CLAIMS

1. An Atomic Layer Deposition or a Plasma Enhanced Atomic Layer Deposition composition for depositing a silicon doped orthorhombic phase ferroelectric hafnium oxide film, comprising:
   (a) at least one organoaminosilane precursor compound having a formula of $Si(NR^1R^2)$; wherein
   R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein
   R^1 and R^2 are linked to form a cyclic ring structure; or R^1 and R^2 are not linked to form a cyclic ring structure;
   and
   (b) at least one organoaminohafnium precursor compound having a formula of $Hf(NR^1R^2)$; wherein
   R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein
   R^1 and R^2 are linked to form a cyclic ring structure or R^1 and R^2 are not linked to form a cyclic ring structure;
   wherein the composition has a melting point, and the melting point of the composition is ≤30º C.;
   wherein the at least one organoaminosilane precursor and the at least one organoaminohafnium precursor have the same organoamino group;
   wherein the at least one organoaminosilane precursor is selected from the group consisting of tetrakis(dimethylamino)silane (TDMAS), tetrakis(diethylamino)silane (TDEAS), tetrakis(ethylmethylamino)silane (TEMAS), tetrakis(pyrrolidino)silane, and combinations thereof;
   wherein the at least one organoaminohafnium precursor is selected from the group consisting of tetrakis(dimethylamino)hafnium (TDMAH), tetrakis(diethylamino)hafnium (TDEAH), tetrakis(ethylmethylamino)hafnium (TEMAH), tetrakis(pyrrolidino)hafnium, and combinations thereof; and
   wherein the at least one organoaminosilane precursor compound is between about 0.10 to about 10.00 weight percent of the composition.

2. The Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition of claim 1, wherein the at least one organoaminosilane precursor compound is selected from the group consisting of tetrakis(dimethylamino)silane and tetrakis(ethylmethylamino)silane; and the at least one organoaminohafnium precursor compound is selected the group consisting of tetrakis(dimethylamino)hafnium and tetrakis(ethylmethylamino)hafnium.

3. The Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition of claim 1, wherein the at least one organoaminosilane precursor compound has a range

selected from the group consisting of 5.00 to 10.00 wt. %, and 0.10 to 5.00 wt. %; and the at least one organoaminohafnium precursor compound has a range selected from the group consisting of 0.10 to 30.00 wt. %, 0.10 to 20.00 wt. %, 0.10 to 10.00 wt. %, 5.00 to 30.00 wt. %, 5.00 to 20.00 wt. %, 5.00 to 10.00 wt. %, and 0.10 to 5.00 wt. %.

4. The Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition of claim 1 further comprises (c) a solvent selected from the group consisting of ether, tertiary amine, alkyl hydrocarbon, aromatic hydrocarbon, siloxanes, tertiary aminoether, and combinations thereof; and the at least one organoaminohafnium precursor compound has a range selected from the group consisting of 10.00 to 90.00 wt. %, 20.00 to 80.00 wt. %, 30.00 to 70.00 wt. %, and 40.00 to 60.00 wt. %.

5. A method to deposit an orthorhombic phase ferroelectric film comprising silicon, hafnium and oxygen onto a substrate, comprising:
   a) providing the substrate in a reactor;
   b) introducing into the reactor a composition comprising:
      (i) at least one organoaminosilane precursor compound having a formula of $Si(NR^1R^2)$; wherein
      R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein
      R^1 and Ware linked to form a cyclic ring structure; or R^1 and R^2 are not linked to form a cyclic ring structure; and
      (ii) at least one organoaminohafnium precursor compound having a formula of $Hf(NR^1R^2)$; wherein R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein
      R^1 and R^2 are linked to form a cyclic ring structure or R^1 and R^2 are not linked to form a cyclic ring structure;

   c) purging the reactor with a purge gas;

   d) introducing an oxygen-containing source into the reactor; and

   e) purging the reactor with the purge gas;

   wherein the composition has a melting point, and the melting point of the composition is ≤30º C.;
   wherein the oxygen-containing source is selected from the group consisting of an oxygen plasma, ozone, a water vapor, water vapor plasma, nitrogen oxide plasma, a carbon oxide plasma, and combinations thereof;
   wherein the purge gas is selected from the group consisting of argon (Ar), nitrogen (N2), helium (He), neon, hydrogen (H2), and combinations thereof;

