 W or less, and no bias power for drawing ions is applied to a pedestal that supports the workpiece.

5. The workpiece processing method of claim 4, wherein the plasma processing apparatus is a capacitively coupled plasma processing apparatus, and

before etching the antireflective film, the method further comprises:

irradiating secondary electrons to the resist mask by generating plasma in the processing container and applying a negative DC voltage to an upper electrode of the

plasma processing apparatus.

6. The workpiece processing method of claim 4, further comprising:

forming a silicon oxide protective film on the workpiece after etching the antireflective film and before executing the sequence including the first process to the fourth process.

7. The workpiece processing method of claim 6, wherein the plasma processing apparatus is a capacitively coupled plasma processing apparatus, and

in the forming of the silicon oxide protective film, plasma is generated in the processing container and a negative DC voltage is applied to a silicon upper electrode of the plasma processing apparatus.

8. The workpiece processing method of claim 6, wherein, in the forming of the silicon oxide protective film, plasma of a mixed gas containing a silicon halide gas and oxygen gas is generated in the processing container.

9. The workpiece processing method of claim 6, wherein the plasma processing apparatus is a capacitively coupled plasma processing apparatus, and

in the forming of the silicon oxide protective film, a high frequency power for plasma generation is supplied to a silicon oxide upper electrode of the plasma processing apparatus to generate plasma of a mixed gas containing hydrogen gas and a noble gas.