

NEW GROUP V METAL CONTAINING PRECURSORS AND THEIR USE FOR METAL CONTAINING FILM DEPOSITION

The invention relates to a new class or chemical compounds and their use in metal
5 containing film deposition.

With the shrink of the critical dimensions of the future generation CMOS devices, the introduction of new materials, in particular Tantalum and Niobium, are required. For instance, it is well acknowledged that dual metal gate will be required along to high dielectric constant (high-k) materials for the CMOS gate stack. The metal gate is in particular required to achieve
10 a 0.2 V threshold voltage, thus allowing drastically reduced devices power consumption. To do so, the metal gate approach requires having two metal compounds of different work function, typically ~5 eV for pMOS gate and ~4 eV for nMOS gate. The requirements for a suitable metal gate material generally include: lowest resistivity as possible (however, it is generally always below p-Si for metal compounds), suitable work function (which is drastically
15 affected by additional elements in the metal based film), thermal stability on the high-k gate oxide, adhesion on the high-k and etch selectivity. Group V metal containing films, and in particular Tantalum based materials such as Tantalum carbide, Tantalum silicide, Tantalum silico-nitride, Tantalum carbo-nitride, show promising properties for metal gate application. TaCN has been suggested as a suitable pMOS metal, TaCN work function was estimated to
20 4.8-5 eV.

Besides, group V metal containing films are used as electrodes (in the case of pure metal or metal nitride), and also as high-k layers (in the case of oxide) in the Metal-Insulator-Metal structures (DRAM...). For example, TaN may be used for electrodes deposition, and Ta₂O₅ and TaO_xN_y for high-k layers.

25 Besides, group V metal containing films find also application in back-end-of-the-line (BEOL) layers of modern semiconductor devices as metal diffusion barriers. In particular, pure group V metals are targeted, such as Ta on TaN for copper diffusion. Nitrogen incorporation also helps reducing the copper diffusion. Tantalum films are currently deposited using a sputtering deposition method, so as to achieve a low-k/TaN-Ta/Cu patterned structure. With the
30 shrinkage of the chip dimensions, sputtering will quickly become inadequate for conformal depositions.

The main industrial options to enable the deposition of such thin films with reasonable throughput and acceptable purity are vapor phase deposition techniques, such as MOCVD (Metal-organic Chemical Vapor Deposition) or ALD (Atomic Layer Deposition). For

instance, ALD (or plasma assisted ALD) is generally considered as a suitable method to form the highly conformal films needed for BEOL applications, when associated with a relevant precursor. Metal-organic and halide compounds are required for those processes.

Many Group V precursors have been considered to enable such deposition. Examples
5 can be given as follows:

Halides such as Tantalum pentachloride, $TaCl_5$, have been widely investigated such as disclosed in US 6,268,288 by Hautala et al.. However, some by-products generated during the deposition process, such as HCl or Cl_2 , can cause surface/interface roughness that can be detrimental to the final properties. Moreover, Cl or F impurities are highly detrimental to the
10 final electrical properties. It is therefore expected to find new compounds having sufficient volatility but without containing Cl, F, or Br atoms.

Alkoxides such as penta-ethoxy-Tantalum (PET) are widely used and described. However, they lead to oxygen containing films and are not suitable for the deposition of metal containing films such as nitrides, carbides, carbo-nitrides, silicides which are used in
15 particular as electrodes and which should not contain oxygen even at trace level.

US-A-6,379,748 discloses an improvement to PET alkyl bonds have been introduced, e.g. by using $TaMe_3(OEt)_2$ instead of $Ta(OEt)_5$ (PET). Volatility was thereby significantly improved without affecting the melting point. However, $TaMe_3(OEt)_2$ does not allow versatile deposition: in particular, oxygen free metal nitride or carbide cannot
20 be obtain.

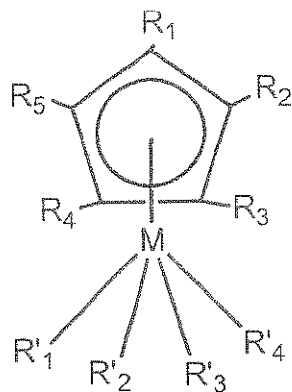
US-A-6,368,398 discloses another improvement with the use for instance of $Ta[OC(O)C(CH_3)_3]_5$, however with the same limitation as disclosed here above.

WO 02/20870 discloses the use of tert-butyimido(tris(diethylamido)Tantalum, TBTDDET, for the deposition of Ta_2O_5 US-A-6,593,484, US 2004/0219784 disclose a method
25 of deposition of Tantalum nitride films by sequential injection of TBTDDET or TAIMATA and other N source. However, their use to deposit Ta, TaC, TaSi films is not possible as they contain nitrogen which is always present in the deposited films.

US-A-6,379,748 discloses $Ta(Me_3SiCp)_2H_3$, which is a biscyclopentadienyl Ta hydride which is a solid having a low volatility.

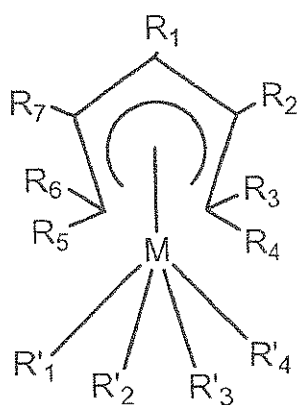
30 Today, there still exist the need for metal organic precursors having a high volatility in order to be in liquid state at room temperature (or close to room temperature) and having a high versatility, i.e. suitable for various applications in the semi-conductor manufacture such as metal gates, electrodes and/or high-k layer in Metal-Insulator-Metal structures for DRAM and/or copper diffusion barriers, or the like in TFT-LCD applications.

According to a first aspect, there is provided the use, of at least one compound of the formula (Ia):



(Ia)

or of the formula (Ib):



(Ib)

as metal precursors in a process for depositing a group V metal containing film on a substrate comprising the steps of:

- Introducing a substrate into a reactor;
- Preferably heating the substrate at a temperature above 150°C;
- Feeding a compound of the formula (Ia) or of the formula (Ib), or a mixture of said compounds thereof in the vapor phase into the reactor;
- Optionally a second compound of the formula (Ia) or of the formula (Ib), or a second mixture of said compounds thereof in vapor phase into the reactor;
- Depositing a film containing at least one of said compound of the formula (Ia) or

of the formula (Ib), onto said substrate;

Formulas (Ia) and (Ib) wherein,

M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

R_1 , R_2 , R_3 , R_4 , R_5 , R_6 and R_7 ; which may be identical or different, are independently

5 chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

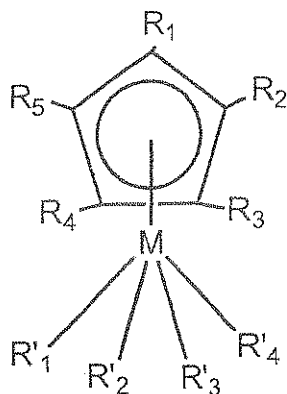
either R'_1 , R'_2 , R'_3 and R'_4 ; which may be identical or different, are independently

10 chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms or linear or branched alkylsilylamide groups having from one to four carbon atoms;

or R'_1 , R'_2 , which may be identical or different, are independently chosen from

15 Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms or linear or branched alkylsilylamide groups having from one to four carbon atoms; and R'_3 and R'_4 together represent an oxo group (=O) or alkyl imino group having from one to four carbon atoms (=N-R)

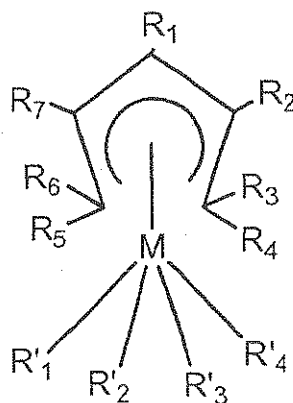
According to a first embodiment, the disclosure relates to a method of depositing metal containing films using at least one compound as a metal precursor of the formula (Ia)



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(Ia)

or of the formula (Ib):



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(Ib)

Formulas (Ia) and (Ib) wherein,

M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V), R_1 , R_2 , R_3 , R_4 , R_5 , R_6 and R_7 ; which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

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either R'_1 , R'_2 , R'_3 and R'_4 ; which may be identical or different, are independently chosen from

Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms or linear or branched alkylsilylamide groups having from one to four carbon atoms;

- 5 either R'₁, R'₂, which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms or linear or branched alkylsilylamide groups having from one to four carbon atoms; and R'₃ and R'₄ together represent an oxo group (=O) or an alkyl imino group having from one to four carbon atoms (=N-R)

According to a first particular embodiment the disclosure relates to a method of depositing a metal containing film using a compound of the formula (Ia) or of the formula (Ib) as defined above, having a melting point lower than or equal to about 35°C, i.e. shall be in liquid form or close to liquid form at room temperature, which makes their delivery easier.

