

THIOGUANIDINE GROUP IV TRANSITION METAL CATALYSTS AND POLYMERIZATION SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Serial No. 62/402,210, filed September 30, 2016, which is incorporated herein by reference in its entirety.

BACKGROUND

Field

[0002] The present specification generally relates to transition-metal catalysts and, more specifically, to thioguanidine group IV transition metal catalysts for polymerization reactions, including the synthesis of ethylene/ α -olefin copolymers.

Technical Background

[0003] Olefin based polymers are utilized in the manufacture of a variety of articles and products, and thus, there is a high industrial demand for such polymers. Olefin based polymers, such as polyethylene and/or polypropylene, are produced via various catalyst systems. Selection of such catalyst systems used in the polymerization process is an important factor contributing to the characteristics and properties of such olefin based polymers.

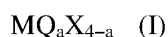
[0004] The polyolefin polymerization process can be varied in a number of ways to produce a wide variety of resultant polyolefin resins having different physical properties suitable for use in different applications. It is generally known that polyolefin can be produced in solution phase polymerization process, gas phase polymerization process, and/or slurry phase polymerization process in one or more reactors, for example, connected in series or parallel, in the presence of one or more catalyst systems.

[0005] Despite the research efforts in developing catalyst systems suitable for polyolefin polymerization, such as polyethylene, there is still a need for improved polymerization catalysts to meet industrial demand for olefin based polymers.

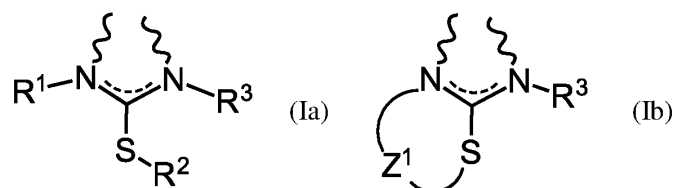
SUMMARY

[0006] Accordingly, the present embodiments are directed to catalyst systems, which provide alternative synthetic schemes for meeting industrial demand of olefin based polymers.

[0007] According to some embodiments, compositions or catalytic compositions include at least one thioguanidine complex according to the Formula (I):

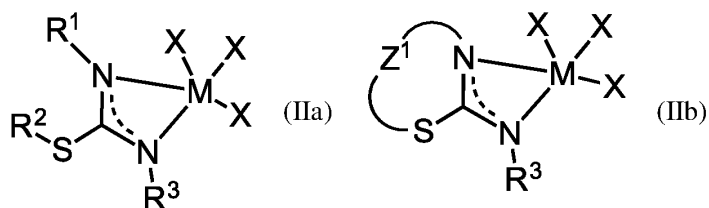


in which M is Ti, Zr, or Hf; a is 1 or 2; each X is covalently bonded or coordinated to the metal center and is independently chosen from moieties such as alkyl groups, halides, or amides; and each group Q of the thioguanidine complex is a bidentate thioguanidine ligand bound to the metal center and having Formula (Ia) or Formula (Ib):



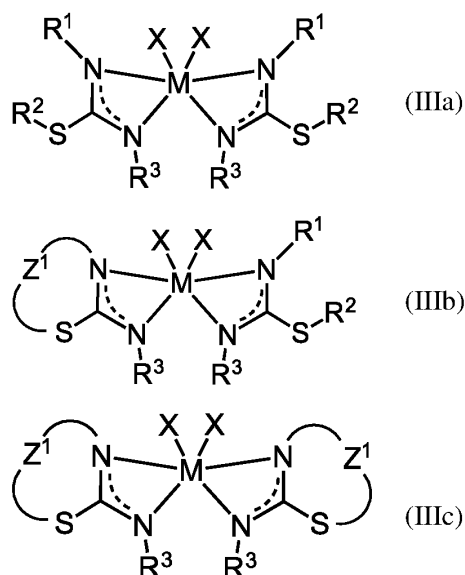
[0008] In Formulas (Ia) and (Ib), each group R^1 , R^2 , and R^3 is independently chosen from alkyl groups or aryl groups; each group Z^1 is independently chosen from alkylene groups. If $a = 2$, groups R^3 of the two groups Q are optionally linked to each other through at least one covalent bond. The polymerization systems may be configured to copolymerize ethylene and α -olefins.

[0009] According to some embodiments, the at least one thioguanidine complex according to the Formula (I) has Formula (IIa) or Formula (IIb):



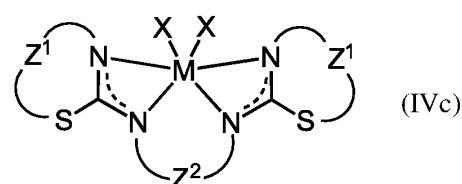
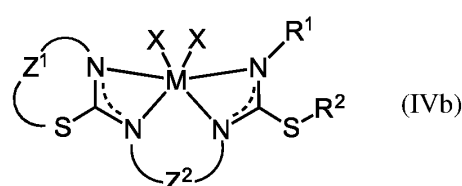
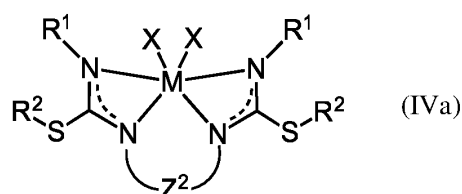
where M, R^1 , R^2 , R^3 , Z^1 , and X are as defined in Formula (I). Each group X in complexes of Formula (IIa) or Formula (IIb) may be the same or different.

[0010] According to some embodiments, the at least one thioguanidine complex according to the Formula (I) has Formula (IIIa), Formula (IIIb), or Formula (IIIc):



where M, R^1 , R^2 , R^3 , Z^1 , and X are as defined in Formula (I). The two groups R^1 in complexes of Formula (IIIa) may be the same or different. The two groups R^2 of complexes of Formula (IIIa) may be the same or different. The two groups R^3 in complexes of Formula (IIIa), Formula (IIIb), Formula (IIIc) may be the same or different. The two groups Z^1 in complexes of Formula (IIIc) may be the same or different. The two groups X in complexes of any of Formulas (IIIa)–(IIIc) may be the same or different.

[0011] According to some embodiments, the at least one thioguanidine complex according to the Formula (I) has Formula (IVa), Formula (IVb), or Formula (IVc):



where M, R¹, R², Z¹, and X are as defined in Formula (I), and Z² is an alkylene group formed from joining of two groups R³ as defined in Formula (I) through at least one covalent bond. The two groups R¹ in complexes of Formula (IVa) may be the same or different. The two groups R² in complexes of Formula (IVa) may be the same or different. The two groups Z¹ in complexes of Formula (IVc) may be the same or different. The two groups X in complexes of any of Formulas (IVa)–(IVc) may be the same or different.

[0012] Further embodiments are directed to polymerization systems configured to copolymerize ethylene and an α -olefin comonomer in the presence of a catalytic amount of compositions that include at least one thioguanidine complex according to at least one embodiment of this disclosure.

[0013] Further embodiments are directed to ethylene-co-alkylene copolymers produced from a polymerization system in which a catalytic amount of a composition containing at least one

thioguanidine complex according to at least one embodiment of this disclosure is present during polymerization of ethylene and an α -olefin.

[0014] Further embodiments are directed to polymerization methods including reacting ethylene and an α -olefin comonomer in the presence of a catalytic amount of a composition containing at least one thioguanidine complex according to at least one embodiment of this disclosure to form an ethylene-co-alkylene copolymer. In some embodiments, the α -olefin comonomer may include at least one C₃-C₁₂ α -olefin such as, for example, 1-octene.

[0015] Additional features and advantages of the embodiments described herein will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the embodiments described herein, including the detailed description which follows, the claims, as well as the appended drawing.

[0016] It is to be understood that both the foregoing general description and the following detailed description describe various embodiments and are intended to provide an overview or framework for understanding the nature and character of the claimed subject matter. The accompanying drawings are included to provide a further understanding of the various embodiments, and are incorporated into and constitute a part of this specification. The drawings illustrate the various embodiments described herein, and together with the description serve to explain the principles and operations of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWING

[0017] The FIGURE is a molecular structure of one catalyst according to an illustrative embodiment of this specification.

DETAILED DESCRIPTION

Definitions

[0018] Common abbreviations used in this disclosure may include **Me** : methyl; **Et** : ethyl; **Ph** : phenyl; **Bn** : benzyl ($-\text{CH}_2\text{-Ph}$); **THF** : tetrahydrofuran; **Et₂O** : diethyl ether; **C₆D₆** : deuterated benzene; **CDCl₃** : deuterated chloroform; **DMSO-*d*₆** : deuterated dimethylsulfoxide;

MeI : methyl iodide; **MgSO₄** : magnesium sulfate; **HfBn₄** : hafnium(IV) tetrabenzyl; **ZrBn₄** : zirconium(IV) tetrabenzyl; **N₂** : nitrogen gas; **MMAO** : modified methylaluminoxane; **NMR** : nuclear magnetic resonance; **DSC** : differential scanning calorimetry; **mmol** : millimoles; **mL** : milliliters; **M** : molar; **min** : minutes; **h** : hours; **d** : days; **GPC** : gel permeation chromatography; **M_w** : weight average molecular weight; **M_n** : number average molecular weight.

[0019] The term “independently selected” is used herein to indicate that multiple instances in a single molecule of defined groups such as R¹, R², R³, and Z¹, for example, may be identical or different. Use of the singular includes use of the plural and vice versa (e.g., a hexane solvent, includes hexanes). A named R group will generally have the structure that is recognized in the art as corresponding to R groups having that name. These definitions are intended to supplement and illustrate, not limit, the definitions known to those of skill in the art.

[0020] The terms “moiety,” “functional group,” or “group,” may be used interchangeably in this specification, but those of skill in the art may recognize certain parts of a complex or compound as being a moiety rather than a functional group and vice versa. Additionally, the term “moiety” includes functional groups and/or discrete bonded residues that are present in the compounds or metal complexes of this disclosure. The term “moiety” as used in the present application is inclusive of individual units in the copolymers or the individual units within a polymeric ligand, as described in the general formulas of the present disclosure.

[0021] The term “complex” means a metal and ligand coordinated together to form a single molecular compound. The coordination may be formed through dative or covalent bonds. For the purposes of illustration, certain representative groups are defined within this disclosure. These definitions are intended to supplement and illustrate, not limit, the definitions known to those of skill in the art.

[0022] The term “aliphatic” encompasses the terms “alkyl,” “branching alkyl,” “(C₁-C₄₀)hydrocarbyls,” “substituted (C₁-C₄₀)hydrocarbyls,” “(C₃-C₄₀)hydrocarbylene,” and “substituted (C₃-C₄₀)hydrocarbylene.”

[0023] The term “heteroaliphatic” includes “(C₁-C₄₀)heterohydrocarbyls,” and “substituted (C₁-C₄₀)heterohydrocarbyls,” “[C(C+Si)₃-(C+Si)₄₀]organosilylene,” “substituted [(C+Si)₃-(C+Si)₄₀]organosilylene,” “[C(C+Ge)₃-(C+Ge)₄₀]organogermylene,” and substituted [(C+Ge)₃-(C+Ge)₄₀]organogermylene.”

[0024] The term “aromatic” or “aryl” encompasses the terms: “(C₆-C₄₀)aryl” and “substituted (C₆-C₄₀)aryl group.” The term “heteroaromatic” includes “(C₁-C₄₀)heteroaryl,” and “(C₂-C₄₀)heteroaryl.”

[0025] When used to describe certain carbon atom-containing chemical groups (e.g., (C₁-C₄₀)alkyl), the parenthetical expression (C₁-C₄₀) can be represented by the form “(C_x-C_y),” which means that the unsubstituted version of the chemical group comprises from a number x carbon atoms to a number y carbon atoms, wherein each x and y independently is an integer as described for the chemical group. The R^S substituted version of the chemical group can contain more than y carbon atoms depending on nature of R^S. Thus, for example, an unsubstituted (C₁-C₄₀)alkyl contains from 1 to 40 carbon atoms (x = 1 and y = 40). When the chemical group is substituted by one or more carbon atom-containing R^S substituents, the substituted (C_x-C_y) chemical group may comprise more than y total carbon atoms; i.e., the total number of carbon atoms of the carbon atom-containing substituent(s)-substituted (C_x-C_y) chemical group is equal to y plus the sum of the number of carbon atoms of each of the carbon atom-containing substituent(s). Any atom of a chemical group that is not specified herein is understood to be a hydrogen atom.

