[0007] Meeting microscopic and macroscopic etch uniformity requirements to an acceptable degree with known etch techniques has become increasingly difficult as the size of features being etched continues to decrease. Thus, it would be desirable to provide an improved etching process.

SUMMARY

[0007a] According to an aspect of the present invention, there is provided a method of etching a substrate, comprising:
receiving the substrate, the substrate having a first material exposed, the first material comprising a polycrystalline material; and
selectively etching the polycrystalline material, the selectively etching including chemical modification of a surface of the polycrystalline material by
exposing the surface to a chemical solution to provide a modified surface layer, and
selective removal of the modified surface layer of the polycrystalline material by exposing the modified surface layer to a liquid-phase chemical solution; wherein:
the polycrystalline material has a first portion and a second portion,
the first portion of the polycrystalline material corresponds to a top portion of the substrate,
the modified surface layer corresponds to the first portion of the polycrystalline material, and
the selective removal of the modified surface layer corresponds to removing the top portion of the substrate.

[0008] A method for improving both the microscopic and macroscopic uniformity of materials during etching is disclosed herein. These improvements may be accomplished through the formation and dissolution of thin, self-limiting layers on the material surface by the use of wet ALE techniques. For etching of polycrystalline materials, these self-limiting reactions can be used to prevent this roughening of the surface during etching. Thus, as disclosed herein, a wet ALE process uses sequential, self-limiting reactions to first modify the surface layer of a material and then selectively remove the modified layer.

[0009] In one embodiment, a method of etching a substrate is provided. The method may comprise receiving the substrate, the substrate having a first material exposed,

the first material comprising a polycrystalline material. The method further comprises selectively etching the polycrystalline material, the selectively etching including chemical modification of a surface of the polycrystalline material by exposing the surface to a chemical solution to provide a modified surface layer, and selective removal of the modified surface layer of the polycrystalline material by exposing the modified surface layer to a liquid-phase chemical solution.

[0010] In one embodiment, the chemical modification of the surface of the polycrystalline material includes oxidation of the polycrystalline material using an oxidizing agent. In one embodiment, the oxidizing agent includes an oxygen-containing gaseous environment, a chemical solution containing dissolved oxygen or other oxidizing agent, or a solvent – such as water – that directly participates in the oxidation of the surface. In another embodiment, the oxidizing agent is an oxygen-saturated chemical solution that includes oxygen dissolved in water, alcohol, or acetone.

What is claimed is:

1. A method of etching a substrate, comprising:

receiving the substrate, the substrate having a first material exposed, the first material comprising a polycrystalline material; and

selectively etching the polycrystalline material, the selectively etching including:

a) chemically modifying a surface of the polycrystalline material by oxidation of the polycrystalline material using an oxidizing agent,

b) binding a complexing agent to the modified surface layer of the polycrystalline material, and

c) selectively removing the complex-bound modified surface layer of the polycrystalline material by exposing the modified surface layer to a liquid-phase chemical solution, wherein the selectively removing includes exposing the modified surface layer of the polycrystalline material to an aqueous or non-aqueous solution to dissolve the modified layer, and

wherein at least two of a), b), and c) have no temporal overlap.

2. The method of claim 1, wherein a) and b) have no temporal overlap.

3. The method of claim 1, wherein a) and b) have at least partial overlap in time.

4. The method of claim 1, wherein the oxidizing agent is an oxygen-saturated chemical solution that includes oxygen dissolved in water, in an alcohol, or in a ketone.

5. The method of claim 1, wherein the complexing agent is dissolved in acetone or isopropyl alcohol.

6. The method of claim 1, wherein the polycrystalline material is a transition metal.

7. The method of claim 1, wherein the polycrystalline material comprises ruthenium (Ru) or cobalt (Co).

8. The method of claim 1, wherein the complexing agent includes a citrate.

9. The method of claim 1, further comprising rinsing the substrate with a solvent following b) and preceding c).

10. A method of etching a substrate, comprising:

receiving the substrate, the substrate having a first material exposed, the first material comprising a polycrystalline material; and

selectively etching the polycrystalline material, the selectively etching including:

a) chemically modifying a surface of the polycrystalline material by oxidation of the polycrystalline material using an oxidizing agent that includes oxygen dissolved in in water,in an alcohol, or in acetone,

b) binding a complexing agent to the modified surface layer of the polycrystalline material using a complexing agent that is dissolved in acetone or isopropyl alcohol, and

c) selectively removing the complex-bound modified surface layer of the polycrystalline material by exposing the modified surface layer to a liquid-phase chemical solution, wherein the selectively removing includes exposing the modified surface layer of the polycrystalline material to an aqueous solution to dissolve the modified layer, and

wherein b) and c) have no temporal overlap.