wherein the deposition process is selected from the group consisting of a thermal atomic layer deposition (ALD), plasma enhanced atomic layer deposition (PEALD) process, and combinations thereof;
wherein the method is conducted at a temperature ranging from 10º C. to 600º C.;
wherein the at least one organoaminosilane precursor and the at least one organoaminohafnium precursor have the same organoamino group;
wherein the at least one organoaminosilane precursor is selected from the group consisting of tetrakis(dimethylamino)silane (TDMAS), tetrakis(diethylamino)silane (TDEAS), tetrakis(ethylmethylamino)silane (TEMAS), tetrakis(pyrrolidino)silane, and combinations thereof; and
wherein the at least one organoaminohafnium precursor is selected from the group consisting of tetrakis(dimethylamino)hafnium (TDMAH), tetrakis(diethylamino)hafnium (TDEAH), tetrakis(ethylmethylamino)hafnium (TEMAH), tetrakis(pyrrolidino)hafnium, and combinations thereof;
wherein the at least one organoaminosilane precursor compound is between about 0.10 to about 10.00 weight percent of the composition; and
wherein steps b) through e) are repeated until a desired thickness of film is deposited.

6. The method of claim 5, wherein the composition comprises tetrakis(dimethylamino)silane; and tetrakis(dimethylamino)hafnium.

7. The method of claim 5, wherein the composition further comprises (iii) a solvent selected from the group consisting of ether, tertiary amine, alkyl hydrocarbon, aromatic hydrocarbon, siloxanes, tertiary aminoether, and combinations thereof.

8. The method of claim 5, wherein the composition is delivered via direct liquid injection into the reactor.

9. The method of claim 5, wherein the oxygen-containing source further comprises an inert gas selected from the group consisting of argon, helium, nitrogen, hydrogen, and combinations thereof.

10. A system to deposit a silicon doped orthorhombic phase ferroelectric film comprising silicon, hafnium, and oxygen onto a substrate, comprising:
the substrate in a reactor; and
an Atomic Layer Deposition or a Plasma Enhanced Atomic Layer Deposition composition comprising:
(i) at least one organoaminosilane precursor compound having a formula of $Si(NR^1R^2)$;
wherein R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein

R^1 and R^2 are linked to form a cyclic ring structure; or R^1 and R^2 are not linked to form a cyclic ring structure; and

(ii) at least one organoaminohafnium precursor compound having a formula of $Hf(NR^1R^2)$; wherein

R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein

R^1 and R^2 are linked to form a cyclic ring structure or R^1 and R^2 are not linked to form a cyclic ring structure; and

wherein the composition has a melting point, and the melting point of the composition is ≤30º C.;

wherein the at least one organoaminosilane precursor and the at least one organoaminohafnium precursor have the same organoamino group;

wherein the at least one organoaminosilane precursor is selected from the group consisting of tetrakis(dimethylamino)silane (TDMAS), tetrakis(diethylamino)silane (TDEAS), tetrakis(ethylmethylamino)silane (TEMAS), tetrakis(pyrrolidino)silane, and combinations thereof;

wherein the at least one organoaminohafnium precursor is selected from the group consisting of tetrakis(dimethylamino)hafnium (TDMAH), tetrakis(diethylamino)hafnium (TDEAH), tetrakis(ethylmethylamino)hafnium (TEMAH), tetrakis(pyrrolidino)hafnium, and combinations thereof;

wherein the at least one organoaminosilane precursor compound is between about 0.10 to about 10.00 weight percent of the composition; and

wherein the system is at a temperature ranging from 100º C. to 600º C.

11. The system of claim 10, wherein the Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition comprises tetrakis(dimethylamino)silane and tetrakis(dimethylamino)hafnium.

12. The system of claim 10, wherein the Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition further comprises (iii) a solvent selected from the group consisting of ether, tertiary amine, alkyl hydrocarbon, aromatic hydrocarbon, siloxanes, tertiary aminoether, and combinations thereof.

