CLAIMS

1. A method of doping a patterned substrate in a reaction chamber, the method comprising:

forming a first conformal film layer directly on a surface of the patterned substrate having three-dimensional features or on a material adhered to the surface, the first conformal film layer comprising a dopant source, the dopant source comprising a dopant, wherein forming the first film layer comprises:

(a) introducing a dopant precursor into the reaction chamber;

(b) adsorbing the dopant precursor directly onto the surface or onto a material adhered to the surface under conditions whereby the dopant precursor forms an adsorption-limited layer; and

(c) reacting the adsorbed dopant precursor to form the dopant source; and

forming a second conformal film layer comprising the dopant source, after forming the first conformal film layer, wherein forming the second conformal film layer comprises: (a)-(c);

forming a third conformal film layer comprising a dielectric material, after forming the second conformal film layer, wherein forming the third conformal film layer comprises:

(i) introducing a dielectric precursor into the reaction chamber;

(ii) adsorbing the dielectric precursor onto a material adhered to the substrate under conditions whereby the dielectric precursor forms an adsorption-limited layer; and

(iii) reacting the adsorbed dielectric precursor to form the dielectric material;

forming a fourth conformal film layer comprising a dielectric material, after forming the third conformal film layer, wherein forming the fourth conformal film layer comprises: (i)-(iii);

forming a fifth conformal film layer comprising the dopant source, after forming the fourth conformal film layer, wherein forming the fifth conformal film layer comprises: (a)-(c);

forming a sixth conformal film layer comprising the dopant source, after forming the fifth conformal film layer, wherein forming the sixth conformal film layer comprises: (a)-(c); and

driving some of the dopant from the first, second, fifth, and sixth conformal film layers into the substrate to form a conformal doping profile in the substrate.

2. The method of Claim 1, wherein forming the first, second, fifth, and sixth conformal film layers comprise atomic layer deposition.

3. The method of Claim 2, wherein forming the first, second, fifth, and sixth conformal film layers further comprises: (d) removing unadsorbed dopant precursor from the reaction chamber.

4. The method of Claim 3, wherein (d) occurs after (a) but prior to (c).

5. The method of Claim 4, wherein (d) comprises pumping unadsorbed dopant precursor out of the reaction chamber by pumping the reaction chamber to a base pressure with a vacuum pump.

6. The method of Claim 4, wherein (d) comprises purging the reaction chamber with an inert gas.

7. The method of Claim 1, wherein (c) comprises activation with a plasma.

8. The method of Claim 7, wherein the plasma is an oxidizing plasma.

9. The method of Claim 7, wherein the plasma is an inert plasma.

10. The method of Claim 1, wherein the driving of some of the dopant from the first, second, fifth, and sixth conformal film layers comprises a thermally mediated diffusion process.

11. The method of Claim 10, wherein the thermally mediated diffusion process involves annealing.

12. The method of Claim 11, wherein the annealing is laser spike annealing.

13. The method of Claim 1, wherein the dopant comprises a valence III or V element.

14. The method of Claim 13, wherein the element is boron, phosphorus, germanium, or arsenic.

15. The method of Claim 14, wherein the dopant is boron, the dopant precursor is an alkyl borate, and the dopant source is a boron oxide or boron oxyhydride.

16. The method of Claim 15, wherein the alkyl borate is trimethyl borate.

17. The method of Claim 16, wherein the boron oxide is B_2O_3.

18. The method of Claim 14, wherein the dopant is arsenic, the dopant precursor is a selected from the alkylarsine, alkoxyarsine, and aminoarsine chemical families, and the dopant source is an arseno-silicate, an arsenic-doped silicate glass, an arsenic oxide, or an arsenic oxyhydride.

19. The method of Claim 18, wherein the dopant precursor is arsine, triethylaresenate, trimethylarsine, triethylarsine, triphenylarsine, triphenylarsine oxide, ethylenebis(diphenylarsine), tris(dimethylamino)arsine, or an arsenic containing compound having the chemical formula $As(OR)_3$ where R is $-CH_3$ or $-C_2H_5$.