11. The method of claim 10, wherein the polycrystalline material is a transition metal.

12. The method of claim 10, wherein the polycrystalline material comprises ruthenium (Ru) or cobalt (Co).

13. The method of claim 10, wherein the complexing agent includes a citrate.

14. The method of claim 10, further comprising rinsing the substrate with a solvent following b) and preceding c).

15. A method of etching a substrate, comprising:

receiving the substrate with a first material composed of a polycrystalline material, and a second material composed of a different material, wherein an exposed surface of the polycrystalline material has a surface roughness characterized by a first surface roughness value;

reducing the surface roughness to a second surface roughness value by:

~~selectively etching the polycrystalline material, the selectively etching including~~

~~a) chemically modifying a surface of the polycrystalline material by oxidation of the polycrystalline material using an oxidizing agent,~~

~~b) binding a complexing agent to the modified surface layer of the polycrystalline material, and~~

~~c) selectively removing the complex-bound modified surface layer of the polycrystalline material by exposing the modified surface layer to a liquid-phase chemical solution, wherein the selective removal includes exposing the modified surface layer of the polycrystalline material to an aqueous solution to dissolve the modified layer, and~~

~~wherein at least two of a), b), and c) have no temporal overlap.~~

~~16. The method of claim 15, wherein the oxidizing agent is an oxygen-saturated chemical solution that includes oxygen dissolved in water, in an alcohol, or in acetone.~~

~~17. The method of claim 15, wherein the polycrystalline material comprises ruthenium (Ru) or cobalt (Co).~~

~~18. The method of claim 15, wherein the complexing agent includes a citrate.~~

~~19. The method of claim 15, further comprising rinsing the substrate with a solvent following b) and preceding c).~~

~~20. The method of claim 15, further comprising etching the polycrystalline material on the substrate using a dry etching process, wherein the first surface roughness value is an outcome of the dry etching process.~~

1. A method of etching a substrate, comprising:

receiving the substrate, the substrate having a first material exposed, the first material comprising a polycrystalline material; and

selectively etching the polycrystalline material, the selectively etching including chemical modification of a surface of the polycrystalline material by

exposing the surface to a chemical solution to provide a modified surface layer, and selective removal of the modified surface layer of the polycrystalline material by exposing the modified surface layer to a liquid-phase chemical solution; wherein:

the polycrystalline material has a first portion and a second portion,

the first portion of the polycrystalline material corresponds to a top portion of the substrate,

the modified surface layer corresponds to the first portion of the polycrystalline material, and

the selective removal of the modified surface layer corresponds to removing the top portion of the substrate.

2. The method of claim 1, wherein the polycrystalline material is a transition metal.

3. The method of claim 1, wherein the polycrystalline material comprises ruthenium (Ru) or cobalt (Co).

4. The method of claim 1, wherein the chemical modification of the surface of the polycrystalline material includes oxidation of the polycrystalline material using an oxidizing agent.

5. The method of claim 4, wherein the oxidizing agent includes an oxygen-containing gaseous environment, or an oxygen-saturated chemical solution.

6. The method of claim 4, wherein the oxidizing agent is an oxygen-saturated chemical solution that includes oxygen dissolved in water, alcohol, or acetone.

7. The method of claim 4, wherein the chemical modification further includes passivation of the modified surface layer in the polycrystalline material by exposing the substrate to citric acid.

8. The method of claim 4, wherein the chemical modification includes exposing the substrate to molecular oxygen and a citrate.

9. The method of claim 4, further comprising rinsing the substrate with a solvent following the chemical modification, and preceding the selective removal.

10. The method of claim 4, wherein the selective removal includes exposing the modified surface layer of the polycrystalline material to an aqueous solution to dissolve the modified layer.

11. The method of claim 4, wherein the chemical modification further includes passivation of the modified surface layer of the polycrystalline material using a complexing agent.

12. The method of claim 11, wherein the complexing agent includes a citrate.

13. The method of claim 1, further comprising, prior to performing the selective etching, selectively dry etching the polycrystalline material by exposing the polycrystalline material to a gas-phase environment.

14. The method of claim 1, wherein the chemical modification and the selective removal are sequentially and alternatingly performed.

15. The method of claim 14, wherein sequential steps of the chemical modification and the selective removal are (1) partially overlapped in time or (2) continuously performed.

16. The method of claim 14, wherein sequential steps of the chemical modification and the selective removal are not overlapped in time.

17. The method of claim 1, wherein the substrate further includes a second material composed of a different material than the first material, wherein the polycrystalline material has a surface roughness characterized by a first surface roughness value; and

the selectively etching includes reducing the surface roughness to a second surface roughness value by exposing the substrate to the chemical solution as a first wet chemical solution which chemically modifies the polycrystalline material to form the modified surface layer, followed by exposing the substrate to the liquid-phase chemical solution as a second wet chemical solution to dissolve the modified surface layer.

18. The method of claim 17, wherein the polycrystalline material is a transition metal.

19. The method of claim 17 wherein chemical modification of the polycrystalline material includes oxidation of the polycrystalline material using an oxidizing agent.

20. The method of claim 17, further comprising etching the polycrystalline material on the substrate using a dry etching process, wherein the first surface roughness value is an outcome of the dry etching process.