

HYDROCARBYL-MODIFIED METHYLALUMINOXANE COCATALYST FOR BIS-PHENYLPHENOXY METAL-LIGAND COMPLEXES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 63/053,354, filed on July 17, 2020, the entire disclosure of which is hereby incorporated by reference.

TECHNICAL FIELD

[0002] Embodiments of the present disclosure generally relate to modified-hydrocarbyl methylaluminoxane activators for catalysts systems that include bis-phenylphenoxy metal-ligand complexes with a three atom ether linker.

BACKGROUND

[0003] Since the discovery of Ziegler and Natta on heterogeneous olefin polymerizations, global polyolefin production reached approximately 150 million tons per year in 2015, and it is rising due to increasing market demand. This success is based in part on a series of important breakthroughs in co-catalyst technology. The co-catalysts discovered include aluminoxanes, boranes, and borates with triphenylcarbenium or ammonium cations. These co-catalysts activate the homogeneous single-site olefin polymerization catalysts, and polyolefins have been produced using these co-catalysts in industry.

[0004] As part of the catalyst composition in α -olefin polymerization reactions, the activator may have characteristics that are beneficial for the production of the α -olefin polymer and for final polymer compositions including the α -olefin polymer. Activator characteristics that increase the production of α -olefin polymers include, but are not limited to: rapid procatalyst activation, high catalyst efficiency, high temperature capability, consistent polymer composition, and selective deactivation.

[0005] Borate based co-catalysts in particular have contributed significantly to the fundamental understanding of olefin polymerization mechanisms, and have enhanced the ability for precise control over polyolefin microstructures by deliberately tuning catalyst structures and

processes. This results in stimulated interest in mechanistic studies and lead to the development of novel homogeneous olefin polymerization catalyst systems that have precise control over polyolefin microstructures and performance. However, once the cations of the activator or co-catalyst activate the procatalyst, the ions of the activator may remain in the polymer composition. As a result, the borate anions may affect the polymer composition. In particular, the size of the borate anion, the charge of the borate anion, the interaction of the borate anion with the surrounding medium, and the dissociation energy of the borate anion with available counterions will affect the ion's ability to diffuse through a surrounding medium such as a solvent, a gel, or a polymer material.

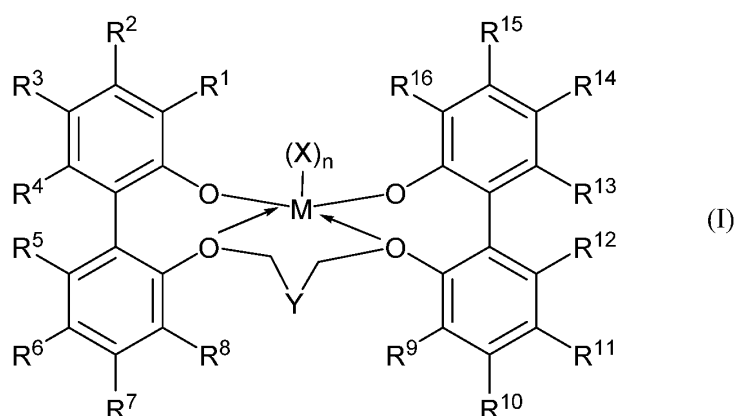
[0006] Modified methylaluminoxanes (MMAOs) can be described as a mixture of aluminoxane structures and trihydrocarbylaluminum species. Trihydrocarbylaluminum species, like trimethylaluminum are used as scavengers to remove impurities in the polymerization process which may contribute to the deactivation of the olefin polymerization catalyst. However, it is believed that trihydrocarbylaluminum species may be active in some polymerization systems. Catalyst inhibition has been noted when trimethylaluminum is present in propylene homopolymerizations with hafnocene catalysts at 60 °C (Busico, V. et. al. *Macromolecules* **2009**, *42*, 1789-1791). However, these observations convolute differences in MAO-activation versus borate activation, and even in direct comparison only possibly capture differences between some trimethylaluminum and none. Additionally, it is unclear that such observations extend to other catalysts systems, to ethylene polymerization, or to polymerizations conducted at higher temperatures. Regardless, the preference for soluble MAOs necessitates the use of MMAO and hence the presence of trihydrocarbylaluminum species.

[0007] Modified methylaluminoxanes (MMAO) are used as activators in some PE processes replacing borate based activators. However, MMAO has been found to have negative impact on the performance of some catalysts, such as bis-biphenylphenoxy metal–ligand complexes and negatively impacted the production of polyvinyl resins. The negative impact on the polymerization process includes decreasing catalyst activity, broadening composition distribution of the produced polymer, and negatively affecting the pellet handling.

SUMMARY

[0008] There is an ongoing need to create a catalyst system while maintaining catalyst efficiency, reactivity, and the ability to produce polymers with good physical properties. There is a further need to produce uniformed polymer compositions.

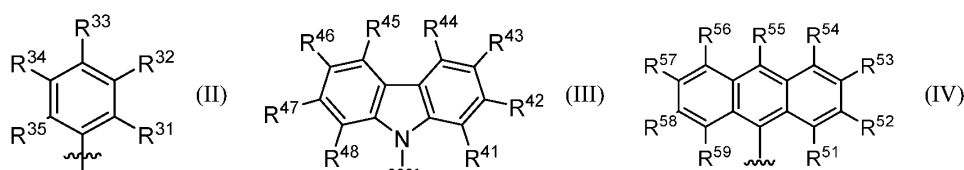
[0009] Embodiments of this disclosure includes processes of polymerizing olefin monomers. In one or more embodiments, the process includes reacting ethylene and optionally one or more olefin monomers in the presence of a catalyst system. The catalyst system includes modified-hydrocarbyl methylaluminoxane and a procatalyst. The modified-hydrocarbyl methylaluminoxane having less than 50 mole $\text{AlR}^{\text{A}}\text{R}^{\text{B}}\text{R}^{\text{C}}$ based on the total moles of aluminum, where R^{A} , R^{B} , and R^{C} are independently linear $(\text{C}_1\text{--C}_{40})$ alkyl, branched $(\text{C}_1\text{--C}_{40})$ alkyl, or $(\text{C}_6\text{--C}_{40})$ aryl; and one or more metal–ligand complexes according to formula (I):



[0010] In formula (I), M is titanium, zirconium, or hafnium. Subscript n of $(\text{X})_n$ is 1, 2, or 3. Each X is a monodentate ligand independently chosen from unsaturated $(\text{C}_2\text{--C}_{50})$ hydrocarbon, unsaturated $(\text{C}_2\text{--C}_{50})$ heterohydrocarbon, $(\text{C}_1\text{--C}_{50})$ hydrocarbyl, $(\text{C}_6\text{--C}_{50})$ aryl, $(\text{C}_6\text{--C}_{50})$ heteroaryl, cyclopentadienyl, substituted cyclopentadienyl, $(\text{C}_4\text{--C}_{12})$ diene, halogen, $-\text{N}(\text{R}^{\text{N}})_2$, and $-\text{N}(\text{R}^{\text{N}})\text{COR}^{\text{C}}$; and the metal–ligand complex is overall charge-neutral.

[0011] In formula (I), R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 , R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , and R^{15} are independently selected from $-\text{H}$, $(\text{C}_1\text{--C}_{40})$ hydrocarbyl, $(\text{C}_1\text{--C}_{40})$ heterohydrocarbyl, $-\text{Si}(\text{R}^{\text{C}})_3$, $-\text{Ge}(\text{R}^{\text{C}})_3$, $-\text{P}(\text{R}^{\text{P}})_2$, $-\text{N}(\text{R}^{\text{N}})_2\text{OR}^{\text{C}}$, $-\text{SR}^{\text{C}}$, $-\text{NO}_2$, $-\text{CN}$, $-\text{CF}_3$, $\text{R}^{\text{C}}\text{S}(\text{O})-$, $\text{R}^{\text{C}}\text{S}(\text{O})_2-$, $(\text{R}^{\text{C}})_2\text{C}=\text{N}-$, $\text{R}^{\text{C}}\text{C}(\text{O})\text{O}-$, $\text{R}^{\text{C}}\text{OC}(\text{O})-$, $\text{R}^{\text{C}}\text{C}(\text{O})\text{N}(\text{R})-$, $(\text{R}^{\text{C}})_2\text{NC}(\text{O})-$, and halogen.

[0012] In formula (I), R^1 and R^{16} are independently selected from the group consisting of $-H$, (C_1-C_{40}) hydrocarbyl, (C_1-C_{40}) heterohydrocarbyl, $-\text{Si}(R^C)_3$, $-\text{Ge}(R^C)_3$, $-\text{P}(R^P)_2$, $-\text{N}(R^N)_2$, $-\text{OR}^C$, $-\text{SR}^C$, $-\text{NO}_2$, $-\text{CN}$, $-\text{CF}_3$, $R^C\text{S}(\text{O})-$, $R^C\text{S}(\text{O})_2-$, $-\text{N}=\text{C}(R^C)_2$, $R^C\text{C}(\text{O})\text{O}-$, $R^C\text{OC}(\text{O})-$, $R^C\text{C}(\text{O})\text{N}(R)-$, $(R^C)_2\text{NC}(\text{O})-$, halogen, radicals having formula (II), radicals having formula (III), and radicals having formula (IV):



[0013] In formulas (II), (III), and (IV), each of R^{31-35} , R^{41-48} , and R^{51-59} is independently chosen from $-H$, (C_1-C_{40}) hydrocarbyl, (C_1-C_{40}) heterohydrocarbyl, $-\text{Si}(R^C)_3$, $-\text{Ge}(R^C)_3$, $-\text{P}(R^P)_2$, $-\text{N}(R^N)_2$, $-\text{OR}^C$, $-\text{SR}^C$, $-\text{NO}_2$, $-\text{CN}$, $-\text{CF}_3$, $R^C\text{S}(\text{O})-$, $R^C\text{S}(\text{O})_2-$, $(R^C)_2\text{C}=\text{N}-$, $R^C\text{C}(\text{O})\text{O}-$, $R^C\text{OC}(\text{O})-$, $R^C\text{C}(\text{O})\text{N}(R^N)-$, $(R^C)_2\text{NC}(\text{O})-$, or halogen.

[0014] In formula (I), Y is CH_2 , CHR^{21} , $\text{CR}^{21}\text{R}^{22}$, $\text{SiR}^{21}\text{R}^{22}$, or $\text{GeR}^{21}\text{R}^{22}$, where R^{21} and R^{22} are (C_1-C_{20}) alkyl; provided that when Y is CH_2 , at least one of R^8 and R^9 is not $-H$.

[0015] In formulas (I), (II), (III), and (IV), each R^C , R^P , and R^N in formula (I) is independently a (C_1-C_{30}) hydrocarbyl, (C_1-C_{30}) heterohydrocarbyl, or $-H$.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a chart of the catalyst efficiency of metal-ligand complexes I1, I3, and I7 as a function of the type of MMAO co-catalyst.

DETAILED DESCRIPTION

[0017] Specific embodiments of catalyst systems will now be described. It should be understood that the catalyst systems of this disclosure may be embodied in different forms and should not be construed as limited to the specific embodiments set forth in this disclosure. Rather, embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the subject matter to those skilled in the art.

[0018] Common abbreviations are listed below:

[0019] **Me** : methyl; **Et** : ethyl; **Ph** : phenyl; **Bn** : benzyl; **i-Pr** : *iso*-propyl; **t-Bu** : *tert*-butyl; **t-Oct** : *tert*-octyl (2,4,4-trimethylpentan-2-yl); **Tf** : trifluoromethane sulfonate; **THF** : tetrahydrofuran; **Et₂O** : diethyl ether; **CH₂Cl₂** : dichloromethane; **CV** : column volume (used in column chromatography); **EtOAc** : ethyl acetate; **C₆D₆** : deuterated benzene or benzene-*d*₆ ; **CDCl₃** : deuterated chloroform; **Na₂SO₄** : sodium sulfate; **MgSO₄** : magnesium sulfate; **HCl** : hydrogen chloride; ***n*-BuLi** : butyllithium; ***t*-BuLi** : *tert*-butyllithium; **MAO** : methylaluminoxane; **MMAO** : modified methylaluminoxane; **GC** : gas chromatography; **LC** : liquid chromatography; **NMR** : nuclear magnetic resonance; **MS** : mass spectrometry; **mmol** : millimoles; **mL** : milliliters; **M** : molar; **min or mins** : minutes; **h or hrs** : hours; **d** : days.

[0020] The term “independently selected” is used herein to indicate that the R groups, such as, R¹, R², R³, R⁴, and R⁵, can be identical or different (e.g., R¹, R², R³, R⁴, and R⁵ may all be substituted alkyls or R¹ and R² may be a substituted alkyl and R³ may be an aryl, etc). A chemical name associated with an R group is intended to convey the chemical structure that is recognized in the art as corresponding to that of the chemical name. Thus, chemical names are intended to supplement and illustrate, not preclude, the structural definitions known to those of skill in the art.

[0021] The term “procatalyst” refers to a transition metal compound that has olefin polymerization catalytic activity when combined with an activator. The term “activator” refers to a compound that chemically reacts with a procatalyst in a manner that converts the procatalyst to a catalytically active catalyst. As used herein, the terms “co-catalyst” and “activator” are interchangeable terms.

[0022] When used to describe certain carbon atom-containing chemical groups, a parenthetical expression having the form “(C_x–C_y)” means that the unsubstituted form of the chemical group has from x carbon atoms to y carbon atoms, inclusive of x and y. For example, a (C₁–C₅₀)alkyl is an alkyl group having from 1 to 50 carbon atoms in its unsubstituted form. In some embodiments and general structures, certain chemical groups may be substituted by one or more substituents such as R^S. An R^S substituted chemical group defined using the “(C_x–C_y)” parenthetical may contain more than y carbon atoms depending on the identity of any groups R^S. For example, a “(C₁–C₅₀)alkyl substituted with exactly one group R^S, where R^S is phenyl (–C₆H₅)” may contain from 7 to 56 carbon atoms. Thus, in general when a chemical group defined using the “(C_x–C_y)” parenthetical is substituted by one or more carbon atom-containing substituents R^S, the minimum and maximum total number of carbon atoms of the chemical group is determined

by adding to both x and y the combined sum of the number of carbon atoms from all of the carbon atom-containing substituents R^S .

[0023] The term “substitution” means that at least one hydrogen atom ($-H$) bonded to a carbon atom of a corresponding unsubstituted compound or functional group is replaced by a substituent (e.g. R^S). The term “ $-H$ ” means a hydrogen or hydrogen radical that is covalently bonded to another atom. “Hydrogen” and “ $-H$ ” are interchangeable, and unless clearly specified have identical meanings.