20. The method of Claim 19, wherein the dopant source is As_2O_3 and/or As_2O_5.

21. The method of Claim 1, wherein the dielectric material of the second and third conformal film layers is SiO_2.

22. The method of Claim 1, further comprising:

forming a seventh conformal film layer comprising the dielectric material, after forming the sixth conformal film layer, wherein forming the seventh conformal film layer comprises: (i)-(iii);

forming an eighth conformal film layer comprising a dielectric material, after forming the seventh conformal film layer, wherein forming the eighth conformal film layer comprises: (i)-(iii);

forming a ninth conformal film layer comprising the dopant source, after forming the eighth conformal film layer, wherein forming the ninth conformal film layer comprises: (a)-(c);

forming a tenth conformal film layer comprising the dopant source, after forming the ninth conformal film layer, wherein forming the tenth conformal film layer comprises: (a)-(c); and

driving some of the dopant from the ninth and tenth conformal film layers into the substrate to form a conformal doping profile in the substrate.

23. The method of Claim 1, further comprising:

forming a seventh film layer which is a capping layer, the capping layer being the outermost film layer of the first through seventh film layers relative to the substrate.

24. The method of Claim 23, wherein the capping layer comprises SiO_2.

25. The method of Claim 1, wherein (c) comprises exposing the adsorbed dopant precursor to an oxidant.

26. The method of Claim 25, wherein the oxidant is elemental oxygen, nitrous oxide, water, an alkyl alcohol, carbon monoxide, or carbon dioxide.

27. The method of Claim 1, wherein (iii) comprises activation with a plasma.

28. The method of Claim 1, wherein the dielectric precursor 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.

29. The method of Claim 1, wherein the dielectric precursor is BTBAS.

30. The method of Claim 1, wherein each of the first through sixth conformal film layers is a monolayer.

31. The method of Claim 1, wherein the average thickness of each of the first through sixth conformal film layers is between 0.1 and 2 Angstroms.

32. The method of Claim 1, wherein at least one of the three-dimensional features has a width of not greater than about 40 nanometers.

33. The method of Claim 1, wherein the average concentration of dopant over the first through sixth conformal film layers is between about 0.01 and 10 percent by weight.

34. A method of doping a patterned substrate in a reaction chamber, the method comprising:

forming an alloy comprising a dielectric and a dopant source directly on a surface of the patterned substrate having three-dimensional features, or onto a material adhered to the surface, the dopant source comprising a dopant, wherein forming the alloy comprises:

introducing a dopant precursor and a dielectric precursor into the reaction chamber, and coadsorbing the dopant precursor and the dielectric precursor onto the substrate or onto a material adhered to the substrate under conditions whereby the dopant precursor and the dielectric precursor form an adsorption-limited layer; and

reacting the adsorbed dopant precursor and adsorbed dielectric precursor to form the dopant source and alloy having the dopant source; and

driving some of the dopant from the alloy into the substrate to form a conformal doping profile in the substrate.

35. The method of Claim 34, wherein forming the alloy further comprises introducing a third reactant into the reaction chamber and reacting the third reactant with the adsorbed dielectric precursor.

36. The method of Claim 35, wherein the third reactant is an oxidant.

37. The method of Claim 36, wherein reacting the third reactant with the adsorbed dielectric precursor further comprises activation with a plasma.

38. An apparatus for doping a substrate, the apparatus comprising:

a reaction chamber;

a substrate holder within the reaction chamber;

one or more gas inlets coupled to the reaction chamber;

one or more vacuum pumps;

one or more gas outlets coupling the reaction chamber to the one or more vacuum pumps; and

a controller comprising machine readable instructions, the instructions comprising:

instructions for forming a first conformal film layer comprising:

(a) instructions for operating the one or more gas inlets to introduce dopant precursor into the reaction chamber so that the dopant precursor adsorbs onto the substrate or onto a material adhered to the substrate;