- 15 According to a second particular embodiment the disclosure relates to a method of depositing a metal containing film using a compound of the formula (Ia) or of the formula (Ib) as defined above, having a vapor pressure higher than 1 Torr at 100°C. In order to do so, the man skilled in the art shall select the appropriate molecules in the group of molecules having a lower molecule weight and/or those having a structure, which induces lowered inter molecular forces.

- 20 According to a third particular embodiment, in the formula (Ia) or (Ib), R₁, R₂, R₃, R₄, R₅, R₆ and R₇; which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms.

- According to a fourth particular embodiment, in the formula (Ia) or (Ib), R'₁, R'₂, R'₃, and R'₄, which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms.

According to a fifth particular embodiment, in the formula (Ia) or (Ib), M is Tantalum.

According to a sixth particular embodiment, in the formula (Ia), R₂, R₃, R₄, and R₅, each represent an Hydrogen atom.

- According to a seventh particular embodiment, in the formula (Ib), R₂, R₃, R₄, R₅, R₆ and R₇, each represent an Hydrogen atom.

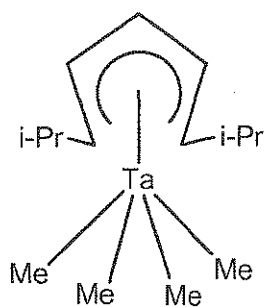
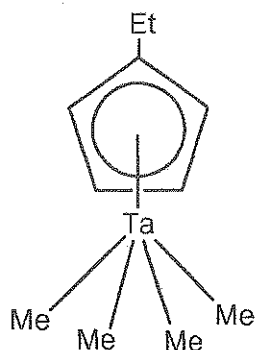
According to an eight particular embodiment, in the formula (Ia) or (Ib), R₁ is chosen from ethyl, isopropyl or tert-butyl.

According to a ninth particular embodiment, in the formula (Ia) or (Ib), R'₁, R'₂, R'₃, and R'₄ each represent a methyl group.

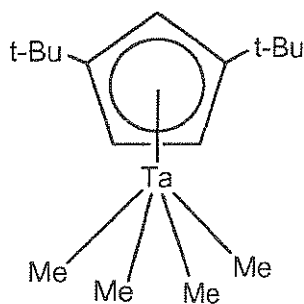
According to a tenth particular embodiment, in the formula (Ia) or (Ib), R'_1 and R'_2 , which may be identical or different, are independently chosen from methyl or methoxy, and R'_3 and R'_4 together represent an oxo group ($=O$) or a tert-butyl imino group ($=N-tBu$).

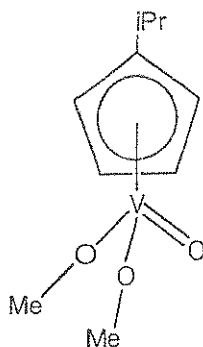
Examples of such particular embodiments are :

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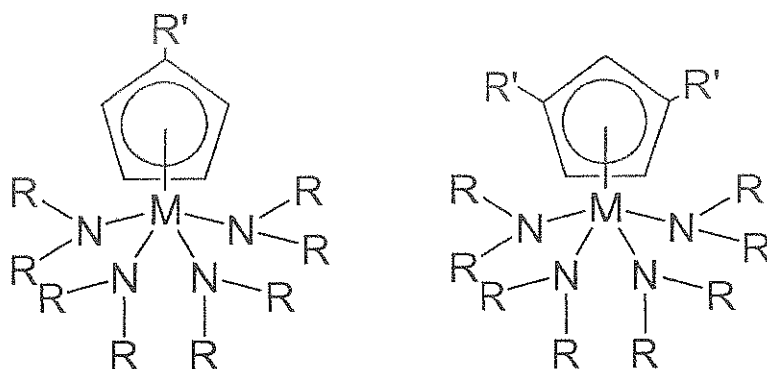


- According to a second aspect, the compounds of the formulas (Ia) or (Ib) as defined herein before are selected from the following compounds: (Isopropyl-Cyclopentadienyl)
- 5 tetrakis(methyl) Tantalum;
- (1,5-diisopropyl-pentadienyl) tetrakis(methyl) Tantalum;
- (1,3-di-tert-butyl-cyclopentadienyl) tetrakis(methyl) Tantalum;
- (Ethyl-Cyclopentadienyl) tetrakis(methyl) Tantalum,
- (Isopropyl-Cyclopentadienyl) tetrakis(methyl) Vanadium;
- 10 (Isopropyl-Cyclopentadienyl) tetrakis(methyl) Niobium;
- (1,3-di-tert-butyl-cyclopentadienyl) tetrakis(methyl) Niobium.

According to a third aspect, there is provided a process for depositing a group V metal containing film on a substrate comprising the steps of:

- 15
- Introducing a substrate into a reactor;
 - Preferably heating the substrate at a temperature above 150°C;
 - Feeding a compound of the formula (Ia) or of the formula (Ib) as disclosed above, or a mixture of said compounds thereof in the vapor phase into the reactor;
 - Optionally a second compound of the formula (Ia) or of the formula (Ib) as disclosed above, or a second mixture of said compounds thereof in vapor phase into the reactor;
 - Depositing a film containing at least one of said compound of the formula (Ia) or of the formula (Ib), onto said substrate.

According to another embodiment, the disclosure relates to compounds having the characteristic to contain only one cyclopentadienyl ring and 4 alkylamide ligand, said compounds having the formula :



Where:

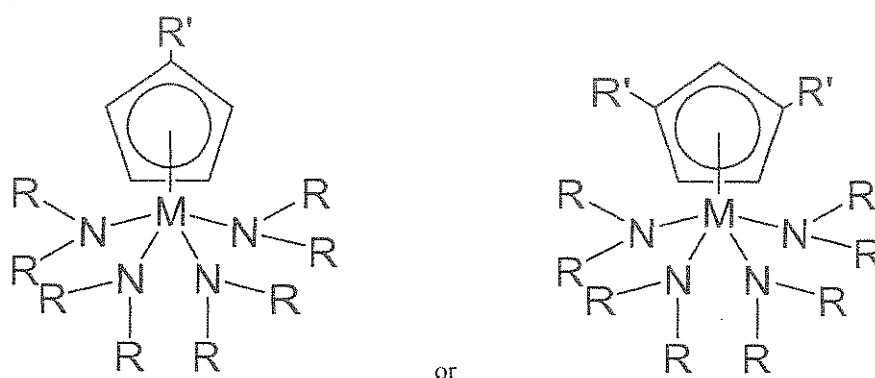
M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

Each R is independently selected from the group consisting of linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one

to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

Each R' are independently selected from the group consisting of Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

According to a fourth aspect, there is provided a compound wherein the formula (Ia) is:



Where:

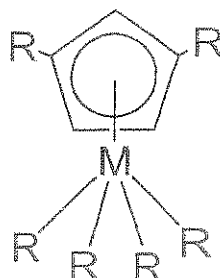
M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

Each R is independently selected from the group consisting of linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

Each R' are independently selected from the group consisting of Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four

carbon atoms;

or the formula :



(b)

Where:

M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

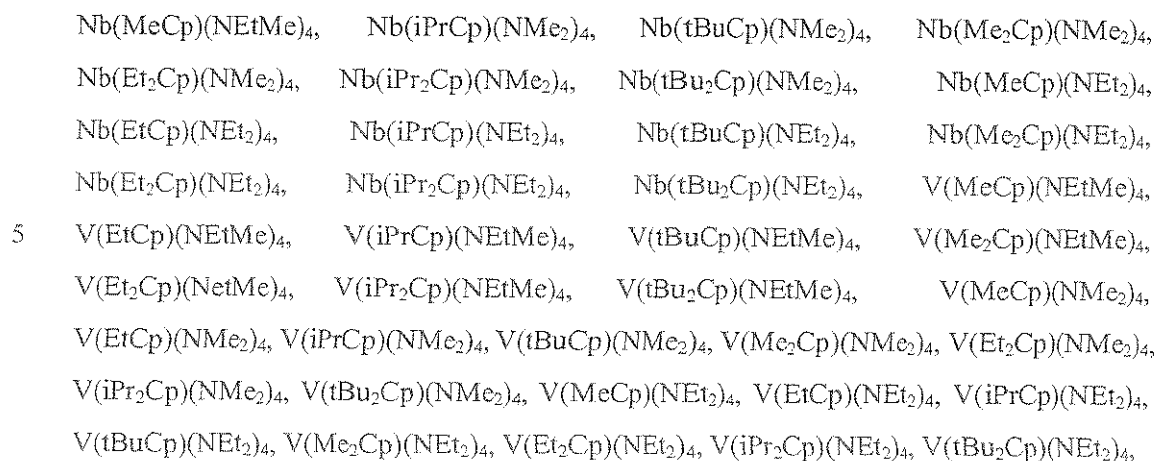
Each R is independently selected from the group consisting of linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms.

