

photon particles. Such particles are ordinarily required to achieve anisotropic etch with atomic oxygen plasmas in the prior art, but cause secondary damage to the underlying substrate. Furthermore, the reaction products should be highly volatile and easily removed from the etched substrate. In addition, the aforementioned limitations that are encountered when etching Cu-containing layers using conventional chlorine chemistry, show that there is a need for new low temperature dry etching methods in semiconductor manufacturing using chemical approaches that do not involve chlorine-based reactants.

#### SUMMARY OF THE INVENTION

**[0011]** Embodiments of the present invention seek to provide a method and an apparatus for anisotropic dry etching of pure Cu layers and Cu-containing layers used in integrated circuits.

**[0012]** There is disclosed a method and an apparatus that uses a directional beam of high kinetic energy (hyperthermal) neutral O-atoms to anisotropically oxidize Cu layers, and an etching gas comprising an organic compound gas such as  $\text{CH}_3\text{COOH}$  that readily reacts with the oxidized Cu layers to form volatile Cu-containing etch products. The high directionality of the O-atom beam allows for anisotropic etching of the Cu layers in accordance with a patterned hard mask or photoresist.

**[0012a]** According to a first aspect of the present invention, there is provided a method for etching a copper-containing layer on a substrate, comprising: loading a substrate into a processing chamber having a neutral beam source and a substrate holder, the substrate having a copper-containing layer and etch mask formed thereupon; maintaining pressure of a reducing gas in said processing chamber within a pressure range of  $10^{-4}$  Torr to  $10^{-6}$  Torr; exposing, at said pressure range, the copper-containing layer to a directional neutral beam comprising a reacting gas that comprises  $\text{O}_2$ , the reacting gas anisotropically forming a first copper-containing compound on exposed surfaces of features formed in the copper-containing layer based on directionality of the neutral beam; introducing, at said pressure range, the reducing gas comprising a carboxylic acid into processing chamber, proximate the substrate holder, the reducing gas spontaneously reacting with the first copper-containing compound to form a volatile second copper-containing compound; pumping the volatile second copper-containing compound from the processing chamber, to anisotropically etch and form a pattern in the copper-containing layer.

**[0012b]** According to a second aspect of the present invention, there is provided a method for anisotropically etching a Cu-containing layer comprising the steps of: loading a substrate into a vacuum chamber, the substrate comprising a Cu-containing layer overlying a

substrate; maintaining pressure of a carboxylic acid gas in said vacuum chamber within a pressure range of  $10^{-4}$  Torr to  $10^{-6}$  Torr; introducing, at said pressure range, a directional beam of neutral oxygen atoms having a kinetic energy between 100eV and 1eV; anisotropically oxidizing a portion of the Cu-containing layer by exposure to the beam of oxygen atoms based on directionality of the beam; introducing, at said pressure range, the carboxylic acid gas spontaneously forming volatile etch products when reacted with the oxidized Cu-containing layer; and removing the etch products from the Cu-containing layer.

**[0012c]** According to a third aspect of the present invention, there is provided a method for etching a copper-containing layer on a substrate, comprising: loading a substrate into a processing chamber having a neutral beam source and a substrate holder, the substrate having a copper-containing layer and etch mask formed thereupon; maintaining pressure of an acetic acid gas in said processing chamber within a pressure range of  $10^{-4}$  Torr to  $10^{-6}$  Torr; exposing, at said pressure range, the copper-containing layer to a neutral beam comprising a reacting gas that comprises  $O_2$ , the reacting gas anisotropically forming a first copper-containing compound on a portion of exposed surfaces of features formed in the copper-containing layer based on directionality of the neutral beam; introducing, at said pressure range, the acetic acid gas into the processing chamber, proximate the substrate holder, the acetic acid gas spontaneously reacting with the first copper-containing compound to form a volatile copper-containing compound; and pumping the volatile copper-containing compound from the processing chamber, to anisotropically etch and form a pattern in the copper-containing layer.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0013]** A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a flowchart for etching a Cu-containing layer in accordance with the present invention;

FIGS. 2a-2d show a schematic cross-sectional representation of anisotropic etching of Cu-containing layers in accordance with the present invention;

FIG. 3 shows a schematic cross-sectional representation of anisotropic etching of Cu-containing layers in accordance with the present invention;

FIG. 4 shows a processing system according to a preferred embodiment of the present invention;

FIG. 5 shows an example of an organic compound gas supply unit in the etching apparatus of FIG. 4.