[0026] In some embodiments, each of the chemical groups (e.g. R¹, R², R³) of the compounds and metal complex of the general formulas in this disclosure may be unsubstituted, that is, can be defined without use of a substituent R^S, provided the above-mentioned conditions are satisfied. In other embodiments, at least one of the chemical groups of the compounds and metal complexes of the general formulas of this disclosure independently contain one or more of the substituents R^S. When a compound contains two or more substituents R^S, each R^S independently is bonded to a same or different substituted chemical group. When two or more R^S are bonded to a same chemical group, they independently are bonded to a same or different carbon atom or heteroatom, as the case may be, in the same chemical group up to and including persubstitution of the chemical group.

[0027] The term “persubstitution” means each hydrogen atom (H) bonded to a carbon atom or heteroatom of a corresponding unsubstituted compound or functional group, as the case may be, is replaced by a substituent (e.g., R^S). The term “polysubstitution” means each of at least two, but not all, hydrogen atoms (H) bonded to carbon atoms or heteroatoms of a corresponding unsubstituted compound or functional group, as the case may be, is replaced by a substituent (e.g., R^S). The term “monosubstitution” means that only one hydrogen atom (H) bonded to a carbon atom or heteroatom of a corresponding unsubstituted compound or functional group, as the case may be, is replaced by a substituent (e.g., R^S). The (C_1-C_{18}) alkylene and (C_1-C_8) alkylene substituents are especially useful for forming substituted chemical groups that are bicyclic or tricyclic analogs, as the case may be, of corresponding monocyclic or bicyclic unsubstituted chemical groups.

[0028] As used herein, the definitions of the terms hydrocarbyl, heterohydrocarbyl, hydrocarbylene, heterohydrocarbylene, alkyl, alkylene, heteroalkyl, heteroalkylene, aryl, arylene, heteroaryl, heteroarylene, cycloalkyl, cycloalkylene, heterocycloalkyl, heterocycloalkylene, organosilylene, organogermylene are intended to include every possible stereoisomer.

[0029] Heteroalkyl and heteroalkylene groups are saturated straight or branched chain radicals or diradicals, respectively, containing (C_1-C_{40}) carbon atoms, and one or more of the heteroatoms or heteroatomic groups O; S; N; S(O); S(O)₂; S(O)₂N; Si(R^C)₂; Ge(R^C)₂; P(R^C); P(O)(R^C); and N(R^C), as defined above, wherein each of the heteroalkyl and heteroalkylene groups independently are unsubstituted or substituted by one or more R^S . Examples of substituted and unsubstituted heteroalkyl groups are methoxyl; ethoxyl; trimethylsilyl; dimethylphenylsilyl; *tert*-butyldimethylsilyl; and dimethylamino.

[0030] As used herein, the term “ (C_1-C_{40}) hydrocarbyl” means a hydrocarbon radical of from 1 to 40 carbon atoms and the term “ (C_1-C_{40}) hydrocarbylene” means a hydrocarbon diradical of from 1 to 40 carbon atoms, wherein each hydrocarbon radical and diradical independently is aromatic (6 carbon atoms or more) or non-aromatic, saturated or unsaturated, straight chain or branched chain, cyclic (including mono- and polycyclic, fused and non-fused polycyclic, including bicyclic; 3 carbon atoms or more) or acyclic, or a combination of two or more thereof; and each hydrocarbon radical and diradical independently is the same as or different from

another hydrocarbon radical and diradical, respectively, and independently is unsubstituted or substituted by one or more R^S.

[0031] In some embodiments, (C₁-C₄₀)hydrocarbonyl independently is an unsubstituted or substituted (C₁-C₄₀)alkyl, (C₃-C₄₀)cycloalkyl, (C₃-C₂₀)cycloalkyl-(C₁-C₂₀)alkylene, (C₆-C₄₀)aryl, or (C₆-C₂₀)aryl-(C₁-C₂₀)alkylene. In further embodiments, each of the aforementioned (C₁-C₄₀)hydrocarbonyl groups independently has a maximum of 20 carbon atoms (i.e., (C₁-C₂₀)hydrocarbonyl), and in other embodiments, a maximum of 15 carbon atoms.

[0032] The term “(C₁-C₄₀)alkyl” means a saturated straight or branched hydrocarbon radical of from 1 to 40 carbon atoms, that is unsubstituted or substituted by one or more R^S. Examples of unsubstituted (C₁-C₄₀)alkyl include unsubstituted (C₁-C₂₀)alkyl; unsubstituted (C₁-C₁₀)alkyl; unsubstituted (C₁-C₅)alkyl; methyl; ethyl; 1-propyl; 2-propyl; 2,2-dimethylpropyl, 1-butyl; 2-butyl; 2-methylpropyl; 1,1-dimethylethyl; 1-pentyl; 1-hexyl; 2-ethylhexyl, 1-heptyl; 1-nonyl; 1-decyl; 2,2,4-trimethylpentyl. Examples of substituted (C₁-C₄₀)alkyl include substituted (C₁-C₂₀)alkyl; substituted (C₁-C₁₀)alkyl; trifluoromethyl; trimethylsilylmethyl; methoxymethyl; dimethylaminomethyl; trimethylgermylmethyl; phenylmethyl (benzyl); 2-phenyl-2,2-methylethyl; 2-(dimethylphenylsilyl)ethyl; and dimethyl(*t*-butyl)silylmethyl.

[0033] The term “(C₆-C₄₀)aryl” means an unsubstituted or substituted (by one or more R^S) mono-, bi- or tricyclic aromatic hydrocarbon radical of from 6 to 40 carbon atoms, of which at least from 6 to 14 of the carbon atoms are aromatic ring carbon atoms, and the mono-, bi- or tricyclic radical comprises 1, 2 or 3 rings, respectively; wherein one ring is aromatic and the optional second and third rings independently are fused or non-fused and the second and third rings are each independently optionally aromatic. Examples of unsubstituted (C₆-C₄₀)aryl include unsubstituted (C₆-C₂₀)aryl; unsubstituted (C₆-C₁₈)aryl; phenyl; biphenyl; *ortho*-terphenyl; *meta*-terphenyl; fluorenyl; tetrahydrofluorenyl; indacenyl; hexahydroindacenyl; indenyl; dihydroindenyl; naphthyl; tetrahydronaphthyl; phenanthrenyl and triptycenyl. Examples of substituted (C₆-C₄₀)aryl include substituted (C₆-C₂₀)aryl; substituted (C₆-C₁₈)aryl; 2,6-bis[(C₁-C₂₀)alkyl]-phenyl; 2-(C₁-C₅)alkyl-phenyl; 2,6-bis(C₁-C₅)alkyl-phenyl; 2,4,6-tris(C₁-C₅)alkyl-phenyl; polyfluorophenyl; pentafluorophenyl; 2,6-dimethylphenyl, 2,6-diisopropylphenyl; 2,4,6-triisopropylphenyl; 2,4,6-trimethylphenyl; 2-methyl-6-

trimethylsilylphenyl; 2-methyl-4,6-diisopropylphenyl; 4-methoxyphenyl; and 4-methoxy-2,6-dimethylphenyl.

[0034] The term “(C₃-C₄₀)cycloalkyl” means a saturated cyclic or polycyclic (i.e. fused or unfused) hydrocarbon radical of from 3 to 40 carbon atoms that is unsubstituted or substituted by one or more R^S. Other cycloalkyl groups (e.g., (C₃-C₁₂)alkyl) are defined in an analogous manner. Examples of unsubstituted (C₃-C₄₀)cycloalkyl include unsubstituted (C₃-C₂₀)cycloalkyl, unsubstituted (C₃-C₁₀)cycloalkyl; cyclopropyl; cyclobutyl; cyclopentyl; cyclohexyl; cycloheptyl; cyclooctyl; cyclononyl; cyclodecyl; octahydroindenyl; bicyclo[4.4.0]decyl; bicyclo[2.2.1]heptyl; and tricyclo[3.3.1.1]decyl. Examples of substituted (C₃-C₄₀)cycloalkyl include substituted (C₃-C₂₀)cycloalkyl; substituted (C₃-C₁₀)cycloalkyl; 2-methylcyclohexyl; and perfluorocyclohexyl.

[0035] Examples of (C₁-C₄₀)hydrocarbylene include unsubstituted or substituted (C₃-C₄₀)hydrocarbylene; (C₆-C₄₀)arylene, (C₃-C₄₀)cycloalkylene, and (C₃-C₄₀)alkylene (e.g., (C₃-C₂₀)alkylene). In some embodiments, the diradicals are on the terminal atoms of the hydrocarbylene as in a 1,3-alpha, omega diradical (e.g., -CH₂CH₂CH₂-) or a 1,5-alpha, omega diradical with internal substitution (e.g., -CH₂CH₂CH(CH₃)CH₂CH₂-). In other embodiments, the diradicals are on the non-terminal atoms of the hydrocarbylene as in a C₇ 2,6-diradical (e.g., CH₃[|]CHCH₂CH₂CH₂CH₂[|]CHCH₃) or a C₇ 2,6-diradical with internal substitution (e.g., CH₃[|]CHCH₂CH(CH₃)CH₂CH[|]CHCH₃).

[0036] The terms [(C+Si)₃-(C+Si)₄₀] organosilylene and [(C+Ge)₃-(C+Ge)₄₀] organogermylene are defined as diradicals in which the two radical bearing atoms of the diradical unit are spaced apart by one or more intervening carbon, silicon and/or germanium atoms. Such [(C+Si)₃-(C+Si)₄₀] organosilylene and [(C+Ge)₃-(C+Ge)₄₀] organogermylene groups can be substituted or unsubstituted. In some embodiments the diradicals are on the terminal atoms of the organosilylene or organogermylene as in a 1,5- α,ω -diradical (e.g. -CH₂CH₂Si(C₂H₅)₂CH₂CH₂- and -CH₂CH₂Ge(C₂H₅)₂CH₂CH₂-). In other embodiments, the diradicals are on the non-terminal atoms of the organosilylene or organogermylene as in a

substituted (C+Si)₇ 2,6-diradical ($\text{CH}_3\overset{|}{\text{CH}}\text{CH}_2\text{Si}(\text{C}_2\text{H}_5)_2\text{CH}_2\overset{|}{\text{CH}}\text{CH}_3$) and a substituted (C+Ge)₇ 2,6-diradical ($\text{CH}_3\overset{|}{\text{CH}}\text{CH}_2\text{Ge}(\text{C}_2\text{H}_5)_2\text{CH}_2\overset{|}{\text{CH}}\text{CH}_3$).

[0037] The term “(C₁-C₄₀)alkylene” means a saturated or unsaturated straight chain or branched chain diradical of from 1 to 40 carbon atoms that is unsubstituted or substituted by one or more R^S. Examples of unsubstituted (C₁-C₄₀)alkylene include unsubstituted (C₃-C₂₀)alkylene, including unsubstituted 1,3-(C₃-C₁₀)alkylene; 1,4-(C₄-C₁₀)alkylene; -(CH₂)₃-; -(CH₂)₄-; -(CH₂)₅-; -(CH₂)₆-; -(CH₂)₇-; -(CH₂)₈-; and -(CH₂)₄CH(CH₃)-. Examples of substituted (C₁-C₄₀)alkylene include substituted (C₃-C₂₀)alkylene; -CF₂CF₂CF₂-; and -(CH₂)₁₄C(CH₃)₂(CH₂)₅- (i.e., a 6,6-dimethyl substituted normal-1,20-eicosylene). As mentioned previously, two R^S may be taken together to form a (C₁-C₄₀)alkylene. Thus, examples of substituted (C₁-C₄₀)alkylene also include 1,2-bis(methylene)cyclopentane; 1,2-bis(methylene)cyclohexane; 2,3-bis(methylene)-7,7-dimethyl-bicyclo[2.2.1]heptane; and 2,3-bis(methylene)bicyclo[2.2.2]octane.

[0038] The term “(C₃-C₄₀)cycloalkylene” means a cyclic diradical (i.e., the radicals are on ring atoms) of from 3 to 40 carbon atoms that is unsubstituted or substituted by one or more R^S. Examples of unsubstituted (C₃-C₄₀)cycloalkylene are 1,3-cyclobutylene, 1,3-cyclopentylene, and 1,4-cyclohexylene. Examples of substituted (C₃-C₄₀)cycloalkylene are 2-trimethylsilyl-1,4-cyclohexylene and 1,2-dimethyl-1,3-cyclohexylene.