According to a fifth aspect, there is provided the following compounds:

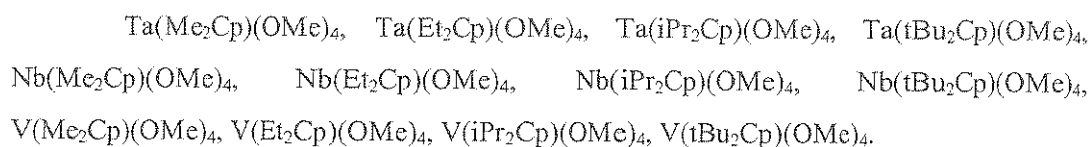
Ta(Me₂Cp)Me₄, Ta(Et₂Cp)Me₄, Ta(iPr₂Cp)Me₄, Ta(tBu₂Cp)Me₄, Ta(Me₂Cp)Et₄,
 15 Ta(Et₂Cp)Et₄, Ta(iPr₂Cp)Et₄, Ta(tBu₂Cp)Et₄, Ta(Me₂Cp)Me₂Et₂, Ta(Et₂Cp)Me₂Et₂,
 Ta(iPr₂Cp)Me₂Et₂, Ta(tBu₂Cp)Me₂Et₂, Nb(Me₂Cp)Me₄, Nb(Et₂Cp)Me₄, Nb(iPr₂Cp)Me₄,
 Nb(tBu₂Cp)Me₄, Nb(Me₂Cp)Et₄, Nb(Et₂Cp)Et₄, Nb(iPr₂Cp)Et₄, Nb(tBu₂Cp)Et₄,
 Nb(Me₂Cp)Me₂Et₂, Nb(Et₂Cp)Me₂Et₂, Nb(iPr₂Cp)Me₂Et₂, Nb(tBu₂Cp)Me₂Et₂,
 Nb(MeEtCp)Me₄, V(Me₂Cp)Me₄, V(Et₂Cp)Me₄, V(iPr₂Cp)Me₄, V(tBu₂Cp)Me₄, V(Me₂Cp)Et₄,
 20 V(Et₂Cp)Et₄, V(iPr₂Cp)Et₄, V(tBu₂Cp)Et₄, V(Me₂Cp)Me₂Et₂, V(Et₂Cp)Me₂Et₂,
 V(iPr₂Cp)Me₂Et₂, V(tBu₂Cp)Me₂Et₂,

According to a sixth aspect, there is provided the following compounds:

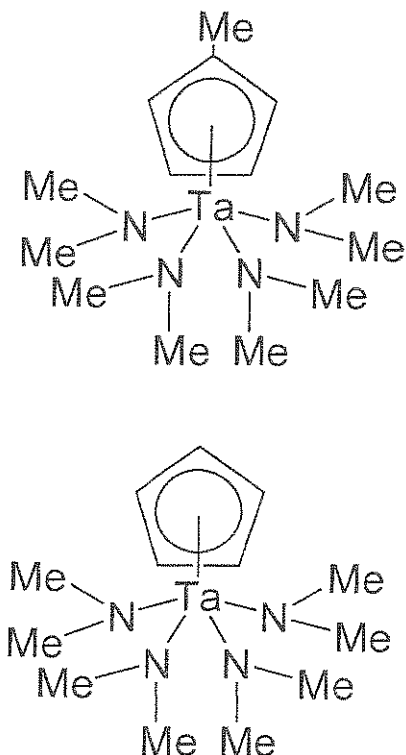
Ta(MeCp)(NEtMe)₄, Ta(EtCp)(NEtMe)₄, Ta(iPrCp)(NEtMe)₄, Ta(tBuCp)(NEtMe)₄,
 Ta(Me₂Cp)(NEtMe)₄, Ta(Et₂Cp)(NEtMe)₄, Ta(iPr₂Cp)(NEtMe)₄, Ta(tBu₂Cp)(NEtMe)₄,
 25 Ta(MeCp)(NMe₂)₄, Ta(EtCp)(NMe₂)₄, Ta(iPrCp)(NMe₂)₄, Ta(tBuCp)(NMe₂)₄,
 Ta(Me₂Cp)(NMe₂)₄, Ta(Et₂Cp)(NMe₂)₄, Ta(iPr₂Cp)(NMe₂)₄, Ta(tBu₂Cp)(NMe₂)₄,
 Ta(MeCp)(NEt₂)₄, Ta(EtCp)(NEt₂)₄, Ta(iPrCp)(NEt₂)₄, Ta(tBuCp)(NEt₂)₄, Ta(Me₂Cp)(NEt₂)₄,
 Ta(Et₂Cp)(NEt₂)₄, Ta(iPr₂Cp)(NEt₂)₄, Ta(tBu₂Cp)(NEt₂)₄, Nb(EtCp)(NEtMe)₄,
 Nb(iPrCp)(NEtMe)₄, Nb(tBuCp)(NEtMe)₄, Nb(Me₂Cp)(NEtMe)₄, Nb(Et₂Cp)(NEtMe)₄,
 30 Nb(iPr₂Cp)(NEtMe)₄, Nb(tBu₂Cp)(NEtMe)₄, Nb(MeCp)(NMe₂)₄, Nb(EtCp)(NMe₂)₄,



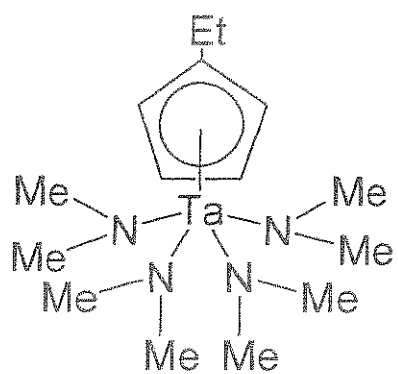
10 According to a seventh aspect, there is provided the following compounds:



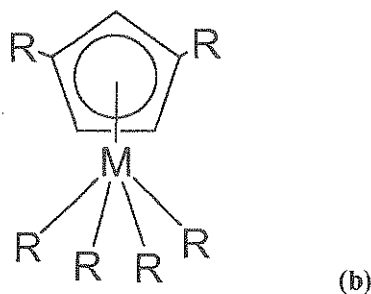
Examples of such particular embodiment are:



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According to another embodiment, the invention related to compounds having the characteristic to contain only one cyclopentadienyl ring and 4 alkylamide ligand, said compounds having the formula:



Where:

M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

Each R is independently selected from the group consisting of linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms.

The compounds of the formula (Ia) or (Ib) alone or in admixture, are used to deposit films of various compositions (as disclosed herein after) using any well-known deposition method using vapor phase deposition, such as MOCVD (Metal Organic Chemical Vapor Deposition), ALD (atomic layer deposition) and any other deposition method such as PECVD (plasma enhanced chemical vapor deposition) or as pulsed CVD. These new group V metal precursors are thus useful for pure metal, metallic oxide, oxynitride, nitride and/or silicide film deposition to make electrodes and/or high k layers, and/or copper diffusion barrier layers and the like. In the ALD process the preferred temperature is in the range of 150 to 400°C, more preferably 200 to 350°C, the preferred pulse duration in ALD is 1s and the preferred pressure is in the range of 0.1 Torr to 500 Torr, more preferably from 1 Torr to 100Torr.

In the CVD process, the preferred temperature is in the range of 300°C to 700°C, more preferably from 300°C to 500°C, the preferred pressure is in the range of 0.1 Torr to 500Torr, preferably from 1 Torr to 100 Torr and the preferred carrier gas is selected from N₂, He, Ar, H₂, more preferably Ar or N₂. The preferred N₂ canister flow is in the 30-200 sccm range, preferably 50 to 100 sccm.

In the PECVD process, the preferred temperature is in the range of 300°C to 700°C,

more preferably from 300°C to 500°C, the preferred pressure is in the range of 0.1Torr to 500Torr, preferably from 1Torr to 100Torr, the preferred carrier gas is selected from N₂, He, Ar, H₂, more preferably Ar or N₂ and the preferred N₂ canister flow is in the 30 - 200 sccm range, preferably 50 to 100 sccm. H or NH radicals are produced by a remote plasma system and used as co-reactant.

In these above mentioned uses, any of the compound of the formula (Ia) or of the formula (Ib) as defined above, can be used alone or in admixture with one or several other compounds of the said formulas (Ia) or (Ib) and/or with any appropriate additive which are useful when depositing a metal containing film as provided hereafter. According to a first particular embodiment the invention relates to a use as defined above of such an admixture having a melting point lower than or equal to about 35°C, i.e. shall be in liquid form or close to liquid form at room temperature, which makes their delivery easier, and or having a vapor pressure higher than 1 Torr at 100°C.

Various films can be obtained on a substrate by using the precursors described here above, such as nitrides, carbides, silicides, nitro-silicides (MSiN), oxydes (e.g. MeO_j), oxynitrides (MO_xN_y) and oxynitrides from two different metals M₁ and M₂ (M¹M²O_xN_y).

The invention also relates to a process for depositing a group V metal containing film on a substrate comprising the steps of:

- introducing a substrate into a reactor,
- preferably heating the substrate at a temperature above 150°C;
- feeding a compound of the formula (Ia) or of the formula (Ib) as disclosed herein before or of a mixture of said compounds thereof in the vapor phase into the reactor;
- optionally feeding at least one second precursor in vapor phase into the reactor;
- depositing a film containing at least one of said group V metal.

