CLAIMS

1. A method of depositing a film on a substrate surface in a reaction chamber, the method comprising:

(a) introducing a first reactant into the reaction chamber under conditions allowing the first reactant to adsorb onto the substrate surface;

(b) introducing a second reactant into the reaction chamber while the first reactant is adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction between the first and second reactants on the substrate surface to form a portion of the film;

(d) repeating (a)-(c) at least once;

(e) introducing a dopant containing material, not introduced during (a)-(d), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the film; and

(f) introducing a dopant into the film from the dopant containing material.

2. The method of claim 1, further comprising:

(g) repeating (a)-(c) after (e) or (f).

3. The method of claim 1, further comprising (g) repeating (a)-(e).

4. The method of claim 1, wherein the thickness of the film deposited during (a)-(c) is between about 0.5 to 1 Angstroms.

5. The method of claim 1, further comprising driving the dopant from the film into features of the substrate surface on which the film resides.

6. The method of claim 5, wherein driving the dopant from the film comprises annealing the film.

7. The method of claim 5, wherein the film resides on a three-dimensional feature of the substrate surface and wherein driving the dopant from the film provides conformal diffusion of the dopant into the feature.

8. The method of claim 7, wherein the feature has a width of not greater than about 40 nanometers.

9. The method of claim 1, further comprising purging the second reactant from the reaction chamber prior to exposing the substrate surface to plasma.

10. The method of claim 9, wherein the purging comprises flowing a gas comprising an oxidant into the reaction chamber.

11. The method of claim 1, wherein the first and second reactants co-exist in vapor phase in the reaction chamber and wherein the first and second reactants do not appreciably react with one another in the reaction chamber until exposure to plasma in (c).

12. The method of claim 1, wherein introducing the dopant into the film comprises exposing the dopant containing material to a plasma.

13. The method of claim 1, wherein the first reactant is an oxidizing agent.

14. The method of claim 13, wherein the oxidizing agent is nitrous oxide.

15. The method of claim 1, wherein the second reactant is selected from the group consisting of

alkylamino silanes ($SiH_x(NR_2)_{4-x}$), where x=1-3, and R includes alkyl groups, and

halosilanes (SiH_xY_{4-x}), where x=1-3, and Y includes Cl, Br, and I).

16. The method of claim 1, wherein the second reactant is BTBAS.

17. The method of claim 1, wherein the dopant containing material is selected from the group consisting of phosphine, arsine, alkylboranes, alkyl gallanes, alkylphosphines, phosphorus halides, arsenic halides, gallium halides, boron halides, alkylboranes, and diborane.

18. The method of claim 1, wherein the film is a dielectric film.

19. The method of claim 1, wherein the total film thickness is between about 10-100 Angstroms.

20. The method of claim 1, wherein the concentration of dopant in the film is between about 0.01 and 10 percent by weight.

21. The method of claim 1 further comprising:

applying photoresist to the substrate surface;

exposing the photoresist to light;

patterning the resist and transferring the pattern to the substrate surface; and

selectively removing the photoresist from the substrate surface.

22. A method of depositing a dielectric film on a substrate surface in a reaction chamber, the method comprising:

(a) flowing an oxidant into the reaction chamber under conditions allowing the oxidant to adsorb onto the substrate surface;

(b) introducing a dielectric precursor into the reaction chamber while the oxidant continues to flow into the reaction chamber;

(c) exposing the substrate surface to plasma to drive a reaction between the dielectric precursor and oxidant on the substrate surface to form a portion of the dielectric film;

(d) introducing a dopant containing material, not introduced during (a)-(c), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the dielectric film; and

(e) causing a dopant from the dopant containing material to integrate into the dielectric film.

23. The method of claim 22, wherein the dielectric precursor is BTBAS.

24. The method of claim 22, further comprising driving the dopant from the dielectric film into the substrate.

25. The method of claim 22, wherein operations (a)-(c) are repeated.

26. The method of claim 25, wherein the oxidant contains a first ratio of oxygen to nitrogen when (a) is initially performed and wherein the oxidant contains a second ratio of oxygen to nitrogen, which second ratio is smaller than the first ratio, when (a) is repeated.

27. The method of claim 26, wherein the oxidant comprises elemental oxygen when (a) is initially performed and wherein the oxidant comprises nitrous oxide when (a) is repeated.

28. The method of claim 25, wherein the substrate is at a first temperature when (c) is initially performed, and wherein the substrate is at a second temperature, which is higher than the first temperature, when (c) is repeated.