[0039] The terms “(C₁-C₄₀)heterohydrocarbyl” and “(C₁-C₄₀)heterohydrocarbylene” mean a heterohydrocarbon radical or diradical, respectively, of from 1 to 40 carbon atoms, and each heterohydrocarbon independently has one or more heteroatoms or heteroatomic groups O; S; N; S(O); S(O)₂; S(O)₂N; Si(R^C)₂; Ge(R^C)₂; P(R^C); P(O)(R^C); and N(R^C), wherein independently each R^C is hydrogen, unsubstituted (C₁-C₁₈)hydrocarbyl or an unsubstituted (C₁-C₁₈)heterohydrocarbyl, or absent (e.g., absent when N comprises -N=). Each (C₁-C₄₀)heterohydrocarbyl and (C₁-C₄₀)heterohydrocarbylene independently is unsubstituted or substituted (by one or more R^S), aromatic or non-aromatic, saturated or unsaturated, straight chain or branched chain, cyclic (including mono- and poly-cyclic, fused and non-fused polycyclic) or acyclic, or a combination of two or more thereof; and each is respectively the same as or different from another.

[0040] The (C₁-C₄₀)heterohydrocarbyl independently may be unsubstituted or substituted (C₁-C₄₀)heteroalkyl, (C₁-C₄₀)hydrocarbyl-O-, (C₁-C₄₀)hydrocarbyl-S-, (C₁-C₄₀)hydrocarbyl-S(O)-, (C₁-C₄₀)hydrocarbyl-S(O)₂-, (C₁-C₄₀)hydrocarbyl-Si(R^C)₂-, (C₁-C₄₀)hydrocarbyl-Ge(R^C)₂-, (C₁-C₄₀)hydrocarbyl-N(R^C)-, (C₁-C₄₀)hydrocarbyl-P(R^C)-, (C₂-C₄₀)heterocycloalkyl, (C₂-C₁₉)heterocycloalkyl-(C₁-C₂₀)alkylene, (C₃-C₂₀)cycloalkyl-(C₁-C₁₉)heteroalkylene, (C₂-C₁₉)heterocycloalkyl-(C₁-C₂₀)heteroalkylene, (C₁-C₄₀)heteroaryl, (C₁-C₁₉)heteroaryl-(C₁-C₂₀)alkylene, (C₆-C₂₀)aryl-(C₁-C₁₉)heteroalkylene, or (C₁-C₁₉)heteroaryl-(C₁-C₂₀)heteroalkylene.

[0041] The term “(C₁-C₄₀)heteroaryl” means an unsubstituted or substituted (by one or more R^S) monocyclic, bicyclic or tricyclic heteroaromatic hydrocarbon radical of from 1 to 40 total carbon atoms and from 1 to 6 heteroatoms, and the monocyclic, bicyclic or tricyclic radical comprises 1, 2 or 3 rings, respectively, wherein one ring is heteroaromatic and the optional second and third rings independently are fused or non-fused; and the second or third rings are each independently optionally heteroaromatic. Other heteroaryl groups (e.g., (C₁-C₁₂)heteroaryl)) are defined in an analogous manner. The monocyclic heteroaromatic hydrocarbon radical is a 5-membered or 6-membered ring. The 5-membered ring has from 1 to 4 carbon atoms and from 4 to 1 heteroatoms, respectively, each heteroatom being O, S, N, or P. Examples of 5-membered ring heteroaromatic hydrocarbon radical are pyrrol-1-yl; pyrrol-2-yl; furan-3-yl; thiophen-2-yl; pyrazol-1-yl; isoxazol-2-yl; isothiazol-5-yl; imidazol-2-yl; oxazol-4-yl; thiazol-2-yl; 1,2,4-triazol-1-yl; 1,3,4-oxadiazol-2-yl; 1,3,4-thiadiazol-2-yl; tetrazol-1-yl; tetrazol-2-yl; and tetrazol-5-yl. The 6-membered ring has 3 to 5 carbon atoms and 1 to 3 heteroatoms, the heteroatoms being N or P. Examples of 6-membered ring heteroaromatic hydrocarbon radical are pyridine-2-yl; pyrimidin-2-yl; and pyrazin-2-yl. The bicyclic heteroaromatic hydrocarbon radical is a fused 5,6- or 6,6-ring system. Examples of the fused 5,6-ring system bicyclic heteroaromatic hydrocarbon radical are indol-1-yl; and benzimidazole-1-yl. Examples of the fused 6,6-ring system bicyclic heteroaromatic hydrocarbon radical are quinolin-2-yl; and isoquinolin-1-yl. The tricyclic heteroaromatic hydrocarbon radical is a fused 5,6,5-; 5,6,6-; 6,5,6-; or 6,6,6-ring system. An example of the fused 5,6,5-ring system is 1,7-dihydropyrrolo[3,2-f]indol-1-yl. An example of the fused 5,6,6-ring system is 1*H*-benzo[*f*]indol-1-yl. An example of the fused 6,5,6-ring system is 9*H*-carbazol-9-yl. An example of the fused 6,6,6-ring system is acridin-9-yl.

[0042] The (C₂-C₄₀)heteroaryl may include 2,7-disubstituted carbazolyl or 3,6-disubstituted carbazolyl, wherein each R^S independently is phenyl, methyl, ethyl, isopropyl, or tertiary-butyl, 2,7-di(tertiary-butyl)-carbazolyl, 3,6-di(tertiary-butyl)-carbazolyl, 2,7-di(tertiary-octyl)-carbazolyl, 3,6-di(tertiary-octyl)-carbazolyl, 2,7-diphenylcarbazolyl, 3,6-diphenylcarbazolyl, 2,7-bis(2,4,6-trimethylphenyl)-carbazolyl or 3,6-bis(2,4,6-trimethylphenyl)-carbazolyl.

[0043] Examples of unsubstituted (C₂-C₄₀)heterocycloalkyl are unsubstituted (C₂-C₂₀)heterocycloalkyl, unsubstituted (C₂-C₁₀)heterocycloalkyl, aziridin-1-yl, oxetan-2-yl, tetrahydrofuran-3-yl, pyrrolidin-1-yl, tetrahydrothiophen-S,S-dioxide-2-yl, morpholin-4-yl, 1,4-dioxan-2-yl, hexahydroazepin-4-yl, 3-oxa-cyclooctyl, 5-thio-cyclononyl, and 2-aza-cyclodecyl.

[0044] The term “halogen atom” means fluorine atom (F), chlorine atom (Cl), bromine atom (Br), or iodine atom (I) radical. The term “halide” means fluoride (F⁻), chloride (Cl⁻), bromide (Br⁻), or iodide (I⁻) anion.

[0045] 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. When a saturated chemical group is substituted by one or more substituents R^S, one or more double and/or triple bonds optionally may or may not be present in substituents R^S.

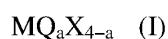
[0046] The term “unsaturated” means containing one or more carbon-carbon double bonds, carbon-carbon triple bonds, and (in heteroatom-containing groups) carbon-nitrogen, carbon-phosphorous, carbon-silicon double bonds, or carbon-nitrogen triple bonds, not including any such double bonds that may be present in substituents R^S, if any, or in (hetero)aromatic rings, if any.

Compositions, Thioguanidine Complexes, and Catalyst Systems

[0047] In view of the foregoing definitions, specific embodiments of the present application will now be described. It should be understood that the disclosure may be embodied in different forms and should not be construed as limited to any specific embodiment set forth. Rather, the

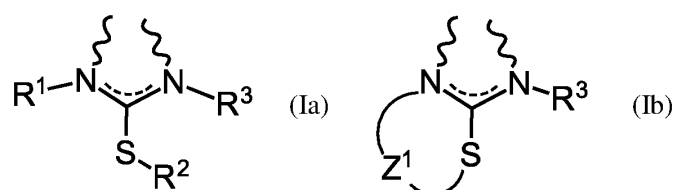
embodiments are provided so that this disclosure will be thorough and complete and will fully convey the scope of the subject matter to those skilled in the art.

[0048] Compositions according to embodiments of this disclosure include at least one thioguanidine complex according to Formula (I):



[0049] In Formula (I), M is a metal center chosen from Ti, Zr, or Hf. In some embodiments, M is titanium. In other embodiments, M is zirconium. In still other embodiments, M is hafnium. In some embodiments, M is in a formal oxidation state of +2, +3, or +4. In illustrative embodiments, M is in a formal oxidation state of +4.

[0050] In Formula (I), *a* is 1 or 2 and represents a number of groups Q present in the thioguanidine complex. Thus, the at least one thioguanidine complex may have either one group Q or two groups Q. When two groups Q are present (*i.e.*, when *a* = 2), each group Q may be the same or different. Each group Q of the at least one thioguanidine complex is a bidentate thioguanidine ligand bound to the metal center. The bidentate thioguanidine ligand may have Formula (Ia) or Formula (Ib), in which wavy bonds denote a coordination of an atom to the metal center M and dotted lines denote delocalization of electrons across multiple bonds:



[0051] In embodiments for which *a* = 1, the group Q may have either Formula (Ia) or Formula (Ib). In embodiments for which *a* = 2, both groups Q may have Formula (Ia), both groups Q may have Formula (Ib), or one group Q may have Formula (Ia) while the other group Q has Formula (Ib).

[0052] In the at least one thioguanidine complex, each group R^1 , R^2 , and R^3 is independently chosen from alkyl groups or aryl groups. Thus, if *a* = 2 and two groups Q are present, each group R^1 , R^2 , and R^3 in the at least one thioguanidine complex may be the same or different

from other groups R^1 , R^2 , and R^3 in the at least one thioguanidine complex. Each group Z^1 in the at least one thioguanidine complex is independently chosen from alkylene groups. Likewise, if $a=2$ and two groups Q are present, both having Formula (Ib), for example, each group Z^1 , in the at least one thioguanidine complex may be the same or different from other groups Z^1 in the at least one thioguanidine complex.

[0053] In Formula (I), if $a=2$, groups R^3 of the two groups Q are optionally linked to each other through at least one covalent bond. In embodiments for which the at least one thioguanidine complex according to Formula (I) has $a=2$ and for which the groups R^3 of the two groups Q are linked to each other through at least one covalent bond, the two groups Q of the complex form a single tetradentate ligand bound to the metal center M .

[0054] In Formula (I), each X is covalently bonded or coordinated to the metal center and is independently chosen from alkyl groups, halides, or amides. According to embodiments, each X of the at least one thioguanidine complex according to Formula (I) independently is a monodentate or polydentate ligand that is neutral, monoanionic, or dianionic. Generally, X and a of the at least one thioguanidine complex of Formula (I) are chosen in such a way that the thioguanidine complexes according to Formula (I) are overall neutral. In some embodiments, each X independently is a monodentate ligand. In one embodiment when there are two or more X monodentate ligands, each X is the same. In some embodiments the monodentate ligand is the monoanionic ligand. The monoanionic ligand has a net formal oxidation state of -1 . Each monoanionic ligand may independently be hydride, (C_1-C_{40}) hydrocarbyl carbanion, (C_1-C_{40}) heterohydrocarbyl carbanion, halide, nitrate, carbonate, phosphate, borate, borohydride, sulfate, $HC(O)O^-$, alkoxide or aryloxide (RO^-), (C_1-C_{40}) hydrocarbyl $C(O)O^-$, $HC(O)N(H)^-$, (C_1-C_{40}) hydrocarbyl $C(O)N(H)^-$, (C_1-C_{40}) hydrocarbyl $C(O)N((C_1-C_{20})$ hydrocarbyl) $^-$, $R^K R^L B^-$, $R^K R^L N^-$, $R^K O^-$, $R^K S^-$, $R^K R^L P^-$, or $R^M R^K R^L Si^-$, wherein each R^K , R^L , and R^M independently is hydrogen, (C_1-C_{40}) hydrocarbyl, or (C_1-C_{40}) heterohydrocarbyl, or R^K and R^L are taken together to form a (C_2-C_{40}) hydrocarbylene or (C_1-C_{40}) heterohydrocarbylene and R^M as defined previously.

[0055] In some embodiments at least one monodentate ligand of X independently is the neutral ligand. In one embodiment, the neutral ligand is a neutral Lewis base group that is $R^X N R^K R^L$, $R^K O R^L$, $R^K S R^L$, or $R^X P R^K R^L$, wherein each R^X independently is hydrogen,

(C₁-C₄₀)hydrocarbyl, [(C₁-C₁₀)hydrocarbyl]₃Si, [(C₁-C₁₀)hydrocarbyl]₃Si(C₁-C₁₀)hydrocarbyl, or (C₁-C₄₀)heterohydrocarbyl and each R^K and R^L independently is as defined previously.

