

CLAIMS

What is claimed is:

1. A method of forming a silicon-containing layer on a semiconductor substrate, the method comprising:

(a) exposing the semiconductor substrate to a silicon-containing precursor in a process chamber, wherein the silicon-containing precursor is a compound that has:

at least one Si-Si bond;

at least one Si-X bond, wherein X is selected from the group consisting of a halogen, triflate, tosylate, CN, N₃, and NR₁R₂, wherein R₁ and R₂ are independently selected from the group consisting of H, and an alkyl, wherein R₁ and R₂ are either linked to form a cyclic ring structure or not linked; and

at least one Si-R bond, wherein R is selected from the group consisting of H, and an alkyl;

(b) exposing the semiconductor substrate to a reactant in the process chamber; and

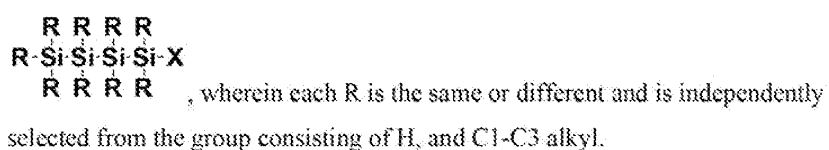
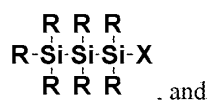
(c) reacting the silicon-containing precursor with the reactant on a surface of the semiconductor substrate to form at least a portion of the silicon-containing layer, wherein operations (a) – (c) are performed at a temperature of at least about 500 °C

2. The method of claim 1, wherein the reactant is an oxygen-containing reactant and wherein (c) comprises reacting the silicon-containing precursor with the oxygen-containing reactant in an absence of plasma to form a silicon oxide layer.

3. The method of claim 1, further comprising purging the process chamber between exposures of the semiconductor substrate to the silicon-containing precursor and the reactant.

4. The method of claim 1, wherein operations (a) – (c) are performed at a temperature of at least about 550 °C.

5. The method of claim 1, wherein the silicon-containing precursor is selected from the group consisting of:



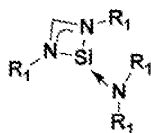
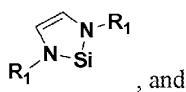
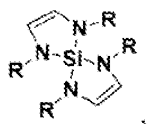
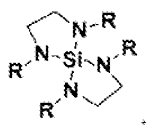
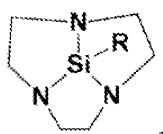
6. The method of claim 1, wherein the silicon-containing precursor is selected from the group consisting of: 1-chlorodisilane, 1-dimethylaminodisilane, 1-diethylaminotrisilane, 1-bromotetrasilane, and 1,2-bis(diisopropylamino)disilane.
7. The method of claim 1, wherein R is an alkyl, and wherein the silicon-containing precursor does not include Si-H bonds.
8. The method of claim 1, further comprising repeating operations (a)-(c) until the silicon-containing layer reaches a target thickness.
9. The method of claim 1, wherein the method comprises depositing a first portion of the silicon-containing layer in an absence of plasma and a second portion of the silicon-containing layer using a plasma-assisted reaction while using the same silicon-containing precursor for both thermal and plasma-assisted deposition.
10. A method of forming a silicon-containing layer on a semiconductor substrate, the method comprising:
- (a) exposing the semiconductor substrate to a silicon-containing precursor in a process chamber, wherein the silicon-containing precursor is a compound that has:

at least one silicon atom that forms bonds with at least two nitrogen atoms, wherein the at least two nitrogen atoms are linked to form a cyclic ring;

(b) exposing the semiconductor substrate to a reactant in the process chamber; and

(c) reacting the silicon-containing precursor with the reactant on a surface of the semiconductor substrate to form at least a portion of the silicon-containing layer, wherein operations (a) – (c) are performed at a temperature of at least about 500 °C.

11. The method of claim 10, wherein the silicon-containing precursor is a compound selected from the group consisting of:



wherein each R is the same or different and is independently selected from the group consisting of H, and alkyl, and wherein each R₁ is the same or different and is an alkyl.

12. The method of claim 10, wherein the reactant is an oxygen-containing reactant and wherein (c) comprises reacting the silicon-containing precursor with the oxygen-containing reactant in an absence of plasma to form a silicon oxide layer.

13. The method of claim 10, further comprising purging the process chamber between exposures of the semiconductor substrate to the silicon-containing precursor and the reactant.

14. The method of claim 10, wherein operations (a) – (c) are performed at a temperature of at least about greater than about 550 °C.

15. The method of claim 10, further comprising repeating operations (a)-(c) until the silicon-containing layer reaches a target thickness.

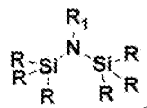
16. The method of claim 10, wherein the method comprises depositing a first portion of the silicon-containing layer in an absence of plasma and a second portion of the silicon-containing layer using a plasma-assisted reaction while using the same silicon-containing precursor for both thermal and plasma-assisted deposition.

17. A method of forming a silicon-containing layer on a semiconductor substrate, the method comprising:

- (a) exposing the semiconductor substrate to a silicon-containing precursor in a process chamber, wherein the silicon-containing precursor is a compound that has:
 - at least one nitrogen atom that forms bonds with at least two silicon atoms;
- (b) exposing the semiconductor substrate to a reactant in the process chamber; and
- (c) reacting the silicon-containing precursor with the reactant on a surface of the semiconductor substrate to form at least a portion of the silicon-containing

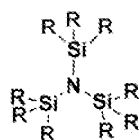
layer, wherein operations (a) – (c) are performed at a temperature of at least about 500 °C.