29. The method of claim 22, further comprising contacting the substrate surface with the dopant containing material prior to (a).

30. A method of depositing a dielectric film on a substrate surface in a reaction chamber, the method comprising:

(a) introducing a dielectric precursor into the reaction chamber under conditions allowing the dielectric precursor to adsorb onto the substrate surface;

(b) thereafter purging the dielectric precursor from the reaction chamber while the dielectric precursor remains adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction of the dielectric precursor on the substrate surface to form a portion of the dielectric film; and

(d) introducing a dopant precursor, not introduced during (a)-(c), into the reaction chamber under conditions allowing the dopant precursor to contact the portion of the dielectric film.

31. The method of claim 30, further comprising flowing an oxidant into the reaction chamber prior to and during (a)-(c).

32. The method of claim 30, further comprising (e) reacting the dopant precursor to introduce a dopant to the dielectric film.

33. The method of claim 1:

wherein during the step (e) of introducing the dopant containing material, the conditions are such that the dopant containing material is adsorbed onto the exposed surface of the film forming an adsorption-limited layer; and

wherein the step (f) of introducing the dopant into the film comprises reacting the adsorbed dopant containing material to form a layer of the film containing a dopant source.

34. The method of claim 33, wherein reacting the adsorbed dopant containing material in step (f) comprises exposing the dopant containing material to a plasma.

35. The method of claim 33, wherein steps (e) and (f) comprise atomic layer deposition.

36. The method of claim 33, further comprising:

(g) forming a capping layer after steps (e) or (f), the capping layer being a protective diffusion barrier layer.

37. The method of claim 22:

wherein during the step (d) of introducing the dopant containing material, the conditions are such that the dopant containing material is adsorbed onto the exposed surface of the film forming an adsorption-limited layer; and

wherein the step (e) of causing the dopant to integrate into the dielectric film comprises reacting the adsorbed dopant containing material to form a layer of the dielectric film containing a dopant source.

38. The method of claim 37, wherein reacting the adsorbed dopant containing material in step (f) comprises exposing the dopant containing material to a plasma.

39. The method of claim 37, wherein steps (d) and (e) comprise atomic layer deposition.

40. The method of claim 37, further comprising:

(f) forming a capping layer after steps (d) or (e), the capping layer being a protective diffusion barrier layer.

41. The method of claim 30:

wherein during the step (d) of introducing the dopant precursor, the conditions are such that the dopant precursor is adsorbed onto the portion of the dielectric film forming an adsorption-limited layer; and

wherein the method further comprises:

(e) reacting the adsorbed dopant precursor to form a layer of the dielectric film containing a dopant source.

42. The method of claim 41, wherein reacting the adsorbed dopant precursor in step (e) comprises exposing the dopant precursor to a plasma.

43. The method of claim 41, wherein steps (d) and (e) comprise atomic layer deposition.

44. The method of claim 41, further comprising:

(f) forming a capping layer after steps (d) or (e), the capping layer being a protective diffusion barrier layer.

CLAIMS

what is claimed is:

1. A method of depositing a film on a substrate surface in a reaction chamber, the method comprising:

(a) introducing a first reactant into the reaction chamber under conditions allowing the first reactant to adsorb onto the substrate surface;

(b) introducing a second reactant into the reaction chamber while the first reactant is adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction between the first and second reactants on the substrate surface to form a portion of the film;

(d) repeating (a)-(c) at least once;

(e) introducing a dopant containing material, not introduced during (a)-(d), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the film; and

(f) introducing a dopant into the film from the dopant containing material.

2. The method of claim 1, further comprising:

(g) repeating (a)-(c) after (e) or (f).

3. The method of claim 1, further comprising

(g) repeating (a)-(e).

4. The method of claim 1, wherein the amount of film deposited during (a)-(c) is between about 0.5 to 1 Angstroms.

5. The method of claim 1, further comprising driving the dopant from the film into features of the substrate surface on which the film resides.

6. The method of claim 5, wherein driving the dopant from the film comprises annealing the film.

7. The method of claim 5, wherein the film resides on a three-dimensional feature of the substrate surface and wherein driving the dopant from the film provides conformal diffusion of the dopant into the feature.

8. The method of claim 7, wherein the feature has a width of not greater than about 40 nanometers.

9. The method of claim 1, further comprising purging the second reactant from the reaction chamber prior to exposing the substrate surface to plasma.

