

CLAIMS

1. An apparatus for processing substrates, the apparatus comprising:
one or more process chambers, each process chamber comprising a chuck for holding a substrate;
one or more gas inlets into the process chambers and associated flow-control hardware; and
a controller having at least one processor and a memory, wherein
the at least one processor and the memory are communicatively connected with one another,
the at least one processor is at least operatively connected with the flow-control hardware, and
the memory stores computer-executable instructions for controlling the at least one processor to at least control the flow-control hardware by:
causing the substrate to be etched by atomic layer etch in a chamber; and
causing a film to be deposited by atomic layer deposition in the chamber, wherein the etching and the depositing are performed without breaking vacuum.
2. The apparatus of claim 1, wherein the instructions for the etching comprise instructions for controlling the at least one processor to at least control the flow-control hardware to perform cycles of:
causing an etching gas to flow to the chamber to modify a surface of the substrate; and
causing a removal gas to flow to the chamber to remove at least some of the modified surface.
3. The apparatus of claim 1, wherein the instructions for the depositing comprise instructions for controlling the at least one processor to at least control the flow-control hardware by to perform cycles of:
causing a deposition precursor to flow to the chamber to modify a surface of the substrate; and
causing a reducing agent to flow to the chamber to deposit the film.

4. The apparatus of claim 2, wherein the instructions further comprise instructions for causing a plasma to be ignited when flowing the etching gas to the chamber.
5. The apparatus of claim 2, wherein the instructions further comprise instructions to cause a bias to be applied to the substrate.
6. The apparatus of claim 3, wherein the instructions further comprise instructions for causing a plasma to be ignited.
7. The apparatus of claim 2, wherein the instructions further comprise instructions to cause a purge gas to flow to the chamber between flowing the etching gas and flowing the removal gas.
8. The apparatus of claim 3, wherein the instructions further comprise instructions to cause a purge gas to flow to the chamber between flowing the deposition precursor and flowing the reducing agent.
9. The apparatus of any of claims 1-8, wherein the etching and the depositing is performed in the same chamber.
10. The apparatus of any of claims 1-8, wherein the instructions- cause material to be deposited on the substrate.
11. The apparatus of any of claims 1-8, wherein the instructions-cause material on the substrate to be etched.
12. The apparatus of any of claims 1-8, wherein the instructions for the etching further comprises instructions for causing directional sputtering the substrate.
13. An apparatus for processing substrates, the apparatus comprising:
one or more process chambers, each process chamber comprising a chuck;
one or more gas inlets into the process chambers and associated flow-control hardware; and
a controller having at least one processor and a memory, wherein

the at least one processor and the memory are communicatively connected with one another,
the at least one processor is at least operatively connected with the flow-control hardware, and
the memory stores computer-executable instructions for controlling the at least one processor to at least control the flow-control hardware by:

(a) causing alternating pulses of an etchant and purge gas to flow to the one or more process chambers to etch the substrate layer by layer;

(b) causing alternating pulses of a reducing agent and a precursor to flow to the one or more process chambers to deposit a film on the etched substrate; and

(c) causing repeating of (a) and (b) without breaking vacuum between performing (a) and (b).

14. A method of processing a substrate, the method comprising:
etching the substrate by atomic layer etch in a chamber; and
depositing a film comprising a first material by atomic layer deposition in the chamber,
wherein the etching and the depositing are performed without breaking vacuum.
15. The method of claim 14, wherein the etching is performed nonconformally.
16. A method of processing a substrate, the method comprising:
depositing a first material onto the substrate by atomic layer deposition; and
etching a second material on the substrate by atomic layer etch in a chamber,
wherein the etching and the depositing are performed without breaking vacuum, and
wherein the second material comprises a semiconductor material.
17. The method of claim 16, wherein the first material is selected from the group consisting of oxides, nitrides, silicon oxynitride, metals, and metal-containing films.
18. The method of claim 16, wherein the second material is selected from the group consisting of silicon and germanium.

19. The method of claim 16, wherein the depositing is performed in the chamber.
20. A method of processing a substrate, the method comprising:
providing a substrate having one or more features, each feature comprising sidewalls;
depositing a protective layer comprising a first material by atomic layer deposition;
and
after depositing the protective layer on the sidewalls, etching a second material on the substrate by atomic layer etch to leave the first material on the sidewalls,
wherein the depositing and the etching are performed without breaking vacuum.
21. The method of claim 20, wherein each feature comprises a feature opening less than 150 nm in diameter.
22. The method of claim 20, wherein each feature has an aspect ratio of at least 5:1.
23. The method of any of claims 16-22, wherein the surface of the second material on the substrate is modified by a thermal reaction between an etching gas and the second material on the substrate.
24. The method of claim 23, wherein the etching is performed in cycles, a cycle comprising
exposing the substrate to the etching gas to modify a surface of the substrate; and
exposing the substrate to a removal gas to remove at least some of the modified surface.
25. The method of claim 24, wherein the etching gas is a halide.
26. The method of claim 24, wherein the etching gas is a chlorine-containing compound.
27. The method of claim 24, wherein a cycle etches between about 1 Å to about 50 Å of film.
28. The method of claim 24, wherein the removal gas is selected from the group consisting of nitrogen, argon, helium, neon, and oxygen.

29. The method of claim 24, wherein the removal gas is an inert gas.
30. The method of any of claims 14-22, wherein the depositing is performed in cycles, a cycle comprising
exposing the substrate to a deposition precursor to modify a surface of the substrate;
and
exposing the substrate to a second reactant to deposit the first material.
31. The method of claim 30, wherein at least some of the deposition precursor adsorbs onto the surface of the substrate during the exposing of the substrate to the deposition precursor.
32. The method of claim 30, wherein the deposition precursor is a metal-containing precursor.
33. The method of claim 30, wherein the second reactant is selected from the group consisting of oxygen, nitrogen, and combinations thereof.
34. The method of claim 30, wherein the second reactant is a reducing agent.
35. The method of claim 30, wherein the depositing is performed using sub-saturated atomic layer deposition.
36. A method comprising:
(a) exposing a substrate housed in a chamber to alternating pulses of an etching gas and a removal gas to etch the substrate layer by layer;
(b) exposing the substrate to alternating pulses of a first reactant and a second reactant to deposit a film over the substrate; and
(c) repeating (a) and (b) in the same chamber.
37. The method of claim 36, wherein the substrate is selected from the group consisting of metals and dielectrics.
38. The method of claim 36, wherein (a) further comprises applying a bias to the

substrate.

- 39. The method of any of claims 14-38, further comprising igniting a plasma.
- 40. The method of claim 39, wherein the plasma is ignited in the chamber.
- 41. The method of claim 39, wherein the plasma is ignited remotely.
- 42. The method of any of claims 14-41, wherein the etching further comprises directionally sputtering the substrate.
- 43. The method of any of claims 14-34 and 36-42, wherein at least one of the etching or the depositing is a self-limiting reaction.
- 44. The method of any of claims 14-22 and 36-41, wherein the etching and the depositing is performed in the same chamber.
- 45. The method of any of claims 14-22 and 36-41, wherein the etching and the depositing are performed to deposit material on the substrate.
- 46. The method of any of claims 14-22 and 36-41, wherein the etching and the depositing are performed to etch material on the substrate.