18. The method of claim 17, wherein the silicon-containing precursor is:



wherein each R is the same or different and is independently selected from the group consisting of H, and alkyl, and wherein each R^1 is independently selected from the group consisting of H, alkyl, and $Si(R^2)_3$, wherein each R^2 is independently selected from the group consisting of H, and an alkyl.

19. The method of claim 17, wherein the silicon-containing precursor is:



20. The method of claim 17, wherein the silicon-containing precursor is selected from the group consisting of tris(trimethylsilyl)amine, trisilylamine, isopropyl(disilyl)amine, ethyl-bis(trimethylsilyl)amine, disilylhydrazine.

21. The method of claim 17, wherein the reactant is an oxygen-containing reactant and wherein (c) comprises reacting the silicon-containing precursor with the oxygen-containing reactant in an absence of plasma to form a silicon oxide layer.

22. The method of claim 17, further comprising purging the process chamber between exposures of the semiconductor substrate to the silicon-containing precursor and the reactant.

23. The method of claim 17, wherein operations (a) – (c) are performed at a temperature of at least about greater than about 550 °C.

24. The method of claim 17, further comprising repeating operations (a)-(c) until the silicon-containing layer reaches a target thickness.
25. The method of claim 17, wherein the method comprises depositing a first portion of the silicon-containing layer in an absence of plasma and a second portion of the silicon-containing layer using a plasma-assisted reaction while using the same silicon-containing precursor for both thermal and plasma-assisted deposition.
26. A method of forming a silicon-containing layer on a semiconductor substrate, the method comprising:
- (a) exposing the semiconductor substrate to a silicon-containing precursor in a process chamber, wherein the silicon-containing precursor is a compound that has:
 - at least one silicon atom that forms a bond with a moiety selected from the group consisting of $-N_3$, $-CN$, $-OTf$ (triflate), and $-OTs$ (tosylate);
 - (b) exposing the semiconductor substrate to a reactant in the process chamber; and
 - (c) reacting the silicon-containing precursor with the reactant on a surface of the semiconductor substrate to form at least a portion of the silicon-containing layer, wherein operations (a) – (c) are performed at a temperature of at least about 500 °C.
27. The method of claim 26, wherein the silicon-containing precursor is: SiX_nR_m , wherein each X is independently selected from the group consisting of $-N_3$, $-CN$, $-OTf$ (triflate), and $-OTs$ (tosylate), each R is independently selected from the group consisting of H, an alkyl, and NR^1R^2 , wherein each R^1 and R^2 is independently selected from the group consisting of H, and an alkyl, wherein R^1 and R^2 are either linked to form a cyclic ring structure or not linked, and wherein n is 1-3, m is 1-3, and $n+m$ is 4.
28. The method of claim 26, wherein the reactant is an oxygen-containing reactant and wherein (c) comprises reacting the silicon-containing precursor with the oxygen-containing reactant in an absence of plasma to form a silicon oxide layer.

29. A method of forming a silicon-containing layer on a semiconductor substrate, the method comprising:

(a) exposing the semiconductor substrate to a silicon-containing precursor in a process chamber, wherein the silicon-containing precursor is a compound that has:

at least one silicon atom that forms bonds with at least two oxygen atoms, wherein the at least two oxygen atoms are linked to form a cyclic ring;

(b) exposing the semiconductor substrate to a reactant in the process chamber; and

(c) reacting the silicon-containing precursor with the reactant on a surface of the semiconductor substrate to form at least a portion of the silicon-containing layer, wherein operations (a) – (c) are performed at a temperature of at least about 500 °C.

30. The method of claim 29, wherein the two oxygen atoms are derived from a β -diketonate moiety.

31. A method of forming a silicon-containing layer on a semiconductor substrate, the method comprising:

(a) exposing the semiconductor substrate to a silicon-containing precursor in a process chamber, wherein the silicon-containing precursor is a compound that has:

at least one silicon atom that is part of a cyclic ring;

(b) exposing the semiconductor substrate to a reactant in the process chamber; and

(c) reacting the silicon-containing precursor with the reactant on a surface of the semiconductor substrate to form at least a portion of the silicon-containing layer, wherein operations (a) – (c) are performed at a temperature of at least about 500 °C.

32. The method of claim 31, wherein the silicon-containing precursor is selected from the group consisting of compounds 12, 13, 14, and 15.

33. The method as in any of the claims 1, 10, 17, 26, 29, and 31, wherein the silicon-containing layer is selected from the group consisting of silicon nitride, silicon oxynitride, silicon carbide, and silicon oxycarbide.

34. The method of claim 1, wherein the silicon-containing precursor is $\text{Si}_n\text{R}_{(2n+1)}\text{X}$, wherein n is selected from 2 to 10, and wherein each R is the same or different and is independently selected from the group consisting of H , an alkyl, an alkenyl, and an alkynyl.

35. The method of claim 1, wherein the silicon-containing precursor comprises at least one silicon atom that is part of a cycle.

36. The method as in any of the claims 1, 10, 17, 26, 29, and 31, further comprising:

applying photoresist to a semiconductor substrate;

exposing the photoresist to light;

patterning the photoresist;

transferring the pattern to the semiconductor substrate; and

selectively removing the photoresist from the semiconductor substrate.

37. An apparatus for depositing a silicon-containing layer on a semiconductor substrate, the apparatus comprising:

a process chamber configured for housing the semiconductor substrate, wherein the process chamber includes an inlet for introduction of a silicon-containing precursor; and a controller comprising program instructions for causing deposition of the silicon-containing layer on the semiconductor substrate in accordance with any of the methods of claims 1, 10, 17, 26, 29, and 31.