## SUMMARY

**[0009]** Embodiments are described herein that use illumination of etch solutions to provide controlled etching of materials. Disclosed processing systems and platforms deposit liquid etch solutions over a material to be etched and illuminate the liquid etch solutions to adjust reactant levels. The material being etched can be, for example, a polycrystalline material, a polycrystalline metal, and/or other material to be etched. The disclosed embodiments use illumination as a tool to control etchant reactivity in the etch solution contacting the material, thereby allowing for modifications to the etch behavior. Chemical composition as well as other parameters can also be used in part to control the etch behavior and post-etch surface morphology and chemistry. The disclosed embodiments thereby control and/or reduce surface roughness during etching of materials, such as polycrystalline materials, both at microscopic and macroscopic level. These results are achieved through illumination of etch solutions applied to the material surface to provide point-of-use generation of highly reactive etchants that etch the material independent of surface chemistry of the material. For one example embodiment, the liquid etch solution is an aqueous solution including hydrogen peroxide, and hydroxyl radicals are generated by illumination, such as ultraviolet light, to form highly reactive etchants. Different or additional features, variations, and embodiments can also be implemented, and related systems and methods can be utilized as well.

**[0010]** According to an aspect of the present invention, there is provided a processing system to perform a wet etch process on a substrate, comprising: a wet process chamber configured to perform a wet etch process, a substrate holder within the wet process chamber configured to support a substrate, a delivery system including a dispending nozzle arranged to supply a liquid etch solution to the substrate, the liquid etch solution having a first level of reactants with respect to a material on a surface of the substrate; an illumination system including a light source configured to illuminate the liquid etch solution with spatially resolved light to cause the liquid etch solution to have a second level of reactants with respect to the material that is different than the first level in a region exposed to the spatially resolved light, and a controller coupled to the delivery system to control delivery of the liquid etch solution and coupled to the illumination system to control illumination of different spatial regions of the liquid etch solution by the illumination system.

**[0011]** There is disclosed a processing system to perform a wet etch process on a substrate, comprising: a wet process chamber configured to perform a wet etch process; a substrate holder within the wet process chamber configured to support a substrate; a delivery system including a dispensing nozzle arranged to supply a liquid etch solution to the substrate, the liquid solution having a first level of reactants with respect to a material on a surface of the substrate; an illumination system configured to illuminate the liquid etch solution to cause the etch solution to have a second level of reactants with respect to the material that is different than the first level; and a controller coupled to the delivery system to control delivery of the liquid etch solution and coupled to the illumination system to control illumination output by the illumination system, where the controller is configured to control the illumination system and the delivery system to etch the material in a cyclic manner.

**[0012]** In additional embodiments, the liquid etch solution, when illuminated, oxidizes the surface of the material to form oxidized material as a modified layer. In further embodiments,

a uniform layer of oxidized material is formed as the modified layer, and the liquid etch solution further dissolves the oxidized material. In still further embodiments, the liquid etch solution includes an aqueous solution including hydrogen peroxide and citrate. In further embodiments, the delivery system is further configured to deliver an aqueous solution including a complexing agent to dissolve the oxidized material. In still further embodiments, the complexing agent includes at least one of citrate, ethylene diamine, ethylendiamintetraacetate (EDTA), malic acid, oxalic acid, glycine, alanine, or iminodiacetic acid.

**[0013]** In additional embodiments, the material to be etched includes a polycrystalline material. In further embodiments, the polycrystalline material includes at least one of polycrystalline metal, polycrystalline cobalt, ruthenium, tungsten, titanium, tantalum, titanium nitride, or tantalum nitride.

**[0014]** In additional embodiments, the illumination system is configured to selectively illuminate the liquid etch solution. In further embodiments, the illumination system is configured to selectively illuminate the liquid etch solution with ultraviolet (UV) light in one or more on/off patterns. In further embodiments, the illumination system is configured to selectively illuminate with two or more different colors of light.