If pure metal needs to be deposited onto the surface of the substrate, then no second precursor injection is needed.

However, if a film of nitride, carbide, silicide, nitro-silicide, oxyde, oxynitrides or the like is needed, then such second precursor injection may be necessary, providing the adequate species to obtain the final desired composition of the film.

TaN: preferred reactants are NH₃, N₂H₄, methylhydrazine

TaSi: preferred second precursor is SiH₄,

TaSiN: preferred second precursor is TSA and NH₃, TriDMAS and NH₃

TaO: preferred oxygen source is O₃

TaSiN: preferred second precursor is TSA and NH₃, TriDMAS and NH₃

TaO: preferred oxygen source is O₃

TaHfO: preferred second precursor is TEMAH

TaC: precursor can be used alone, C₂H₄ can also be used to enhance C content.

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The process according to the invention may be summarized according to diagram 1.

In accordance with one embodiment, the vaporization of the new metal source is realized by introducing a carrier gas into a heated container containing the said new metal source. The container is preferably heated at a temperature allowing to get the said metal source in liquid phase and at a sufficient vapor pressure. The carrier gas can be selected, without limitation, from Ar, He, H₂, N₂ or mixtures of them. The said metal source can be mixed to a solvent or to another metal source or to a mixture of them in the container. The container can for instance be heated at temperatures in the range of 80-110°C. Those skilled in the art will consider that the temperature of the container can be adjusted to control the amount of precursor vaporized.

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In accordance with another embodiment, the said metal source is fed in liquid state to a vaporizer where it is vaporized. The said metal source can be mixed to a solvent. The said metal source can be mixed to another metal source. The said mixture of metal sources can be

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mixed to a solvent or a mixture of solvent. The said metal source can be mixed to a stabilizer.

The vaporized metal source is there after introduced into a reaction chamber where it is contacted to a substrate. The substrate can be heated to a sufficient temperature to obtain the desired film at sufficient growth rate and with desired physical state and composition. Typical
5 temperature range from 150°C to 600°C. Preferably the temperature is lower or equal to 450°C. The pressure in the reaction chamber is controlled to obtain the desired metal containing film at sufficient growth rate. Typical pressure range from 1 m Torr to 100Torr or higher.

According to another embodiment, it is possible to mix the metal source to a reactant species prior to the introduction of the mixture into the reaction chamber.

10 In another embodiment of the invention, the metal source may be mixed to a reactant species in the reaction chamber.

According to a further embodiment, the metal source and the reactant species are introduced simultaneously (chemical vapor deposition), sequentially (atomic layer deposition) or any combination thereof (one example is to introduce the metal source and the other metal
15 source together in one pulse and oxygen in a separate pulse [modified atomic layer deposition]; another example is to introduce oxygen continuously and to introduce the metal sources by pulse (pulsed-chemical vapor deposition).

It is also possible to introduce the reactant species into a plasma system localized remotely from the reaction chamber to decompose these species into radicals before their
20 introduction into the reaction chamber.

According to a further embodiment, wherein the targeted metal based film contains oxygen, such as for example, without limitation metal, oxide or metal oxy-nitride, the reactant species shall include an oxygen source which is selected from the group comprising oxygen (O_2), oxygen radicals (for instance O or OH), for instance generated by a remote plasma, ozone (O_3),
25 NO , N_2O , NO_2 , moisture (H_2O) and H_2O_2 or any mixture thereof;

According to still a further embodiment, wherein the targeted metal based film contains nitrogen, such as for example metal nitride or metal carbo-nitride, the reactant species include a nitrogen source which is selected from, but not limited to, nitrogen (N_2), ammonia, hydrazine and alkyl derivatives, N-containing radicals (for instance N , NH , NH_2), NO , N_2O ,
30 NO_2 , amines.

If the targeted metal based film contains carbon, such as for example without limitation metal carbide or metal carbo-nitride, the reactant species include a carbon source which is selected from, but not limited to, methane, ethane, propane, butane, ethylene, propylene, t-butylene, isobutylene, CCl_4 .

If the targeted metal based film contains silicon, such as for example metal silicide, silico-nitride, silicate, silico-carbo-nitride, the reactant species shall include a silicon source which is selected from the group comprising SiH_4 , Si_2H_6 , Si_3H_8 , TriDMAS, BDMAS, BDEAS, TDEAS, TDMAS, TEMAS, $(\text{SiH}_3)_3\text{N}$, $(\text{SiH}_3)_2\text{O}$, trisilylamine, disiloxane, trisilylamine, 5 disilane, trisilane, an alkoxysilane $\text{SiH}_x(\text{OR}^1)_{4-x}$, a silanol $\text{Si}(\text{OH})_x(\text{OR}^1)_{4-x}$ (preferably $\text{Si}(\text{OH})(\text{OR}^1)_3$; more preferably $\text{Si}(\text{OH})(\text{OtBu})_3$ an aminosilane $\text{SiH}_x(\text{NR}^1\text{R}^2)_{4-x}$ (where x is comprised between 0 and 4; R^1 and R^2 are independently H or a C1-C6 carbon chain, either linear, branched or cyclic; preferably TriDMAS $\text{SiH}(\text{NMe}_2)_3$, BTBAS $\text{SiH}_2(\text{NHtBu})_2$; BDEAS $\text{SiH}_2(\text{NEt}_2)_2$) and mixtures thereof. The targeted film can alternatively contain 10 Germanium. The above-mentioned Si containing sources, may be replaced by similar Ge containing sources.

It is quite possible to mix a metal source to another metal source to deposit a multi-metal containing film, prior to their introduction into the reaction chamber or to 15 simultaneously introduce into the reaction chamber, these metal source and mix them together and/or with other reactant species in the reaction chamber.

But it is also possible to introduce the first metal source, the second metal source and the reactant species in the reaction chamber simultaneously (chemical vapor deposition), sequentially (atomic layer deposition) or any combination thereof (one example is to introduce 20 the first metal source and the second metal sources together in one pulse and oxygen in a separate pulse [modified atomic layer deposition]; another example is to introduce oxygen continuously and to introduce the metal source by pulse (pulsed-chemical vapor deposition).

The second metal source shall be selected from the group comprising lanthanide and rare-earth metal source (Sc, Y, La, Ce, Pr, Nd, Gd...) source such as rare earth diketonates 25 $\text{Ln}(-\text{O}-\text{C}(\text{R}^1)-\text{C}(\text{R}^2)-\text{C}(\text{R}^3)-\text{O}-)(-\text{O}-\text{C}(\text{R}^4)-\text{C}(\text{R}^5)-\text{C}(\text{R}^6)-\text{O}-)(-\text{O}-\text{C}(\text{R}^7)-\text{C}(\text{R}^8)-\text{C}(\text{R}^9)-\text{O}-)$, where each R^i is independently H or a C1-C6 carbon chain, either linear, branched or cyclic), a cyclopentadienyl $\text{Ln}(\text{R}^1\text{Cp})(\text{R}^2\text{Cp})(\text{R}^3\text{Cp})$ (where each R^i is independently H or a C1-C6 carbon chain, either linear, branched or cyclic), $\text{Ln}(\text{NR}^1\text{R}^2)(\text{NR}^3\text{R}^4)(\text{NR}^5\text{R}^6)$ and mixtures thereof. The second metal source can alternatively be an aluminum source, selected from the group consisting 30 of trimethyl aluminum, dimethyl aluminum hydride, an alkoxyalane $\text{AlR}_x^i(\text{OR}^1)_{3-x}$ (where x is comprised between 0 and 3; R^1 and R^2 are independently H or a C1-C6 carbon chain, either linear, branched or cyclic; preferably $\text{AlR}^i\text{R}^2(\text{OR}^1)$, most preferably $\text{AlMe}_2(\text{OiPr})$), an amidoalane $\text{AlR}_x^i(\text{NR}^1\text{R}^2)_{3-x}$ (where x is comprised between 0 and 3; R^1 and R^2 are independently H or a C1-C6 carbon chain, either linear, branched or cyclic) and mixtures thereof. The other

- metal source can alternatively be a tungsten, molybdenum source. The other metal source can alternatively be a hafnium, zirconium or titanium source such as $M(OR^1)_4$ or other alkoxide-containing metal sources, $M(NR^1R^2)_4$, or adducts containing these species. The second metal source can alternatively be a divalent metal source (preferably Mg, Ca, Zn) selected from,
- 5 but not limited to metal β -diketonates or adducts containing these species.

The reactants can be introduced simultaneously (chemical vapor deposition), sequentially (atomic layer deposition) any combination thereof.