[0056] In some embodiments, each X is a monodentate ligand that independently is a halogen atom, unsubstituted (C₁-C₂₀)hydrocarbyl, unsubstituted (C₁-C₂₀)hydrocarbylC(O)O-, or an amide such as R^KR^LN- 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 an amide such as R^KR^LN- wherein each of R^K and R^L independently is an unsubstituted (C₁-C₁₀)hydrocarbyl.

[0057] In some embodiments there are at least two Xs and the two Xs are taken together to form a bidentate ligand. In some embodiments the bidentate ligand is a neutral bidentate ligand. In one embodiment, the neutral bidentate ligand is a diene of formula (R^D)₂C=C(R^D)-C(R^D)=C(R^D)₂, wherein each R^D independently is H, unsubstituted (C₁-C₆)alkyl, phenyl, or naphthyl. In some embodiments the bidentate ligand is a monoanionic-mono(Lewis base) ligand. The monoanionic-mono(Lewis base) ligand may be a 1,3-dionate of formula (D): R^E-C(O⁻)=CH-C(=O)-R^E (D), wherein each R^D independently is H, unsubstituted (C₁-C₆)alkyl, phenyl, or naphthyl. In some embodiments the bidentate ligand is a dianionic ligand. The dianionic ligand has a net formal oxidation state of -2. In one embodiment, each dianionic ligand independently is carbonate, oxalate (i.e., -O₂CC(O)O-), (C₂-C₄₀)hydrocarbylene dicarbanion, (C₁-C₄₀) heterohydrocarbylene dicarbanion, phosphate, or sulfate.

[0058] As previously mentioned, the number and charge (neutral, monoanionic, dianionic) of X are selected depending on the formal oxidation state of M such that the polymerization catalysts of Formula (I) and overall neutral.

[0059] In some embodiments each X is the same, wherein each X is methyl; isobutyl; neopentyl; neophyl; trimethylsilylmethyl; phenyl; benzyl; or chloro. In some embodiments, *a* is 1 and all groups X are identical. In some embodiments, *a* is 2 and all groups X are identical. In some embodiments, all groups X are benzyl. In some embodiments, all groups X are chloro.

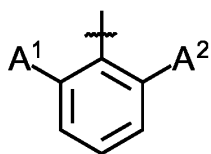
[0060] In some embodiments at least two X are different. In some embodiments, each X is a different one of methyl; isobutyl; neopentyl; neophyl; trimethylsilylmethyl; phenyl; benzyl; and chloro.

[0061] Further non-limiting embodiments of the at least one thioguanidine complex having Formula (I) will now be described.

[0062] Each group R^1 of the at least one thioguanidine complex according to Formula (I), bound to a nitrogen atom of the thioguanidine ligand, is independently chosen from alkyl groups or aryl groups. Thus, if multiple groups R^1 are present in one thioguanidine complex, each individual group R^1 may be an alkyl group, each individual group R^1 may be an aryl group, or one or more individual group R^1 may be an alkyl group while one or more other individual groups R^1 may be an aryl group. In some embodiments, one or more individual groups R^1 may be an alkyl group chosen from (C_1-C_{40}) hydrocarbyls; substituted (C_1-C_{40}) hydrocarbyls; (C_1-C_{40}) heterohydrocarbyls; substituted (C_1-C_{40}) heterohydrocarbyls; (C_1-C_{10}) hydrocarbyls; substituted (C_1-C_{10}) hydrocarbyls; (C_1-C_{10}) heterohydrocarbyls; or substituted (C_1-C_{10}) heterohydrocarbyls, for example. In some embodiments, one or more individual groups R^1 may be an aryl group chosen from (C_6-C_{40}) aryl groups, substituted (C_6-C_{40}) aryl groups; (C_6-C_{10}) aryl groups, substituted (C_6-C_{10}) aryl groups, for example.

[0063] In illustrative embodiments, each group R^1 may be independently chosen from phenyl or a C_1 to C_{10} alkyl group. In further illustrative embodiments, each group R^1 may be independently chosen from phenyl or a C_1 to C_4 alkyl group. In further illustrative embodiments, each group R^1 may be independently chosen from phenyl or *n*-butyl. In further illustrative embodiments, each group R^1 may be phenyl. In further illustrative embodiments, each group R^1 may be *n*-butyl.

[0064] In further illustrative embodiments, one or more group R^1 may be independently chosen from groups according to the following formula:



in which A^1 and A^2 are independently hydrogen or a (C_1-C_{10}) alkyl group. In some embodiments, groups A^1 and A^2 may be independently hydrogen or methyl. In other embodiments, groups A^1 and A^2 may both be hydrogen, whereby group R^1 would be phenyl. In other embodiments, groups A^1 and A^2 may both be methyl.

[0065] Each group R^2 of the at least one thioguanidine complex according to Formula (I), bound to a sulfur atom of the thioguanidine ligand, is independently chosen from alkyl groups or aryl groups. Thus, if multiple groups R^2 are present in one thioguanidine complex, each individual group R^2 may be an alkyl group, each individual group R^2 may be an aryl group, or one or more individual group R^2 may be an alkyl group while one or more other individual groups R^2 may be an aryl group. In some embodiments, one or more individual groups R^2 may be an alkyl group chosen from (C_1-C_{40}) hydrocarbyls; substituted (C_1-C_{40}) hydrocarbyls; (C_1-C_{40}) heterohydrocarbyls; substituted (C_1-C_{40}) heterohydrocarbyls; (C_1-C_{10}) hydrocarbyls; substituted (C_1-C_{10}) hydrocarbyls; (C_1-C_{10}) heterohydrocarbyls; or substituted (C_1-C_{10}) heterohydrocarbyls, for example. In some embodiments, one or more individual groups R^2 may be an aryl group chosen from (C_6-C_{40}) aryl groups, substituted (C_6-C_{40}) aryl groups; (C_6-C_{10}) aryl groups, or substituted (C_6-C_{10}) aryl groups, for example.

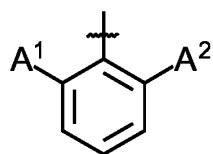
[0066] In illustrative embodiments, each group R^2 may be independently chosen from phenyl or a C_1 to C_{10} alkyl group. In further illustrative embodiments, each group R^2 may be independently chosen from phenyl or a C_1 to C_4 alkyl group. In further illustrative embodiments, each group R^2 may be independently chosen from phenyl or methyl. In further illustrative embodiments, each group R^2 may be methyl. In further illustrative embodiments, each group R^2 may be phenyl.

[0067] Each group R^3 of the at least one thioguanidine complex according to Formula (I), bound to a nitrogen atom of the thioguanidine ligand, is independently chosen from alkyl groups or aryl groups. Thus, if multiple groups R^3 are present in one thioguanidine complex, each

individual group R^3 may be an alkyl group, each individual group R^3 may be an aryl group, or one or more individual group R^3 may be an alkyl group while one or more other individual groups R^3 may be an aryl group. In some embodiments, one or more individual groups R^3 may be an alkyl group chosen from (C_1-C_{40}) hydrocarbyls; substituted (C_1-C_{40}) hydrocarbyls; (C_1-C_{40}) heterohydrocarbyls; substituted (C_1-C_{40}) heterohydrocarbyls; (C_1-C_{10}) hydrocarbyls; substituted (C_1-C_{10}) hydrocarbyls; (C_1-C_{10}) heterohydrocarbyls; or substituted (C_1-C_{10}) heterohydrocarbyls, for example. In some embodiments, one or more individual groups R^3 may be an aryl group chosen from (C_6-C_{40}) aryl groups, substituted (C_6-C_{40}) aryl groups; (C_6-C_{10}) aryl groups, substituted (C_6-C_{10}) aryl groups, for example.

[0068] In illustrative embodiments, each group R^3 may be independently chosen from phenyl or a C_1 to C_{10} alkyl group. In further illustrative embodiments, each group R^3 may be independently chosen from phenyl or a C_1 to C_4 alkyl group. In further illustrative embodiments, each group R^3 may be independently chosen from phenyl or *n*-butyl. In further illustrative embodiments, each group R^3 may be phenyl. In further illustrative embodiments, each group R^3 may be *n*-butyl.

[0069] In further illustrative embodiments, one or more group R^3 may be independently chosen from groups according to the following formula:



in which A^1 and A^2 are independently hydrogen or a (C_1-C_{10}) alkyl group. In some embodiments, groups A^1 and A^2 may be independently hydrogen or methyl. In other embodiments, groups A^1 and A^2 may both be hydrogen, whereby group R^3 would be phenyl. In other embodiments, groups A^1 and A^2 may both be methyl.

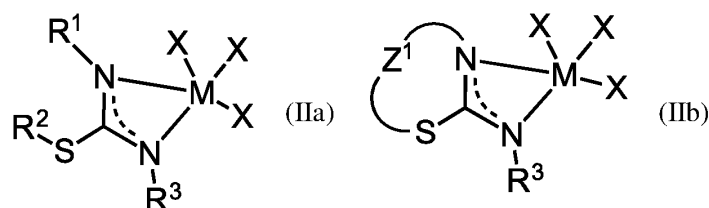
[0070] As previously described, in the at least one thioguanidine complex according to Formula (I), if $a = 2$, groups R^3 of the two groups Q are optionally linked to each other through at least one covalent bond. In embodiments for which the at least one thioguanidine complex

according to Formula (I) has $a = 2$ and for which the groups R^3 of the two groups Q are linked to each other through at least one covalent bond, the groups R^3 may form a bridging group Z^2 . When present, bridging groups Z^2 of the at least one thioguanidine complex according to Formula (I) may be independently chosen from alkylene groups such as, for example, (C_3-C_{40}) hydrocarbylene, substituted (C_3-C_{40}) hydrocarbylene, (C_3-C_{10}) hydrocarbylene, substituted (C_3-C_{10}) hydrocarbylene, (C_4-C_5) hydrocarbylene, substituted (C_4-C_5) hydrocarbylene, $[(C+Si)_3-(C+Si)_{40}]$ organosilylene, substituted $[(C+Si)_3-(C+Si)_{40}]$ organosilylene, $[(C+Ge)_3-(C+Ge)_{40}]$ organogermylene, or substituted $[(C+Ge)_3-(C+Ge)_{40}]$ organogermylene. Bridging groups Z^2 will be described subsequently in greater detail, with reference to thioguanidine complexes of Formulas (IVa), (IVb), and (IVc).

[0071] When present, each group Z^1 of the at least one thioguanidine complex according to Formula (I) is independently chosen from alkylene groups such as, for example, (C_3-C_{40}) hydrocarbylene, substituted (C_3-C_{40}) hydrocarbylene, (C_3-C_{10}) hydrocarbylene, substituted (C_3-C_{10}) hydrocarbylene, $[(C+Si)_3-(C+Si)_{40}]$ organosilylene, substituted $[(C+Si)_3-(C+Si)_{40}]$ organosilylene, $[(C+Ge)_3-(C+Ge)_{40}]$ organogermylene, or substituted $[(C+Ge)_3-(C+Ge)_{40}]$ organogermylene.

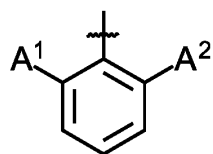
[0072] Further non-limiting embodiments of the at least one thioguanidine complex having Formula (I) will now be described.

[0073] According to some embodiments, the at least one thioguanidine complex may have Formula (I), in which a is 1, such that the at least one thioguanidine complex has Formula (IIa) or Formula (IIb):



where M, R^1 , R^2 , R^3 , Z^1 , and X are as defined in Formula (I).

[0074] In illustrative embodiments, the at least one thioguanidine complex has Formula (IIa) and groups R^1 and R^3 are independently chosen from groups according to the following formula:

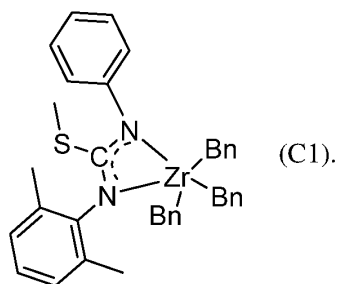


in which A^1 and A^2 are independently hydrogen or a (C_1 – C_{10}) alkyl group. In some such embodiments, groups A^1 and A^2 may be independently hydrogen or methyl. In other such embodiments, groups A^1 and A^2 may both be hydrogen, whereby group R^1 or R^3 would be phenyl. In other such embodiments, groups A^1 and A^2 may both be methyl.