CLAIMS:

1. A method for etching a copper-containing layer on a substrate, comprising:  
loading a substrate into a processing chamber having a neutral beam source and a substrate holder, the substrate having a copper-containing layer and etch mask formed thereupon;  
maintaining pressure of a reducing gas in said processing chamber within a pressure range of  $10^{-4}$  Torr to  $10^{-6}$  Torr;  
exposing, at said pressure range, the copper-containing layer to a directional neutral beam comprising a reacting gas that comprises  $O_2$ , the reacting gas anisotropically forming a first copper-containing compound on exposed surfaces of features formed in the copper-containing layer based on directionality of the neutral beam;  
introducing, at said pressure range, the reducing gas comprising a carboxylic acid into processing chamber, proximate the substrate holder, the reducing gas spontaneously reacting with the first copper-containing compound to form a volatile second copper-containing compound;  
pumping the volatile second copper-containing compound from the processing chamber, to anisotropically etch and form a pattern in the copper-containing layer.
2. The method of Claim 1, wherein the carboxylic acid comprises at least one of acetic acid, formic acid, propionic acid, butyric acid and valeric acid.
3. The method of Claim 2, wherein the reducing gas comprises  $CH_3COOH$ .

4. The method of Claim 1, wherein the first copper-containing compound is formed at the bottom surfaces of features formed in the copper-containing layer.
5. The method of Claim 1, wherein the substrate is maintained at a temperature between 0 and 100°C during the exposing and introducing steps.
6. The method of Claim 1, wherein the substrate is maintained at a temperature of about 25°C during the exposing and introducing steps.

7. The method of Claim 1, further comprising introducing an inert gas into the processing chamber.
8. The method of Claim 1, wherein the kinetic energy of the reacting gas of the neutral beam is between 1meV and 1keV.
9. The method of Claim 1, wherein the kinetic energy of the reacting gas of the neutral beam is between 10eV and 300eV.
10. The method of Claim 1, wherein the kinetic energy of the reacting gas of the neutral beam is between 50meV and 1eV.
11. The method of Claim 1, wherein the divergence angle of the neutral beam of the reacting gas is less than about 20°.
12. The method of Claim 1, wherein the divergence angle of the neutral beam of the reacting gas is less than about 10°.
13. A method for anisotropically etching a Cu-containing layer comprising the steps of:
  - loading a substrate into a vacuum chamber, the substrate comprising a Cu-containing layer overlying a substrate;
  - maintaining pressure of a carboxylic acid gas in said vacuum chamber within a pressure range of  $10^{-4}$  Torr to  $10^{-6}$  Torr;
  - introducing, at said pressure range, a directional beam of neutral oxygen atoms having a kinetic energy between 100eV and 1eV;
  - anisotropically oxidizing a portion of the Cu-containing layer by exposure to the beam of oxygen atoms based on directionality of the beam;

introducing, at said pressure range, the carboxylic acid gas spontaneously forming volatile etch products when reacted with the oxidized Cu-containing layer; and

removing the etch products from the oxidized Cu-containing layer to anisotropically etch the Cu-containing layer.

14. The method according to Claim 7, wherein the inert gas comprises at least one of argon, helium, xenon, and nitrogen.

15. The method according to Claim 13, wherein the carboxylic acid gas comprises  $\text{CH}_3\text{COOH}$ .

16. A method for etching a copper-containing layer on a substrate, comprising:

loading a substrate into a processing chamber having a neutral beam source and a substrate holder, the substrate having a copper-containing layer and etch mask formed thereupon;

maintaining pressure of an acetic acid gas in said processing chamber within a pressure range of  $10^{-4}$  Torr to  $10^{-6}$  Torr;

exposing, at said pressure range, the copper-containing layer to a neutral beam comprising a reacting gas that comprises  $O_2$ , the reacting gas anisotropically forming a first copper-containing compound on a portion of exposed surfaces of features formed in the copper-containing layer based on directionality of the neutral beam;

introducing, at said pressure range, the acetic acid gas into the processing chamber, proximate the substrate holder, the acetic acid gas spontaneously reacting with the first copper-containing compound to form a volatile copper-containing compound; and

pumping the volatile copper-containing compound from the processing chamber, to anisotropically etch and form a pattern in the copper-containing layer.

17. The method of Claim 16, wherein the first copper-containing compound is formed at the bottom surfaces of features formed in the copper-containing layer.