[0024] The term “ (C_1-C_{50}) alkyl” means a saturated straight or branched hydrocarbon radical containing from 1 to 50 carbon atoms; and the term “ (C_1-C_{30}) alkyl” means a saturated straight or branched hydrocarbon radical of from 1 to 30 carbon atoms. Each (C_1-C_{50}) alkyl and (C_1-C_{30}) alkyl may be unsubstituted or substituted by one or more R^S . In some examples, each hydrogen atom in a hydrocarbon radical may be substituted with R^S , such as, for example trifluoromethyl. Examples of unsubstituted (C_1-C_{50}) alkyl are unsubstituted (C_1-C_{20}) alkyl; unsubstituted (C_1-C_{10}) alkyl; unsubstituted (C_1-C_5) alkyl; methyl; ethyl; 1-propyl; 2-propyl; 1-butyl; 2-butyl; 2-methylpropyl; 1,1-dimethylethyl; 1-pentyl; 1-hexyl; 1-heptyl; 1-nonyl; and 1-decyl. Examples of substituted (C_1-C_{40}) alkyl are substituted (C_1-C_{20}) alkyl, substituted (C_1-C_{10}) alkyl, trifluoromethyl, and $[C_{45}]$ alkyl. The term “ $[C_{45}]$ alkyl” means there is a maximum of 45 carbon atoms in the radical, including substituents, and is, for example, a $(C_{27}-C_{40})$ alkyl substituted by one R^S , which is a (C_1-C_5) alkyl, such as, for example, methyl, trifluoromethyl, ethyl, 1-propyl, 1-methylethyl, or 1,1-dimethylethyl.

[0025] The term (C_3-C_{50}) alkenyl means a branched or unbranched, cyclic or acyclic monovalent hydrocarbon radical containing from 3 to 50 carbon atoms, at least one double bond and is unsubstituted or substituted by one or more R^S . Examples of unsubstituted (C_3-C_{50}) alkenyl: n-propenyl, isopropenyl, n-butenyl, isobutenyl, octenyl, decenyl, cyclopentenyl, cyclopentadienyl, cyclohexenyl, and cyclohexadienyl. Examples of substituted (C_3-C_{50}) alkenyl: (2-trifluoromethyl)pent-1-enyl, (3-methyl)hex-1-enyl, (3-methyl)hexa-1,4-dienyl and (Z)-1-(6-methylhept-3-en-1-yl)cyclohex-1-enyl.

[0026] The term “ (C_3-C_{50}) cycloalkyl” means a saturated cyclic hydrocarbon radical of from 3 to 50 carbon atoms that is unsubstituted or substituted by one or more R^S . Other cycloalkyl groups (e.g., (C_x-C_y) cycloalkyl) are defined in an analogous manner as having from x to y carbon atoms and being either unsubstituted or substituted with one or more R^S . Examples of

unsubstituted (C₃–C₄₀)cycloalkyl are unsubstituted (C₃–C₂₀)cycloalkyl, unsubstituted (C₃–C₁₀)cycloalkyl, cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, cyclooctyl, cyclononyl, and cyclodecyl. Examples of substituted (C₃–C₄₀)cycloalkyl are substituted (C₃–C₂₀)cycloalkyl, substituted (C₃–C₁₀)cycloalkyl, and 1-fluorocyclohexyl.

[0027] The term “halogen atom” or “halogen” means the radical of a fluorine atom (F), chlorine atom (Cl), bromine atom (Br), or iodine atom (I). The term “halide” means anionic form of the halogen atom: fluoride (F[−]), chloride (Cl[−]), bromide (Br[−]), or iodide (I[−]).

[0028] The term “saturated” means lacking carbon–carbon double bonds, carbon–carbon triple bonds, and (in heteroatom-containing groups) carbon–nitrogen, carbon–phosphorous, and carbon–silicon double bonds. Where a saturated chemical group is substituted by one or more substituents R^S, one or more double or triple bonds optionally may be present in substituents R^S. The term “unsaturated” means containing one or more carbon–carbon double bonds or carbon–carbon triple bonds, or (in heteroatom-containing groups) one or more carbon–nitrogen double bonds, carbon–phosphorous double bonds, or carbon–silicon double bonds, not including double bonds that may be present in substituents R^S, if any, or in aromatic rings or heteroaromatic rings, if any.

[0029] Embodiments of this disclosure includes processes of polymerizing olefin monomers. In one or more embodiments, the process includes reacting ethylene and optionally one or more olefin monomers in the presence of a catalyst system.

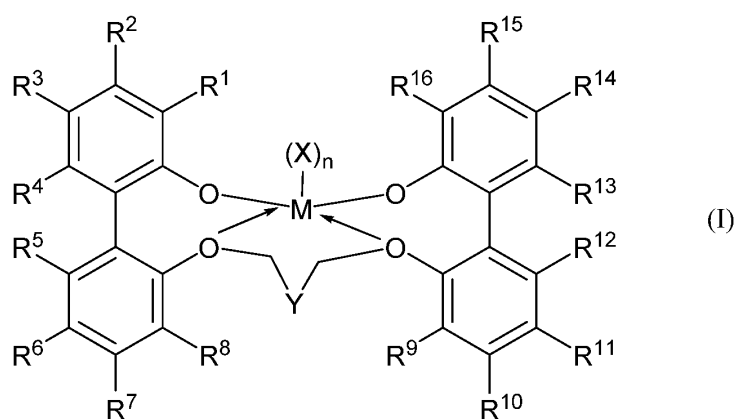
[0030] In various embodiments, the catalyst system does not contain a borate activator.

[0031] In some embodiments, the olefin monomer is (C₃–C₂₀) α -olefin. In other embodiments, the olefin monomer is not (C₃–C₂₀) α -olefin. In various embodiments, the olefin monomer is cyclic olefin.

[0032] In one or more embodiments, the catalyst system includes hydrocarbyl-modified methylaluminoxane and a procatalyst. The hydrocarbyl-modified methylaluminoxane having less than 50 mole percent AlR^{Al}R^{Bl}R^{Cl} based on the total moles of aluminum. In the formula AlR^{Al}R^{Bl}R^{Cl}, R^{Al}, R^{Bl}, and R^{Cl} are independently linear (C₁–C₄₀)alkyl, branched (C₁–C₄₀)alkyl, (C₁–C₄₀)aryl, or combinations thereof.

[0033] The term “hydrocarbyl-modified methylaluminoxane” refers to a methylaluminoxane (MMAO) structure comprising an amount of trihydrocarbyl aluminum. The hydrocarbyl-modified methylaluminoxane includes a combination of a hydrocarbyl-modified methylaluminoxane matrix and trihydrocarbylaluminum. A total molar amount of aluminum in the hydrocarbyl-modified methylaluminoxane is composed of the aluminum contribution from the moles of aluminum from the hydrocarbyl-modified methylaluminoxane matrix and moles of aluminum from the trihydrocarbyl aluminum. The hydrocarbyl-modified methylaluminoxane includes greater than 2.5 mole percent of trihydrocarbylaluminum based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane. These additional hydrocarbyl substituents can impact the subsequent aluminosiloxane structure and result in differences in the distribution and size of aluminosiloxane clusters (Bryliakov, K. P et. al. *Macromol. Chem. Phys.* **2006**, 207, 327-335). The additional hydrocarbyl substituents can also impart increased solubility of the aluminosiloxane in hydrocarbon solvents such as, but not limited to, hexane, heptane, methylcyclohexane, and ISOPAR E™ as demonstrated in US5777143. Modified methylaluminoxane compositions are generically disclosed and can be prepared as described in US5066631 and US5728855, both of which are incorporated herein by reference.

[0034] In embodiments of this disclosure, the catalyst system includes one or more metal-ligand complexes according to formula (I):

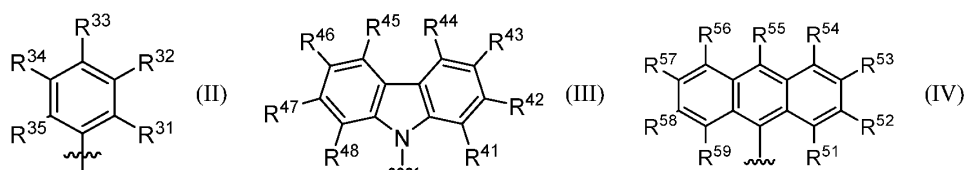


[0035] In formula (I), M is titanium, zirconium, or hafnium having a formal oxidation state of +2, +3, or +4. Subscript n of $(X)_n$ is 1, 2, or 3. Each X is a monodentate ligand independently chosen from unsaturated (C_2-C_{50}) hydrocarbon, unsaturated (C_2-C_{50}) heterohydrocarbon, (C_1-C_{50}) hydrocarbyl, (C_6-C_{50}) aryl, (C_6-C_{50}) heteroaryl, cyclopentadienyl, substituted

cyclopentadienyl, (C₄–C₁₂)diene, halogen, –N(R^N)₂, and –N(R^N)COR^C; and the metal–ligand complex is overall charge-neutral.

[0036] In formula (I), R², R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, and R¹⁵ are independently selected from –H, (C₁–C₄₀)hydrocarbyl, (C₁–C₄₀)heterohydrocarbyl, –Si(R^C)₃, –Ge(R^C)₃, –P(R^P)₂, –N(R^N)₂, –OR^C, –SR^C, –NO₂, –CN, –CF₃, R^CS(O)–, R^CS(O)₂–, (R^C)₂C=N–, R^CC(O)O–, R^COC(O)–, R^CC(O)N(R)–, (R^C)₂NC(O)–, and halogen.

[0037] In formula (I), R¹ and R¹⁶ are independently selected from the group consisting of –H, (C₁–C₄₀)hydrocarbyl, (C₁–C₄₀)heterohydrocarbyl, –Si(R^C)₃, –Ge(R^C)₃, –P(R^P)₂, –N(R^N)₂, –OR^C, –SR^C, –NO₂, –CN, –CF₃, R^CS(O)–, R^CS(O)₂–, –N=C(R^C)₂, R^CC(O)O–, R^COC(O)–, R^CC(O)N(R)–, (R^C)₂NC(O)–, halogen, radicals having formula (II), radicals having formula (III), and radicals having formula (IV):



[0038] In formulas (II), (III), and (IV), each of R^{31–35}, R^{41–48}, and R^{51–59} is independently chosen from –H, (C₁–C₄₀)hydrocarbyl, (C₁–C₄₀)heterohydrocarbyl, –Si(R^C)₃, –Ge(R^C)₃, –P(R^P)₂, –N(R^N)₂, –OR^C, –SR^C, –NO₂, –CN, –CF₃, R^CS(O)–, R^CS(O)₂–, (R^C)₂C=N–, R^CC(O)O–, R^COC(O)–, R^CC(O)N(R^N)–, (R^C)₂NC(O)–, or halogen.

[0039] In formula (I), Y is CH₂, CHR²¹, CR²¹R²², SiR²¹R²², or GeR²¹R²², where R²¹ and R²² are (C₁–C₂₀)alkyl; provided that when Y is CH₂, at least one of R⁸ and R⁹ is not –H.

[0040] Without intent to be bound by theory, it is believed that these preferred substitution patterns comprising the three-atom bridge (–CH₂YCH₂–), in combination with the substitution pattern at the R⁸ and R⁹ groups, of this disclosure, leads to largely single site behavior. A second polymerization site, which is often observed in the case of MMAO activation, is not created in conjunction with these inventive catalyst systems. The second polymerization site can detrimentally produce additional modalities in the resultant polymer. These modalities can in turn manifest as a broadening of the molecular weight distribution curve or through non-uniform comonomer distribution.

[0041] In formulas (I), (II), (III), and (IV), each R^C , R^P , and R^N in formula (I) is independently a (C_1-C_{30}) hydrocarbyl, (C_1-C_{30}) heterohydrocarbyl, or $-H$.

[0042] In embodiments, the modified-hydrocarbyl methylaluminoxane in the polymerization process has less than 20 mole percent and greater than 5 mole percent trihydrocarbyl aluminum based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane. In some embodiments, the modified-hydrocarbyl methylaluminoxane has less than 15 mole percent trihydrocarbyl aluminum based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane. In one or more embodiments, the modified-hydrocarbyl methylaluminoxane has less than 10 mole percent trihydrocarbyl aluminum based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane. In various embodiments, the modified-hydrocarbyl methylaluminoxane is modified methylaluminoxane.

[0043] In some embodiments, the trihydrocarbyl aluminum has a formula of $AlR^{A1}R^{B1}R^{C1}$, where R^{A1} , R^{B1} , and R^{C1} are independently linear (C_1-C_{40}) alkyl, branched (C_1-C_{40}) alkyl, or (C_6-C_{40}) aryl. In one or more embodiments, R^{A1} , R^{B1} , and R^{C1} are independently methyl, ethyl, propyl, 2-propyl, butyl, *tert*-butyl, or octyl. In some embodiments, R^{A1} , R^{B1} , and R^{C1} are the same. In other embodiments, at least one of R^{A1} , R^{B1} , and R^{C1} is different from the other R^{A1} , R^{B1} , and R^{C1} .

[0044] The groups R^1 and R^{16} in the metal–ligand complex of formula (I) are chosen independently of one another. For example, R^1 may be chosen from a radical having formula (II), (III), or (IV) and R^{16} may be a (C_1-C_{40}) hydrocarbyl; or R^1 may be chosen from a radical having formula (II), (III), or (IV) and R^{16} may be chosen from a radical having formula (II), (III), or (IV) the same as or different from that of R^1 . Both R^1 and R^{16} may be radicals having formula (II), for which the groups R^{31-35} are the same or different in R^1 and R^{16} . In other examples, both R^1 and R^{16} may be radicals having formula (III), for which the groups R^{41-48} are the same or different in R^1 and R^{16} ; or both R^1 and R^{16} may be radicals having formula (IV), for which the groups R^{51-59} are the same or different in R^1 and R^{16} .

[0045] In some embodiments, at least one of R^1 and R^{16} is a radical having formula (II), where R^{32} and R^{34} are *tert*-butyl. In one or more embodiments, R^{32} and R^{34} are (C_1-C_{12}) hydrocarbyl or $-Si[(C_1-C_{10})alkyl]_3$.

[0046] In some embodiments, when at least one of R^1 or R^{16} is a radical having formula (III), one of or both of R^{43} and R^{46} is *tert*-butyl and R^{41-42} , R^{44-45} , and R^{47-48} are $-H$. In other embodiments, one of or both of R^{42} and R^{47} is *tert*-butyl and R^{41} , R^{43-46} , and R^{48} are $-H$. In some embodiments, both R^{42} and R^{47} are $-H$. In various embodiments, R^{42} and R^{47} are (C_1-C_{20}) hydrocarbyl or $-Si[(C_1-C_{10})alkyl]_3$. In other embodiments, R^{43} and R^{46} are (C_1-C_{20}) hydrocarbyl or $-Si(C_1-C_{10})alkyl]_3$.

[0047] In embodiments, when at least one of R^1 or R^{16} is a radical having formula (IV), each R^{52} , R^{53} , R^{55} , R^{57} , and R^{58} are $-H$, (C_1-C_{20}) hydrocarbyl, $-Si[(C_1-C_{20})hydrocarbyl]_3$, or $-Ge[(C_1-C_{20})hydrocarbyl]_3$. In some embodiments, at least one of R^{52} , R^{53} , R^{55} , R^{57} , and R^{58} is $(C_3-C_{10})alkyl$, $-Si[(C_3-C_{10})alkyl]_3$, or $-Ge[(C_3-C_{10})alkyl]_3$. In one or more embodiments, at least two of R^{52} , R^{53} , R^{55} , R^{57} , and R^{58} is a $(C_3-C_{10})alkyl$, $-Si[(C_3-C_{10})alkyl]_3$, or $-Ge[(C_3-C_{10})alkyl]_3$. In various embodiments, at least three of R^{52} , R^{53} , R^{55} , R^{57} , and R^{58} is a $(C_3-C_{10})alkyl$, $-Si[(C_3-C_{10})alkyl]_3$, or $-Ge[(C_3-C_{10})alkyl]_3$.