13. A silicon doped orthorhombic phase hafnium oxide film suitable as ferroelectric materials deposited by using an Atomic Layer Deposition or a Plasma Enhanced Atomic Layer Deposition composition, comprising:

(1) at least one organoaminosilane precursor compound having a formula of $Si(NR^1R^2)$; wherein R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl; wherein R^1 and R^2 are linked to form a cyclic ring structure; or R^1 and R^2 are not linked to form a cyclic ring structure; and

(2) at least one organoaminohafnium precursor compound having a formula of $Hf(NR^1R^2)$;
R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl; wherein
R^1 and R^2 are linked to form a cyclic ring structure or R^1 and R^2 are not linked to form a cyclic ring structure; and
wherein the composition has a melting point, and the melting point of the composition is ≤30º C.;
wherein the at least one organoaminosilane precursor and the at least one organoaminohafnium precursor have the same organoamino group;
wherein the at least one organoaminosilane precursor is selected from the group consisting of tetrakis(dimethylamino)silane (TDMAS), tetrakis(diethylamino)silane (TDEAS), tetrakis(ethylmethylamino)silane (TEMAS), tetrakis(pyrrolidino)silane, and combinations thereof;
wherein the at least one organoaminohafnium precursor is selected from the group consisting of tetrakis(dimethylamino)hafnium (TDMAH), tetrakis(diethylamino)hafnium (TDEAH), tetrakis(ethylmethylamino)hafnium (TEMAH), tetrakis(pyrrolidino)hafnium, and combinations thereof;
wherein deposition process is selected from the group consisting of a thermal atomic layer deposition (ALD), plasma enhanced atomic layer deposition (PEALD) process, and combinations thereof;
wherein the at least one organoaminosilane precursor compound is between about 0.10 to about 10.00 weight percent of the composition; and
wherein the silicon doped hafnium oxide film has a silicon doping level ranging from about 2.00 to about 5.00 mol %.

14. The silicon doped hafnium oxide film of claim 13, wherein the composition comprises tetrakis(dimethylamino)silane and tetrakis(dimethylamino)hafnium.

15. The silicon doped hafnium oxide film of claim 13, wherein the composition further comprises (3) a solvent selected from the group consisting of ether, tertiary amine, alkyl hydrocarbon, aromatic hydrocarbon, siloxanes, tertiary aminoether, and combinations thereof.

16. A vessel employing an Atomic Layer Deposition or a Plasma Enhanced Atomic Layer Deposition composition for depositing a silicon doped orthorhombic phase ferroelectric hafnium oxide film, comprising:
    (1) at least one organoaminosilane precursor compound having a formula of $Si(NR^1R^2)$; wherein
    R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein
    R^1 and R^2 are linked to form a cyclic ring structure;
    or R^1 and R^2 are not linked to form a cyclic ring structure;

and

(2) at least one organoaminohafnium precursor compound having a formula of $Hf(NR^1R^2)$; wherein

R^1 and R^2 are independently selected from linear or branched C_1 to C_6 alkyl in organoamino group; wherein

R^1 and R^2 are linked to form a cyclic ring structure or R^1 and R^2 are not linked to form a cyclic ring structure; and

wherein the composition has a melting point, and the melting point of the composition is ≤30º C.;

wherein the at least one organoaminosilane precursor and the at least one organoaminohafnium precursor have the same organoamino group;

wherein the at least one organoaminosilane precursor is selected from the group consisting of tetrakis(dimethylamino)silane (TDMAS), tetrakis(diethylamino)silane (TDEAS), tetrakis(ethylmethylamino)silane (TEMAS), tetrakis(pyrrolidino)silane, and combinations thereof;

wherein the at least one organoaminohafnium precursor is selected from the group consisting of tetrakis(dimethylamino)hafnium (TDMAH), tetrakis(diethylamino)hafnium (TDEAH), tetrakis(ethylmethylamino)hafnium (TEMAH), tetrakis(pyrrolidino)hafnium, and combinations thereof;

wherein the vessel is a pressurizable vessel comprising valves and fittings to allow the delivery of the composition to a reactor for a deposition process selected from the group consisting of a thermal atomic layer deposition (ALD), plasma enhanced atomic layer deposition (PEALD) process, and combinations thereof;

wherein the at least one organoaminosilane precursor compound is between about 0.10 to about 10.00 weight percent of the composition.

17. The vessel of claim 16, wherein the Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition comprises tetrakis(dimethylamino)silane; and tetrakis(dimethylamino)hafnium.

18. The vessel of claim 16, wherein the Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition further comprises a solvent selected from the group consisting of ether, tertiary amine, alkyl hydrocarbon, aromatic hydrocarbon, siloxanes, tertiary aminoether, and combinations thereof.

19. The vessel of claim 16, wherein the Atomic Layer Deposition or Plasma Enhanced Atomic Layer Deposition composition further comprises an inert gas selected from the group consisting of nitrogen, helium, and argon, and combinations thereof.