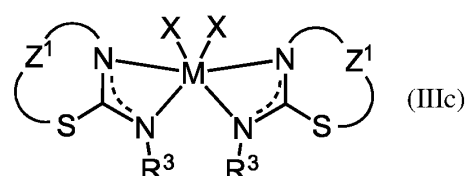
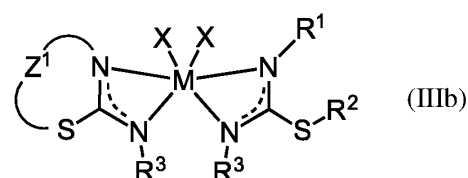
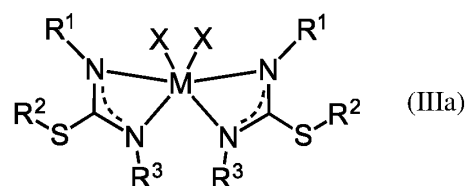
[0075] In illustrative embodiments, the at least one thioguanidine complex has Formula (IIa) or Formula (IIb) and R^2 is a (C_1 – C_{10}) alkyl group. For example, the at least one thioguanidine complex may have Formula (IIa) or Formula (IIb) and R^2 may be methyl.

[0076] In illustrative embodiments, the at least one thioguanidine complex has Formula (IIa) or Formula (IIb) and all groups X are identical. For example, each group X may be benzyl or each group X may be chloride.

[0077] In a specific illustrative embodiment, the at least one thioguanidine complex of the general Formula (IIa) may be a thioguanidine complex of Formula C1:



[0078] According to some embodiments, the at least one thioguanidine complex may have Formula (I), in which a is 2, and the at least one thioguanidine complex may have Formula (IIIa), Formula (IIIb), or Formula (IIIc):

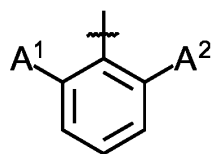


where M, R¹, R², R³, Z¹, and X are as defined in Formula (I).

[0079] In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) or Formula (IIIb), in which each R¹ is independently chosen from phenyl or a (C₁–C₁₀) alkyl group. In further illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) or Formula (IIIb), in which each R¹ is independently chosen from phenyl or a (C₁–C₄) alkyl group. In further illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) or Formula (IIIb), in which each R¹ is independently chosen from phenyl or *n*-butyl. In further illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) or Formula (IIIb), in which each R¹ is phenyl or each R¹ is *n*-butyl.

[0080] In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) or Formula (IIIb), in which each R² is a (C₁–C₁₀) alkyl group. In further illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) or Formula (IIIb), in which each R² is methyl.

[0081] In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa), Formula (IIIb), or Formula (IIIc), in which each R³ is independently chosen from groups according to the formula

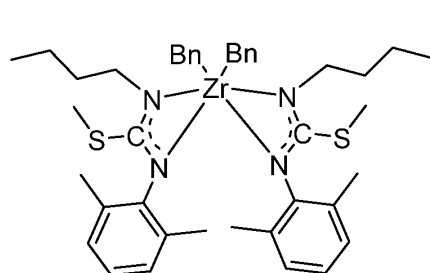


in which A¹ and A² are independently hydrogen or a (C₁–C₁₀) alkyl group. In some such embodiments, groups A¹ and A² may be independently hydrogen or methyl. In other such embodiments, groups A¹ and A² may both be hydrogen, whereby group R³ would be phenyl. In other such embodiments, groups A¹ and A² may both be methyl.

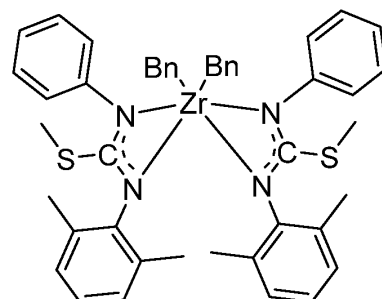
[0082] In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa), Formula (IIIb), or Formula (IIIc), in which each X is independently a benzyl group or a chloride coordinated to the metal center. In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa), Formula (IIIb), or Formula (IIIc), in which each X is a benzyl group coordinated to the metal center. In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa), Formula (IIIb), or Formula (IIIc), in which each X is a chloride coordinated to the metal center.

[0083] In illustrative embodiments, the at least one thioguanidine composition has Formula (IIIa) in which both groups R¹ are identical, both groups R² are identical, both groups R³ are identical, and both groups X are identical. Such embodiments represent examples of thioguanidine complexes of Formula (I), in which both groups Q are identical. In further illustrative embodiments, the at least one thioguanidine composition has Formula (IIIc) in which both groups Z¹ are identical and both groups X are identical. Such embodiments represent additional examples of thioguanidine complexes of Formula (I), in which both groups Q are identical.

[0084] In specific illustrative embodiments, the at least one thioguanidine complex of the general Formula (IIIa) may be a thioguanidine complex of Formula C2 or Formula C3:

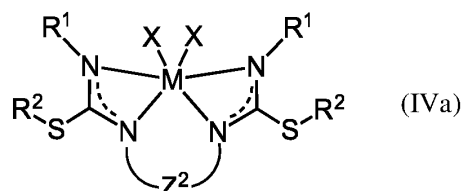


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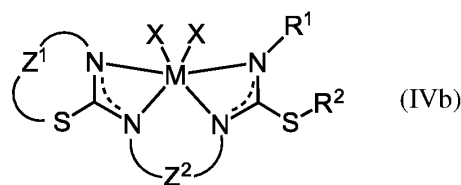


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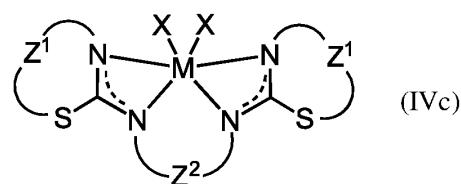
[0085] According to some embodiments, the at least one thioguanidine complex may have Formula (I), in which a is 2; R^3 of the two groups Q are linked to each other as a bridging group Z^2 ; and the at least one thioguanidine complex may have Formula (IVa), Formula (IVb), or Formula (IVc):



(IVa)



(IVb)



(IVc)

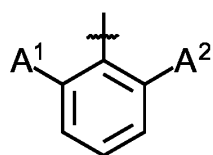
where M , R^1 , R^2 , Z^1 , and X are as defined in Formula (I), and Z^2 is an alkylene group formed from two groups R^3 as defined in Formula (I).

[0086] In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa), Formula (IVb), or Formula (IVc), in which the bridging group Z^2 is $-(CH_2)_n-$, where n is from 4 to 10. In further illustrative embodiments, the at least one thioguanidine

composition has Formula (IVa), Formula (IVb), or Formula (IVc), in which the bridging group Z^2 is $-(CH_2)_n-$, where n is 4 or 5.

[0087] In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa) or Formula (IVb), in which each R^2 is a C_1 to C_{10} alkyl group. In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa) or Formula (IVb), in which each R^2 is methyl.

[0088] In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa) or Formula (IVb), in which each R^1 is independently chosen from groups having the formula:



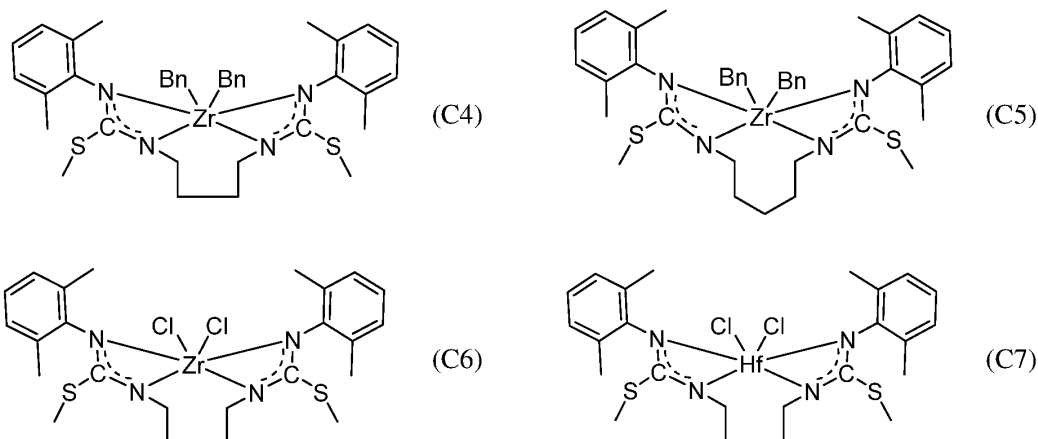
in which A^1 and A^2 are independently hydrogen or a (C_1-C_{10}) alkyl group. In some such embodiments, groups A^1 and A^2 may be independently hydrogen or methyl. In other such embodiments, groups A^1 and A^2 may both be hydrogen, whereby group R^3 would be phenyl. In other such embodiments, groups A^1 and A^2 may both be methyl.

[0089] In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa), Formula (IVb), or Formula (IVc), in which each X is independently a benzyl group or a chloride coordinated to the metal center. In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa), Formula (IVb), or Formula (IVc), in which each X is a benzyl group coordinated to the metal center. In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa), Formula (IVb), or Formula (IVc), in which each X is a chloride coordinated to the metal center.

[0090] In illustrative embodiments, the at least one thioguanidine composition has Formula (IVa) in which both groups R^1 are identical, both groups R^2 are identical, and both groups X are identical. Such embodiments represent examples of thioguanidine complexes of Formula (I), in which both groups Q are identical. In further illustrative embodiments, the at

least one thioguanidine composition has Formula (IVc) in which both groups Z^1 are identical and both groups X are identical. Such embodiments represent additional examples of thioguanidine complexes of Formula (I), in which both groups Q are identical.

[0091] In specific illustrative embodiments, the at least one thioguanidine complex of the general Formula (IVa) may be a thioguanidine complex chosen from compounds of Formula C4, C5, C6, or C7:



[0092] In some embodiments, thioguanidine complexes of Formula (IVa), Formula (IVb), or Formula (IVc), such as, for example, complexes in which both groups X are chloride, or the complexes of Formula C6 or Formula C7, may exist in the composition in dimeric form. The dimeric form may result from chloro-bridging between two discrete molecules of the thioguanidine complexes.

[0093] In further embodiments, the compositions may include combinations or mixtures of a plurality of thioguanidine complexes according to Formula (I). For example, the compositions may include two, three, four, five, or more than five thioguanidine complexes according to Formula (I). In illustrative embodiments, the plurality of thioguanidine complexes according to Formula (I) may include any of the compounds C1, C2, C3, C4, C5, C6, C7, as previously described, in any combination or proportion.

Polyolefin Compositions

[0094] Polyolefin compositions such as ethylene-co-alkylene copolymers according to embodiments of this disclosure include the reaction product of ethylene and one or more olefinic monomers in the presence of a catalytic amount of at least one of the compositions previously described, which include at least one thioguanidine complex, under polymerization conditions and optionally in the presence of one or more co-catalysts and/or scavengers.

[0095] The polyolefin compositions can be, for example, be an ethylene-based polymer, for example homopolymers and/or interpolymers (including copolymers) of ethylene and optionally one or more comonomers such as α -olefins. Such ethylene-based polymers can have a density in the range of 0.860 g/cm³ to 0.973 g/cm³. All individual values and subranges from 0.860 g/cm³ to 0.973 g/cm³ are included herein and disclosed herein; for example, the density can be from a lower limit of 0.860, 0.880, 0.885, 0.900, 0.905, 0.910, 0.915, or 0.920 g/cm³ to an upper limit of 0.973, 0.963, 0.960, 0.955, 0.950, 0.925, 0.920, 0.915, 0.910, or 0.905 g/cm³.

[0096] As used herein, the term “ethylene-based polymer” means a polymer having greater than 50 mol.% units derived from ethylene monomer.

[0097] In one embodiment, the ethylene-based polymers can have a long chain branching frequency in the range of from 0.0 to 3 long chain branches (LCB) per 1000 carbon atoms. In one embodiment, the ethylene-based polymers can have a molecular weight distribution (M_w/M_n , also known as polydispersity index (PDI)) (measured according to the conventional GPC method) in the range of from greater than or equal to 2.0. All individual values and subranges from greater than or equal to 2 are included herein and disclosed herein; for example, the ethylene/ α -olefin copolymer may have a molecular weight distribution (M_w/M_n) in the range of from 2 to 20; or in the alternative, the ethylene/ α -olefin interpolymer may have a molecular weight distribution (M_w/M_n) in the range of from 2 to 5.