[0048] In some embodiments, when at least one of R^1 or R^{16} is a radical having formula (IV), at least two of R^{52} , R^{53} , R^{55} , R^{57} , and R^{58} are (C_1-C_{20}) hydrocarbyl or $-C(H)_2Si[(C_1-C_{20})hydrocarbyl]_3$.

[0049] Examples of $(C_3-C_{10})alkyl$ include, but are not limited to: propyl, 2-propyl (also called *iso*-propyl), 1,1-dimethylethyl (also called *tert*-butyl), cyclopentyl, cyclohexyl, 1-butyl, pentyl, 3-methylbutyl, hexyl, 4-methylpentyl, heptyl, *n*-octyl, *tert*-octyl (also called 2,4,4-trimethylpentan-2-yl), nonyl, and decyl.

[0050] In formula (I), R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 , R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , and R^{15} is independently selected from $-H$, (C_1-C_{40}) hydrocarbyl, (C_1-C_{40}) heterohydrocarbyl, $-Si(R^C)_3$, $-Ge(R^C)_3$, $-P(R^P)_2$, $-N(R^N)_2$, $-OR^C$, $-SR^C$, $-NO_2$, $-CN$, $-CF_3$, $R^CS(O)-$, $R^CS(O)_2-$, $(R^C)_2C=N-$, $R^CC(O)O-$, $R^COC(O)-$, $R^CC(O)N(R)-$, $(R^C)_2NC(O)-$, and halogen.

[0051] In one or more embodiments, R^2 , R^4 , R^5 , R^{12} , R^{13} , and R^{15} are hydrogen.

[0052] In various embodiments, at least one of R^5 , R^6 , R^7 , and R^8 is a halogen atom; and at least one of R^9 , R^{10} , R^{11} , and R^{12} is a halogen atom. In some embodiments, R^8 and R^9 are independently $(C_1-C_4)alkyl$.

[0053] In some embodiments, R^3 and R^{14} are (C_1-C_{20}) alkyl. In one or more embodiments, R^3 and R^{14} are methyl and R^6 and R^{11} are halogen. In embodiments, R^6 and R^{11} are *tert*-butyl. In other embodiments, R^3 and R^{14} are *tert*-octyl or *n*-octyl.

[0054] In various embodiments, R^3 and R^{14} are (C_1-C_{24}) alkyl. In one or more embodiments, R^3 and R^{14} are (C_4-C_{24}) alkyl. In some embodiments, R^3 and R^{14} are 1-propyl, 2-propyl (also called *iso*-propyl), 1,1-dimethylethyl (also called *tert*-butyl), cyclopentyl, cyclohexyl, 1-butyl, pentyl, 3-methyl-1-butyl, hexyl, 4-methyl-1-pentyl, heptyl, *n*-octyl, *tert*-octyl (also called 2,4,4-trimethylpentan-2-yl), nonyl, and decyl. In embodiments, R^3 and R^{14} are $-OR^C$, wherein R^C is (C_1-C_{20}) hydrocarbon, and in some embodiments, R^C is methyl, ethyl, 1-propyl, 2-propyl (also called *iso*-propyl), or 1,1-dimethylethyl.

[0055] In one or more embodiments, one of R^8 and R^9 is not $-H$. In various embodiments, at least one of R^8 and R^9 is (C_1-C_{24}) alkyl. In some embodiments, both R^8 and R^9 are (C_1-C_{24}) alkyl. In some embodiments, R^8 and R^9 are methyl. In other embodiments, R^8 and R^9 are halogen.

[0056] In some embodiments, R^3 and R^{14} are methyl; In one or more embodiments, R^3 and R^{14} are (C_4-C_{24}) alkyl. In some embodiments, R^8 and R^9 are 1-propyl, 2-propyl (also called *iso*-propyl), 1,1-dimethylethyl (also called *tert*-butyl), cyclopentyl, cyclohexyl, 1-butyl, pentyl, 3-methyl-1-butyl, hexyl, 4-methyl-1-pentyl, heptyl, *n*-octyl, *tert*-octyl (also called 2,4,4-trimethylpentan-2-yl), nonyl, and decyl.

[0057] In various embodiments, in the metal-ligand complex of formula (I), R^6 and R^{11} are halogen. In some embodiments, R^6 and R^{11} are (C_1-C_{24}) alkyl. In various embodiments, R^6 and R^{11} independently are chosen from methyl, ethyl, 1-propyl, 2-propyl (also called *iso*-propyl), 1,1-dimethylethyl (also called *tert*-butyl), cyclopentyl, cyclohexyl, 1-butyl, pentyl, 3-methylbutyl, hexyl, 4-methylpentyl, heptyl, *n*-octyl, *tert*-octyl (also called 2,4,4-trimethylpentan-2-yl), nonyl, and decyl. In some embodiments, R^6 and R^{11} are *tert*-butyl. In embodiments, R^6 and R^{11} are $-OR^C$, wherein R^C is (C_1-C_{20}) hydrocarbyl, and in some embodiments, R^C is methyl, ethyl, 1-propyl, 2-propyl (also called *iso*-propyl), or 1,1-dimethylethyl. In other embodiments, R^6 and R^{11} are $-SiR^C_3$, wherein each R^C is independently (C_1-C_{20}) hydrocarbyl, and in some embodiments, R^C is methyl, ethyl, 1-propyl, 2-propyl (also called *iso*-propyl), or 1,1-dimethylethyl.

[0058] In some embodiments, any or all of the chemical groups (e.g., X and R^{1-59}) of the metal-ligand complex of formula (I) may be unsubstituted. In other embodiments, none, any, or

all of the chemical groups X and R^{1-59} of the metal–ligand complex of formula (I) may be substituted with one or more than one R^S . When two or more than two R^S are bonded to a same chemical group of the metal–ligand complex of formula (I), the individual R^S of the chemical group may be bonded to the same carbon atom or heteroatom or to different carbon atoms or heteroatoms. In some embodiments, none, any, or all of the chemical groups X and R^{1-59} may be persubstituted with R^S . In the chemical groups that are persubstituted with R^S , the individual R^S may all be the same or may be independently chosen. In one or more embodiments, R^S is chosen from (C₁–C₂₀)hydrocarbyl, (C₁–C₂₀)alkyl, (C₁–C₂₀)heterohydrocarbyl, or (C₁–C₂₀)heteroalkyl.

[0059] In formulas (I), (II), (III), and (IV), each R^C , R^P , and R^N is independently a (C₁–C₃₀)hydrocarbyl, (C₁–C₃₀)heterohydrocarbyl, or –H.

[0060] In some embodiments, in the metal–ligand complex according to formula (I), both R^8 and R^9 are methyl. In other embodiments, one of R^8 and R^9 is methyl and the other of R^8 and R^9 is –H.

[0061] In the metal–ligand complex according to formula (I), X bonds with M through a covalent bond or an ionic bond. In some embodiments, X may be a monoanionic ligand having a net formal oxidation state of –1. Each monoanionic ligand may independently be hydride, (C₁–C₄₀)hydrocarbyl carbanion, (C₁–C₄₀)heterohydrocarbyl carbanion, halide, nitrate, carbonate, phosphate, sulfate, $HC(O)O^-$, $HC(O)N(H)^-$, (C₁–C₄₀)hydrocarbylC(O)O[–], (C₁–C₄₀)hydrocarbylC(O)N((C₁–C₂₀)hydrocarbyl)[–], (C₁–C₄₀)hydrocarbylC(O)N(H)[–], $R^K R^L B^-$, $R^K R^L N^-$, $R^K O^-$, $R^K S^-$, $R^K R^L P^-$, or $R^M R^K R^L Si^-$, where each R^K , R^L , and R^M independently is hydrogen, (C₁–C₄₀)hydrocarbyl, or (C₁–C₄₀)heterohydrocarbyl, or R^K and R^L are taken together to form a (C₂–C₄₀)hydrocarbylene or (C₁–C₂₀)heterohydrocarbylene and R^M is as defined above.

[0062] In some embodiments, X is a halogen, unsubstituted (C₁–C₂₀)hydrocarbyl, unsubstituted (C₁–C₂₀)hydrocarbylC(O)O[–], or $R^K R^L N^-$, wherein each of R^K and R^L independently is an unsubstituted (C₁–C₂₀)hydrocarbyl. In some embodiments, each monodentate ligand X is a chlorine atom, (C₁–C₁₀)hydrocarbyl (e.g., (C₁–C₆)alkyl or benzyl), unsubstituted (C₁–C₁₀)hydrocarbylC(O)O[–], or $R^K R^L N^-$, wherein each of R^K and R^L independently is an unsubstituted (C₁–C₁₀)hydrocarbyl

[0063] In further embodiments, X is selected from methyl; ethyl; 1-propyl; 2-propyl; 1-butyl; 2,2,-dimethylpropyl; trimethylsilylmethyl; phenyl; benzyl; or chloro. X is methyl; ethyl; 1-propyl; 2-propyl; 1-butyl; 2,2,-dimethylpropyl; trimethylsilylmethyl; phenyl; benzyl; and chloro. In one embodiment, n is 2 and at least two X independently are monoanionic monodentate ligands. In a specific embodiment, n is 2 and the two X groups join to form a bidentate ligand. In further embodiments, the bidentate ligand is 2,2-dimethyl-2-silapropane-1,3-diyl or 1,3-butadiene.

[0064] In one or more embodiments, each X is independently $-(CH_2)SiR^X_3$, in which each R^X is independently a (C_1-C_{30}) alkyl or a (C_1-C_{30}) heteroalkyl and at least one R^X is (C_1-C_{30}) alkyl. In some embodiments, when one of R^X is a (C_1-C_{30}) heteroalkyl, the heteroatom is silica or oxygen atom. In some embodiments, R^X is methyl, ethyl, propyl, 2-propyl, butyl, 1,1-dimethylethyl (or *tert*-butyl), pentyl, hexyl, heptyl, n-octyl, *tert*-octyl, or nonyl.

[0065] In one or more embodiments X is $-(CH_2)Si(CH_3)_3$, $-(CH_2)Si(CH_3)_2(CH_2CH_3)$; $-(CH_2)Si(CH_3)(CH_2CH_3)_2$, $-(CH_2)Si(CH_2CH_3)_3$, $-(CH_2)Si(CH_3)_2(n\text{-butyl})$, $-(CH_2)Si(CH_3)_2(n\text{-hexyl})$, $-(CH_2)Si(CH_3)(n\text{-Oct})R^X$, $-(CH_2)Si(n\text{-Oct})R^X_2$, $-(CH_2)Si(CH_3)_2(2\text{-ethylhexyl})$, $-(CH_2)Si(CH_3)_2(\text{dodecyl})$, $-CH_2Si(CH_3)_2CH_2Si(CH_3)_3$ (herein referred to as $-CH_2Si(CH_3)_2CH_2TMS$). Optionally, in some embodiments, the metal–ligand complex according to formula (I), exactly two R^X are covalently linked or exactly three R^X are covalently linked.

[0066] In some embodiments, X is $-CH_2Si(R^C)_{3-Q}(OR^C)_Q$, $-Si(R^C)_{3-Q}(OR^C)_Q$, $-OSi(R^C)_{3-Q}(OR^C)_Q$, in which subscript Q is 0, 1, 2 or 3 and each R^C is independently a substituted or unsubstituted (C_1-C_{30}) hydrocarbyl, or a substituted or unsubstituted (C_1-C_{30}) heterohydrocarbyl.

Cocatalyst Component

[0067] The catalyst system comprising a metal–ligand complex of formula (I) may be rendered catalytically active by any technique known in the art for activating metal-based catalysts of olefin polymerization reactions. For example, the precatalyst according to a metal–ligand complex of formula (I) may be rendered catalytically active by contacting the complex to, or combining the complex with, an activating co-catalyst. Additionally, the metal–ligand complex according for formula (I) includes both a precatalyst form, which is neutral, and a catalytic form, which may be positively charged due to the loss of a monoanionic ligand, such a benzyl or phenyl.

Suitable activating co-catalysts for use herein include oligomeric alumoxanes or modified alkyl aluminoxanes.

Polyolefins

[0068] The catalytic systems described in the preceding paragraphs are utilized in the polymerization of olefins, primarily ethylene and propylene, to form ethylene-based polymers or propylene-based polymers. In some embodiments, there is only a single type of olefin or α -olefin in the polymerization scheme, creating a homopolymer. However, additional α -olefins may be incorporated into the polymerization procedure. The additional α -olefin co-monomers typically have no more than 20 carbon atoms. For example, the α -olefin co-monomers may have 3 to 10 carbon atoms or 3 to 8 carbon atoms. Exemplary α -olefin co-monomers include, but are not limited to, propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 1-octene, 1-nonene, 1-decene, and 4-methyl-1-pentene. For example, the one or more α -olefin co-monomers may be selected from the group consisting of propylene, 1-butene, 1-hexene, and 1-octene; or in the alternative, from the group consisting of 1-hexene and 1-octene.

[0069] The ethylene-based polymers, for example homopolymers and/or interpolymers (including copolymers) of ethylene and optionally one or more co-monomers such as α -olefins, may comprise from at least 50 mole percent (mol%) monomer units derived from ethylene. All individual values and subranges encompassed by “from at least 50 mole percent” are disclosed herein as separate embodiments; for example, the ethylene based polymers, homopolymers and/or interpolymers (including copolymers) of ethylene and optionally one or more co-monomers such as α -olefins may comprise at least 60 mole percent monomer units derived from ethylene; at least 70 mole percent monomer units derived from ethylene; at least 80 mole percent monomer units derived from ethylene; or from 50 to 100 mole percent monomer units derived from ethylene; or from 80 to 100 mole percent monomer units derived from ethylene.

[0070] In some embodiments, the ethylene-based polymers may comprise at least 90 mole percent units derived from ethylene. All individual values and subranges from at least 90 mole percent are included herein and disclosed herein as separate embodiments. For example, the ethylene based polymers may comprise at least 93 mole percent units derived from ethylene; at least 96 mole percent units; at least 97 mole percent units derived from ethylene; or in the alternative, from 90 to 100 mole percent units derived from ethylene; from 90 to 99.5 mole percent units derived from ethylene; or from 97 to 99.5 mole percent units derived from ethylene.

[0071] In some embodiments of the ethylene-based polymer, the amount of additional α -olefin is less than 50 mol%; other embodiments include at least 1 mole percent (mol%) to 25 mol%; and in further embodiments the amount of additional α -olefin includes at least 5 mol% to 103 mol%. In some embodiments, the additional α -olefin is 1-octene.

