

[0009] According to a first aspect of the present invention, there is provided a method of etching a substrate, including: disposing the substrate in a plasma processing system configured to facilitate an etching process; performing an atomic layer etching process cycle to etch a monolayer of an exposed surface of the substrate, the process cycle sequentially comprising: forming an adsorption monolayer comprising an etchant on the exposed surface of the substrate by introducing the etchant while concurrently coupling electromagnetic power to the plasma processing system at a first applied power level targeted to achieve an etchant radical flux at the exposed surface greater than a total ion flux at the exposed surface, purging the plasma processing system to remove any excess etchant, desorbing the adsorption monolayer comprising the etchant by coupling electromagnetic power to the plasma processing system at a second applied power level and exposing the adsorption monolayer to gas ions to activate a reaction of the etchant, and purging the plasma processing system to remove the desorbed adsorption monolayer; and repeating the atomic layer etching process cycle until a target depth is reached wherein each process cycle etches the monolayer from the exposed surface, wherein the first applied power level is less than or equal to 50 W and the second applied power level is greater than the first applied power level.

[0010] According to a second aspect of the present invention, there is provided a method of etching a substrate, including: disposing the substrate in a plasma processing system configured to facilitate an etching process; etching an exposed surface of the substrate one monolayer of substrate material per process cycle, wherein each process cycle comprises alternately performing an adsorption step and a desorption step, wherein the adsorption step includes adsorbing an etchant on the exposed surface of the substrate while coupling electromagnetic power to the plasma processing system at a first applied power level less than or equal to 50 W to achieve an etchant radical flux at the exposed surface greater than a total ion flux at the exposed surface, and wherein the desorption step includes activating a reaction between the adsorbed etchant and the monolayer of substrate material to desorb a reaction product by coupling electromagnetic power to the plasma processing system at a second applied power level that is greater than the first applied power level.

CLAIMS:

1. A method of etching a substrate, comprising:
 - disposing the substrate in a plasma processing system configured to facilitate an etching process;
 - performing an atomic layer etching process cycle to etch a monolayer of an exposed surface of the substrate, the process cycle sequentially comprising:
 - forming an adsorption monolayer comprising an etchant on the exposed surface of the substrate by introducing the etchant while concurrently coupling electromagnetic power to the plasma processing system at a first applied power level targeted to achieve an etchant radical flux at the exposed surface greater than a total ion flux at the exposed surface,
 - purging the plasma processing system to remove any excess etchant,
 - desorbing the adsorption monolayer comprising the etchant by coupling electromagnetic power to the plasma processing system at a second applied power level and exposing the adsorption monolayer to gas ions to activate a reaction of the etchant, and
 - purging the plasma processing system to remove the desorbed adsorption monolayer; and
 - repeating the atomic layer etching process cycle until a target depth is reached wherein each process cycle etches the monolayer from the exposed surface,
 - wherein the first applied power level is less than or equal to 50 W and the second applied power level is greater than the first applied power level.
2. The method of claim 1, wherein the first applied power level is less than or equal to 10 W.
3. The method of claim 1, wherein the electromagnetic power at the first applied power level is coupled to the plasma processing system at least in part as bias power coupled to a substrate holder upon which the substrate rests.

4. The method of claim 3, wherein the electromagnetic power at the first applied power level is exclusively applied as bias power to the substrate holder.
5. The method of claim 3, wherein the electromagnetic power at the first applied power level is further coupled to the plasma processing system as source power to an electrode opposing and facing the substrate holder.
6. The method of claim 1, wherein the electromagnetic power at the first applied power level is coupled to the plasma processing system at least in part as source power coupled to an electrode opposing and facing a substrate holder upon which the substrate rests.
7. The method of claim 6, wherein the electromagnetic power at the first applied power level is exclusively applied as source power to the electrode opposite the substrate holder.
8. The method of claim 1, wherein the etchant includes a halogen element.
9. The method of claim 8, wherein the etchant includes a halide, a halomethane, a halosilane, or a combination of two or more thereof.
10. The method of claim 8, wherein the etchant includes Cl_2 , Br_2 , F_2 , HBr , BCl_3 , SF_6 , NF_3 , a fluorocarbon compound of the form C_xF_y wherein x and y are real numbers greater than zero, a fluorohydrocarbon compound of the form $\text{C}_x\text{F}_y\text{H}_z$ wherein x , y and z are real numbers greater than zero, or any combination of two or more thereof.
11. The method of claim 1, wherein the first applied power level is targeted to achieve a ratio of the etchant radical flux to the total ion flux at the substrate that exceeds a value of 100.

12. The method of claim 1, wherein the first applied power level is targeted to achieve a ratio of the etchant radical flux to the total ion flux at the substrate that exceeds a value of 1000.
13. The method of claim 1, wherein forming the adsorption monolayer proceeds for less than or equal to 2 seconds per process cycle.
14. The method of claim 1, wherein forming the adsorption monolayer proceeds for less than or equal to 0.5 second per process cycle.
15. The method of claim 1, wherein the exposed surface of the substrate includes silicon, the etchant includes Cl_2 , and the gas ions include Ar ions.
16. A method of etching a substrate, comprising:
disposing the substrate in a plasma processing system configured to facilitate an etching process;
etching an exposed surface of the substrate one monolayer of substrate material per process cycle, wherein each process cycle comprises alternatingly performing an adsorption step and a desorption step,
wherein the adsorption step includes adsorbing an etchant on the exposed surface of the substrate while coupling electromagnetic power to the plasma processing system at a first applied power level less than or equal to 50 W to achieve an etchant radical flux at the exposed surface greater than a total ion flux at the exposed surface, and
wherein the desorption step includes activating a reaction between the adsorbed etchant and the monolayer of substrate material to desorb a reaction product by coupling electromagnetic power to the plasma processing system at a second applied power level that is greater than the first applied power level.

17. The method of claim 16, wherein the desorption step includes coupling the electromagnetic power to the plasma processing system as bias power coupled to a substrate holder upon which the substrate rests and as source power coupled to an electrode opposing and facing the substrate holder while flowing a noble gas into the plasma processing system to form gas ions having an energy sufficient to activate the reaction.
18. The method of claim 16, further comprising purging the plasma processing system between the adsorption step and the desorption step and after the desorption step.
19. The method of claim 16, wherein the first applied power level is less than or equal to 20 W.
20. The method of claim 16, wherein the first applied power level is adjusted to achieve a ratio of the etchant radical flux to the total ion flux at the substrate that exceeds a value of 100.