Example 1: group V metal compounds

- 10 Hereafter are listed some of the precursors of the formula (Ia) or (Ib) as defined herein before (cp means cyclopentadienyl, C_5 means pentadienyl): Ta(MeCp)Me₄, Ta(EtCp)Me₄, Ta(iPrCp)Me₄, Ta(tBuCp)Me₄, Ta(Me₂Cp)Me₄, Ta(Et₂Cp)Me₄, Ta(iPr₂Cp)Me₄, Ta(tBu₂Cp)Me₄, Ta(Et₅C₅)Me₄, Ta(iPr₅C₅)Me₄, Ta(MeCp)Et₄, Ta(EtCp)Et₄, Ta(iPrCp)Et₄, Ta(tBuCp)Et₄, Ta(Me₂Cp)Et₄, Ta(Et₂Cp)Et₄, Ta(iPr₂Cp)Et₄, Ta(tBu₂Cp)Et₄, Ta(Et₅C₅)Et₄, Ta(iPr₅C₅)Et₄,
- 15 Ta(MeCp)Me₂Et₂, Ta(EtCp)Me₂Et₂, Ta(iPrCp)Me₂Et₂, Ta(tBuCp)Me₂Et₂, Ta(Me₂Cp)Me₂Et₂, Ta(Et₂Cp)Me₂Et₂, Ta(iPr₂Cp)Me₂Et₂, Ta(tBu₂Cp)Me₂Et₂, Ta(Et₅C₅)Me₂Et₂, Ta(iPr₅C₅)Me₂Et₂, Ta(MeEtCp)Me₄, Ta(MeCp)(NEtMe)₄, Ta(EtCp)(NEtMe)₄, Ta(iPrCp)(NEtMe)₄, Ta(tBuCp)(NEtMe)₄, Ta(Me₂Cp)(NEtMe)₄, Ta(Et₂Cp)(NEtMe)₄, Ta(iPr₂Cp)(NEtMe)₄, Ta(tBu₂Cp)(NEtMe)₄, Ta(Et₅C₅)(NEtMe)₄, Ta(iPr₅C₅)(NEtMe)₄,
- 20 Ta(MeCp)(NMe₂)₄, Ta(EtCp)(NMe₂)₄, Ta(iPrCp)(NMe₂)₄, Ta(tBuCp)(NMe₂)₄, Ta(Me₂Cp)(NMe₂)₄, Ta(Et₂Cp)(NMe₂)₄, Ta(iPr₂Cp)(NMe₂)₄, Ta(tBu₂Cp)(NMe₂)₄, Ta(Et₅C₅)(NMe₂)₄, Ta(iPr₅C₅)(NMe₂)₄, Ta(MeCp)(NEt₂)₄, Ta(EtCp)(NEt₂)₄, Ta(iPrCp)(NEt₂)₄, Ta(tBuCp)(NEt₂)₄, Ta(Me₂Cp)(NEt₂)₄, Ta(Et₂Cp)(NEt₂)₄, Ta(iPr₂Cp)(NEt₂)₄, Ta(tBu₂Cp)(NEt₂)₄, Ta(Et₅C₅)(NEt₂)₄, Ta(iPr₅C₅)(NEt₂)₄, Ta(MeCp)(OMe)₄,
- 25 Ta(EtCp)(OMe)₄, Ta(iPrCp)(OMe)₄, Ta(tBuCp)(OMe)₄, Ta(Me₂Cp)(OMe)₄, Ta(Et₂Cp)(OMe)₄, Ta(iPr₂Cp)(OMe)₄, Ta(tBu₂Cp)(OMe)₄, Ta(Et₅C₅)(OMe)₄, Ta(iPr₅C₅)(OMe)₄, Nb(MeCp)Me₄, Nb(EtCp)Me₄, Nb(iPrCp)Me₄, Nb(tBuCp)Me₄, Nb(Me₂Cp)Me₄, Nb(Et₂Cp)Me₄, Nb(iPr₂Cp)Me₄, Nb(tBu₂Cp)Me₄, Nb(Et₅C₅)Me₄, Nb(iPr₅C₅)Me₄, Nb(MeCp)Et₄, Nb(EtCp)Et₄, Nb(iPrCp)Et₄, Nb(tBuCp)Et₄, Nb(Me₂Cp)Et₄, Nb(Et₂Cp)Et₄, Nb(iPr₂Cp)Et₄, Nb(tBu₂Cp)Et₄, Nb(Et₅C₅)Et₄, Nb(iPr₅C₅)Et₄,
- 30 Nb(MeCp)Me₂Et₂, Nb(EtCp)Me₂Et₂, Nb(iPrCp)Me₂Et₂, Nb(tBuCp)Me₂Et₂, Nb(Me₂Cp)Me₂Et₂, Nb(Et₂Cp)Me₂Et₂, Nb(iPr₂Cp)Me₂Et₂, Nb(tBu₂Cp)Me₂Et₂, Nb(Et₅C₅)Me₂Et₂, Nb(iPr₅C₅)Me₂Et₂, Nb(MeEtCp)Me₄, Nb(MeCp)(NEtMe)₄, Nb(EtCp)(NEtMe)₄, Nb(iPrCp)(NEtMe)₄, Nb(tBuCp)(NEtMe)₄, Nb(Me₂Cp)(NEtMe)₄,

- $\text{Nb}(\text{Et}_2\text{Cp})(\text{NEtMe})_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{NEtMe})_4$, $\text{Nb}(\text{tBu}_2\text{Cp})(\text{NEtMe})_4$, $\text{Nb}(\text{Et}_5\text{C}_5)(\text{NEtMe})_4$,
 $\text{Nb}(\text{iPr}_5\text{C}_5)(\text{NEtMe})_4$, $\text{Nb}(\text{MeCp})(\text{NMe}_2)_4$, $\text{Nb}(\text{EtCp})(\text{NMe}_2)_4$, $\text{Nb}(\text{iPrCp})(\text{NMe}_2)_4$,
 $\text{Nb}(\text{tBuCp})(\text{NMe}_2)_4$, $\text{Nb}(\text{Me}_2\text{Cp})(\text{NMe}_2)_4$, $\text{Nb}(\text{Et}_2\text{Cp})(\text{NMe}_2)_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{NMe}_2)_4$,
 $\text{Nb}(\text{tBu}_2\text{Cp})(\text{NMe}_2)_4$, $\text{Nb}(\text{Et}_5\text{C}_5)(\text{NMe}_2)_4$, $\text{Nb}(\text{iPr}_5\text{C}_5)(\text{NMe}_2)_4$, $\text{Nb}(\text{MeCp})(\text{NEt}_2)_4$,
5 $\text{Nb}(\text{EtCp})(\text{NEt}_2)_4$, $\text{Nb}(\text{iPrCp})(\text{NEt}_2)_4$, $\text{Nb}(\text{tBuCp})(\text{NEt}_2)_4$, $\text{Nb}(\text{Me}_2\text{Cp})(\text{NEt}_2)_4$,
 $\text{Nb}(\text{Et}_2\text{Cp})(\text{NEt}_2)_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{NEt}_2)_4$, $\text{Nb}(\text{tBu}_2\text{Cp})(\text{NEt}_2)_4$, $\text{Nb}(\text{Et}_5\text{C}_5)(\text{NEt}_2)_4$,
 $\text{Nb}(\text{iPr}_5\text{C}_5)(\text{NEt}_2)_4$, $\text{Nb}(\text{MeCp})(\text{OMe})_4$, $\text{Nb}(\text{EtCp})(\text{OMe})_4$, $\text{Nb}(\text{iPrCp})(\text{OMe})_4$,
 $\text{Nb}(\text{tBuCp})(\text{OMe})_4$, $\text{Nb}(\text{Me}_2\text{Cp})(\text{OMe})_4$, $\text{Nb}(\text{Et}_2\text{Cp})(\text{OMe})_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{OMe})_4$,
 $\text{Nb}(\text{tBu}_2\text{Cp})(\text{OMe})_4$, $\text{Nb}(\text{Et}_5\text{C}_5)(\text{OMe})_4$, $\text{Nb}(\text{iPr}_5\text{C}_5)(\text{OMe})_4$, $\text{V}(\text{MeCp})\text{Me}_4$, $\text{V}(\text{EtCp})\text{Me}_4$,
10 $\text{V}(\text{iPrCp})\text{Me}_4$, $\text{V}(\text{tBuCp})\text{Me}_4$, $\text{V}(\text{Me}_2\text{Cp})\text{Me}_4$, $\text{V}(\text{Et}_2\text{Cp})\text{Me}_4$, $\text{V}(\text{iPr}_2\text{Cp})\text{Me}_4$, $\text{V}(\text{tBu}_2\text{Cp})\text{Me}_4$,
 $\text{V}(\text{Et}_5\text{C}_5)\text{Me}_4$, $\text{V}(\text{iPr}_5\text{C}_5)\text{Me}_4$, $\text{V}(\text{MeCp})\text{Et}_4$, $\text{V}(\text{EtCp})\text{Et}_4$, $\text{V}(\text{iPrCp})\text{Et}_4$, $\text{V}(\text{tBuCp})\text{Et}_4$,
 $\text{V}(\text{Me}_2\text{Cp})\text{Et}_4$, $\text{V}(\text{Et}_2\text{Cp})\text{Et}_4$, $\text{V}(\text{iPr}_2\text{Cp})\text{Et}_4$, $\text{V}(\text{tBu}_2\text{Cp})\text{Et}_4$, $\text{V}(\text{Et}_5\text{C}_5)\text{Et}_4$, $\text{V}(\text{iPr}_5\text{C}_5)\text{Et}_4$,
 $\text{V}(\text{MeCp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{EtCp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{iPrCp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{tBuCp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{Me}_2\text{Cp})\text{Me}_2\text{Et}_2$,
 $\text{V}(\text{Et}_2\text{Cp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{iPr}_2\text{Cp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{tBu}_2\text{Cp})\text{Me}_2\text{Et}_2$, $\text{V}(\text{Et}_5\text{C}_5)\text{Me}_2\text{Et}_2$, $\text{V}(\text{iPr}_5\text{C}_5)\text{Me}_2\text{Et}_2$,
15 $\text{V}(\text{MeEtCp})\text{Me}_4$, $\text{V}(\text{MeCp})(\text{NEtMe})_4$, $\text{V}(\text{EtCp})(\text{NEtMe})_4$, $\text{V}(\text{iPrCp})(\text{NEtMe})_4$,
 $\text{V}(\text{tBuCp})(\text{NEtMe})_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{NEtMe})_4$, $\text{V}(\text{Et}_2\text{Cp})(\text{NEtMe})_4$, $\text{V}(\text{iPr}_2\text{Cp})(\text{NEtMe})_4$,
 $\text{V}(\text{tBu}_2\text{Cp})(\text{NEtMe})_4$, $\text{V}(\text{Et}_5\text{C}_5)(\text{NEtMe})_4$, $\text{V}(\text{iPr}_5\text{C}_5)(\text{NEtMe})_4$, $\text{V}(\text{MeCp})(\text{NMe}_2)_4$,
 $\text{V}(\text{EtCp})(\text{NMe}_2)_4$, $\text{V}(\text{iPrCp})(\text{NMe}_2)_4$, $\text{V}(\text{tBuCp})(\text{NMe}_2)_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{NMe}_2)_4$, $\text{V}(\text{Et}_2\text{Cp})(\text{NMe}_2)_4$,
 $\text{V}(\text{iPr}_2\text{Cp})(\text{NMe}_2)_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{NMe}_2)_4$, $\text{V}(\text{Et}_5\text{C}_5)(\text{NMe}_2)_4$, $\text{V}(\text{iPr}_5\text{C}_5)(\text{NMe}_2)_4$,
20 $\text{V}(\text{MeCp})(\text{NEt}_2)_4$, $\text{V}(\text{EtCp})(\text{NEt}_2)_4$, $\text{V}(\text{iPrCp})(\text{NEt}_2)_4$, $\text{V}(\text{tBuCp})(\text{NEt}_2)_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{NEt}_2)_4$,
 $\text{V}(\text{Et}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{iPr}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{Et}_5\text{C}_5)(\text{NEt}_2)_4$, $\text{V}(\text{iPr}_5\text{C}_5)(\text{NEt}_2)_4$,
 $\text{V}(\text{MeCp})(\text{OMe})_4$, $\text{V}(\text{EtCp})(\text{OMe})_4$, $\text{V}(\text{iPrCp})(\text{OMe})_4$, $\text{V}(\text{tBuCp})(\text{OMe})_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{OMe})_4$,
 $\text{V}(\text{Et}_2\text{Cp})(\text{OMe})_4$, $\text{V}(\text{iPr}_2\text{Cp})(\text{OMe})_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{OMe})_4$, $\text{V}(\text{Et}_5\text{C}_5)(\text{OMe})_4$, $\text{V}(\text{iPr}_5\text{C}_5)(\text{OMe})_4$,
 $\text{V}(\text{iPrCp})(=\text{O})(\text{OMe})_2$, $\text{V}(\text{iPrCp})(=\text{O})(\text{OEt})_2$, $\text{Ta}(\text{iPrCp})(=\text{NtBu})\text{Me}_2$, $\text{Ta}(\text{iPrCp})_2(=\text{NiPr})\text{Me}_2$

