scheme. However, the damascene method includes complicated processes which make it difficult to define extremely fine features, and CMP suffers from yield-detracting problems of scratching, peeling, dishing and erosion. Further, overwhelming electron scattering at copper grain boundaries from the standard plating-CMP steps will likely have an adverse effect on transistor speed due to its resultant RC delay in the post ~ 14nm generation technology (i.e., line width regime less than 30nm). Thus, continued use of the damascene process for Cu patterning is unlikely and there is a need to develop improved reliable Cu etch techniques (as in the case of Al) for next generation device fabrication.

It is also expected that after dry etching copper of a large number of wafers, the chamber condition may become severely altered. As such, chamber stability is expected to suffer and the etching results are expected to drift. Thus, there is also a need to clean off the Cu deposits on the surfaces of the chamber parts, restoring the proper seasoning condition of the chamber.

SUMMARY OF THE INVENTION

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.

According to a first aspect of the present invention, there is provided a method for anisotropically etching a feature in a Cu-containing layer includes providing a substrate having a Cu-containing layer and a patterned etch mask formed on the Cu-containing layer such that an exposed Cu-containing layer is exposed to processing through the patterned etch mask, passivating a first surface of the exposed Cu-containing layer, and inhibiting passivation of a second surface of the Cu-containing layer. A Cu compound is formed on said second surface of the Cu-containing layer, and the Cu compound is removed from the second surface of the Cu-containing layer to anisotropically etch a feature in the Cu-containing layer.

Another aspect of the invention is a method for etching a Cu-containing layer on a substrate, which includes loading a substrate into a plasma processing chamber having a plasma source and a substrate holder, the substrate having a Cu-containing layer and a patterned etch mask formed thereupon. A passivation gas is introduced into the plasma processing chamber, the passivation gas forming a passivation layer on exposed surfaces of the Cu-containing layer, and a reacting gas is introduced into the plasma processing chamber, the reacting gas forming a first Cu-containing compound on exposed surfaces of features formed in the Cu-containing layer. The method includes introducing a reducing gas into the plasma processing chamber, the reducing gas reacting with the first Cu-containing compound to form a volatile Cu-containing compound, energizing a plasma in the plasma processing chamber, by applying at least one of DC, RF, or microwave power, to the plasma source, and applying RF bias to the substrate holder. The volatile Cu-containing compound is pumped from the plasma processing chamber, to form a pattern in the Cu-containing layer.

Still another aspect is a method for chamber cleaning. The method includes providing a plasma processing chamber having a plasma source and a substrate holder, the interior surfaces of the plasma processing chamber having a Cu-containing layer deposited thereon, and introducing a reacting gas into the plasma processing chamber, the reacting gas forming a first Cu-containing compound in the Cu-containing layer on the interior surfaces. A reducing gas is introduced into the plasma processing chamber, the reducing gas reacting with the first Cu-containing compound to form a volatile Cu-containing compound. A plasma is energized in the plasma processing chamber, by applying at least one of DC, RF, or microwave power, to the plasma source, and the volatile Cu-containing compound is pumped from the plasma processing chamber, to remove the Cu-containing layer from the interior surfaces.

What is claimed is:

1. A method for anisotropically etching a feature in a Cu-containing layer, the method comprising:

providing a substrate having a Cu-containing layer and a patterned etch mask formed on the Cu-containing layer such that an exposed Cu-containing layer is exposed to processing through the patterned etch mask;

passivating a first surface of the exposed Cu-containing layer;

inhibiting passivation of a second surface of the Cu-containing layer;

forming a Cu compound on said second surface of the Cu-containing layer; and

removing the Cu compound from the second surface of the Cu-containing layer to anisotropically etch a feature in the Cu-containing layer.

2. The method of claim 1, wherein said passivating comprises depositing a passivation layer on the first surface of the Cu-containing layer or growing a Cu compound on the first surface of the Cu-containing layer.

