[CLAIMS]

[Claim 1]

A method of manufacturing a semiconductor device comprising:

(a) generating an oxygen active species and a hydrogen active species by exciting a process gas containing an oxygen-containing gas and a hydrogen-containing gas; and

(b) forming an oxide layer by supplying the oxygen active species and the hydrogen active species to a substrate with a concave structure formed thereon to subject a film formed on an inner surface of the concave structure including a sidewall surface and a bottom surface to oxidation from a surface of the film,

wherein the oxide layer is formed in (b) such that a thickness of the oxide layer at an uppermost portion of the sidewall surface is smaller than that of the oxide layer at other portion of the sidewall surface and the bottom surface by setting a ratio of a flow rate of the hydrogen active species to a total flow rate of the oxygen active species and the hydrogen active species supplied to the substrate to a predetermined ratio greater than a first ratio at which a rate of forming the oxide layer is maximized at the uppermost portion of the sidewall surface.

[Claim 2]

The method of claim 1, wherein the oxide layer is formed in (b) such that the thickness of the oxide layer increases toward the bottom surface by setting the ratio of the flow rate of the hydrogen active species to the total flow rate of the oxygen active species and the hydrogen active species supplied to the substrate to the predetermined ratio greater than a second ratio at which a thickness distribution of the oxide layer in a depth direction of the concave structure is uniform.

[Claim 3]

The method of claim 1, wherein the oxide layer is formed in (b) such that the thickness of the oxide layer increases toward the bottom surface and is maximized at the

bottom surface by setting the ratio of the flow rate of the hydrogen active species to the total flow rate of the oxygen active species and the hydrogen active species supplied to the substrate to the predetermined ratio equal to or greater than a third ratio at which the rate of forming the oxide layer is maximized at the bottom surface.

[Claim 4]

The method of claim 3, wherein the third ratio is greater than the first ratio.

[Claim 5]

The method of claim 1, wherein a ratio of a flow rate of the hydrogen-containing gas to a total flow rate of the process gas is set in (a) such that a ratio of the hydrogen active species generated in (a) to a total of the oxygen active species and the hydrogen active species generated in (a) is equal to the predetermined ratio.

[Claim 6]

The method of claim 3, wherein a ratio of a flow rate of the hydrogen-containing gas to a total flow rate of the process gas is set in (a) such that a ratio of the hydrogen active species generated in (a) to a total of the oxygen active species and the hydrogen active species generated in (a) is equal to the predetermined ratio.

[Claim 7]

The method of claim 5, wherein the ratio of the flow rate of the hydrogen-containing gas to the total flow rate of the process gas is greater than 5 %.

[Claim 8]

The method of claim 6, wherein the ratio of the flow rate of the hydrogen-containing gas to the total flow rate of the process gas is greater than 5 % and equal to or less than 20 %.

[Claim 9]

The method of claim 6, further comprises (c) loading the substrate into a process chamber before (a),

wherein the oxygen active species and the hydrogen active species are generated in (a) by plasma-exciting the process gas supplied into the process chamber.

[Claim 10]

The method of claim 9, wherein each of a supply system of the oxygen-containing gas and a supply system of the hydrogen-containing gas are controlled in order to adjust the ratio of the flow rate of the hydrogen-containing gas to the total flow rate of the process gas and a ratio of a flow rate of the oxygen-containing gas to the total flow rate of the process gas.

[Claim 11]

The method of claim 3, wherein the film formed on the inner surface of the concave structure comprises an exposed layer whose oxygen concentration is reduced by an etching process, and the oxygen concentration of the exposed layer is lowest at the bottom surface.

[Claim 12]

The method of claim 1, wherein the film formed on the inner surface of the concave structure is constituted by an oxide film and a base film of the oxide film, and a thickness of the oxide film decreases toward the bottom surface.

[Claim 13]

A method of manufacturing a semiconductor device comprising:

(a) generating an oxygen active species and a hydrogen active species by exciting a process gas containing an oxygen-containing gas and a hydrogen-containing gas; and

(b) forming an oxide layer by supplying the oxygen active species and the hydrogen active species to a substrate with a concave structure formed thereon to

subject a film formed on an inner surface of the concave structure including a sidewall surface and a bottom surface to oxidation from a surface of the film,

wherein the oxide layer is formed in (b) such that a thickness of the oxide layer on the sidewall surface increases toward the bottom surface and a rate of forming the oxide layer is maximized at a lowermost portion of the sidewall surface by adjusting a flow velocity of the oxygen active species and the hydrogen active species flowing on a surface of the substrate.

[Claim 14]

The method of claim 13, wherein the oxide layer is formed in (b) such that the thickness of the oxide layer increases toward the bottom surface by setting the flow velocity of the oxygen active species and the hydrogen active species flowing on the surface of the substrate to a predetermined flow velocity greater than a flow velocity at which a thickness distribution of the oxide layer in a depth direction of the concave structure is uniform.

[Claim 15]

A program that causes, by a computer, a substrate processing apparatus to perform:

(a) generating an oxygen active species and a hydrogen active species by exciting a process gas containing an oxygen-containing gas and a hydrogen-containing gas; and

(b) forming an oxide layer by supplying the oxygen active species and the hydrogen active species to a substrate with a concave structure formed thereon to subject a film formed on an inner surface of the concave structure including a sidewall surface and a bottom surface to oxidation from a surface of the film such that a thickness of the oxide layer at an uppermost portion of the sidewall surface is smaller than that of the oxide layer at other portion of the sidewall surface and the bottom surface by setting a ratio of a flow rate of the hydrogen active species to a total flow rate of the oxygen active species and the hydrogen active species supplied to the substrate to

a predetermined ratio greater than a first ratio at which a rate of forming the oxide layer is maximized at the uppermost portion of the sidewall surface.

[Claim 16]

A substrate processing apparatus comprising:

a process chamber comprising a plasma generation space in which a process gas is plasma-excited and a substrate processing space in communication with the plasma generation space wherein a substrate is processed in the substrate processing space;

a plasma generator configured to plasma-excite the process gas supplied to the plasma generation space;

a gas supply system configured to supply a hydrogen-containing gas and an oxygen-containing gas as the process gas to the plasma generation space;

a substrate support provided in the substrate processing space and on which the substrate with a concave structure formed thereon is placed; and

a controller configured to control the gas supply system to supply the process gas to the plasma generation space, to control the plasma generator to plasma-excite the process gas supplied to the plasma generation space to generate an oxygen active species and a hydrogen active species, and to form an oxide layer by supplying the oxygen active species and the hydrogen active species to the substrate with the concave structure formed thereon to subject a film formed on an inner surface of the concave structure including a sidewall surface and a bottom surface to oxidation from a surface of the film,

wherein the controller is further configured to form the oxide layer such that a thickness of the oxide layer at an uppermost portion of the sidewall surface is smaller than that of the oxide layer at other portion of the sidewall surface and the bottom surface by setting a ratio of a flow rate of the hydrogen active species to a total flow rate of the oxygen active species and the hydrogen active species supplied to the substrate to a predetermined ratio greater than a first ratio at which a rate of forming the oxide layer is maximized at the uppermost portion of the sidewall surface.