**[0015]** In additional embodiments, the controller is configured to control the illumination system to cause different exposures to different regions of the liquid etch solution to provide different amounts of etching for the material within the different regions. In further embodiments, different exposures are based upon measurements of at least one of a topology for a surface of the material or a thickness of the material.

**[0016]** According to a second aspect of the present invention, there is provided a platform to etch a substrate, comprising: a dry etch processing system to etch a polycrystalline material on a substrate with dry etch chemistry, a wet etch processing system to etch the polycrystalline material to mitigate roughness of the polycrystalline material caused by the dry etch chemistry, a transfer module coupled to the dry etch module and configured to move the substrate between the dry etch processing system and the wet etch processing system, and an isolation pass-through module coupled between the transfer module and the wet etch processing tool where the isolation pass-through module separates an ambient environment of the transfer module from an ambient environment of the wet etch processing system and being configured to permit the substrate to be moved between the transfer module and the wet etch processing tool without being exposed to an environment outside of the platform. For the platform, the wet etch processing system includes a wet process chamber configured to perform a wet etch process, a substrate holder within the wet process chamber configured to support a

substrate, a delivery system arranged to supply a liquid etch solution to the substrate, the liquid etch solution having a first level of reactants with respect the polycrystalline material, an illumination system including a light source configured to illuminate the liquid etch solution with spatially resolved light to cause the liquid etch solution to have a second level of reactants with respect to the polycrystalline material that is different than the first level in a region exposed to the spatially resolved light, and a controller coupled to the delivery system to control delivery of the liquid etch solution and coupled to the illumination system to control illumination of different spatial regions of the liquid etch solution by the illumination system.

**[0017]** In additional embodiments, the controller is configured to control the illumination system and the delivery system to etch the polycrystalline material in a cyclic manner.

**[0018]** In additional embodiments, the liquid etch solution, when illuminated, oxidizes the surface of the polycrystalline material to form oxidized material as a modified layer. In further additional embodiments, the liquid etch solution includes an aqueous solution including hydrogen peroxide, and the illumination includes ultraviolet (UV) light.

**[0019]** In additional embodiments, the dry etch processing system implements one or more dry etch processes. In further embodiments, the one or more dry etch processes include at least one of a plasma etch process, a reactive ion etch (RIE) process, a chemical vapor etch (CVE) process, or an atomic layer etch (ALE) process.

**[0020]** In additional embodiments, the dry etch processing system is configured to etch the polycrystalline material resulting in a first surface roughness, and the wet etch process chamber is configured to adjust the first surface roughness to a second surface roughness less than the first surface roughness. In further embodiments, the controller is configured to control the illumination system to cause different exposures to different regions of the liquid etch solution to provide different amounts of etching for the polycrystalline material based upon measurements of at least one of a topology for a surface of the material or a thickness of the material.

**[0021]** Different or additional features, variations, and embodiments can also be implemented, and related systems and methods can be utilized as well.

**CLAIMS**

What is claimed is:

1. A processing system to perform a wet etch process on a substrate, comprising:
a wet process chamber configured to perform a wet etch process;
a substrate holder within the wet process chamber configured to support a substrate;
a delivery system including a dispensing nozzle arranged to supply a liquid etch solution to the substrate, the liquid etch solution having a first level of reactants with respect to a material on a surface of the substrate;
an illumination system including a light source configured to illuminate the liquid etch solution with spatially resolved light to cause the liquid etch solution to have a second level of reactants with respect to the material that is different than the first level in a region exposed to the spatially resolved light; and
a controller coupled to the delivery system to control delivery of the liquid etch solution and coupled to the illumination system to control illumination of different spatial regions of the liquid etch solution by the illumination system.

2. The processing system of claim 1, wherein the liquid etch solution, when illuminated, oxidizes the surface of the material to form oxidized material as a modified layer.

3. The processing system of claim 2, wherein a uniform layer of oxidized material is formed as the modified layer, and wherein the liquid etch solution further dissolves the oxidized material.