(b) instructions for operating the one or more gas outlets to evacuate unadsorbed dopant precursor from the reaction chamber; and

(c) instructions for reacting the adsorbed dopant precursor to form a film layer containing a dopant source;

instructions for forming a second conformal film layer to be executed after executing the instructions for forming the first conformal film layer, the instructions comprising: (a)-(c);

instructions for forming a third conformal film layer to be executed after the instructions for forming the second conformal film layer, the instructions comprising:

(i) instructions for operating the one or more gas inlets to introduce a dielectric precursor into the reaction chamber so that the dielectric precursor adsorbs onto a material adhered to the substrate;

(ii) instructions for operating the one or more gas outlets to evacuate unadsorbed dielectric precursor from the reaction chamber; and

(iii) instructions for reacting the adsorbed dielectric precursor to form a film layer containing the dielectric material;

instructions for forming a fourth conformal film layer to be executed after the instructions for forming the third conformal film layer, the instructions comprising: (i)-(iii).

39. The apparatus of Claim 38, further comprising an RF generator configured to excite a plasma within the reaction chamber, and wherein (c) comprises instructions for operating the RF generator to excite a plasma which causes the adsorbed dopant precursor to react.

40. The apparatus of Claim 38, wherein the instructions comprising the controller further comprise instructions for driving some of the dopant source from the film into the substrate.

41. The apparatus of Claim 40, further comprising a heater configured to heat the film containing the dopant source, and wherein the instructions for driving some of the dopant into the substrate comprise instructions for operating the heater to heat the film causing a thermally mediated diffusion of dopant from the film into the substrate.

We Claim:

1. A method of doping a patterned substrate in a reaction chamber, the method comprising:

forming a first conformal film layer directly on a surface of the patterned substrate having three-dimensional features or on a material adhered to the surface, the first film layer comprising a dopant source, the dopant source comprising a dopant wherein the dopant is boron, and wherein forming the first film layer comprises:

introducing a dopant precursor into the reaction chamber, wherein the dopant precursor is an alkyl borate;

adsorbing the dopant precursor directly onto the surface or onto a material adhered to the surface under conditions whereby the dopant precursor forms an adsorption-limited layer; and

reacting the adsorbed dopant precursor to form the dopant source; and

driving some of the dopant from the first film layer into the substrate to form a conformal doping profile in the substrate.

2. The method of Claim 1, wherein forming the first film layer comprises atomic layer deposition.

3. The method of Claim 2, wherein forming the first film layer further comprises removing unadsorbed dopant precursor from the reaction chamber.

4. The method of Claim 3, wherein the removing step occurs after the adsorbing step but prior to the reacting step.

5. The method of Claim 4, wherein the removing step comprises pumping unadsorbed dopant precursor out of the reaction chamber, by pumping the reaction chamber to a base pressure with a vacuum pump.

6. The method of Claim 4, wherein the removing step comprises purging the reaction chamber with an inert gas.

7. The method of Claim 1, further comprising:

forming a second conformal film layer containing a dielectric material; and

forming a third conformal film layer on a material adhered to the surface of the substrate, the third film layer comprising the dopant source, the dopant source comprising the dopant, wherein forming the third film layer comprises:

introducing the dopant precursor into the reaction chamber;

adsorbing the dopant precursor onto a material adhered to the surface under conditions whereby the dopant precursor forms an adsorption-limited layer; and

reacting the adsorbed dopant precursor to form the dopant source;

wherein a substantial portion of the second film layer is interspersed between the first and third film layers; and

driving some of the dopant from the third film layer into the substrate to form a conformal doping profile in the substrate.

8. The method of Claim 7, wherein adsorbing the dopant precursor when forming the first film layer comprises atomic layer deposition, and wherein adsorbing the dopant precursor when forming the third film layer comprises atomic layer deposition.

9. The method of Claim 8, wherein forming the first film layer further comprises removing unadsorbed dopant precursor from the reaction chamber, and wherein forming the third film layer further comprises removing unadsorbed dopant precursor from the reaction chamber.