[0098] In another embodiment, the ethylene-based polymers may have molecular weight distribution, M_w/M_n , of less than 2, e.g., when chain transfer agents are used in the polymerization. All individual values and subranges less than 2 are included and disclosed herein. For example, the M_w/M_n of the ethylene-based polymers may be less than 2, or in the alternative, less than 1.9, or in the alternative, less than 1.8, or in the alternative, less than 1.5.

In a particular embodiment, the ethylene-based polymer has a molecular weight distribution from 0.5 to 2.

[0099] In one embodiment, the ethylene-based polymers can have a molecular weight (M_w) in the range of from equal to or greater than 20,000 g/mole, for example, in the range of from 20,000 to 1,000,000 g/mole, or in the alternative, from 20,000 to 350,000 g/mole, or in the alternative, from 100,000 to 750,000 g/mole.

[00100] In one embodiment, the ethylene-based polymers can have a melt index (I_2) in the range of 0.02 to 200 g/10 minutes. All individual values and subranges from 0.02 to 200 g/10 minutes are included herein and disclosed herein; for example, the melt index (I_2) can be from a lower limit of 0.1, 0.2, 0.5, 0.6, 0.8, 1, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 10, 15, 20, 30, 40, 50, 60, 80, 90, 100, or 150 g/10 minutes, to an upper limit of 0.9, 1, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 10, 15, 20, 30, 40, 50, 60, 80, 90, 100, 150, or 200 g/10 minutes.

[0100] In one embodiment, the ethylene-based polymers can have a melt flow ratio (I_{10}/I_2) in the range of from 5 to 30. All individual values and subranges from 5 to 30 are included herein and disclosed herein; for example, the melt flow ratio (I_{10}/I_2) can be from a lower limit of 5, 5.5, 6, 6.5, 8, 10, 12, 15, 20, or 25 to an upper limit of 5.5, 6, 6.5, 8, 10, 12, 15, 20, 25, or 30.

[0101] The ethylene-based polymers may comprise less than 50 mole percent of units derived from one or more α -olefin comonomers. All individual values and subranges from less than 50 mole percent are included herein and disclosed herein; for example, the ethylene-based polymers may comprise from less than 30 mole percent of units derived from one or more α -olefin comonomers; or in the alternative, less than 20 mole percent of units derived from one or more α -olefin comonomers; or in the alternative, from 1 to 20 mole percent of units derived from one or more α -olefin comonomers; or in the alternative, from 1 to 10 mole percent of units derived from one or more α -olefin comonomers.

[0102] The α -olefin comonomers typically have no more than 20 carbon atoms. For example, the α -olefin comonomers may preferably have 3 to 10 carbon atoms, and more preferably 3 to 8 carbon atoms. Exemplary α -olefin comonomers 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. The one or more α -olefin comonomers may, for example, 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.

[0103] The ethylene-based polymers may comprise greater than 50 mole percent of units derived from ethylene. All individual values and subranges from greater than 50 mole percent are included herein and disclosed herein; for example, the ethylene-based polymers may comprise at least 52 mole percent of units derived from ethylene; or in the alternative, at least 65 percent by weight of units derived from ethylene; or in the alternative, at least 85 mole percent of units derived from ethylene; or in the alternative, from 50 to 100 mole percent of units derived from ethylene; or in the alternative, from 80 to 100 mole percent of units derived from ethylene.

[0104] In one embodiment, the ethylene-based polymer comprises an olefin block copolymer prepared according to an aforementioned chain-shuttling polymerization process. The olefin block copolymer or poly(ethylene alpha-olefin) block copolymer comprises an ethylene-derived hard segment (i.e., polyethylene hard segment) and a soft segment comprising residuals from the alpha-olefin and ethylene. The residuals of the alpha-olefin and ethylene typically are approximately randomly distributed in the soft segment. Preferably, the polyethylene hard segment is characterizable as having less than 5 mole percent (mol %) of a residual of the alpha-olefin covalently incorporated therein. Preferably, the poly(ethylene alpha-olefin) block copolymer is characterizable as having a melting temperature of greater than 100 °C, and more preferably greater than 120 °C, as determined by Differential Scanning Calorimetry using the procedure described later. The poly(ethylene alpha-olefin) block copolymers comprise ethylene residuals and one or more copolymerizable α -olefin comonomer residuals (i.e., ethylene and one or more copolymerizable α -olefin comonomers in polymerized form). The poly(ethylene alpha-olefin) block copolymers are characterized by multiple blocks or segments of two or more polymerized monomer units differing in chemical or physical properties. That is, the ethylene/ α -olefin interpolymers are block interpolymers, preferably multi-block interpolymers or copolymers. The terms “interpolymer” and “copolymer” are used interchangeably herein. In some embodiments, the multi-block copolymer can be represented by the following formula: $(AB)_n$, where n is at least 1, preferably an integer greater than 1, such as 2, 3, 4, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, or higher, “A” represents a hard block or segment and “B” represents

a soft block or segment. Preferably, As and Bs are linked in a linear fashion, not in a branched or a star fashion.

[0105] “Hard” segments refer to blocks of polymerized units in which ethylene residuals are present in an amount greater than 95 weight percent, and preferably greater than 98 weight percent in the poly(ethylene alpha-olefin) block copolymers. In other words, the comonomer (i.e., alpha-olefin) residuals content in the hard segments is less than 5 weight percent, and preferably less than 2 weight percent. In some embodiments, the hard segments comprise all or substantially all ethylene residuals. The phrases “polyethylene hard segment” and “ethylene-derived hard segment” are synonymous and mean the hard segment portion of a poly(ethylene alpha-olefin) block copolymer.

[0106] “Soft” segments refer to blocks of polymerized units in which the comonomer (i.e., alpha-olefin) residuals content is greater than 5 weight percent, preferably greater than 8 weight percent, greater than 10 weight percent, or greater than 15 weight percent in the poly(ethylene alpha-olefin) block copolymers. In some embodiments, the comonomer residuals content in the soft segments can be greater than 20 weight percent, greater than 25 weight percent, greater than 30 weight percent, greater than 35 weight percent, greater than 40 weight percent, greater than 45 weight percent, greater than 50 weight percent, or greater than 60 weight percent.

Polymerization Process

[0107] Any conventional polymerization processes may be employed to produce the polyolefin composition according to the present invention. Such conventional polymerization processes include, but are not limited to, solution polymerization process, particle forming polymerization process, and combinations thereof using one or more conventional reactors e.g. loop reactors, isothermal reactors, fluidized bed reactors, stirred tank reactors, batch reactors in parallel, series, and/or any combinations thereof.

[0108] In one embodiment, the polyolefin composition may be produced, for example, via solution-phase polymerization process using one or more loop reactors, isothermal reactors, and combinations thereof.

[0109] In general, the solution phase polymerization process occurs in one or more well-stirred reactors such as one or more loop reactors or one or more spherical isothermal reactors at

a temperature in the range of from 120 °C to 300 °C; for example, from 160 °C to 215 °C, and at pressures in the range of from 300 to 1500 psi; for example, from 400 to 750 psi. The residence time in solution phase polymerization process is typically in the range of from 2 to 30 minutes; for example, from 5 to 15 minutes. Ethylene, one or more solvents, one or more high temperature olefin polymerization catalyst systems, one or more co-catalysts and/or scavengers, and optionally one or more comonomers are fed continuously to the one or more reactors. Exemplary solvents include, but are not limited to, isoparaffins. For example, such solvents are commercially available under the name ISOPAR E from ExxonMobil Chemical Co., Houston, Texas. The resultant mixture of the ethylene-based polymer and solvent is then removed from the reactor and the ethylene-based polymer is isolated. Solvent is typically recovered via a solvent recovery unit, i.e. heat exchangers and vapor liquid separator drum, and is then recycled back into the polymerization system.

[0110] In one embodiment, the ethylene-based polymer may be produced via solution polymerization in a single reactor system, for example a single loop reactor system, wherein ethylene and optionally one or more α -olefins are polymerized in the presence of one or more high temperature olefin polymerization catalyst systems, optionally one or more other catalysts, and optionally one or more co-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 one or more an olefin polymerization catalyst systems, optionally one or more other catalysts, and optionally one or more co-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 one or more high temperature olefin polymerization catalyst systems, as described herein, in both reactors.

[0111] In one embodiment, the ethylene-based polymer may be made using a gas phase polymerization process, e.g., utilizing a fluidized bed reactor. This type reactor and means for operating the reactor are well known and completely described in, for example, US 3,709,853; 4,003,712; 4,011,382; 4,302,566; 4,543,399; 4,882,400; 5,352,749; 5,541,270; EP-A- 0 802 202 and Belgian Patent No. 839,380. These patents disclose gas phase polymerization processes

wherein the polymerization medium is either mechanically agitated or fluidized by the continuous flow of the gaseous monomer and diluent.

[0112] A polymerization process may be effected as a continuous gas phase process such as a fluid bed process. A fluid bed reactor may comprise a reaction zone and a so-called velocity reduction zone. The reaction zone may comprise a bed of growing polymer particles, formed polymer particles and a minor amount of catalyst particles fluidized by the continuous flow of the gaseous monomer and diluent to remove heat of polymerization through the reaction zone. Optionally, some of the re-circulated gases may be cooled and compressed to form liquids that increase the heat removal capacity of the circulating gas stream when readmitted to the reaction zone. A suitable rate of gas flow may be readily determined by simple experiment. Make up of gaseous monomer to the circulating gas stream is at a rate equal to the rate at which particulate polymer product and monomer associated therewith is withdrawn from the reactor and the composition of the gas passing through the reactor is adjusted to maintain an essentially steady state gaseous composition within the reaction zone. The gas leaving the reaction zone is passed to the velocity reduction zone where entrained particles are removed. Finer entrained particles and dust may optionally be removed in a cyclone and/or fine filter. The gas is passed through a heat exchanger wherein the heat of polymerization is removed, compressed in a compressor and then returned to the reaction zone.

[0113] The reactor temperature of the fluid bed process herein preferably ranges from 30 °C or 40 °C or 50 °C to 90 °C or 100 °C or 110 °C or 120 °C. In general, the reactor temperature is operated at the highest temperature that is feasible taking into account the sintering temperature of the polymer product within the reactor. In this fluid bed process, the polymerization temperature, or reaction temperature should be below the melting or “sintering” temperature of the polymer to be formed. Thus, the upper temperature limit in one embodiment is the melting temperature of the polyolefin produced in the reactor.

[0114] A slurry polymerization process can also be used. A slurry polymerization process generally uses pressures in the range of from 1 to 50 atmospheres and even greater and temperatures in the range of 0 °C to 120 °C, and more particularly from 30 °C to 100 °C. In a slurry polymerization, a suspension of solid, particulate polymer is formed in a liquid polymerization diluent medium to which ethylene and comonomers and often hydrogen along with catalyst are added. The suspension including diluent is intermittently or continuously

removed from the reactor where the volatile components are separated from the polymer and recycled, optionally after a distillation, to the reactor. The liquid diluent employed in the polymerization medium is typically an alkane having from 3 to 7 carbon atoms, a branched alkane in one embodiment. The medium employed should be liquid under the conditions of polymerization and relatively inert. When a propane medium is used the process must be operated above the reaction diluent critical temperature and pressure. In one embodiment, a hexane, isopentane or isobutane medium is employed.

[0115] Also useful is particle form polymerization, a process where the temperature is kept below the temperature at which the polymer goes into solution. Other slurry processes include those employing a loop reactor and those utilizing a plurality of stirred reactors in series, parallel, or combinations thereof. Non-limiting examples of slurry processes include continuous loop or stirred tank processes. Also, other examples of slurry processes are described in US 4,613,484 and Metallocene-Based Polyolefins Vol. 2 pp. 322-332 (2000), the disclosure of which are incorporated herein to the extent permitted.

[0116] In one embodiment, the catalyst composition containing at least one thioguanidine complex according to Formula (I) or of any embodiment of this disclosure may be combined with one or more additional catalysts in a polymerization process. Suitable catalysts for use include any compound or combination of compounds that is adapted for preparing polymers of the desired composition or type. Both heterogeneous and homogeneous catalysts may be employed. Examples of heterogeneous catalysts include the well known Ziegler–Natta compositions, especially Group 4 metal halides supported on Group 2 metal halides or mixed halides and alkoxides and the well known chromium or vanadium based catalysts. Preferably however, for ease of use and for production of narrow molecular weight polymer segments in solution, the catalysts for use herein are homogeneous catalysts comprising a relatively pure organometallic compound or metal complex, especially compounds or complexes based on metals selected from Groups 3–10 or the Lanthanide series of the Periodic Table of the Elements. It is preferred that any catalyst employed herein, not significantly detrimentally affect the performance of the other catalyst under the conditions of the present polymerization. Desirably, no catalyst is reduced in activity by greater than 25 percent, more preferably greater than 10 percent under the conditions of the present polymerization.