[0072] Any conventional polymerization processes may be employed to produce the ethylene based polymers. Such conventional polymerization processes include, but are not limited to, solution polymerization processes, slurry phase polymerization processes, and combinations thereof using one or more conventional reactors such as loop reactors, isothermal reactors, stirred tank reactors, batch reactors in parallel, series, or any combinations thereof, for example.

[0073] In one embodiment, the ethylene-based polymer may be produced via solution polymerization in a dual reactor system, for example a dual loop reactor system, wherein ethylene and optionally one or more α -olefins are polymerized in the presence of the catalyst system, as described herein, and optionally one or more co-catalysts. In another embodiment, the ethylene based polymer may be produced via solution polymerization in a dual reactor system, for example a dual loop reactor system, wherein ethylene and optionally one or more α -olefins are polymerized in the presence of the catalyst system in this disclosure, and as described herein, and optionally one or more other catalysts. The catalyst system, as described herein, can be used in the first reactor, or second reactor, optionally in combination with one or more other catalysts. In one embodiment, the ethylene based polymer may be produced via solution polymerization in a dual reactor system, for example a dual loop reactor system, wherein ethylene and optionally one or more α -olefins are polymerized in the presence of the catalyst system, as described herein, in both reactors.

[0074] In another embodiment, the ethylene based polymer may be produced via solution polymerization in a single reactor system, for example a single loop reactor system, in which ethylene and optionally one or more α -olefins are polymerized in the presence of the catalyst system, as described within this disclosure, and optionally one or more co-catalysts, as described in the preceding paragraphs.

[0075] The ethylene based polymers may further comprise one or more additives. Such additives include, but are not limited to, antistatic agents, color enhancers, dyes, lubricants, pigments, primary antioxidants, secondary antioxidants, processing aids, UV stabilizers, and

combinations thereof. The ethylene based polymers may contain any amounts of additives. The ethylene based polymers may comprise from about 0 to about 10 percent by the combined weight of such additives, based on the weight of the ethylene based polymers and the one or more additives. The ethylene based polymers may further comprise fillers, which may include, but are not limited to, organic or inorganic fillers. The ethylene based polymers may contain from about 0 to about 20 weight percent fillers such as, for example, calcium carbonate, talc, or $\text{Mg}(\text{OH})_2$, based on the combined weight of the ethylene based polymers and all additives or fillers. The ethylene based polymers may further be blended with one or more polymers to form a blend.

[0076] In some embodiments, a polymerization process for producing an ethylene-based polymer may include polymerizing ethylene and at least one additional α -olefin in the presence of a catalyst system according to the present disclosure. The polymer resulting from such a catalyst system that incorporates the metal-ligand complex of formula (I) may have a density according to ASTM D792 (incorporated herein by reference in its entirety) from 0.850 g/cm³ to 0.970 g/cm³, from 0.880 g/cm³ to 0.920 g/cm³, from 0.880 g/cm³ to 0.910 g/cm³, or from 0.880 g/cm³ to 0.900 g/cm³, for example.

[0077] In another embodiment, the polymer resulting from the catalyst system according to the present disclosure has a melt flow ratio (I_{10}/I_2) from 5 to 15, where the melt index, I_2 , is measured according to ASTM D1238 (incorporated herein by reference in its entirety) at 190 °C and 2.16 kg load, and melt index I_{10} is measured according to ASTM D1238 at 190 °C and 10 kg load. In other embodiments the melt flow ratio (I_{10}/I_2) is from 5 to 10, and in others, the melt flow ratio is from 5 to 9.

[0078] In some embodiments, the polymer resulting from the catalyst system according to the present disclosure has a molecular-weight distribution (MWD) from 1 to 25, where MWD is defined as M_w/M_n with M_w being a weight-average molecular weight and M_n being a number-average molecular weight. In other embodiments, the polymers resulting from the catalyst system have a MWD from 1 to 6. Another embodiment includes a MWD from 1 to 3; and other embodiments include MWD from 1.5 to 2.5.

[0079] Gel Permeation Chromatography (GPC)

[0080] The chromatographic system consisted of a PolymerChar GPC-IR (Valencia, Spain) high temperature GPC chromatograph equipped with an internal IR5 infra-red detector (IR5). The

autosampler oven compartment was set at 160° Celsius and the column compartment was set at 150° Celsius. The columns used were 4 Agilent “Mixed A” 30cm 20-micron linear mixed-bed columns. The chromatographic solvent used was 1,2,4 trichlorobenzene and contained 200 ppm of butylated hydroxytoluene (BHT). The solvent source was nitrogen sparged. The injection volume used was 200 microliters and the flow rate was 1.0 milliliters/minute.

[0081] Calibration of the GPC column set was performed with at least 20 narrow molecular weight distribution polystyrene standards with molecular weights ranging from 580 to 8,400,000 and were arranged in 6 “cocktail” mixtures with at least a decade of separation between individual molecular weights. The standards were purchased from Agilent Technologies. The polystyrene standards were prepared at 0.025 grams in 50 milliliters of solvent for molecular weights equal to or greater than 1,000,000, and 0.05 grams in 50 milliliters of solvent for molecular weights less than 1,000,000. The polystyrene standards were dissolved at 80 degrees Celsius with gentle agitation for 30 minutes. The polystyrene standard peak molecular weights were converted to polyethylene molecular weights using Equation 1 (as described in Williams and Ward, J. Polym. Sci., Polym. Let., 6, 621 (1968)).:

$$[0082] \quad M_{polyethylene} = A \times (M_{polystyrene})^B \quad (EQ1)$$

[0083] where M is the molecular weight, A has a value of 0.4315 and B is equal to 1.0.

[0084] A polynomial 5th order was used to fit the respective polyethylene-equivalent calibration points. A small adjustment to A (from approximately 0.40 to 0.44) was made to correct for column resolution and band-broadening effects such that NIST standard NBS 1475 is obtained at 52,000Mw.

High temperature thermal gradient interaction chromatography (HT-TGIC, or TGIC)

[0085] A commercial Crystallization Elution Fractionation instrument (CEF) (Polymer Char, Spain) was used to perform the high temperature thermal gradient interaction chromatography (HT-TGIC, or TGIC) measurement (Cong, et al., Macromolecules, 2011, 44 (8), 3062-3072.). The CEF instrument is equipped with an IR-5 detector. Graphite has been used as the stationary phase in an HT TGIC column (Freddy, A. Van Damme et al., US8, 476,076; Winniford et al., US 8,318,896.). A single graphite column (250 X 4.6 mm) was used for the separation. Graphite is packed into a column using a dry packing technique followed by a slurry packing technique (Cong et al., EP 2714226B1 and the reference cited). The experimental parameters were: top oven/transfer line/needle temperature at 150°C, dissolution temperature at 150°C, dissolution

stirring setting of 2, pump stabilization time of 15 seconds, a pump flow rate for cleaning the column at 0.500 mL/min, pump flow rate of column loading at 0.300 mL/min, stabilization temperature at 150°C, stabilization time (pre-, prior to load to column) at 2.0 min, stabilization time (post-, after load to column) at 1.0 min, SF(Soluble Fraction) time at 5.0 min, cooling rate of 3.00°C/min from 150°C to 30°C, flow rate during cooling process of 0.04 mL/min, heating rate of 2.00°C/min from 30°C to 160°C, isothermal time at 160°C for 10 min, elution flow rate of 0.500 mL/min, and an injection loop size of 200 microliters.

[0086] The flow rate during cooling process was adjusted according to the length of graphite column such that all polymer fractions must remain on the column at the end of the cooling cycle.

[0087] Samples were prepared by the PolymerChar autosampler at 150°C, for 120 minutes, at a concentration of 4.0 mg/mL in ODCB (defined below). Silica gel 40 (particle size 0.2 ~0.5 mm, catalogue number 10181-3, EMD) was dried in a vacuum oven at 160°C, for about two hours, prior to use. For the CEF instrument equipped with an autosampler with N₂ purging capability, Silica gel 40 is packed into three 300 x 7.5 mm GPC size stainless steel columns and the Silica gel 40 columns are installed at the inlet of the pump of the CEF instrument to purify ODCB; and no BHT is added to the mobile phase. ODCB dried with silica gel 40 is now referred to as “ODCB.” The TGIC data was processed on a PolymerChar (Spain) “GPC One” software platform. The temperature calibration was performed with a mixture of about 4 to 6 mg Eicosane, 14.0 mg of isotactic homopolymer polypropylene iPP (polydispersity of 3.6 to 4.0, and molecular weight M_w reported as polyethylene equivalent of 150,000 to 190,000, and polydispersity (M_w/M_n) of 3.6 to 4.0, wherein the iPP DSC melting temperature was measured to be 158-159°C (DSC method described herein below). 14.0 mg of homopolymer polyethylene HDPE (zero comonomer content, weight average molecular weight (M_w) reported as polyethylene equivalent as 115,000 to 125,000, and polydispersity of 2.5 to 2.8), in a 10 mL vial filled with 7.0 mL of ODCB. The dissolution time was 2 hours at 160°C.

Data processing for polymer samples of HT-TGIC.

[0088] A solvent blank (pure solvent injection) was run at the same experimental conditions as the polymer samples. Data processing for polymer samples includes: subtraction of the solvent blank for each detector channel, temperature extrapolation as described in the calibration process, compensation of temperature with the delay volume determined from the calibration

process, and adjustment in elution temperature axis to the 30°C and 160°C range as calculated from the heating rate of the calibration.

[0089] The chromatogram (measurement channel of the IR-5 detector) was integrated with PolymerChar “GPC One” software. A straight baseline was drawn from the visible difference, when the peak falls to a flat baseline (roughly a zero value in the blank subtracted chromatogram) at high elution temperature and the minimum or flat region of detector signal on the high temperature side of the soluble fraction (SF).

Broadness Indices of TGIC Profiles (B-Indices)

[0090] TGIC chromatogram is related to comonomer content and its distribution. It can be related to the number of catalyst active sites. TGIC profile can be affected by chromatographic related experimental factors at certain extent (Stregel, et al., “Modern size-exclusion liquid chromatography, Wiley, 2nd edition, Chapter 3). The TGIC broadness indices (B-Indices) can be used to make quantitative comparison of the broadness of TGIC chromatogram of samples with different compositions and distributions. B-Indices can be calculated for any fraction of the maximum profile height. For example, the “N” B-Index can be obtained by measuring the profile width at 1/Nth of the profile’s maximum height and utilizing the follow equation:

$$B - \text{Index of TGIC profile (at } 1/N^{\text{th}} \text{ maximum height)} = \text{Profile width (at } \frac{1}{N^{\text{th}}} \text{ maximum height)} \times \frac{T_p}{150} \quad (\text{EQ. 1})$$

Where T_p is the temperature where the maximum height is observed in the profile, where N is an integer 2, 3, 4, 5, 6, or 7. In cases where TGIC chromatograms have multiple peaks with similar peak heights, the peak at the highest elution temperature is defined as the profile temperature (T_p).

U-Index of TGIC profiles (U-Index)

[0091] TGIC was used to measure the composition distribution of polymers. To assess the uniformity of the composition distribution, the resulting chromatograms were fit to a Gaussian distribution according to the following equation:

$$f(x) = A_{\max} * e^{-4\ln(2)\left(\frac{x-\mu}{\sigma}\right)^2} \quad (\text{EQ. 2})$$

[0092] The fit was achieved by using a least-squares approach using the above function. The residual differences between the data and the function $f(x_i, \beta)$ were squared and subsequently summated, , where x_i is the elution temperature above 35 °C where $i=0$, n is the at the final elution temperature of TGIC profile.

$$S = \sum_{i=0}^n (y_i - f(x_i, \beta))^2 \quad (\text{EQ. 3})$$

[0093] The fitted function was adjusted to provide a minimum value for the summation. In addition to the least squares method, the fitting equation was further combined with a weighting function to discourage over-estimation of peak shapes.

$$S = \sum_{i=0}^n w_i (y_i - f(x_i, \beta))^2 \quad (\text{EQ. 4})$$

[0094] Where w_i is equal to 1 for all positive instances of $(y_i - f(x_i, \beta))$ and is equal to 11 for all negative values of $(y_i - f(x_i, \beta))$. Using this method, the fitting function discourages overestimation of the peak shape and provides a better approximation of the area covered by a single site catalyst. Upon fitting the curve, the total area of the distribution covered by fit can be compared to the total area of the sample chromatogram excluding the fraction remaining in 30 °C at the end of cooling step of TGIC experiment. Multiplication of this value by 100 gives us a uniformity index (U-index).

$$\text{U-index} = \left(\frac{\text{Area of Fit}}{\text{Area of Sample}} \right) \times 100 \quad (\text{EQ. 5})$$

[0095] As mentioned in the previous section, low density polymers generally broader molecular weight distribution (MWD) than high density polymers due the elution temperature. TGIC profile can be affected by polymer MWD(Abdulaal, et al., Macromolecular Chem Phy, 2017, 218, 1600332). Therefore, when analyzing the broadness of the MWD curve using TGIC, the breadth of the curve is not an accurate indication of the polymer chemical composition.

[0096] Embodiments of the catalyst systems described in this disclosure yield unique polymer properties as a result of the high molecular weights of the polymers formed and the amount of the co-monomers incorporated into the polymers.

[0097] One or more features of the present disclosure are illustrated in view of the examples as follows:

EXAMPLES

[0098] Procedure for Continuous Process Reactor Polymerization: Raw materials (ethylene, 1-octene) and the process solvent (a narrow boiling range high-purity isoparaffinic solvent trademarked ISOPAR E commercially available from ExxonMobil Corporation) are purified with molecular sieves before introduction into the reaction environment. Hydrogen is supplied in pressurized cylinders as a high purity grade and is not further purified. The reactor monomer feed (ethylene) stream is pressurized to above reaction pressure. The solvent and comonomer feed is pressurized to above reaction pressure. The individual catalyst components (metal–ligand complexes and cocatalysts) are manually batch diluted to specified component concentrations with purified solvent and pressured to above reaction pressure. All reaction feed flows are measured with mass flow meters and independently controlled with computer automated valve control systems.

[0099] The continuous solution polymerizations are carried out in a continuously stirred-tank reactor (CSTR). The combined solvent, monomer, comonomer and hydrogen feed to the reactor is temperature controlled between 5° C and 50° C and is typically 15-25° C. All of the components are fed to the polymerization reactor with the solvent feed. The catalyst is fed to the reactor to reach a specified conversion of ethylene. The cocatalyst component(s) is/are fed separately based on a calculated specified molar ratios or ppm amounts. The effluent from the polymerization reactor (containing solvent, monomer, comonomer, hydrogen, catalyst components, and polymer) exits the reactor and is contacted with water. In addition, various additives such as antioxidants, can be added at this point. The stream then goes through a static mixer to evenly disperse the mixture.

[00100] Following additive addition, the effluent (containing solvent, monomer, comonomer, hydrogen, catalyst components, and molten polymer) passes through a heat exchanger to raise the stream temperature in preparation for separation of the polymer from the other lower-boiling components. The stream then passes through the reactor pressure control valve, across which the pressure is greatly reduced. From there, it enters a two stage separation system consisting of a devolatilizer and a vacuum extruder, where solvent and unreacted hydrogen, monomer, comonomer, and water are removed from the polymer. At the exit of the extruder, the strand of molten polymer formed goes through a cold-water bath, where it solidifies. The strand is then fed through a strand chopper, where the polymer is cut it into pellets after being air-dried.