10. The method of Claim 9, wherein during the formation of each of the first and third film layers the removing step occurs after the adsorbing step but prior to the reacting step.

11. The method of Claim 10, wherein the removing comprises pumping unadsorbed dopant precursor out of the reaction chamber by pumping the reaction chamber to a base pressure with a vacuum pump.

12. The method of Claim 9, wherein the removing comprises purging the reaction chamber with an inert gas.

13. The method of Claim 7, wherein reacting the adsorbed dopant precursor to form the first film layer comprises activation with a plasma, and wherein reacting the adsorbed dopant precursor to form the third film layer comprises activation with the plasma.

14. The method of Claim 13, wherein the plasma is an oxidizing plasma.

15. The method of Claim 13, wherein the plasma is an inert plasma.

16. The method of Claim 7, wherein the driving of some of the dopant from the first and third film layers comprises a thermally mediated diffusion process.

17. The method of Claim 16, wherein the thermally mediated diffusion process involves annealing.

18. The method of Claim 17, wherein the annealing is laser spike annealing.

19. The method of Claim 1, wherein the alkyl borate is trimethyl borate.

20. The method of Claim 1, wherein the dopant source is a boron oxide or boron oxyhydride.

21. The method of Claim 20, wherein the boron oxide is B_2O_3.

22. The method of Claim 7, wherein the dielectric material of the second film layer is SiO_2.

23. The method of Claim 7, further comprising:

forming a fourth conformal film layer containing the dielectric material; and

forming a fifth conformal film layer on a material adhered to the surface of the substrate, the fifth film layer comprising the dopant source, the dopant source comprising the dopant, wherein forming the fifth film layer comprises:

introducing the dopant precursor into the reaction chamber;

adsorbing the dopant precursor onto a material adhered to the surface under conditions whereby the dopant precursor forms an adsorption-limited layer; and

reacting the adsorbed dopant precursor to form the dopant source;

wherein a substantial portion of the fourth film layer is interspersed between the third and fifth film layers; and

driving some of the dopant from the fifth film layer into the substrate to form a conformal doping profile in the substrate.

24. The method of Claim 23, further comprising:

forming a sixth film layer which is a capping layer, the capping layer being the outermost film layer of the first through sixth film layers relative to the substrate.

25. The method of Claim 24, wherein the capping layer comprises SiO_2.

26. The method of Claim 23, wherein forming the second film layer comprises:

introducing a reactant into the reaction chamber;

introducing a dielectric precursor into the reaction chamber;

adsorbing the dielectric precursor onto a material adhered to the substrate under conditions whereby the dielectric precursor forms an adsorption-limited layer; and

reacting the reactant with the adsorbed dielectric precursor to form the dielectric material; and

wherein forming the fourth film layer comprises:

introducing the reactant into the reaction chamber;

introducing the dielectric precursor into the reaction chamber;

adsorbing the dielectric precursor onto a material adhered to the substrate under conditions whereby the dielectric precursor forms an adsorption-limited layer; and

reacting the reactant with the adsorbed dielectric precursor to form the dielectric material.

27. The method of Claim 26, wherein the reactant is an oxidant.

28. The method of Claim 27, wherein the oxidant is elemental oxygen, nitrous oxide, water, an alkyl alcohol, carbon monoxide, or carbon dioxide.

29. The method of Claim 26, wherein the reacting comprises activation with a plasma.

30. The method of Claim 26, wherein the dielectric precursor 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.

31. The method of Claim 26, wherein the dielectric precursor is BTBAS.

32. The method of Claim 23, wherein each of the first through fifth film layers is a monolayer.

33. The method of Claim 23, wherein the average thickness of each of the first through fifth film layers is between 0.1 and 2 Anstroms.

34. The method of Claim 23, wherein at least one of the three-dimensional features has a width of not greater than about 40 nanometers.

35. The method of Claim 23, wherein the average concentration of dopant over the first through fifth film layers is between about 0.01 and 10 percent by weight.