4. The processing system of claim 3, wherein the liquid etch solution comprises an aqueous solution including hydrogen peroxide and citrate.

5. The processing system of claim 2, wherein the delivery system is further configured to deliver an aqueous solution including a complexing agent to dissolve the oxidized material.

6. The processing system of claim 5, wherein the complexing agent comprises at least one of citrate, ethylene diamine, ethylendiamintetraacetate (EDTA), malic acid, oxalic acid, glycine, alanine, or iminodiacetic acid.

7. The processing system of claim 1, wherein the material to be etched comprises a polycrystalline material.

8. The processing system of claim 7, wherein the polycrystalline material comprises at least one of polycrystalline metal, polycrystalline cobalt, ruthenium, tungsten, titanium, tantalum, titanium nitride, or tantalum nitride.

9. The processing system of claim 1, wherein the illumination system is configured to selectively illuminate the liquid etch solution.

10. The processing system of claim 9, wherein the illumination system is configured to selectively illuminate the liquid etch solution with ultraviolet (UV) light in one or more on/off patterns.

11. The processing system of claim 9, wherein the illumination system is configured to selectively illuminate with two or more different colors of light.

12. The processing system of claim 1, wherein the controller is configured to control the illumination system to cause different exposures to different regions of the liquid etch solution to provide different amounts of etching for the material within the different regions.

13. The processing system of claim 12, wherein different exposures are based upon measurements of at least one of a topology for a surface of the material or a thickness of the material.

14. A platform to etch a substrate, comprising:

a dry etch processing system to etch a polycrystalline material on a substrate with dry etch chemistry;

a wet etch processing system to etch the polycrystalline material to mitigate roughness of the polycrystalline material caused by the dry etch chemistry, the wet etch processing system comprising:

a wet process chamber configured to perform a wet etch process;

a substrate holder within the wet process chamber configured to support a substrate;

a delivery system arranged to supply a liquid etch solution to the substrate, the liquid etch solution having a first level of reactants with respect the polycrystalline material;

an illumination system including a light source configured to illuminate the liquid etch solution with spatially resolved light to cause the liquid etch solution to have a second level of reactants with respect to the polycrystalline material that is different than the first level in a region exposed to the spatially resolved light; and

a controller coupled to the delivery system to control delivery of the liquid etch solution and coupled to the illumination system to control illumination of different spatial regions of the liquid etch solution by the illumination system;

a transfer module coupled to the dry etch module and configured to move the substrate between the dry etch processing system and the wet etch processing system; and

an isolation pass-through module coupled between the transfer module and the wet etch processing tool, the isolation pass-through module separating an ambient environment of the transfer module from an ambient environment of the wet etch processing system and being configured to permit the substrate to be moved between the transfer module and the wet etch processing tool without being exposed to an environment outside of the platform.

15. The platform of claim 14, wherein the liquid etch solution, when illuminated, oxidizes the surface of the polycrystalline material to form oxidized material as a modified layer.

16. The platform of claim 14, wherein the liquid etch solution comprises an aqueous solution including hydrogen peroxide, and wherein the illumination comprises ultraviolet (UV) light.

17. The platform of claim 14, wherein the dry etch processing system implements one or more dry etch processes.

18. The platform of claim 17, wherein the one or more dry etch processes comprises at least one of a plasma etch process, a reactive ion etch (RIE) process, a chemical vapor etch (CVE) process, or an atomic layer etch (ALE) process.

19. The platform of claim 14, wherein the dry etch processing system is configured to etch the polycrystalline material resulting in a first surface roughness, and wherein the wet etch process chamber is configured to adjust the first surface roughness to a second surface roughness less than the first surface roughness.

20. The platform of claim 19, wherein the controller is configured to control the illumination system to cause different exposures to different regions of the liquid etch solution to provide different amounts of etching for the polycrystalline material based upon measurements of at least one of a topology for a surface of the material or a thickness of the material.