10. The method of claim 9, wherein the purging comprises flowing a gas comprising an oxidant into the reaction chamber.

11. The method of claim 1, wherein the first and second reactants co-exist in vapor phase in the reaction chamber and wherein the first and second reactants do not appreciably react with one another in the reaction chamber until exposure to plasma in (c).

12. The method of claim 1, wherein introducing the dopant into the film comprises exposing the dopant containing material to a plasma.

13. The method of claim 1, wherein the first reactant is an oxidizing agent.

14. The method of claim 13, wherein the oxidizing agent is nitrous oxide.

15. The method of claim 1, wherein the second reactant is selected from the group consisting of

alkylamino silanes ($SiH_x(NR_2)_{4-x}$), where x = 1-3, and R includes alkyl groups, and

halosilanes (SiH_xY_{4-x}), where x = 1-3, and Y includes Cl, Br, and I).

16. The method of claim 1, wherein the second reactant is BTBAS.

17. The method of claim 1, wherein the dopant containing material is selected from the group consisting of phosphine, arsine, alkylboranes, alkyl gallanes, alkylphosphines, phosphorus halides, arsenic halides, gallium halides, boron halides, alkylboranes, and diborane.

18. The method of claim 1, wherein in the film is a dielectric film.

19. The method of claim 1, wherein the total film thickness is between about 10 – 100 Angstroms.

20. The method of claim 1, wherein the concentration of dopant in the film is between about 0.01 and 10 percent by weight.

21. The method of claim 1 further comprising:
applying photoresist to the substrate surface;
exposing the photoresist to light;
patterning the resist and transferring the pattern to the substrate surface; and
selectively removing the photoresist from the substrate surface.

22. A method of depositing a dielectric film on a substrate surface in a reaction chamber, the method comprising:

(a) flowing an oxidant into the reaction chamber under conditions allowing the first reactant to adsorb onto the substrate surface;

(b) introducing a dielectric precursor into the reaction chamber while the oxidant continues to flow into the reaction chamber;

(c) exposing the substrate surface to plasma to drive a reaction between the dielectric precursor and oxidant on the substrate surface to form a portion of the dielectric film;

(d) introducing a dopant containing material, not introduced during (a)-(c), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the film; and

(e) causing a dopant from the containing material to integrate into the dielectric film.

23. The method of claim 22, wherein the dielectric precursor is BTBAS.

24. The method of claim 22, further comprising driving the dopant from the dielectric film into the substrate.

25. The method of claim 22, wherein operations (a)-(c) are repeated.

26. The method of claim 25, wherein the oxidant contains a first ratio of oxygen to nitrogen when (a) is initially performed and wherein the oxidant contains a second ratio of oxygen to nitrogen, which second ratio is smaller than the first ratio, when (a) is repeated.

27. The method of claim 26, wherein the oxidant comprises elemental oxygen when (a) is initially performed and wherein the oxidant comprises nitrous oxide when (a) is repeated.

28. The method of claim 25, wherein the substrate is at a first temperature when (c) is initially performed, and wherein the substrate is at a second temperature, which is higher than the first temperature, when (c) is repeated.

29. The method of claim 22, further comprising contacting the substrate surface with the dopant containing material prior to (a).

30. A method of depositing a dielectric film on a substrate surface in a reaction chamber, the method comprising:

(a) introducing a dielectric precursor into the reaction chamber under conditions allowing the precursor to adsorb onto the substrate surface;

(b) thereafter purging the dielectric precursor from the reaction chamber while the precursor remains adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction of the dielectric precursor on the substrate surface to form a portion of the dielectric film; and

(d) introducing a dopant precursor, not introduced during (a)-(c), into the reaction chamber under conditions allowing the dopant precursor to contact the portion of the dielectric film.

31. The method of claim 30, further comprising flowing an oxidant into the reaction chamber prior to and during (a)-(c).

32. The method of claim 30, further comprising (e) reacting the dopant precursor to introduce a dopant to the film.

33. An apparatus for depositing a doped film on a substrate surface, the apparatus comprising:

a reaction chamber comprising a device for holding the substrate during deposition of the doped dielectric film;

one or more process gas inlets coupled to the reaction chamber; and

a controller designed or configured to cause the apparatus to perform the following operations:

(a) introducing a first reactant into the reaction chamber under conditions allowing the first reactant to adsorb onto the substrate surface;

(b) introducing a second reactant into the reaction chamber while the first reactant is adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction between the first and second reactants on the substrate surface to form a portion of the film;

(d) repeating (a)-(c) at least once;

(e) introducing a dopant containing material, not introduced during (a)-(d), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the film; and

(f) introducing a dopant into the film from the dopant containing material.