[00101] Procedure for Batch Reactor Polymerization. Raw materials (ethylene, 1-octene) and the process solvent (ISOPAR E) are purified with molecular sieves before introduction into the reaction environment. A stirred autoclave reactor was charged with ISOPAR E, and 1-octene. The reactor was then heated to a temperature and charged with ethylene to reach a pressure. Optionally, hydrogen was also added. The catalyst system was prepared in a drybox under inert atmosphere by mixing the metal–ligand complex and optionally one or more additives, with additional solvent. The catalyst system was then injected into the reactor. The reactor pressure and temperature were kept constant by feeding ethylene during the polymerization and cooling the reactor as needed. After 10 minutes, the ethylene feed was shut off and the solution transferred into a nitrogen-purged resin kettle. The polymer was thoroughly dried in a vacuum oven, and the reactor was thoroughly rinsed with hot ISOPAR E between polymerization runs.

[00102] TEST METHODS

[00103] Unless otherwise indicated herein, the following analytical methods are used in describing aspects of the present disclosure:

[00104] Melt index

[00105] Melt indices I_2 (or I2) and I_{10} (or I10) of polymer samples were measured in accordance to ASTM D-1238 (method B) at 190 °C and at 2.16 kg and 10 kg load, respectively. Their values are reported in g/10 min.

[00106] Density

[00107] Samples for density measurement were prepared according to ASTM D4703. Measurements were made, according to ASTM D792, Method B, within one hour of sample pressing.

[00108] Analysis of Hydrocarbyl-Modified Methylaluminoxanes

[00109] *Example 1 is the analytical procedure for determination of aluminum concentration in a solution.*

[00110] In a nitrogen atmosphere glovebox, aluminum-based analyte having the formula $AlR^A R^B R^C$ was transferred to a tared bottle and the mass of the sample was recorded. The sample was diluted with methylcyclohexane and then quenched with methanol. The mixture was swirled and allowed to react over 15 minutes prior to removal of the sample from the glovebox.

The sample was further hydrolyzed by addition of H₂SO₄. The bottle was capped shaken for five minutes. Periodic venting of the bottle may be necessary depending on aluminum concentration. The solution was transferred to a separatory funnel. The bottle was rinsed repeatedly with water adding each rinse to the separatory funnel. The organic layer was discarded and the remaining aqueous solution was transferred to a volumetric flask. The separatory funnel was further rinsed with water, each rinse being added to the volumetric flask. The flask was diluted to a known volume, thoroughly mixed, and analyzed by complexation with excess EDTA and subsequent back-titration with ZnCl₂ using xylenol orange as an indicator.

[00111] Calculation of the AlR^{A1}R^{B1}R^{C1} Compound in the Hydrocarbyl-modified Alkyl Aluminosiloxane

$$\text{Molarity Al in titrant} = \frac{[(M_{\text{EDTA}} \cdot \text{mL EDTA}) - (M_{\text{ZnCl}_2} \cdot \text{mL ZnCl}_2)]}{\text{mL aqueous solution used in titrated}} \quad (\text{EQ. 6})$$

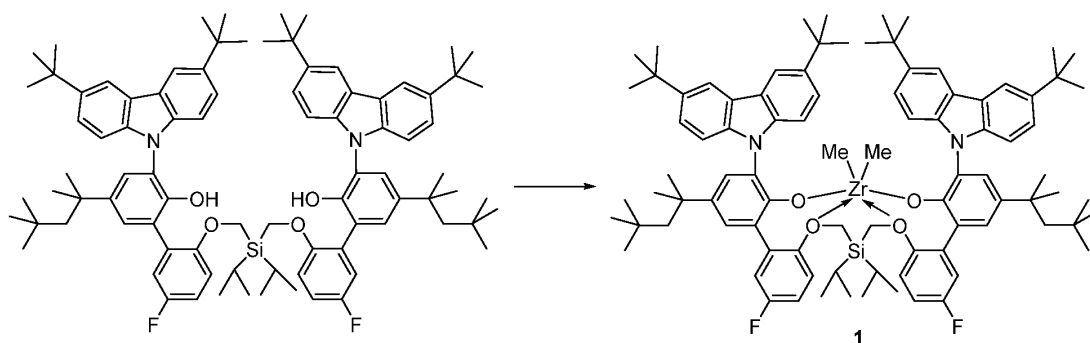
$$\text{mole \% Al in sample} = \frac{(\text{Molarity Al in titrant} \cdot \text{Volume of Volumetric Dilution}) \cdot 26.98 \frac{\text{g}}{\text{mol Al}}}{\text{Mass of Analyte Sample}} * 100 \quad (\text{EQ. 7})$$

[00112] The AlR^{A1}R^{B1}R^{C1} Compound content is analyzed using previously described methods (*Macromol. Chem. Phys.* **1996**, 197, 1537; WO2009029857A1; *Analytical Chemistry* **1968**, 40 (14), 2150-2153; and *Organometallics* **2013**, 32(11), 3354-3362)

[00113] The metal-complexes are conveniently prepared by standard metallation and ligand exchange procedures involving a source of transition metal and a neutral polyfunctional ligand source. In addition, the complexes may also be prepared by means of an amide elimination and hydrocarbylation process starting from the corresponding transition metal tetraamide and a hydrocarbylating agent, such as trimethylaluminum. The techniques employed are the same as of analogous to those disclosed in United States Patent Nos. 6,320,005, 6,103,657, WO 02/38628, WO 03/40195, US-A-2004/0220050.

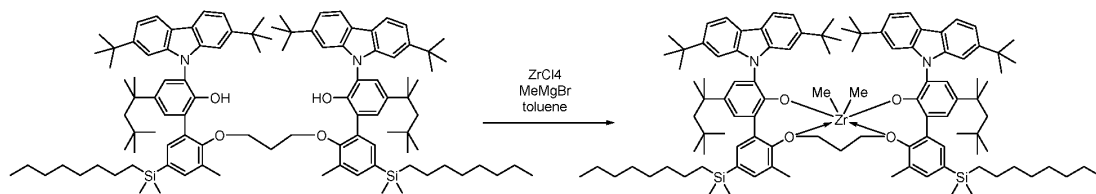
[00114] The synthetic procedures for synthesizing metal-ligand complexes **I1** to **18** and **C1** to **C3** may be found in the procedures below and, where previously disclosed, in the following publications US20040010103A1, WO2007136494A2, WO2012027448A1, WO2016003878A1, WO2016014749A1, WO2017058981A1, WO2018022975A1.

[00115] **Preparation I1** (Ligand disclosed in WO2018022975 A1)



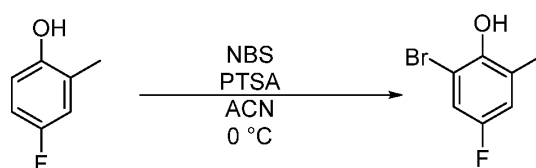
[00116] Synthesis of 6',6'''-(((diisopropylsilanediy)bis(methylene))bis(oxy))bis(3-(3,6-di-tert-butyl-9H-carbazol-9-yl)-3'-fluoro-5-(2,4,4-trimethylpentan-2-yl)-[1,1'-biphenyl]-2-ol)dimethyl-zirconium (I1): MeMgBr in diethyl ether (3.00 M, 5.33 mL, 16.0 mmol) was added to a -30 °C solution of ZrCl₄ (0.895 g, 3.84 mmol) in toluene (60 mL). After stirring for 3 minutes the solid ligand (5.00 g, 3.77 mmol) was added portionwise. The mixture was stirred for 8 h then the solvent was removed under reduced pressure overnight to afford a dark residue. Hexanes/toluene (10:1 70 mL) was added to the residue, the solution was shaken for a few minutes at room temperature, then this material was passed through a fritted funnel CELITE plug. The frit was extracted with hexanes (2 x 15 mL). The combined extracts were concentrated to dryness under reduced pressure. Pentane (20 mL) was added to the tan solid, the heterogeneous mixture was placed in the freezer (-35 °C) for 18 h. The brown pentane layer was removed using a pipette. The remaining material was dried under vacuum, which provided I1 (4.50 g, yield: 83 %) as a white powder:

[00117] ¹H NMR (400 MHz, C₆D₆) δ 8.65 – 8.56 (m, 2H), 8.40 (dd, *J* = 2.0, 0.7 Hz, 2H), 7.66 – 7.55 (m, 8H), 7.45 (d, *J* = 1.9 Hz, 1H), 7.43 (d, *J* = 1.9 Hz, 1H), 7.27 (d, *J* = 2.5 Hz, 2H), 7.10 (d, *J* = 3.2 Hz, 1H), 7.08 (d, *J* = 3.1 Hz, 1H), 6.80 (ddd, *J* = 9.0, 7.4, 3.2 Hz, 2H), 5.21 (dd, *J* = 9.1, 4.7 Hz, 2H), 4.25 (d, *J* = 13.9 Hz, 2H), 3.23 (d, *J* = 14.0 Hz, 2H), 1.64 – 1.52 (m, 4H), 1.48 (s, 18H), 1.31 (s, 24H), 1.27 (s, 6H), 0.81 (s, 18H), 0.55 (t, *J* = 7.3 Hz, 12H), 0.31 (hept, *J* = 7.5 Hz, 2H), -0.84 (s, 6H); ¹⁹F NMR (376 MHz, C₆D₆) δ -116.71.

[00118] Synthesis of I5:

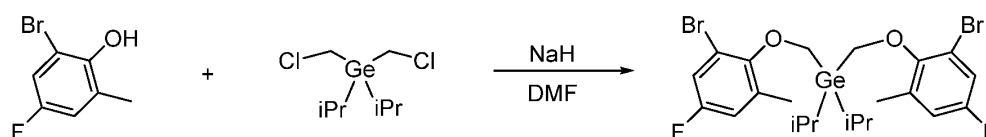
[00119] A 100 mL oven dried glass bottle was charged with ZrCl_4 (798 mg, 3.43 mmol), toluene (30 mL), and a stir bar. The solution was placed in the freezer and cooled to -30°C for 20 min. The solution was taken out of the freezer, and was treated with MeMgBr (4.35 mL, 13.1 mmol, 3 M in Et_2O) and stirred for 15 minutes. To the cold suspension, the I5 ligand (5.00 g, 3.26 mmol) was added as a solid. The reaction was stirred at room temperature for 3 h, and then filtered through a fritted plastic funnel. The filtrate was dried under vacuum. The resulting solid was washed with hexanes, and dried under vacuum, providing I5 as an off-white powder (3.31 g, 62%):

[00120] ^1H NMR (400 MHz, Benzene- d_6) δ 8.19 (d, $J = 8.2$ Hz, 2H), 8.03 – 7.96 (m, 4H), 7.87 (d, $J = 2.5$ Hz, 2H), 7.81 – 7.76 (m, 2H), 7.64 (d, $J = 2.5$ Hz, 2H), 7.56 (d, $J = 1.7$ Hz, 2H), 7.51 (dd, $J = 8.2, 1.7$ Hz, 2H), 7.30 (dd, $J = 8.3, 1.7$ Hz, 2H), 7.06 – 7.01 (m, 2H), 3.57 (dt, $J = 9.9, 4.9$ Hz, 2H), 3.42 (dt, $J = 10.3, 5.2$ Hz, 2H), 1.79 (d, $J = 14.5$ Hz, 2H), 1.66 (d, $J = 14.4$ Hz, 2H), 1.60 (s, 18H), 1.46 (s, 6H), 1.42 (s, 6H), 1.37 – 1.22 (m, 50H), 0.94 – 0.91 (m, 24H), 0.62 – 0.56 (m, 4H), 0.11 (s, 6H), 0.08 (s, 6H), -0.64 (s, 6H).

[00121] Synthetic Scheme of I6

[00122] Synthesis of 2-bromo-4-fluoro-6-methyl-phenol: 1L glass bottle was charged with acetonitrile (400 mL), 4-fluoro-6-methyl-phenol (50 g, 396.4 mmol), and *p*-toluenesulfonic acid (monohydrate) (75.6 g, 396 mmol), making sure everything was in solution. The solution was cooled to 0°C with ice for 25 min (a precipitate formed). The cooled solution, was slowly treated with *N*-bromosuccinimide (70.55 g, 396.4 mmol) (over the course of approx. 5 min), and was allowed reach room temperature while stirring overnight. The reaction was analyzed by ^{19}F NMR

spectroscopy and GC/MS to confirm complete conversion. The volatiles were removed under vacuum, and the resulting solid was treated with dichloromethane (600 mL), cooled in the freezer (0 °C), and filtered through a large plug of silica gel. The silica gel was washed several times with cold CH₂Cl₂. The volatiles were removed under vacuum (1st fraction yield: 46 g, 56%). ¹H NMR (400 MHz, Chloroform-*d*) δ 7.05 (ddd, *J* = 7.7, 3.0, 0.7 Hz, 1H), 6.83 (ddt, *J* = 8.7, 3.0, 0.8 Hz, 1H), 5.35 (s, 1H), 2.29 (d, *J* = 0.7 Hz, 3H). ¹⁹F NMR (376 MHz, Chloroform-*d*) δ -122.84.

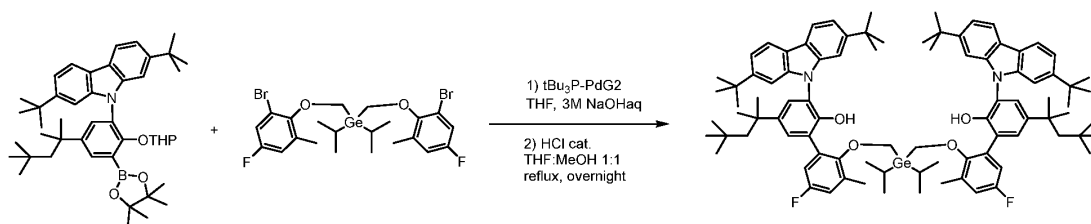


[00123] Synthesis of bis((2-bromo-4-fluoro-6-

methylphenoxy)methyl)diisopropylgermane: In the glove box, in a 250 mL flask equipped with a magnetic stir bar, 95% NaH (1.76 g) (Caution H₂ is generated) was slowly added to a solution of 2-bromo-4-fluoro-6-methyl-phenol (15 g, 73.2 mmol) in N,N-dimethylformamide (DMF) (35 mL) until hydrogen evolution ceased. This mixture was stirred for 30 minutes at room temperature. After this time, the diisopropyl germyl dichloride (6.29 g, 24.4 mmol) was added. The mixture was warmed to 55 °C and held at this temperature for 18 h. The reaction was removed from the glove box and quenched with saturated aqueous NH₄Cl (20 mL) and H₂O (8 mL). Et₂O (30 mL) was added and the phases were transferred to a separatory funnel and separated. The aqueous phase was further extracted with Et₂O (20 mL), and the combined organic extracts were washed with brine (10 mL). The organic layer was then dried (MgSO₄), filtered, and concentrated to dryness. The crude residue was dry loaded onto silica gel and then purified using flash column chromatography (100 mL/min, pure hexanes with ethyl acetate ramping to 10% over 20 minutes) to afford a pale yellow oil as product. All clean fractions (some fractions contained <10% of starting phenol) were combined, and the final product was left under vacuum overnight (Yield: 9 g, 62%):

[00124] ¹H NMR (400 MHz, Chloroform-*d*) δ 7.10 (dd, *J* = 7.7, 3.0 Hz, 2H), 6.84 (ddd, *J* = 8.8, 3.1, 0.8 Hz, 2H), 4.14 (s, 4H), 2.33 (s, 6H), 1.74 (hept, *J* = 7.4 Hz, 2H), 1.35 (d, *J* = 7.4 Hz, 12H); ¹⁹F NMR (376 MHz, Chloroform-*d*) δ -118.03.