[0117] 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. Such fillers, e.g. calcium carbonate, talc, $\text{Mg}(\text{OH})_2$, may be present in levels from about 0 to about 20 percent, based on the weight of the inventive ethylene-based polymers and the one or more additives and/or fillers. The ethylene-based polymers may further be blended with one or more polymers to form a blend.

EXAMPLES

[0118] The following examples illustrate various catalyst compositions according to embodiments previously described but are not intended to limit the scope of the present disclosure in any manner.

[0119] All solvents and reagents were obtained from commercial sources and used as received unless otherwise noted. Anhydrous toluene, hexanes, tetrahydrofuran, and diethyl ether were purified *via* passage through activated alumina and, in some cases, Q-5 reactant. Solvents used for experiments performed in a nitrogen-filled glovebox were further dried by storage over activated 4Å molecular sieves. Glassware for moisture-sensitive reactions was dried in an oven overnight prior to use.

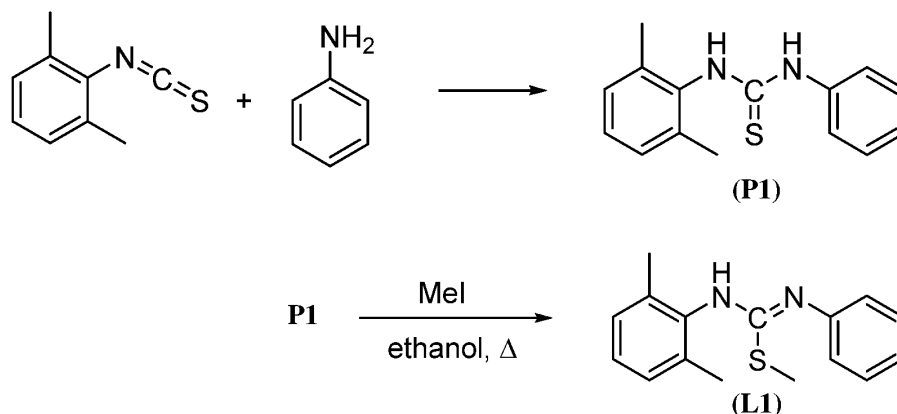
[0120] NMR spectra were recorded on Varian 400-MR and VNMR5-500 spectrometers. ^1H NMR (proton NMR) data are reported as follows: chemical shift (multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, sex = sextet, sept = septet and m = multiplet), integration, and 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 (carbon NMR) data were determined with ^1H decoupling, and the chemical shifts are reported in ppm versus tetramethylsilane.

[0121] Catalyst efficiency is calculated by dividing the number of grams of the polyolefin copolymer prepared by the total number of grams of metal **M** in the catalyst used (that is, grams of metal **M** of the at least one metal-ligand complex of Formula (I)). Thus, catalyst efficiency may be expressed as grams polyolefin copolymer prepared divided by grams metal **M** of metal-ligand complex(es) of Formula (I) used in the polymerization reaction.

[0122] Molecular weight data are determined by analysis on a hybrid Symyx/Dow built Robot-Assisted Dilution High-Temperature Gel Permeation Chromatographer (Sym-RAD-GPC). The polymer samples were dissolved by heating for 120 minutes at 160°C in 1,2,4-trichlorobenzene (TCB) at a concentration of 10 mg/mL stabilized by 300 ppm of butylated hydroxyl toluene (BHT). Each sample was then diluted to 1 mg/mL immediately before the injection of a 250-μL aliquot of the sample. The GPC was equipped with two Polymer Labs PLgel 10-μm MIXED-B columns (300 × 10 mm) at a flow rate of 2.0 mL/minute at 160 °C. Sample detection was performed using a PolyChar IR4 detector in concentration mode. A conventional calibration of narrow polystyrene (PS) standards was utilized with apparent units adjusted to homo-polyethylene (PE) using known Mark-Houwink coefficients for PS and PE in TCB at this temperature.

[0123] Melt temperature (T_m), glass transition temperature (T_g), crystallization temperature (T_c), and Heat of Melt are measured by differential scanning calorimetry (DSC Q2000, TA Instruments, Inc.) using a Heat-Cool-Heat temperature profile. Open-pan DSC samples of 3-6 mg of polymer are first heated from room temperature to setpoint at 10 °C per minute. Traces are analyzed individually using TA Universal Analysis software or TA Instruments TRIOS software.

EXAMPLE 1

Preparation of Ligand L1

[0124] Ligand L1 was prepared in two steps by first preparing 1-(2,6-dimethylphenyl)-3-phenylthiourea (P1) as an intermediate, then reacting P1 with methyl iodide (MeI) in ethanol to form ligand L1. The intermediate compound P1 was prepared by slowly adding a solution of 2,6-dimethylphenyl isothiocyanate (1.000 g, 6.13 mmol) in 5 mL Et₂O to a solution of aniline (0.571 g, 6.13 mmol) in 5 mL of Et₂O at 25 °C. The reaction mixture was stirred vigorously overnight to ensure completion of the reaction. The resulting white suspension was cooled to -30 °C for several hours, then the precipitate was isolated by filtration, rinsed twice with dry, cold Et₂O and dried under vacuum. The yield of intermediate P1 was 0.562 g (36%).

[0125] Intermediate P1 was characterized by proton NMR and carbon-13 NMR as follows: ¹H NMR (400 MHz, DMSO-*d*₆) δ 9.90 (br s, 1H), 8.98 (br s, 1H), 7.51 (br s, 1H), 7.34 (br s, 3H), 7.08 (br s, 4H), 2.21 (s, 6H). ¹³C NMR (101 MHz, DMSO-*d*₆) δ 180.21, 136.32, 128.52, 127.66, 124.36, 123.25, 18.03.

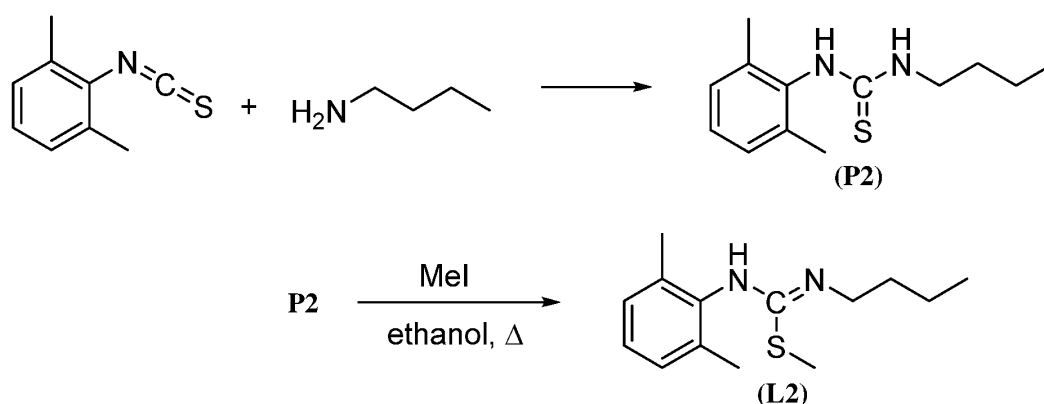
[0126] To prepare ligand L1, in a nitrogen-filled drybox, MeI (0.498 g, 3.51 mmol) was added to a vial containing a suspension of intermediate P1 (0.450 g, 1.76 mmol) in 5 mL of absolute ethanol. The vial was then sealed with a pressure-relief septum cap. The suspension was heated to 78 °C and stirred for 4 hours. The solids dissolved upon heating. Ethanol was removed on a rotary evaporator, and the crude product was mixed with 25 mL of aqueous Na₂CO₃ solution (10 wt%). The product was extracted into ethyl acetate (50 mL). The organic phase was washed with water (2 × 50 mL), dried over MgSO₄, and filtered. The filtrate was evaporated to dryness under vacuum to give ligand L1 as a colorless oil. The yield of ligand L1

was 0.380 g (80%, based on the starting material, intermediate P1). The product was found by ^1H NMR to be a mixture of isomers.

[0127] Ligand L1 was characterized by proton NMR as follows: ^1H NMR (400 MHz, CDCl_3) δ 7.30 (br s, 3H), 7.10 (br m, 2H), 7.05 (d, $J = 7.1$ Hz, 2H), 6.91 (br s, 1H), 6.07 (br s, 0.6H), 5.78 (br s, 0.4H), 2.41 (s, 3H), 2.20 (s, 6H).

EXAMPLE 2

Preparation of Ligand L2



[0128] Ligand L2 was prepared in two steps by first preparing 1-butyl-3-(2,6-dimethylphenyl)thiourea (P2) as an intermediate, then reacting P2 with MeI in ethanol to form ligand L2. The intermediate compound P2 was prepared by slowly adding a solution of 2,6-dimethylphenyl isothiocyanate (1.000 g, 6.13 mmol) in 5 mL Et_2O to a solution of n -butylamine (0.448 g, 6.13 mmol) in 5 mL of Et_2O at 25 °C. The reaction mixture was stirred vigorously overnight to ensure completion of the reaction. The white suspension was cooled to -30 °C for several hours, then the precipitate was isolated by filtration, rinsed twice with dry, cold Et_2O , and dried under vacuum. The yield of intermediate P2 was 0.705 g (49%).

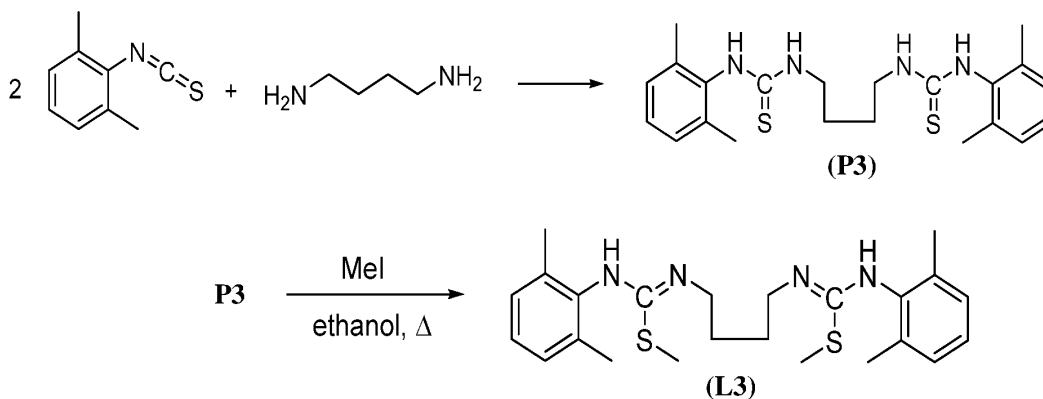
[0129] Intermediate P1 was characterized by proton NMR and carbon-13 NMR as follows: ^1H NMR (400 MHz, CDCl_3) δ 7.29 (br s, 1H), 7.20 (m, 1H), 7.14 (d, $J = 7.4$ Hz, 2H), 5.33 (br s, 1H), 3.58 (q, $J = 7.1$ Hz, 2H), 2.26 (s, 6H), 1.47 (p, $J = 7.4$ Hz, 2H), 1.27 (m, 2H), 0.88 (t, $J = 7.3$ Hz, 3H). ^{13}C NMR (101 MHz, CDCl_3) δ 180.87, 137.38, 132.82, 129.01, 128.97, 45.09, 31.37, 19.91, 18.01, 13.71.

[0130] To prepare ligand L2, in a nitrogen-filled drybox, MeI (0.721 g, 5.08 mmol) was added to a vial containing a suspension of intermediate P2 (0.600 g, 2.54 mmol) in 5 mL of absolute ethanol. The vial was then sealed with a pressure-relief septum cap. The suspension was heated to 78 °C and stirred for 4 hours. The solids dissolved upon heating. Ethanol was removed on a rotary evaporator, and the crude product was mixed with 30 mL of aqueous Na₂CO₃ solution (10 wt%). The product was extracted into ethyl acetate (60 mL). The organic phase was washed with water (2 × 60 mL), dried over MgSO₄, and filtered. The filtrate was evaporated to dryness under vacuum to give ligand L2 as a colorless oil. The yield of ligand L2 was 0.534 g (84%, based on the starting material, intermediate P2).