36. A method of doping a patterned substrate in a reaction chamber, the method comprising:

forming an alloy comprising a dielectric and a dopant source directly on a surface of the patterned substrate having three-dimensional features, or onto a material adhered to the surface, the dopant source comprising a dopant, wherein forming the alloy comprises:

introducing a dopant precursor and a dielectric precursor into the reaction chamber, and coadsorbing the dopant precursor and the dielectric precursor onto the substrate or onto a material adhered to the substrate under conditions whereby the dopant precursor and the dielectric precursor form an adsorption-limited layer; and

reacting the adsorbed dopant precursor and adsorbed dielectric precursor to form the dopant source and alloy having the dopant source; and

driving some of the dopant from the alloy into the substrate to form a conformal doping profile in the substrate.

37. The method of Claim 36, wherein forming the alloy further comprises introducing a third reactant into the reaction chamber and reacting the third reactant with the adsorbed dielectric precursor.

38. The method of Claim 37, wherein the third reactant is an oxidant.

39. The method of Claim 38, wherein reacting the third reactant with the adsorbed dielectric precursor further comprises activation with a plasma.

40. An apparatus for doping a substrate, the apparatus comprising:

a reaction chamber;

a substrate holder within the reaction chamber;

one or more dopant precursor gas inlets coupled to the reaction chamber;

one or more vacuum pumps;

one or more gas outlets coupling the reaction chamber to the one or more vacuum pumps; and

a controller comprising machine readable code, the code comprising:

instructions for determining that a substrate is present on the substrate holder;

instructions for operating the one or more dopant precursor gas inlets to introduce dopant precursor into the reaction chamber so that the dopant precursor adsorbs onto the substrate or onto a material adhered to the substrate;

instructions for operating the one or more gas outlets to evacuate unadsorbed dopant precursor from the reaction chamber; and

instructions for reacting the adsorbed dopant precursor to form a film layer containing a dopant source.

41. The apparatus of Claim 40, further comprising an RF generator configured to excite a plasma within the reaction chamber, and wherein the instructions for reacting the adsorbed dopant precursor comprise instructions for operating the RF generator to excite a plasma which causes the adsorbed dopant precursor to react.

42. The apparatus of Claim 40, wherein the machine readable code comprising the controller further comprises instructions for driving some of the dopant source from the film into the substrate.

43. The apparatus of Claim 42, further comprising a heater configured to heat the film containing the dopant source, and wherein the instructions for driving some of the dopant into the substrate comprise instructions for operating the heater to heat the film causing a thermally mediated diffusion of dopant from the film into the substrate.

44. A method of doping a patterned substrate in a reaction chamber, the method comprising:

forming a first conformal film layer directly on a surface of the patterned substrate having three-dimensional features or on a material adhered to the surface, the first film layer comprising a dopant source, the dopant source comprising a dopant wherein the dopant is arsenic, and wherein forming the first film layer comprises:

introducing a dopant precursor into the reaction chamber, wherein the dopant precursor is selected from the alkylarsine, alkoxyarsine, and aminoarsine chemical families;

adsorbing the dopant precursor directly onto the surface or onto a material adhered to the surface under conditions whereby the dopant precursor forms an adsorption-limited layer; and

reacting the adsorbed dopant precursor to form the dopant source; and

driving some of the dopant from the first film layer into the substrate to form a conformal doping profile in the substrate.

45. The method of Claim 44, wherein the dopant source is an arseno-silicate, an arsenic-doped silicate glass, an arsenic oxide, or an arsenic oxyhydride.

46. The method of Claim 44, wherein the dopant precursor is arsine, triethylaresenate, trimethylarsine, triethylarsine, triphenylarsine, triphenylarsine oxide, ethylenebis(diphenylarsine), tris(dimethylamino)arsine, or an arsenic containing compound having the chemical formula $As(OR)_3$ where R is $-CH_3$ or $-C_2H_5$.

47. The method of Claim 45, wherein the dopant source is As_2O_3 and/or As_2O_5.