34. The apparatus of claim 33, wherein the controller is further designed or configured to cause the apparatus to flow an oxidant into the reaction chamber prior to and during (a)-(d).

35. The apparatus of claim 33, wherein the controller is further designed or configured to cause (g) repeating (a)-(c) after (e) or (f).

36. The apparatus of claim 33, wherein the controller is further designed or configured to cause (g) driving the dopant from the film into features of the substrate surface on which the film resides.

37. The apparatus of claim 36, wherein driving the dopant from the film comprises annealing the film.

38. The apparatus of claim 33, wherein the controller is further designed or configured to cause purging the second reactant from the reaction chamber prior to exposing the substrate surface to plasma.

39. The apparatus of claim 38, wherein the purging comprises flowing a gas comprising an oxidant into the reaction chamber.

40. The apparatus of claim 33, wherein the controller is further designed or configured to cause (e) to be performed at intervals between one or more repetitions of (a)-(d) and wherein said intervals are varied over the course of depositing the film.

41. A system comprising the apparatus of claim 33 and a stepper.

AMENDED CLAIMS
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1. (Original) A method of depositing a film on a substrate surface in a reaction chamber, the method comprising:

(a) introducing a first reactant into the reaction chamber under conditions allowing the first reactant to adsorb onto the substrate surface;

(b) introducing a second reactant into the reaction chamber while the first reactant is adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction between the first and second reactants on the substrate surface to form a portion of the film;

(d) repeating (a)-(c) at least once;

(e) introducing a dopant containing material, not introduced during (a)-(d), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the film; and

(f) introducing a dopant into the film from the dopant containing material.

2. (Original) The method of claim 1, further comprising:

(g) repeating (a)-(c) after (e) or (f).

3. (Original) The method of claim 1, further comprising

(g) repeating (a)-(e).

4. (Original) The method of claim 1, wherein the amount of film deposited during (a)-(c) is between about 0.5 to 1 Angstroms.

5. (Original) The method of claim 1, further comprising driving the dopant from the film into features of the substrate surface on which the film resides.

6. (Original) The method of claim 5, wherein driving the dopant from the film comprises annealing the film.

7. (Original) The method of claim 5, wherein the film resides on a three-dimensional feature of the substrate surface and wherein driving the dopant from the film provides conformal diffusion of the dopant into the feature.

8. The method of claim 7, wherein the feature has a width less than about 40 nanometers.

9. (Original) The method of claim 1, further comprising purging the second reactant from the reaction chamber prior to exposing the substrate surface to plasma.

10. (Original) The method of claim 9, wherein the purging comprises flowing a gas comprising an oxidant into the reaction chamber.

11. (Original) The method of claim 1, wherein the first and second reactants co-exist in vapor phase in the reaction chamber and wherein the first and second reactants do not appreciably react with one another in the reaction chamber until exposure to plasma in (c).

12. (Original) The method of claim 1, wherein introducing the dopant into the film comprises exposing the dopant containing material to a plasma.

13. (Original) The method of claim 1, wherein the first reactant is an oxidizing agent.

14. (Original) The method of claim 13, wherein the oxidizing agent is nitrous oxide.

15. (Original) The method of claim 1, wherein the second reactant is selected from the group consisting of

alkylamino silanes ($SiH_x(NR_2)_{4-x}$), where x = 1-3, and R includes alkyl groups, and

halosilanes (SiH_xY_{4-x}), where x = 1-3, and Y includes Cl, Br, and I).

16. (Original) The method of claim 1, wherein the second reactant is BTBAS.

17. (Original) The method of claim 1, wherein the dopant containing material is selected from the group consisting of phosphine, arsine, alkylboranes, alkyl gallanes, alkylphosphines, phosphorus halides, arsenic halides, gallium halides, boron halides, alkylboranes, and diborane.

18. (Currently Amended) The method of claim 1, wherein ~~in~~ the film is a dielectric film.

19. (Original) The method of claim 1, wherein the total film thickness is between about 10 – 100 Angstroms.

20. (Original) The method of claim 1, wherein the concentration of dopant in the film is between about 0.01 and 10 percent by weight.

21. (Original) The method of claim 1 further comprising:
applying photoresist to the substrate surface;
exposing the photoresist to light;
patterning the resist and transferring the pattern to the substrate surface; and
selectively removing the photoresist from the substrate surface.