25

Example 2: MOCVD of TaC using $\text{Ta}(\text{iPrCp})\text{Me}_4$

$\text{Ta}(\text{iPrCp})\text{Me}_4$ is stored into a container. The container is heated at 90°C and N_2 is used as carrier gas at a flow of 100sccm. The pressure in the container is controlled at 50Torr. $\text{Ta}(\text{iPrCp})\text{Me}_4$ is mixed to a H_2/N_2 gas mixture into the reaction chamber. The substrate is
30 heated at 450°C. The pressure inside the reactor is set at 20Torr. A film of Tantalum carbide is obtained.

To increase the carbon content, C_2H_4 can be simultaneously introduced in the reaction chamber. Similar experiments can be performed with Nb and V analogs.

Example 3: MOCVD of TaSi using Ta(iPrCp)Me₄

Ta(iPrCp)Me₄ is stored into a container. The container is heated at 90°C and N₂ is used as carrier gas at a flow of 100sccm. The pressure in the container is controlled at 50Torr. Ta(iPrCp)Me₄ is mixed to a SiH₄/N₂ gas mixture into the reaction chamber. The substrate is
5 heated at 500°C. The pressure inside the reaction chamber is set at 10Torr. A film of Tantalum silicide is obtained.

Similar experiments can be performed with Nb and V analogs.

Example 4: MOCVD of Ta₂O₅ using Ta(iPrCp)Me₄

10 Ta(iPrCp)Me₄ is stored into a container. The container is heated at 90°C and N₂ is used as carrier gas at a flow of 100sccm. The pressure in the container is controlled at 50Torr. Ta(iPrCp)Me₄ is mixed to an O₂/N₂ gas mixture into the reaction chamber. The substrate is heated at 450°C. The pressure inside the reaction chamber is set at 20Torr. A film of Tantalum oxide is obtained.

15 Similar experiments can be performed with Nb and V analogs.

Example 5: MOCVD of HfTaOx using Ta(iPrCp)Me₄ and another Hf precursor

Ta(iPrCp)Me₄ is stored into a container. The container is heated at 90°C and N₂ is used as carrier gas at a flow of 100sccm. Tetrakis(ethylmethylamino)Hafnum, TEMAH, is stored in
20 another container, heated at 90°C and a N₂ carrier is passed through this second container at 100sccm. The pressure in both containers is controlled at 50Torr. Both precursors are simultaneously fed into the reaction chamber. A O₂/N₂ gas mixture is simultaneously introduced into the reaction chamber. The substrate is heated at 450°C. The pressure inside the reaction chamber is set at 20Torr. A film of Tantalum hafnium oxide is obtained.

25 Similar experiments can be performed with Nb and V analogs.

Example 6: ALD of HfTaOx using Ta(iPrCp)Me₄ and another Hf precursor

Ta(iPrCp)Me₄ is stored into a container. The container is heated at 90°C and N₂ is used as carrier gas at a flow of 100sccm. Tetrakis(ethylmethylamino)Hafnum, TEMAH, is stored in
30 another container, heated at 90°C and a N₂ carrier is passed through this second container at 100sccm. The pressure in both containers is controlled at 50Torr. O₃ is used as oxygen source. The substrate is heated at 300°C. The precursors are sequentially introduced into the reaction chamber: during the first step a pulse of Ta(iPrCp)Me₄ is introduced during 2s, followed by a 2s N₂ purge. A pulse of O₃ is then introduced into the reaction chamber during 2s, followed by a 2s

N₂ purge. A pulse of TEMAH is then introduced into the reaction chamber during 2s, followed by a 2s N₂ purge. A pulse of O₃ is then introduced into the reaction chamber during 2s. The first step is then done again. 100cycles are performed this way. A film of Tantalum hafnium oxide is obtained.

- 5 Similar experiments can be performed with Nb and V analogs.

Example 7: Synthesis of Ta(iPrCp)Me₄

- Ta(iPrCp)Me₄ is prepared in 3 steps. TaCl₂Me₃ is prepared by the reaction of LiMe over TaCl₅. Ta(iPrCp)ClMe₃ is then prepared by the reaction of Li(iPrCp) on TaCl₂Me₃. Ta(iPrCp)Me₄ is finally obtained by the reaction of LiMe over Ta(iPrCp)ClMe₃. The resulting compound is purified by distillation enough times to obtain in reasonable yield a compound of sufficient purity to be used in the semiconductor industry.
- 10