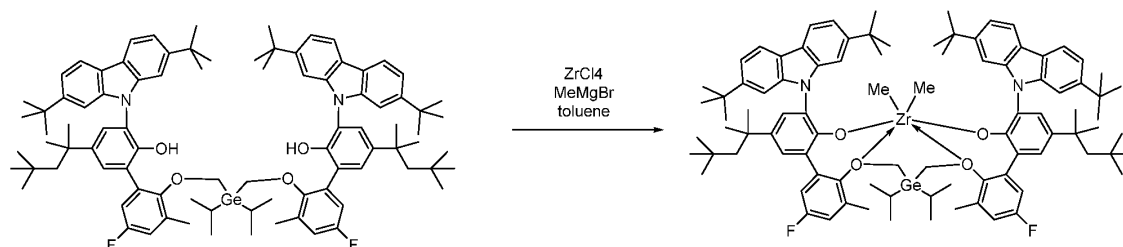
[00125] Synthesis of I6 ligand



[00126] A 500 mL glass-bottle, equipped with a stir bar, was charged with 2,7-di-tert-butyl-9-(2-(((tetrahydro-2H-pyran-2-yl)oxy)-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-5-(2,4,4-trimethylpentan-2-yl)phenyl)-9H-carbazole (Disclosed in WO2014105411 A1) (29.0 g, 41.9 mmol), bis((2-bromo-4-fluoro-6-methylphenoxy)methyl)diisopropylgermane (6.00 g, 8.65 mmol, contains 10% 2-bromo-4-fluoro-2-methyl-phenol), and THF (80 mL). The solution was heated to 55 °C and, while stirring, was treated with chloro[(tri-tert-butylphosphine)-2-(2-aminobiphenyl)] palladium(II) (tBu₃P-PdG2) (199 mg, 0.346 mmol, 4 mol%). An aqueous solution of NaOH (17.3 mL, 51.9 mmol, 3M) was purged with nitrogen for 20 min, and then added to the THF solution. The reaction was stirred overnight at 55 °C. The aqueous phase was separated and discarded, and the remaining organic phase was diluted with diethyl ether and washed with brine twice. The solution was passed through a short plug of silica gel. The filtrate was dried on a rotary evaporator, dissolved in THF/methanol (40 mL/40 mL), treated with HCl (2 mL), and stirred overnight at 70 °C. The solution was dried under vacuum, and purified by C18 reverse-phase column chromatography to provide the I6 ligand as an off-white solid (Yield: 6.5 g, 54%):

[00127] ¹H NMR (400 MHz, Chloroform-*d*) δ 8.01 (d, *J* = 8.2 Hz, 4H), 7.42 (dd, *J* = 25.5, 2.4 Hz, 4H), 7.32 (dd, *J* = 8.2, 1.6 Hz, 4H), 7.17 (s, 4H), 6.87 (ddd, *J* = 16.4, 8.8, 3.0 Hz, 4H), 6.18 (s, 2H), 3.79 (s, 4H), 2.12 (s, 6H), 1.71 (s, 6H), 1.56 (s, 4H), 1.38 (s, 12H), 1.31 (s, 36H), 0.83 – 0.73 (m, 30H); ¹⁹F NMR (376 MHz, Chloroform-*d*) δ -119.02.

[00128] Synthesis of I6:

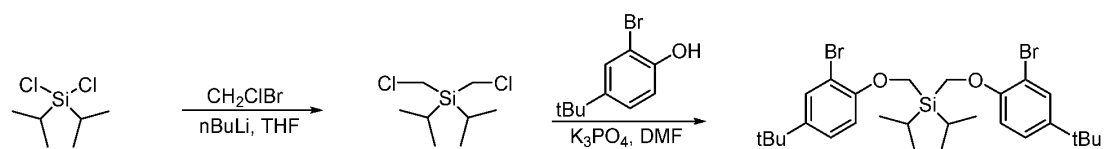


[00129] A 100 mL oven dried glass bottle was charged with ZrCl_4 (402 mg, 1.72 mmol), toluene (83 mL), and a stir bar. The solution was placed in the freezer and cooled to -30°C for 20 min. The solution was taken out of the freezer, and was treated with MeMgBr (2.4 mL, 7.1 mmol, 3 M in Et_2O) and stirred for 3 minutes. To the cold suspension, the I6 ligand (2.3 g, 1.64 mmol) was added as a solid, and the residual powder was dissolved in cold toluene (3 mL) and added to the reaction. The reaction was stirred overnight at room temperature, and then filtered through a fritted plastic funnel. The filtrate was dried under vacuum, redissolved in toluene (40 mL), filtered again through a plug of CELITE, and dried again under vacuum. The resulting solid was washed with pentane (approx. 5 mL) and dried under vacuum, providing I10 as an off-white powder (2.1 g, 84%):

[00130] ^1H NMR (400 MHz, Benzene- d_6) δ 8.20 (dd, $J = 8.2, 0.5$ Hz, 2H), 8.11 (dd, $J = 8.2, 0.6$ Hz, 2H), 7.88 – 7.82 (m, 4H), 7.77 (d, $J = 2.6$ Hz, 2H), 7.50 (dd, $J = 8.3, 1.7$ Hz, 2H), 7.42 – 7.37 (m, 4H), 6.99 (dd, $J = 8.7, 3.1$ Hz, 2H), 6.20 – 6.10 (m, 2H), 4.29 (d, $J = 12.2$ Hz, 2H), 3.90 (d, $J = 12.2$ Hz, 2H), 1.56 (s, 4H), 1.53 (s, 18H), 1.29 (s, 24H), 1.27 (s, 6H), 1.18 (s, 6H), 1.04 – 0.94 (m, 2H), 0.81 (d, $J = 7.4$ Hz, 6H), 0.80 (s, 18H), 0.74 (d, $J = 7.4$ Hz, 6H), -0.47 (s, 6H); ^{19}F NMR (376 MHz, Benzene- d_6) δ -116.24.

[00131] Synthetic Scheme of I7

[00132] Preparation of bis((2-bromo-4-*t*-butylphenoxy)methyl)diisopropylsilane



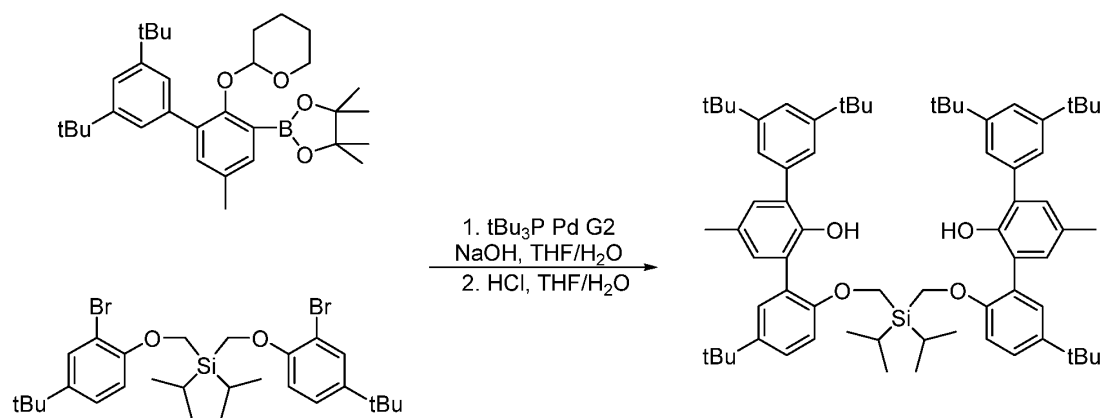
[00133] In a glovebox, diisopropyldichlorosilane (3.703 g, 20 mmol, 1.0 equiv) was dissolved in anhydrous THF (120 mL) in a 250 mL single-neck round-bottom flask. The flask was capped with a septum, sealed, taken out of glovebox, and cooled to -78°C in a dry ice-acetone bath. Bromochloromethane (3.9 mL, 60 mmol, 3.0 equiv) was added. A solution of $n\text{-BuLi}$ (18.4 mL, 46 mmol, 2.3 equiv) in hexane was added to the cooled wall of the flask over a period of 3h using a syringe pump. The mixture was allowed to warm up to room temperature overnight (16h) and saturated NH_4Cl (30 mL) was added. The two layers were separated. The aqueous layer was extracted with ether (2 x 50 mL). The combined organic layer was dried over MgSO_4 , filtered and

concentrated under reduced pressure. The crude product was used for the next step without further purification.

[00134] In a glove box, a 40 mL vial was charged with bis(chloromethyl)diisopropylsilane (2.14 g, 10 mmol, 1.0 equiv), 4-*t*-butyl-2-bromophenol (6.21 g, 27 mmol, 2.7 equiv), K₃PO₄ (7.46 g, 35 mmol, 3.5 equiv), and DMF (10 mL). The reaction mixture was stirred at 80 °C overnight. After cooling down to room temperature, the reaction mixture was purified by column chromatography using ether/hexane (0/100 → 30/70) as the eluent. Collected 4.4 g of a colorless oil, 73% overall yield after 2 steps.

[00135] ¹H NMR (400 MHz, CDCl₃) δ 7.51 (d, *J* = 2.4 Hz, 2H), 7.26 (dd, *J* = 8.6, 2.4 Hz, 2H), 6.98 (d, *J* = 8.6 Hz, 2H), 3.93 (s, 4H), 1.45 – 1.33 (m, 2H), 1.28 (s, 18H), 1.20 (d, *J* = 7.3 Hz, 12H).

[00136] Preparation of 6'',6'''''-(((diisopropylsilanediyl)bis(methylene))bis(oxy))bis(3,3'',5-tri-*tert*-butyl-5'-methyl-[1,1':3',1''-terphenyl]-2'-ol)

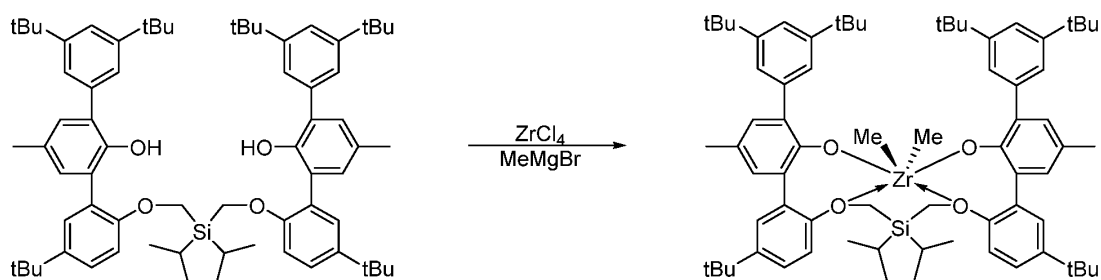


[00137] In a glove box, a 40 mL vial equipped with a stir bar was charged with bis((2-bromo-4-*t*-butylphenoxy)methyl)diisopropylsilane (1.20 g, 2.0 mmol, 1.0 equiv), 2-(3',5'-di-*tert*-butyl-5-methyl-2-((tetrahydro-2H-pyran-2-yl)oxy)-[1,1'-biphenyl]-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.54 g, 5.0 mmol, 2.5 equiv), tBu₃P Pd G2 (0.031 g, 0.06 mmol, 0.03 equiv), THF (3 mL), and NaOH 4 M solution (3.0 mL, 12.0 mmol, 6.0 equiv). The vial was heated under nitrogen at 55 °C for 2 hours. When completed, the top organic layer was extracted with ether and filtered through a short plug of silica gel. Solvents were removed under reduced pressure. The residue was dissolved in THF (10 mL) and MeOH (10 mL). Concentrated HCl (0.5 mL) was then

added. The resulting mixture was heated at 75 °C for 2 hours then cooled to room temperature. Solvents were removed under reduced pressure. The residue was purified by reverse phase column chromatography using THF/MeCN (0/100 → 100/0) as the eluent. Collected 1.62 g of a white solid, 78% yield.

[00138] ^1H NMR (400 MHz, CDCl_3) δ 7.39 (t, J = 1.8 Hz, 2H), 7.36 (d, J = 1.8 Hz, 4H), 7.29 (d, J = 2.5 Hz, 2H), 7.22 (dd, J = 8.6, 2.6 Hz, 2H), 7.10 (d, J = 2.2 Hz, 2H), 6.94 (d, J = 2.3, 2H), 6.75 (d, J = 8.6 Hz, 2H), 5.37 (s, 2H), 3.61 (s, 4H), 2.32 (d, J = 0.9 Hz, 6H), 1.33 (s, 36H), 1.29 (s, 18H), 0.90 – 0.81 (m, 2H), 0.73 (d, J = 7.1 Hz, 12H).

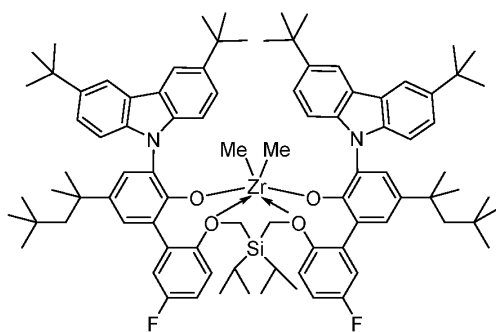
[00139] Preparation of I7



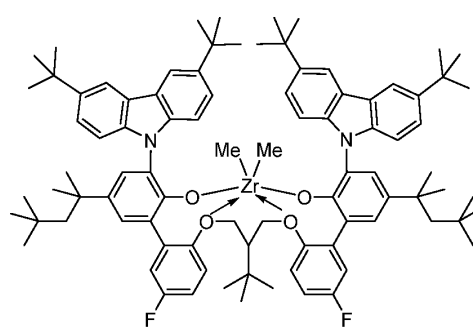
[00140] In a glovebox, an oven dried 40 mL vial with a stir bar was charged with ZrCl_4 (47 mg, 0.2 mmol, 1.0 equiv) and anhydrous toluene (6.0 mL). The vial was cooled to -30 °C in freezer for at least 30 minutes. The vial was taken out of freezer. MeMgBr (3 M, 0.29 mL, 0.86 mmol, 4.3 equiv) was added to the stirring suspension. After 2 minutes, 6",6""-(((diisopropylsilanediyl)bis(methylene))bis(oxy))bis(3,3",5-tri-tert-butyl-5'-methyl-[1,1':3',1"-terphenyl]-2'-ol) (206 mg, 0.2 mmol, 1.0 equiv) was added as solid. The resulting mixture was stirred at room temperature overnight. Solvents were removed under vacuum to yield a dark solid which was washed with hexanes (10 mL) then extracted with toluene (12mL). After filtering, the toluene extract was dried under vacuum. Collected 170 mg of a white solid, 74% yield.