22. (Currently Amended) A method of depositing a dielectric film on a substrate surface in a reaction chamber, the method comprising:

(a) flowing an oxidant into the reaction chamber under conditions allowing the oxidant to adsorb onto the substrate surface;

(b) introducing a dielectric precursor into the reaction chamber while the oxidant continues to flow into the reaction chamber;

(c) exposing the substrate surface to plasma to drive a reaction between the dielectric precursor and oxidant on the substrate surface to form a portion of the dielectric film;

(d) introducing a dopant containing material, not introduced during (a)-(c), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the dielectric film; and

(e) causing a dopant from the dopant containing material to integrate into the dielectric film.

23. (Original) The method of claim 22, wherein the dielectric precursor is BTBAS.

24. (Original) The method of claim 22, further comprising driving the dopant from the dielectric film into the substrate.

25. (Original) The method of claim 22, wherein operations (a)-(c) are repeated.

26. (Original) The method of claim 25, wherein the oxidant contains a first ratio of oxygen to nitrogen when (a) is initially performed and wherein the oxidant contains a second ratio of oxygen to nitrogen, which second ratio is smaller than the first ratio, when (a) is repeated.

27. (Original) The method of claim 26, wherein the oxidant comprises elemental oxygen when (a) is initially performed and wherein the oxidant comprises nitrous oxide when (a) is repeated.

28. (Original) The method of claim 25, wherein the substrate is at a first temperature when (c) is initially performed, and wherein the substrate is at a second temperature, which is higher than the first temperature, when (c) is repeated.

29. (Original) The method of claim 22, further comprising contacting the substrate surface with the dopant containing material prior to (a).

30. (Currently Amended) A method of depositing a dielectric film on a substrate surface in a reaction chamber, the method comprising:

(a) introducing a dielectric precursor into the reaction chamber under conditions allowing the dielectric precursor to adsorb onto the substrate surface;

(b) thereafter purging the dielectric precursor from the reaction chamber while the dielectric precursor remains adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction of the dielectric precursor on the substrate surface to form a portion of the dielectric film; and

(d) introducing a dopant precursor, not introduced during (a)-(c), into the reaction chamber under conditions allowing the dopant precursor to contact the portion of the dielectric film.

31. (Original) The method of claim 30, further comprising flowing an oxidant into the reaction chamber prior to and during (a)-(c).

32. (Currently Amended) The method of claim 30, further comprising (e) reacting the dopant precursor to introduce a dopant to the dielectric film.

33. (Currently Amended) An apparatus for depositing a doped film on a substrate surface, the apparatus comprising:

a reaction chamber comprising a device for holding the substrate during deposition of the doped ~~dielectric~~ film;

one or more process gas inlets coupled to the reaction chamber; and

a controller designed or configured to cause the apparatus to perform the following operations:

(a) introducing a first reactant into the reaction chamber under conditions allowing the first reactant to adsorb onto the substrate surface;

(b) introducing a second reactant into the reaction chamber while the first reactant is adsorbed on the substrate surface;

(c) exposing the substrate surface to plasma to drive a reaction between the first and second reactants on the substrate surface to form a portion of the doped film;

(d) repeating (a)-(c) at least once;

(e) introducing a dopant containing material, not introduced during (a)-(d), into the reaction chamber under conditions allowing the dopant containing material to contact an exposed surface of the doped film; and

(f) introducing a dopant into the doped film from the dopant containing material.

34. (Original) The apparatus of claim 33, wherein the controller is further designed or configured to cause the apparatus to flow an oxidant into the reaction chamber prior to and during (a)-(d).

35. (Original) The apparatus of claim 33, wherein the controller is further designed or configured to cause (g) repeating (a)-(c) after (e) or (f).

36. (Currently Amended) The apparatus of claim 33, wherein the controller is further designed or configured to cause (g) driving the dopant from the doped film into features of the substrate surface on which the doped film resides.

37. (Currently Amended) The apparatus of claim 36, wherein driving the dopant from the doped film comprises annealing the doped film.

38. (Original) The apparatus of claim 33, wherein the controller is further designed or configured to cause purging the second reactant from the reaction chamber prior to exposing the substrate surface to plasma.

39. (Original) The apparatus of claim 38, wherein the purging comprises flowing a gas comprising an oxidant into the reaction chamber.

40. (Currently Amended) The apparatus of claim 33, wherein the controller is further designed or configured to cause (e) to be performed at intervals between one or more repetitions of (a)-(d) and wherein said intervals are varied over the course of depositing the doped film.

41. (Original) A system comprising the apparatus of claim 33 and a stepper.