Example 8: Synthesis of Ta(tBu₂Cp)Me₄

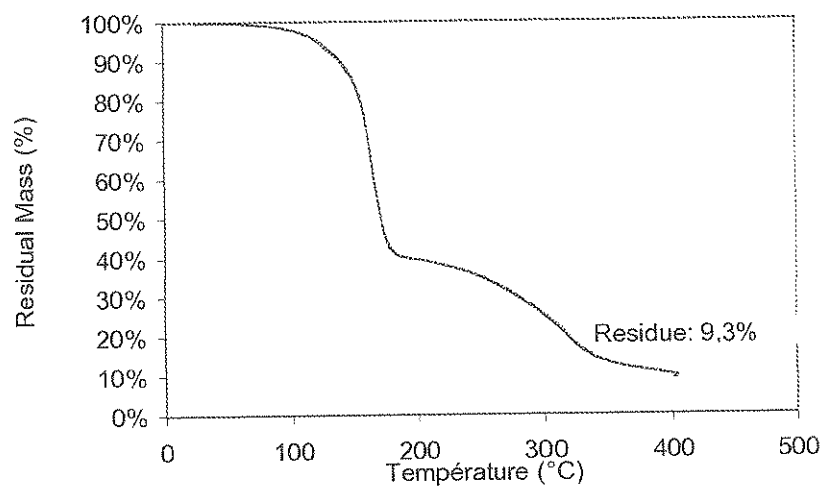
- 15 A solution of *t*-Bu₂C₅H₃SiMe₃ (4,42 g, 17,6 mmol) in toluene is slowly added at – 78°C to a suspension of TaCl₅ (6,31 g, 17,6 mmol) in toluene. The reaction mixture is then allowed to react at room temperature for further 12h. The yellow precipitate of (*t*-Bu₂Cp)TaCl₄ is collected washed with pentane and dried under vacuum. Yield 7,61 g, 86%. Ta(*t*-Bu₂Cp)Me₄ is then obtained by the reaction of LiMe over (*t*-Bu₂Cp)TaCl₄.
- 20

Example 9: Synthesis of Ta(tBu₂Cp)(NMe₂)₄

- A solution of *t*-Bu₂C₅H₃SiMe₃ (4,42 g, 17,6 mmol) in toluene is slowly added at – 78°C to a suspension of TaCl₅ (6,31 g, 17,6 mmol) in toluene. The reaction mixture is then allowed to react at room temperature for further 12h. The yellow precipitate of (*t*-Bu₂Cp)TaCl₄ is collected washed with pentane and dried under vacuum. Yield 7,61 g, 86%. Ta(*t*-Bu₂Cp)Me₄ is then obtained by the reaction of LiNMe₂ (commercially available) over (*t*-Bu₂Cp)TaCl₄.
- 25

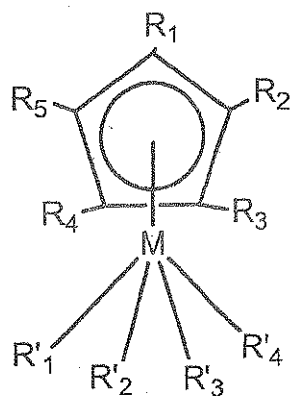
Example 10: Thermal gravimetric analysis of Ta(tBu₂Cp)Me₄

- A sample of 35,445mg of Ta(tBu₂Cp)Me₄ was placed in a crucible in a thermal gravimetric apparatus. Temperature was raised at 10°C/min under reduced pressure condition. Mass loss and sample heat flow were measured by thermal gravimetric analysis and differential scanning calorimetry. TGA curve is shown in Figure.1.
- 30



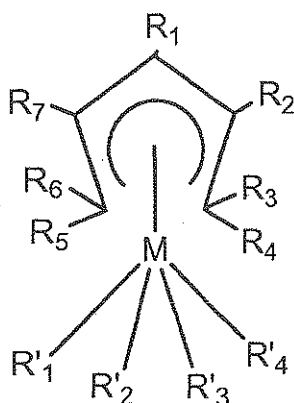
CLAIMS

1 - Use, of at least one compound of the formula (Ia):



(Ia)

or of the formula (Ib):



(Ib)

as metal precursors in a process for depositing a group V metal containing film on a substrate comprising the steps of:

- Introducing a substrate into a reactor;
- Preferably heating the substrate at a temperature above 150°C;
- Feeding a compound of the formula (Ia) or of the formula (Ib), or a mixture of said compounds thereof in the vapor phase into the reactor;
- Optionally a second compound of the formula (Ia) or of the formula (Ib), or a second mixture of said compounds thereof in vapor phase into the reactor;
- Depositing a film containing at least one of said compound of the formula (Ia) or

of the formula (Ib), onto said substrate;

Formulas (Ia) and (Ib) wherein,

M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

5 $R_1, R_2, R_3, R_4, R_5, R_6$ and R_7 ; which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

10 either R'_1, R'_2, R'_3 and R'_4 ; which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms or linear or branched alkylsilylamide groups having from one to four carbon atoms;

15 or R'_1, R'_2 , which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms or linear or branched alkylsilylamide groups having from one to four carbon atoms; and R'_3 and R'_4 together represent an oxo group ($=O$) or alkyl imino group having from one to four carbon atoms ($=N-R$)

20 2 – Use, in metal containing film deposition, of at least one compound of the formula (Ia) or (Ib), according to Claim 1, wherein

$R_1, R_2, R_3, R_4, R_5, R_6$ and R_7 ; which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms.

25 3 – Use, in metal containing film deposition, of at least one compound of the formula (Ia) or (Ib), according to Claim 1 or to Claim 2, wherein R'_1, R'_2, R'_3 , and R'_4 , which may be identical or different, are independently chosen from Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms.

30 4 – Use, in metal containing film deposition, of at least one a compound of the formula (Ia), according to one of Claim 1 to Claim 3, wherein R_2, R_3, R_4 , and R_5 , each represent an Hydrogen atom.

5 – Use, in metal containing film deposition, of at least one compound of the formula (Ib), according to one of Claim 1 to Claim 3, wherein R_2, R_3, R_4, R_5, R_6 and R_7 , each represent an Hydrogen atom.

6 – Use, in metal containing film deposition, of at least one compound of the formula

(Ia) or (Ib), according to one of Claim 1 to Claim 5, wherein R_1 is chosen from ethyl, isopropyl or tert-butyl.

7 – Use, in metal containing film deposition, of a compound of the formula (Ia) or (Ib), according to one of Claim 1 to Claim 6, wherein R'_1 , R'_2 , R'_3 , and R'_4 each represent a methyl group.

8 – Use, in metal containing film deposition, of at least one compound of the formula (Ia) or (Ib), according to one of Claim 1 to Claim 6, wherein R'_1 and R'_2 , which may be identical or different, are independently chosen from methyl or methoxy, and R'_3 and R'_4 together represent an oxo group (=O) or a tert-butyl imino group (=N-tBu).

9 – The following compounds:

(Isopropyl-Cyclopentadienyl) tetrakis(methyl) Tantalum;
(1,5-diisopropyl-pentadienyl) tetrakis(methyl) Tantalum;
(1,3-di-tert-butyl-cyclopentadienyl) tetrakis(methyl) Tantalum;
(Ethyl-Cyclopentadienyl) tetrakis(methyl) Tantalum;
(Isopropyl-Cyclopentadienyl) tetrakis(methyl) Vanadium;
(Isopropyl-Cyclopentadienyl) tetrakis(methyl) Niobium;
(1,3-di-tert-butyl-cyclopentadienyl) tetrakis(methyl) Niobium.

10 – A process for depositing a group V metal containing film on a substrate comprising the steps of:

- Introducing a substrate into a reactor;
- Preferably heating the substrate at a temperature above 150°C;
- Feeding a compound of the formula (Ia) or of the formula (Ib) as disclosed in one of Claim 1 to Claim 9, or a mixture of said compounds thereof in the vapor phase into the reactor;
- Optionally a second compound of the formula (Ia) or of the formula (Ib) as disclosed in one of Claim 1 to Claim 9, or a second mixture of said compounds thereof in vapor phase into the reactor;
- Depositing a film containing at least one of said compound of the formula (Ia) or of the formula (Ib), onto said substrate.

11 – A process for depositing a TaN layer on a substrate, according to Claim 10, further comprising the step of injecting a reactant selected from the group consisting of NH_3 , N_2H_4 , methylhydrazine and any mixture thereof.

12 – A process for depositing a TaSi layer on a substrate, according to Claim 10 or Claim 11, further comprising the step of feeding an additional Si containing precursor,

preferably SiH_4 .

13 – A process for depositing a TaSiN layer on a substrate, according to one of Claim 10 to Claim 12, further comprising the step of feeding a Si containing precursor and a reactant, preferably trisilylamine and NH_3 and/or TriDMAS and NH_3 .

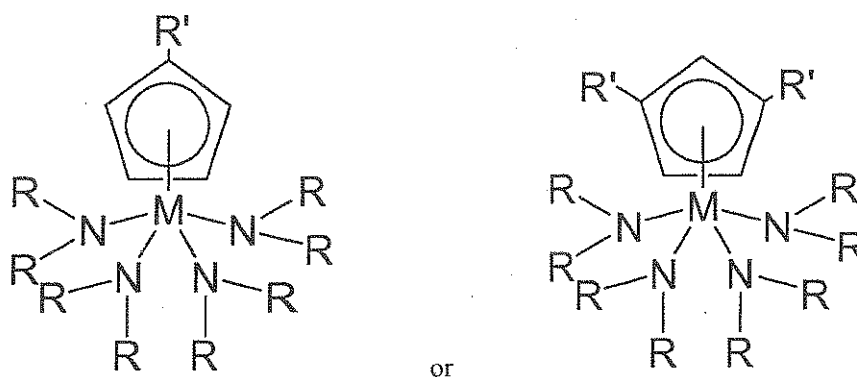
5 14 – A process for depositing a TaO layer on a substrate, according to one of Claim 10 to Claim 13, further comprising the step of injecting an oxygen comprising reactant, preferably O_3 .