[00141] ^1H NMR (400 MHz, C_6D_6) δ 8.20 – 7.67 (m, 4H), 7.79 (t, J = 1.8 Hz, 2H), 7.56 (d, J = 2.5 Hz, 2H), 7.26 (d, J = 2.4, 2H), 7.21 (d, J = 2.4, 2H), 7.18 (d, J = 2.4, 2H), 5.67 (d, J = 8.6 Hz, 2H), 4.61 (d, J = 13.5 Hz, 2H), 3.46 (d, J = 13.5 Hz, 2H), 2.26 (s, 6H), 1.47 (s, 36H), 1.25 (s, 18H), 0.52 (dd, J = 17.0, 7.5 Hz, 12H), 0.30 – 0.18 (m, 2H), - 0.05 (s, 6H)...

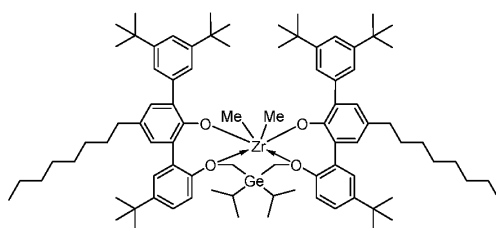
[00142] Metal-Ligand Complexes I1 to I8 have a structure according to formula (I) and are as follows:



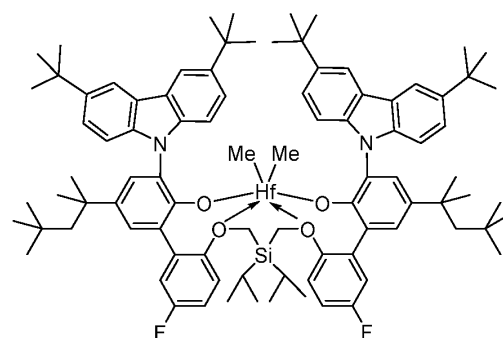
I1



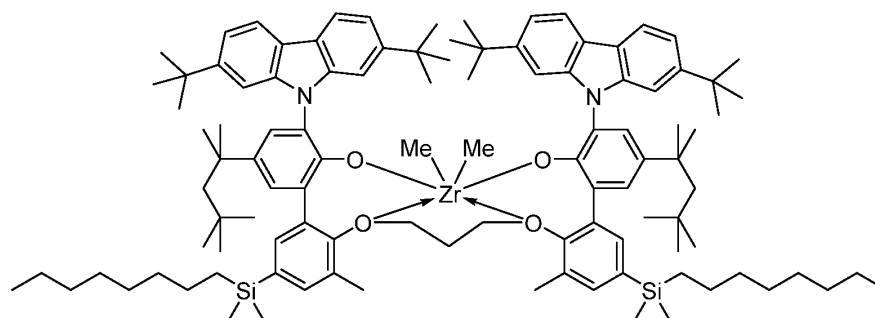
I2



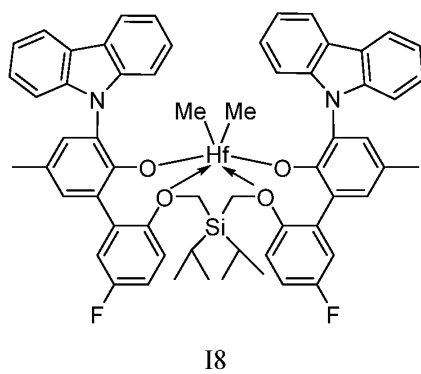
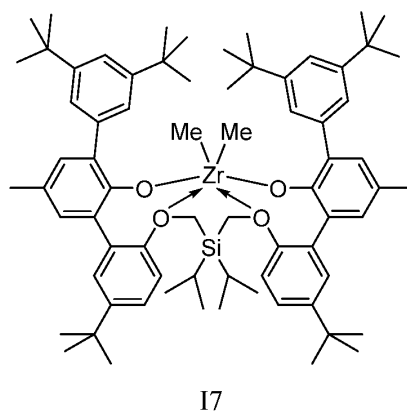
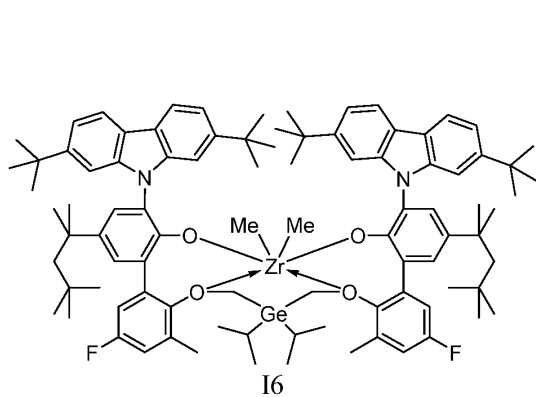
I3



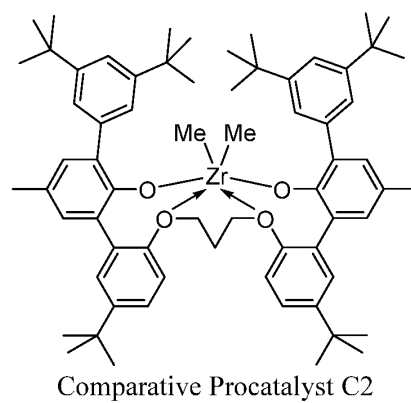
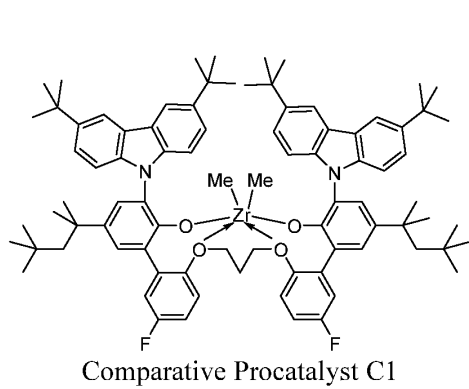
I4

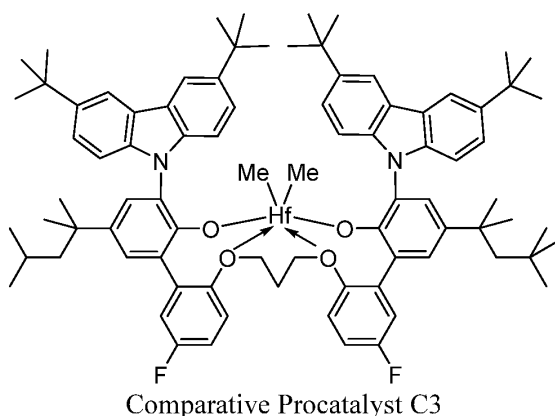


I5



[00143] Metal-Ligand Complexes C1 to C3 are comparative examples and are as follows:





[00144] *Example 2 – Polymerization Reactions*

[00145] Metal–ligand complexes (MLC) I1 to I8 were tested in a continuous polymerization process using MMAO-A1, MMAO-B, MMAO-C, MMAO-D1, MMAO-D2, MMAO-E or MMAO-F as the activator and compared to the Comparative metal ligand complexes C1 to C3, and the data are summarized in Tables 2-9.

Table 1: Alkyl Aluminoxane Composition

Name	Solvent	Methane (mol %)	Isobutane (mol %)	Aluminum (mol %)	Active Aluminum as AlR ^{A1} R ^{B1} R ^{C1} (%)
MMAO-A1	ISOPAR E	98.6	0.4	7	15
MMAO-D	Heptane	65.6	33.3	6.8	38
MMAO-A2	ISOPAR E			6.76	11
MMAO-E	Heptane			6.97	29
MMAO-B	Toluene	99.6	0	7	20
MMAO-C	Toluene	99.7		6.8	24
MMAO-F	Heptane	66.6	31.5	6.8	41
MMAO-G	Heptane	66.1	32.5	6	36

[00146] *MMAO-A1 and A2 are modified with *n*-octyl substituents such that the methyl:*n*-octyl ratio is approximately 6:1. MMAO-B is modified with *n*-octyl substituents such that the methyl:*n*-octyl ratio is approximately 19:1.

Table 2. Continuous Process Ethylene/1-Octene Copolymerization Reactions.

Entry	MLC	Activator	Al conc in reactor (ppm)	Eff. ^[c]	Solids (%)	H ₂ (mol %)	Ethylene conversion (%)	I ₂ (g/10 min)	I ₁₀ /I ₂	Density (g/cc)
1	C2	MMAO-A1	2.0	7.8	14.1	0.2	80.9	1.84	7.83	0.883
2	C4	MMAO-A1	2.0	55.4	14.8	0.0	80.1	11.5	9.53	0.878
3	I3	MMAO-A1	2.0	12.2	13.7	0.4	81.0	2.19	5.92	0.887
4	I1	MMAO-A1	2.0	40.4	15.0	0.1	80.8	1.88	9.93	0.876
5	I7	MMAO-A1	2.0	13.6	13.8	0.4	80.5	2.12	6.09	0.887
6	I2	MMAO-A1	1.0	38.2	15.2	0.0	80.9	140.1	N/D	0.870
7	C2	MMAO-D	2.0	1.3	13.7	0.2	80.5	1.97	7.26	0.885
8	I3	MMAO-D	2.0	2.7	13.6	0.4	81.2	2.1	5.91	0.889
9	I3	Borate ²	2.0	4.7	13.2	0.3	80.7	2.11	5.69	0.893
10	I7	MMAO-D	2.0	4.8	13.8	0.4	80.7	1.92	5.94	0.886
11	I1	MMAO-D	6.1	2.4	14.4	0.1	80.5	2.06	9.51	0.877
12 ¹	I2	MMAO-D	9.8	1.2	8.1	0.0	57.6	145.6	N/D	0.876
13	I3	MMAO-B	4.0	12.4	13.7	0.3	80.8	2.06	5.96	0.884
14	I3	MMAO-C	4.0	12.7	13.5	0.4	80.7	2.01	6.27	0.888
15	I2	MMAO-B	4.0	62.1	15.2	0.0	80.6	153	N/D	0.869
16	I2	MMAO-C	4.0	62.7	15.1	0.0	80.7	182	N/D	0.870
17 ³	I5	MMAO-A1	2.0	124.6	16.0	0.0	85.3	8.89	6.24	0.938
18 ³	I5	MMAO-D	2.0	31.5	16.2	0.0	85.9	8.26	6.21	0.938
19 ³	I6	MMAO-A1	2.0	22.6	12.5	0.3	88.2	1.97	5.38	0.939
20 ³	I6	MMAO-D	5.4	1.5	15.9	0.4	84.8	3.18	5.91	0.941
21	I1	Borate ²	2.0	32.9	14.0	0.1	80.7	1.64	8.71	0.885

[00147] Polymerization at reactor temperature of 160 °C, continuous feed flows of 3.4 kg/h of ethylene, 3.3 kg/h of 1-octene, 21 kg/h ISOPAR E, ^[A]% Solids is the concentration of polymer in the reactor. ^[B]H₂ (mol%) is defined as the mole fraction of hydrogen, relative to ethylene, fed into the reactor, expressed as a percentage. ^[C]The efficiency (Eff.) is measured as 10⁶ g polymer /g metal). ¹Reactor temperature = 153 °C, continuous feed flows of 2.5 kg/h of ethylene, 3.3 kg/h of 1-octene, 21 kg/h ISOPAR E. ²[HNMe(C₁₈H₃₇)₂][B(C₆F₅)₄] was used in a 1.2 molar ratio relative to complex, MMAO-D was used at reported Al conc. in reactor. ³ Reactor temperature = 190 °C, continuous feed flows of 4.6 kg/h of ethylene, 2.0 kg/h of 1-octene, 22 kg/h ISOPAR E.

Table 3. Polymer data produced under continuous operation.

Purpose	Entry	MLC	Activator	Mn (g/mol)	Mw (g/mol)	Mw/Mn	4 B Index	5 B Index	U- Index
Comparative	2	C1	MMAO-A1	21744	56258	2.59	32.3	33.9	68.3
Comparative	21	I1	Borate	36671	84339	2.30	15.5	17.0	87.0
Inventive	4	I1	MMAO-A1	37812	87124	2.30	20.1	21.8	82.0
Inventive	11	I1	MMAO-D	35939	82552	2.30	27.3	29.0	90.5

Inventive	6	I2	MMAO-A1	13707	32203	2.35	24.1	26.6	86.8
Inventive	12	I2	MMAO-D	13393	29855	2.23	26.3	28.3	94.1
Inventive	15	I2	MMAO-B	14108	31444	2.23	22.3	24.9	85.6
Inventive	16	I2	MMAO-C	14215	30773	2.17	22.3	24.8	87.1
Inventive	17	I5	MMAO-A1	26505	56383	2.13	9.6	10.3	81.4
Inventive	18	I5	MMAO-D	27439	57950	2.11	9.3	10.1	80.3
Inventive	19	I6	MMAO-A1	46303	93770	2.03	7.5	8.1	86.3
Inventive	20	I6	MMAO-D	35829	85342	2.38	7.8	8.5	85.1

Entry numbers are in reference to Table 2

Table 4. Polymer data produced under continuous operation.

Purpose	Entry	MLC	Activator	Mn (g/mol)	Mw (g/mol)	Mw/Mn	4 B Index	5 B Index	U- Index
Comparative	1	C2	MMAO-A1	39923	85984	2.15	18.2	19.8	81.4
Comparative	7	C2	MMAO-D	39804	84821	2.13	23.7	25.1	79.5
Comparative	9	I3	Borate	42650	86872	2.04	10.2	11.4	86.8
Inventive	3	I3	MMAO-A1	41695	87934	2.11	11.8	12.9	89.7
Inventive	8	I3	MMAO-D	42817	87747	2.05	12.7	14.0	91.3
Inventive	13	I3	MMAO-B	43727	89380	2.04	11.4	12.7	88.5
Inventive	14	I3	MMAO-C	44412	90663	2.04	11.3	12.6	88.7
Inventive	5	I7	MMAO-A1	43078	89413	2.08	12.5	13.8	91.4
Inventive	10	I7	MMAO-D	43887	88836	2.02	13.7	14.9	95.3

Entry numbers are in reference to Table 2

[00148] The data recorded in Table 2 to 4 indicate that the inventive catalysts in combination with the MMAO activators produce polymers with a narrow MWD as indicated by the U-index regardless of the MMAO activator.

[00149] When the U-index approaches 100, the area of the fit and the area of the sample are similar, thus indicating a single site catalyst. As mentioned previously, it is believed that substitution patterns for the inventive catalyst systems prevent the formation of a second active site and thus leads to narrower composition distributions. Additionally, the narrower the composition distribution, the smaller the expected B-indices will be. Inventive examples presented in Table 3 and 4 all show smaller B indices than comparative examples with non-substituted bridges.