3. The method of claim 2, wherein said depositing a passivation layer comprises depositing a hydrocarbon or a fluorocarbon on the first surface of the Cu-containing layer.

4. The method of claim 2, wherein said growing comprises growing a Cu-fluoride on the first surface of the Cu-containing layer.

5. The method of claim 1, wherein said inhibiting passivation comprises at least one of reactive ion etching (RIE) or ion assisted etching the second surface of the Cu-containing layer to remove passivation material from the second surface of the Cu-containing layer.

6. The method of claim 1, wherein said forming a Cu compound comprises forming Cu_XO

on the second surface of the Cu-containing layer.

7. The method of claim 1, wherein said forming Cu_XO comprises supplying at least one of O_2 neutrals and O ions to the second surface of the Cu-containing layer.

8. The method of claim 1, wherein said removing the Cu compound comprises at least one of anisotropic spontaneous etch (SAE) and reactive ion etch (RIE) of the Cu compound from the second surface to anisotropically etch a feature in the Cu-containing layer.

9. The method of claim 1, wherein the passivation layer is preferentially formed on the sidewalls over bottom surfaces, of features formed in the Cu-containing layer.

10. A method for etching a Cu-containing layer on a substrate, the method comprising:

loading a substrate into a plasma processing chamber having a plasma source and a substrate holder, the substrate having a Cu-containing layer and a patterned etch mask formed thereupon;

introducing a passivation gas into the plasma processing chamber, the passivation gas forming a passivation layer on exposed surfaces of the Cu-containing layer;

introducing a reacting gas into the plasma processing chamber, the reacting gas forming a first Cu-containing compound on exposed surfaces of features formed in the Cu-containing layer;

introducing a reducing gas into the plasma processing chamber, the reducing gas reacting with the first Cu-containing compound to form a volatile Cu-containing compound;

energizing a plasma in the plasma processing chamber, by applying at least one of DC, RF, or microwave power, to the plasma source;

applying RF bias to the substrate holder; and

pumping the volatile Cu-containing compound from the plasma processing chamber, to form a pattern in the Cu-containing layer.

11. The method of claim 10, wherein the reducing gas comprises an acid.

12. The method of claim 10, wherein the reducing gas comprises CH_3COOH.

13. The method of claim 10, wherein the reacting gas comprises O2.

14. The method of claim 10, wherein the reacting gas further comprises an inert gas.

15. The method of claim 14, wherein the inert gas comprises at least one of He, Ne, Ar, Kr, and Xe.

16. The method of claim 10, wherein the passivation gas comprises at least one of a fluorine-containing gas, a hydrocarbon gas, a fluorocarbon gas, and a hydrofluorocarbon gas.

17. The method of claim 10, wherein the passivation gas, reacting gas, and reducing gas, are introduced simultaneously into the plasma processing chamber, in a single-step process.

18. The method of claim 10, wherein the passivation gas, reacting gas, and reducing gas, are introduced sequentially into the plasma processing chamber, in a multi-step process.

19. The method of claim 10, wherein the plasma source and substrate holder are disposed at opposite ends of the plasma processing chamber, wherein the passivation gas and reacting gas are introduced proximate the plasma source, and wherein the reducing gas is

introduced proximate the substrate holder.

20. A method for chamber cleaning, the method comprising:

providing a plasma processing chamber having a plasma source and a substrate holder, the interior surfaces of the plasma processing chamber having a Cu-containing layer deposited thereon;

introducing a reacting gas into the plasma processing chamber, the reacting gas forming a first Cu-containing compound in the Cu-containing layer on the interior surfaces;

introducing a reducing gas into the plasma processing chamber, the reducing gas reacting with the first Cu-containing compound to form a volatile Cu-containing compound;

energizing a plasma in the plasma processing chamber, by applying at least one of DC, RF, or microwave power, to the plasma source;

pumping the volatile Cu-containing compound from the plasma processing chamber, to remove the Cu-containing layer from the interior surfaces.