15 15 – A process for depositing a TaHfO layer on a substrate according to one of Claim 10 to Claim 14, further comprising the step of injecting an oxygen comprising reactant and an Hafnium containing precursor, preferably TEMAH.

16 – A process for depositing a TaC layer on a substrate according to one of Claims 10 to Claim 15, further comprising the step of injecting the Tantalum precursor alone or additionally injecting a carbon precursor such as C_2H_4 when more than about 30% vol. of carbon is needed in the deposited layer.

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17 – A Compound wherein the formula (Ia) is:



Where:

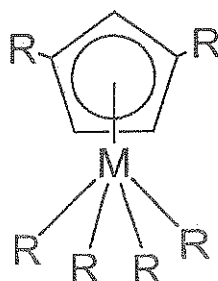
20 M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),

Each R is independently selected from the group consisting of linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four carbon atoms;

25 Each R' are independently selected from the group consisting of Hydrogen atom, linear or branched alkyl groups having from one to four carbon atoms, linear or branched alkoxy groups having from one to four carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms, linear or branched alkylsilylamide groups having from one to four

carbon atoms;

or the formula :



(b)

Where:

M is a group V metal selected from Tantalum (Ta), Niobium (Nb) and Vanadium (V),
Each R is independently selected from the group consisting of linear or branched alkyl groups
10 having from one to four carbon atoms, linear or branched alkoxy groups having from one to four
carbon atoms, linear or branched alkylamide groups having from one to four carbon atoms,
linear or branched alkylsilylamide groups having from one to four carbon atoms.

18 – The following compounds:

Ta(Me₂Cp)Me₄, Ta(Et₂Cp)Me₄, Ta(iPr₂Cp)Me₄, Ta(tBu₂Cp)Me₄, Ta(Me₂Cp)Et₄,
15 Ta(Et₂Cp)Et₄, Ta(iPr₂Cp)Et₄, Ta(tBu₂Cp)Et₄, Ta(Me₂Cp)Me₂Et₂, Ta(Et₂Cp)Me₂Et₂,
Ta(iPr₂Cp)Me₂Et₂, Ta(tBu₂Cp)Me₂Et₂, Nb(Me₂Cp)Me₄, Nb(Et₂Cp)Me₄, Nb(iPr₂Cp)Me₄,
Nb(tBu₂Cp)Me₄, Nb(Me₂Cp)Et₄, Nb(Et₂Cp)Et₄, Nb(iPr₂Cp)Et₄, Nb(tBu₂Cp)Et₄,
Nb(Me₂Cp)Me₂Et₂, Nb(Et₂Cp)Me₂Et₂, Nb(iPr₂Cp)Me₂Et₂, Nb(tBu₂Cp)Me₂Et₂,
Nb(MeEtCp)Me₄, V(Me₂Cp)Me₄, V(Et₂Cp)Me₄, V(iPr₂Cp)Me₄, V(tBu₂Cp)Me₄, V(Me₂Cp)Et₄,
20 V(Et₂Cp)Et₄, V(iPr₂Cp)Et₄, V(tBu₂Cp)Et₄, V(Me₂Cp)Me₂Et₂, V(Et₂Cp)Me₂Et₂,
V(iPr₂Cp)Me₂Et₂, V(tBu₂Cp)Me₂Et₂,

19 – The following compounds:

Ta(MeCp)(NEtMe)₄, Ta(EtCp)(NEtMe)₄, Ta(iPrCp)(NEtMe)₄, Ta(tBuCp)(NEtMe)₄,
Ta(Me₂Cp)(NEtMe)₄, Ta(Et₂Cp)(NEtMe)₄, Ta(iPr₂Cp)(NEtMe)₄, Ta(tBu₂Cp)(NEtMe)₄,
25 Ta(MeCp)(NMe₂)₄, Ta(EtCp)(NMe₂)₄, Ta(iPrCp)(NMe₂)₄, Ta(tBuCp)(NMe₂)₄,
Ta(Me₂Cp)(NMe₂)₄, Ta(Et₂Cp)(NMe₂)₄, Ta(iPr₂Cp)(NMe₂)₄, Ta(tBu₂Cp)(NMe₂)₄,
Ta(MeCp)(NEt₂)₄, Ta(EtCp)(NEt₂)₄, Ta(iPrCp)(NEt₂)₄, Ta(tBuCp)(NEt₂)₄, Ta(Me₂Cp)(NEt₂)₄,
Ta(Et₂Cp)(NEt₂)₄, Ta(iPr₂Cp)(NEt₂)₄, Ta(tBu₂Cp)(NEt₂)₄, Nb(EtCp)(NEtMe)₄,
Nb(iPrCp)(NEtMe)₄, Nb(tBuCp)(NEtMe)₄, Nb(Me₂Cp)(NEtMe)₄, Nb(Et₂Cp)(NEtMe)₄,
30 Nb(iPr₂Cp)(NEtMe)₄, Nb(tBu₂Cp)(NEtMe)₄, Nb(MeCp)(NMe₂)₄, Nb(EtCp)(NMe₂)₄,

$\text{Nb}(\text{MeCp})(\text{NEtMe})_4$, $\text{Nb}(\text{iPrCp})(\text{NMe}_2)_4$, $\text{Nb}(\text{tBuCp})(\text{NMe}_2)_4$, $\text{Nb}(\text{Me}_2\text{Cp})(\text{NMe}_2)_4$,
 $\text{Nb}(\text{Et}_2\text{Cp})(\text{NMe}_2)_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{NMe}_2)_4$, $\text{Nb}(\text{tBu}_2\text{Cp})(\text{NMe}_2)_4$, $\text{Nb}(\text{MeCp})(\text{NEt}_2)_4$,
 $\text{Nb}(\text{EtCp})(\text{NEt}_2)_4$, $\text{Nb}(\text{iPrCp})(\text{NEt}_2)_4$, $\text{Nb}(\text{tBuCp})(\text{NEt}_2)_4$, $\text{Nb}(\text{Me}_2\text{Cp})(\text{NEt}_2)_4$,
 $\text{Nb}(\text{Et}_2\text{Cp})(\text{NEt}_2)_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{NEt}_2)_4$, $\text{Nb}(\text{tBu}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{MeCp})(\text{NEtMe})_4$,
5 $\text{V}(\text{EtCp})(\text{NEtMe})_4$, $\text{V}(\text{iPrCp})(\text{NEtMe})_4$, $\text{V}(\text{tBuCp})(\text{NEtMe})_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{NEtMe})_4$,
 $\text{V}(\text{Et}_2\text{Cp})(\text{NEtMe})_4$, $\text{V}(\text{iPr}_2\text{Cp})(\text{NEtMe})_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{NEtMe})_4$, $\text{V}(\text{MeCp})(\text{NMe}_2)_4$,
 $\text{V}(\text{EtCp})(\text{NMe}_2)_4$, $\text{V}(\text{iPrCp})(\text{NMe}_2)_4$, $\text{V}(\text{tBuCp})(\text{NMe}_2)_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{NMe}_2)_4$, $\text{V}(\text{Et}_2\text{Cp})(\text{NMe}_2)_4$,
 $\text{V}(\text{iPr}_2\text{Cp})(\text{NMe}_2)_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{NMe}_2)_4$, $\text{V}(\text{MeCp})(\text{NEt}_2)_4$, $\text{V}(\text{EtCp})(\text{NEt}_2)_4$, $\text{V}(\text{iPrCp})(\text{NEt}_2)_4$,
 $\text{V}(\text{tBuCp})(\text{NEt}_2)_4$, $\text{V}(\text{Me}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{Et}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{iPr}_2\text{Cp})(\text{NEt}_2)_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{NEt}_2)_4$,

10 20 – The following compounds:

$\text{Ta}(\text{Me}_2\text{Cp})(\text{OMe})_4$, $\text{Ta}(\text{Et}_2\text{Cp})(\text{OMe})_4$, $\text{Ta}(\text{iPr}_2\text{Cp})(\text{OMe})_4$, $\text{Ta}(\text{tBu}_2\text{Cp})(\text{OMe})_4$,
 $\text{Nb}(\text{Me}_2\text{Cp})(\text{OMe})_4$, $\text{Nb}(\text{Et}_2\text{Cp})(\text{OMe})_4$, $\text{Nb}(\text{iPr}_2\text{Cp})(\text{OMe})_4$, $\text{Nb}(\text{tBu}_2\text{Cp})(\text{OMe})_4$,
 $\text{V}(\text{Me}_2\text{Cp})(\text{OMe})_4$, $\text{V}(\text{Et}_2\text{Cp})(\text{OMe})_4$, $\text{V}(\text{iPr}_2\text{Cp})(\text{OMe})_4$, $\text{V}(\text{tBu}_2\text{Cp})(\text{OMe})_4$.

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