[00150] To demonstrate the advantage of MMAO-A1, MMAO-B, and MMAO-C, the continuous process data are presented in Tables 5 to 8. H₂ was adjusted to reach the desired polymer melt index, and the density was allowed to vary.

Table 5. Continuous Process Ethylene/1-Octene Copolymerization Reactions

MLC	Co-catalyst	Active Aluminum as AlR ^A IR ^B IR ^C (%)	Al (ppm)	Eff. ¹	H ₂ (mol%)	I ₂ (g/10 min)	I ₁₀ /I ₂	Density (g/cc)
I3	MMAO-D/Borate	38	2.0	4.7	0.29	2.4	5.9	0.8920
I3	MMAO-A1	15	2.0	12.3	0.37	2.2	5.9	0.8869
I7	MMAO-D/Borate	38	2.0	3.3	0.33	2.3	6.9	0.8918
I7	MMAO-A1	15	2.0	13.6	0.38	2.1	6.1	0.8865
I1	MMAO-D/Borate	38	2.0	33.0	0.12	1.6	8.7	0.8845
I1	MMAO-A1	15	2.0	40.3	0.05	1.9	9.9	0.8758

[00151] Polymerization at 160 °C, continuous feed flows of 3.4 kg/h of ethylene, 3.3 kg/h of 1-octene, 21 kg/h ISOPAR E, 14% solids, 81% ethylene conversion. The efficiency (Eff.) is measured as 10⁶ g polymer /g metal.

Table 6. Continuous Process Ethylene/1-Octene Copolymerization Reactions

MLC	Co-catalyst	Active Aluminum as AlR ^A IR ^B IR ^C (%)	Al (ppm)	Eff.	H ₂ (mol%)	I ₂ (g/10 min)	I ₁₀ /I ₂	Density (g/cc)
I3	MMAO-D	38	2.0	2.7	0.37	2.1	5.9	0.889
I3	MMAO-A1	15	2.0	12.3	0.37	2.2	5.9	0.887
I3	MMAO-B	20	2.0	10.8	0.35	2.1	6.1	0.887
I3	MMAO-C	24	2.0	9.9	0.36	2.0	6.0	0.885
I7	MMAO-D	38	2.0	4.8	0.36	1.9	5.9	0.886
I7	MMAO-A1	15	2.0	13.6	0.38	2.1	6.1	0.887

[00152] Polymerization at 160 °C, continuous feed flows of 3.4 kg/h of ethylene, 3.3 kg/h of 1-octene, 21 kg/h ISOPAR E, 14% solids, 81% ethylene conversion. The efficiency (Eff.) is measured as 10⁶ g polymer /g metal.

Table 7. Continuous Process Ethylene/1-Octene Copolymerization Reactions

MLC	Co-catalyst	Active Aluminum as AlR ^{A1} R ^{B1} R ^{C1} (%)	Al (ppm)	Eff.	H ₂ (mol%)	I ₂ (g/10 min)	I ₁₀ /I ₂	Density (g/cc)
I3	MMAO-G/RIBS	38	3.6	0.84	0.16	0.36	6.2	0.9010
I3	MMAO-A1	15	3.6	1.7	0.15	0.46	6.1	0.8990

[00153] Polymerization at 175 °C, continuous feed flows of 3.3 kg/h of ethylene, 1.6 kg/h of 1-octene, 22 kg/h ISOPAR E, 14% solids, 87% C2 conversion. The efficiency (Eff.) is measured as 10⁶ g polymer /g metal

[00154] FIG. 1 is a graph of the catalyst efficiency as a function of the type of co-catalyst. The efficiency is greater for metal–ligand complexes I1, I3 and I7 when used in combination with MMAO-A1, MMAO-B, and MMAO-C than in combination to the comparative co-catalyst, MMAO-D/Borate.

Table 8. Continuous Process Ethylene/1-Octene Copolymerization Reactions

MLC	C2 exit (g/L)	Co-catalyst	Active Aluminum AlR ^{A1} R ^{B1} R ^{C1} (%)	Al (ppm)	Eff.	H ₂ (mol%)	I ₂ (g/10 min)	I ₁₀ /I ₂	Density (g/cc)
I3	6.2	MMAO-F/ Borate	41	2	1.19	0.31	0.53	6.54	0.9083
I3	6.2	MMAO-A1	15	2	4.97	0.31	0.49	6.58	0.9082

[00155] Polymerization at 175 °C, continuous flows of 140 lbs/h of ethylene, 30.7-35.0 lbs/h of 1-octene, 900 lbs/h ISOPAR E, 14% solids, 93.8% ethylene conversion. The efficiency (Eff.) is measured as 10⁶ g polymer /g metal

Equipment Standards

[00156] All solvents and reagents are obtained from commercial sources and used as received unless otherwise noted. Anhydrous toluene, hexanes, tetrahydrofuran, and diethyl ether are purified *via* passage through activated alumina and, in some cases, Q-5 reactant. Solvents used for experiments performed in a nitrogen-filled glovebox are further dried by storage over activated 4Å molecular sieves. Glassware for moisture-sensitive reactions is dried in an oven overnight prior to use. NMR spectra are recorded on Varian 400-MR and VNMR5-500 spectrometers. LC-

MS analyses are performed using a Waters e2695 Separations Module coupled with a Waters 2424 ELS detector, a Waters 2998 PDA detector, and a Waters 3100 ESI mass detector. LC-MS separations are performed on an XBridge C18 3.5 μm 2.1x50 mm column using a 5:95 to 100:0 acetonitrile to water gradient with 0.1% formic acid as the ionizing agent. HRMS analyses are performed using an Agilent 1290 Infinity LC with a Zorbax Eclipse Plus C18 1.8 μm 2.1x50 mm column coupled with an Agilent 6230 TOF Mass Spectrometer with electrospray ionization. ^1H NMR data are reported as follows: chemical shift (multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, sex = sextet, sept = septet and m = multiplet), integration, and assignment). Chemical shifts for ^1H NMR data are reported in ppm downfield from internal tetramethylsilane (TMS, δ scale) using residual protons in the deuterated solvent as references. ^{13}C NMR data are determined with ^1H decoupling, and the chemical shifts are reported downfield from tetramethylsilane (TMS, δ scale) in ppm versus the using residual carbons in the deuterated solvent as references.

CLAIMS

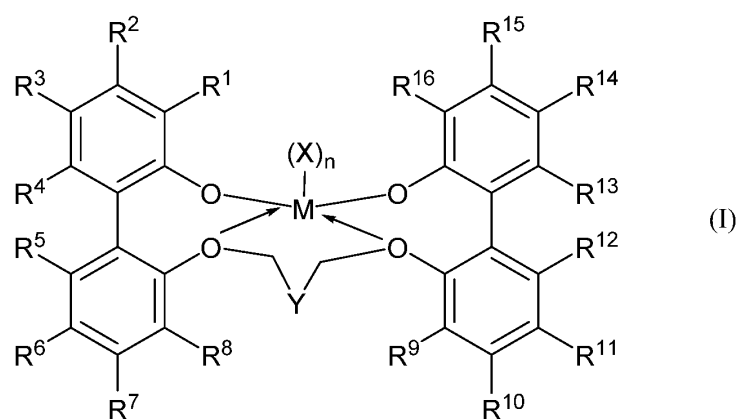
1. A process of polymerizing olefin monomers, the process comprising reacting ethylene and optionally one or more olefin monomers in the presence of a catalyst system, wherein the catalyst system comprises:

modified-hydrocarbyl methylaluminoxane having less than 50 mole percent

$\text{AlR}^{\text{A1}}\text{R}^{\text{B1}}\text{R}^{\text{C1}}$ based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane, where R^{A1} , R^{B1} , and R^{C1} are independently linear

$(\text{C}_1\text{--C}_{40})$ alkyl, branched $(\text{C}_1\text{--C}_{40})$ alkyl, or $(\text{C}_6\text{--C}_{40})$ aryl; and

one or more metal–ligand complexes according to formula (I):



where:

M is titanium, zirconium, or hafnium;

n is 1, 2, or 3;

each X is a monodentate ligand independently chosen from unsaturated

$(\text{C}_2\text{--C}_{50})$ hydrocarbon, unsaturated $(\text{C}_2\text{--C}_{50})$ heterohydrocarbon,

$(\text{C}_1\text{--C}_{50})$ hydrocarbyl, $(\text{C}_6\text{--C}_{50})$ aryl, $(\text{C}_6\text{--C}_{50})$ heteroaryl, cyclopentadienyl,

substituted cyclopentadienyl, $(\text{C}_4\text{--C}_{12})$ diene, halogen, $-\text{N}(\text{R}^{\text{N}})_2$, and

$-\text{N}(\text{R}^{\text{N}})\text{COR}^{\text{C}}$;

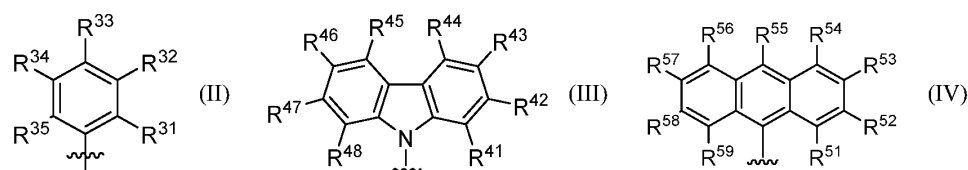
the metal–ligand complex is overall charge-neutral;

R^1 and R^{16} are independently selected from the group consisting of $-\text{H}$, $(\text{C}_6\text{--C}_{40})$ aryl,

$(\text{C}_5\text{--C}_{40})$ heteroaryl, radicals having formula (II), radicals having formula (III),

and radicals having formula (IV):

41



where each of R³¹⁻³⁵, R⁴¹⁻⁴⁸, and R⁵¹⁻⁵⁹ is independently chosen from -H, (C₁-C₄₀)hydrocarbyl, (C₁-C₄₀)heterohydrocarbyl, -Si(R^C)₃, -Ge(R^C)₃, -P(R^P)₂, -N(R^N)₂, -OR^C, -SR^C, -NO₂, -CN, -CF₃, R^CS(O)-, R^CS(O)₂-, (R^C)₂C=N-, R^CC(O)O-, R^COC(O)-, R^CC(O)N(R^N)-, (R^C)₂NC(O)-, or halogen;

R², R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, and R¹⁵ are independently selected from -H, (C₁-C₄₀)hydrocarbyl, (C₁-C₄₀)heterohydrocarbyl, -Si(R^C)₃, -Ge(R^C)₃, -P(R^P)₂, -N(R^N)₂-OR^C, -SR^C, -NO₂, -CN, -CF₃, R^CS(O)-, R^CS(O)₂-, (R^C)₂C=N-, R^CC(O)O-, R^COC(O)-, R^CC(O)N(R)-, (R^C)₂NC(O)-, and halogen; Y is CH₂, CHR²¹, CR²¹R²², SiR²¹R²², or GeR²¹R²², where R²¹ and R²² are (C₁-C₂₀)alkyl; provided that when:

(1) Y is CH₂, then at least one of R⁸ and R⁹ is not -H;

each R^C, R^P, and R^N in formula (I) is independently a (C₁-C₃₀)hydrocarbyl, (C₁-C₃₀)heterohydrocarbyl, or -H; and

wherein the catalysts system does not contain a borate activator.

2. The polymerization process according to claim 1, where the modified-hydrocarbyl methylaluminoxane contains less than 25 mole percent AlR^{A1}R^{B1}R^{C1} based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane.

3. The polymerization process according to claim 1 or claim 2, where the modified-hydrocarbyl methylaluminoxane contains less than 15 mole percent AlR^{A1}R^{B1}R^{C1} based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane.

4. The polymerization process according to claim 1 or claim 2, where the modified-hydrocarbyl methylaluminoxane contains less than 10 mole percent AlR^{A1}R^{B1}R^{C1} based on the total moles of aluminum in the hydrocarbyl-modified methylaluminoxane.

5. The polymerization process according to any one of claim 1 to claim 4, where the modified-hydrocarbyl methylaluminoxane is modified methylaluminoxane.
6. The polymerization process according to any one of the preceding claims, wherein the aluminum to catalyst metal is less than 500:1.
7. The polymerization process according to any one of the preceding claims, wherein the aluminum to catalyst metal is less than 200:1 or is less than 50:1.
8. The polymerization process according to any one of the preceding claims, wherein at least one of R^8 and R^9 is (C_1-C_{40}) hydrocarbyl, (C_1-C_{40}) heterohydrocarbyl, or halogen atom.
9. The polymerization process according to any one of the preceding claims, wherein at least one of R^8 and R^9 is (C_1-C_5) alkyl.
10. The polymerization process according to any one of the preceding claims, wherein R^1 and R^{16} are identical.
11. The polymerization process according to any one of the preceding claims, wherein at least one of R^1 and R^{16} is a radical having formula (III).
12. The polymerization process according to claim 7, wherein R^{42} and R^{47} are (C_1-C_{20}) hydrocarbyl or $-Si[(C_1-C_{20})hydrocarbyl]_3$.
13. The polymerization process according to claim 7, wherein R^{43} and R^{46} are (C_1-C_{20}) hydrocarbyl or $-Si[(C_1-C_{20})hydrocarbyl]_3$.
14. The polymerization process according to any one of claims 1 to 5, wherein at least one of R^1 and R^{16} is a radical having formula (II).
15. The polymerization process according to claim 10, wherein R^{32} and R^{34} are (C_1-C_{12}) hydrocarbyl or $-Si[(C_1-C_{20})hydrocarbyl]_3$.
16. The polymerization process according to any one of claims 1 to 5, wherein at least one of R^1 and R^{16} is a radical having formula (IV).
17. The polymerization process according to claim 12, wherein at least two of R^{52} , R^{53} , R^{55} , R^{57} , and R^{58} are (C_1-C_{20}) hydrocarbyl or $-Si[(C_1-C_{20})hydrocarbyl]_3$.

18. The polymerization process according to any one of claims 1 to 13, wherein R^8 and R^9 are independently selected from methyl, ethyl, 1-propyl, or 2-propyl.
19. The polymerization process according to any of the preceding claims, wherein R^3 and R^{14} are (C_1-C_{20}) alkyl.
20. The polymerization process according to any one of the preceding claims, wherein R^3 and R^{14} are methyl, R^6 and R^{11} are halogen.
21. The polymerization process according to any one of claims 1-20, wherein R^6 and R^{11} are *tert*-butyl.
22. The polymerization process according to any one of claims 1 to 20, wherein R^3 and R^{14} are *tert*-octyl or *n*-octyl.
23. The polymerization process according to any one of the preceding claims, where M is zirconium.
24. The polymerization process according to any one of the preceding claims, wherein the olefin monomer is $(C_3-C_{20})\alpha$ -olefin.
25. The polymerization process according to any one of the preceding claims, wherein the olefin monomer is a cyclic olefin.
26. The polymerization process according to any one of the preceding claims, wherein the polymerization process is a solution polymerization reaction.