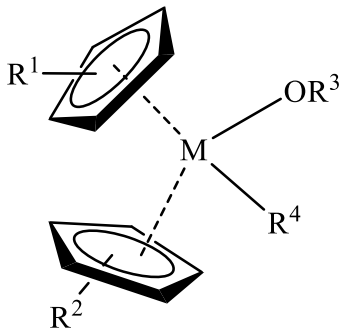
CLAIMS

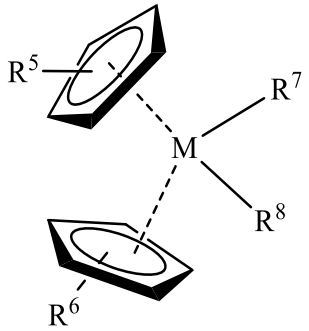
What is claimed is:

1. A thin film crystalline material comprising hafnium oxide and zirconium oxide, wherein the crystalline material exhibits ferroelectric behavior as deposited, wherein the crystalline material is derived from one or more metallocene precursor having Formula I:



I

or Formula II:



II

wherein (i) M is selected from Zr and Hf and (ii) R^1, R^2, R^3, R^4, R^5, R^6, R^7 and R^8 are each independently selected from a C_1-C_6 linear alkyl, a C_1-C_6 branched alkyl, a C_1-C_6 halogenated linear alkyl and a C_1-C_6 halogenated branched alkyl.

2. The crystalline material of claim 1, wherein

(i) greater than 40% of the total volume of the crystalline material is in a ferroelectric phase; and

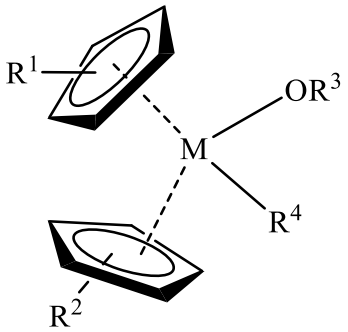
(ii) less than 60% of the total volume of the crystalline material constitutes a non-ferroelectric phase component.

3. The crystalline material of claim 1, wherein a hafnium oxide to zirconium oxide ratio is between 1:3 and 3:1.

4. The crystalline material of any one of claims 1 to 3, wherein the crystalline material has a carbon content below 1 atomic percent.

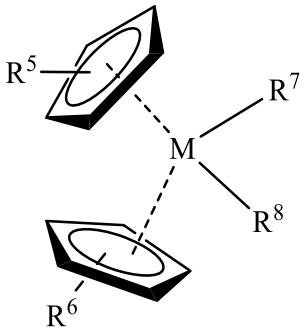
5. The crystalline material of any one of claims 1 to 3, wherein the crystalline material has a carbon content between 1 atomic percent and 6 atomic percent.

6. The crystalline material of any one of claims 1 to 3, wherein the crystalline material is derived from one or more metallocene precursor having Formula I:



I

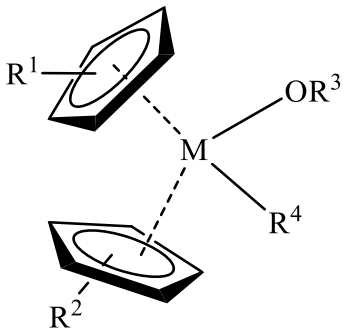
or Formula II:



II

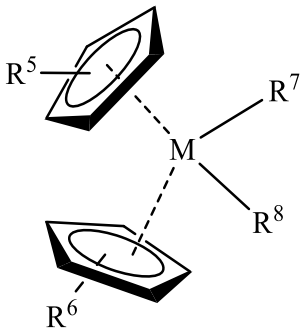
wherein (i) M is selected from Zr and Hf and (ii) R^1, R^2, R^3, R^4, R^5, R^6, R^7 and R^8 are each independently a C_1-C_6 linear alkyl.

7. The crystalline material of any one of claims 1 to 3, wherein the crystalline material is derived from one or more metallocene precursor having Formula I:



I

or Formula II:



II

wherein (i) M is selected from Zr and Hf and (ii) R^1, R^2, R^3, R^4, R^5, R^6, R^7 and R^8 are each a methyl group.

8. A method for depositing the crystalline material a material of any one of claims 1 to 7 comprising:

(i) providing a substrate at a deposition temperature;

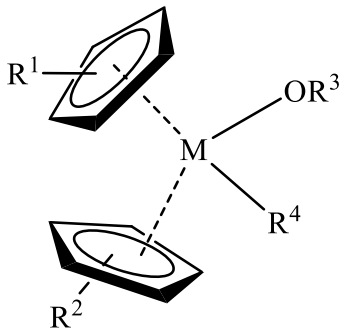
(ii) exposing the substrate to a first precursor that does not decompose at the deposition temperature;

(iii) exposing the substrate to a first reaction gas;

(iv) exposing the substrate to a second precursor that does not decompose at the deposition temperature; and

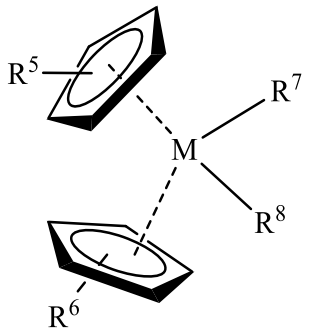
(v) exposing the substrate to a second reaction gas,

wherein one of the first precursor and the second precursor comprises zirconium and the other of the first precursor and the second precursor comprises hafnium, and wherein the first precursor and the second precursor have the structure of Formula I:



I

or Formula II:



II

wherein (i) M is selected from Zr and Hf and (ii) R^1, R^2, R^3, R^4, R^5, R^6, R^7 and R^8 are each independently selected from a C_1-C_6 linear alkyl, a C_1-C_6 branched alkyl, a C_1-C_6 halogenated linear alkyl and a C_1-C_6 halogenated branched alkyl.

9. The method of claim 8, wherein the deposited crystalline material has a thickness of 0.2 nm and 20 nm.

10. The method of claim 8, wherein the deposited crystalline material has a remanent polarization (Pr) of greater than 8 $\mu C/cm^2$ or a total loop opening of greater than 16 $\mu C/cm^2$.

11. A thin film comprising the material of any one of claims 1 to 7, wherein the film has a thickness of 0.2 nm to 10 nm.

12. A thin film comprising the material of any one of claims 1 to 7, wherein the film has a remanent polarization (Pr) of greater than 8 $\mu C/cm^2$ or a total loop opening of greater than 16 $\mu C/cm^2$.