[0131] Ligand L2 was characterized by proton NMR and carbon-13 NMR as follows: ¹H NMR (400 MHz, CDCl₃) δ 7.00 (d, *J* = 7.5 Hz, 2H), 6.85 (t, *J* = 7.5 Hz, 1H), 4.21 (br s, 1H), 3.29 (br s, 2H), 2.38 (br s, 3H), 2.10 (s, 6H), 1.53 (br s, 2H), 1.34 (br m, 2H), 0.93 (t, *J* = 7.3 Hz, 3H). ¹³C NMR (101 MHz, CDCl₃) δ 146.66, 129.30, 127.86, 122.44, 42.90, 32.27, 19.96, 17.95, 13.78, 13.63.

EXAMPLE 3

Preparation of Ligand L3



[0132] Ligand L3 was prepared in two steps by first preparing 1,1'-(butane-1,4-diyl)bis(3-(2,6-dimethylphenyl)thiourea) (P3) as an intermediate, then reacting P3 with MeI in ethanol to form ligand L3. The intermediate compound P3 was prepared by slowly adding a solution of *N*-(2,5-dimethylphenyl)isothiocyanate (2.000 g, 12.25 mmol) dissolved in 10 mL Et₂O to a solution of 1,4-diaminobutane (0.540 g, 6.13 mmol) in 10 mL of Et₂O at 25 °C. A sticky material settled on the bottom of the vial. The mixture was stirred overnight at 25 °C to ensure

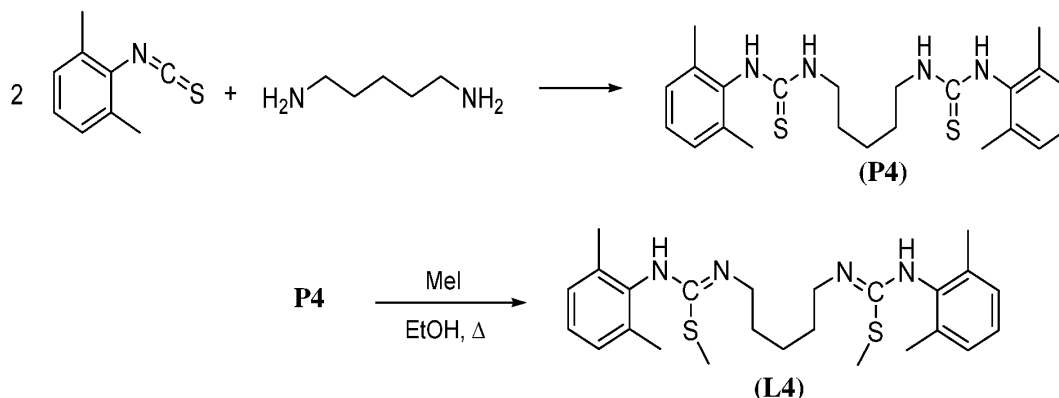
complete reaction. A white suspension formed during this time. The precipitate was isolated by filtration, rinsed with cold Et₂O, and dried under vacuum. The yield of intermediate P3 was 2.373 g (93%).

[0133] Intermediate P3 was characterized by proton NMR and carbon-13 NMR as follows: **¹H NMR** (400 MHz, CDCl₃) δ 7.40 (s, 2H), 7.20 (m, 2H), 7.14 (d, *J* = 7.5 Hz, 4H), 5.45 (s, 2H), 3.56 (m, 4H), 2.23 (s, 12H), 1.50 (m, 4H). **¹³C NMR** (101 MHz, CDCl₃) δ 181.00, 137.26, 132.69, 129.05, 44.36, 26.32, 18.03.

[0134] To prepare ligand L3, in a nitrogen-filled drybox, MeI (1.20 mL, 19.29 mmol; d = 2.28 g/mL) was added to a vial containing a suspension of the intermediate compound P3 (2.000 g, 4.82 mmol) in 20 mL of absolute ethanol. The vial was then sealed with a pressure-relief septum cap. The contents of the vial were heated to 78 °C and stirred for 4 hours. Approximately 10 min after reaching the reaction temperature, the solids dissolved, but about 10 to 15 min later a white block of solids formed quickly and stirring was no longer possible. Ethanol was removed on a rotary evaporator, and the crude product was mixed with 90 mL of aqueous Na₂CO₃ solution (10 wt%). The product was extracted into ethyl acetate (120 mL). The organic phase was washed with water (2 × 120 mL), dried over MgSO₄, and filtered. The filtrate was evaporated to dryness under vacuum to afford the product as a white solid. The yield of ligand L3 was 2.051 g (96%, based on the starting material, intermediate P3).

[0135] Ligand L3 was characterized by proton NMR and carbon-13 NMR as follows: **¹H NMR** (400 MHz, CDCl₃) δ 7.00 (d, *J* = 7.5 Hz, 4H), 6.86 (m, 2H), 4.31 (br s, 2H), 3.35 (br s, 4H), 2.35 (br s, 6H), 2.09 (s, 12H), 1.63 (br s, 4H). **¹³C NMR** (101 MHz, CDCl₃) δ 146.55, 129.21, 127.87, 122.55, 42.73, 27.41, 18.01, 13.63.

EXAMPLE 4

Preparation of Ligand L4

[0136] Ligand L4 was prepared in two steps by first preparing 1,1'-(pentane-1,5-diyl)bis(3-(2,6-dimethylphenyl)thiourea) (P4) as an intermediate, then reacting P4 with MeI in ethanol to form ligand L4. The intermediate compound P4 was prepared by adding a solution of the isothiocyanate (4.080 g, 24.99 mmol) dissolved in 10 mL Et₂O to a solution of cadaverine (1.277 g, 12.50 mmol) in 40 mL of Et₂O at 25 °C. A light white suspension formed, and a yellow dense oily material settled. The mixture was stirred overnight at 25 °C to ensure complete reaction. The settled material turned into a white suspension during this time. The suspension was cooled to −30 °C, and the precipitate was isolated by filtration, rinsed twice with dry, cold Et₂O, and dried under vacuum. The yield of intermediate P4 was 4.910 g (92%).

[0137] Intermediate P4 was characterized by proton NMR and carbon-13 NMR as follows: ¹H NMR (400 MHz, CDCl₃) δ 7.31 (m, 2H), 7.20 (m, 2H), 7.14 (d, *J* = 7.3 Hz, 4H), 5.34 (s, 2H), 3.54 (q, *J* = 6.7 Hz, 4H), 2.24 (s, 12H), 1.51 (m, 4H), 1.21 (m, 2H). ¹³C NMR (101 MHz, CDCl₃) δ 180.96, 137.30, 129.06, 44.96, 28.88, 23.68, 18.04.

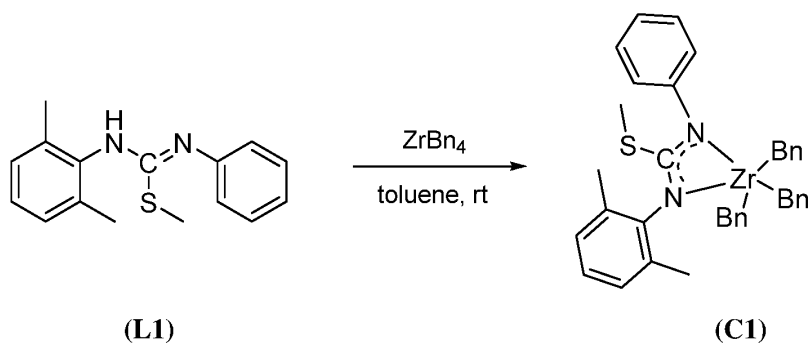
[0138] To prepare ligand P4, in a nitrogen-filled drybox, MeI (1.74 mL, 27.99 mmol; d = 2.28 g/mL) was added to a vial containing a solution of intermediate P4 (3.000 g, 7.00 mmol) in 30 mL of absolute ethanol. The vial then was sealed with a pressure-relief septum cap. The solution was heated to 78 °C and stirred for 4 hours. Ethanol was removed on a rotary evaporator, the crude product was mixed with 90 mL of aqueous Na₂CO₃ solution (10 wt%), and the product was extracted into ethyl acetate (120 mL). The organic phase was washed with water (2 × 120 mL), dried over MgSO₄, and filtered. The filtrate was evaporated to dryness

under vacuum, and the resulting yellow solid was further dried under high vacuum. The yield of ligand P4 was 2.97 g (93%, based on the starting material, intermediate P4).

[0139] Ligand L4 was characterized by proton NMR and carbon-13 NMR as follows: **¹H NMR** (400 MHz, CDCl₃) δ 7.00 (d, *J* = 7.4 Hz, 4H), 6.86 (m, 2H), 4.15 (br s, 2H), 3.31 (br s, 4H), 2.37 (br s, 6H), 2.10 (s, 12H), 1.59 (br s, 4H), 1.36 (br s, 2H). **¹³C NMR** (101 MHz, CDCl₃) δ 146.51, 129.26, 127.87, 122.54, 77.32, 77.20, 77.00, 76.68, 43.00, 29.88, 24.04, 17.99, 13.65.

EXAMPLE 5

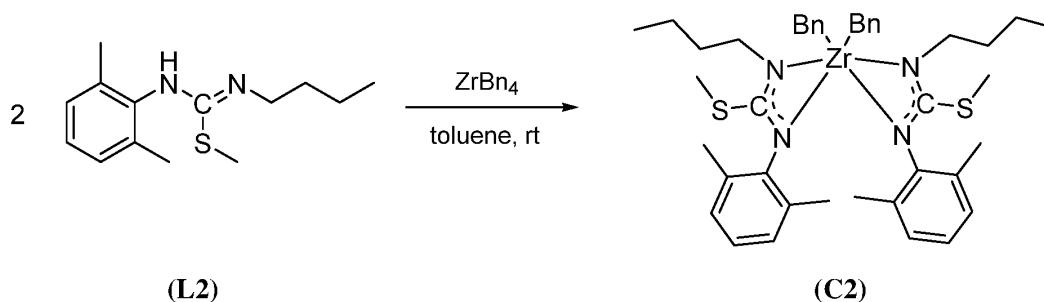
Preparation of Catalyst C1



[0140] To prepare catalyst C1, in a nitrogen-filled drybox, ligand L1 (0.060 g, 0.22 mmol) prepared according to Example 1 of this specification was dissolved in 5 mL of toluene, and the solution was mixed with tetrabenzylzirconium (ZrBn₄) (0.101 g, 0.22 mmol). The reaction mixture was stirred for 10 min at 25 °C, then 20 mL pentane was added, and the vial was cooled to -30 °C overnight. A very small amount of solids formed. The contents were filtered through a syringe filter, then the solvents were removed under vacuum to afford the product (catalyst C1) in quantitative yield.

[0141] Catalyst C1 was characterized by proton NMR and carbon-13 NMR as follows: **¹H NMR** (400 MHz, C₆D₆) δ 7.01 (m, 17H), 6.62 (d, *J* = 7.3 Hz, 6H), 2.28 (s, 6H), 2.10 (s, 6H), 1.29 (s, 3H). **¹³C NMR** (101 MHz, C₆D₆) δ 178.19, 146.50, 144.44, 142.19, 134.00, 131.30, 130.38, 129.70, 129.25, 129.02, 126.50, 125.43, 125.07, 124.00, 76.28, 19.56, 15.18.

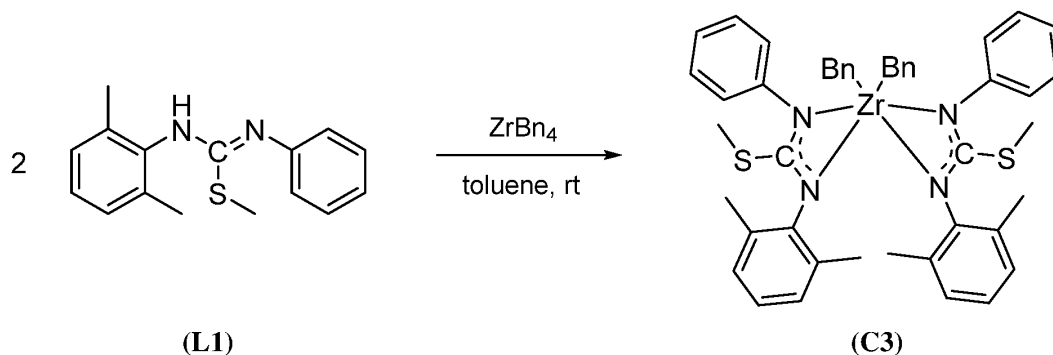
EXAMPLE 6

Preparation of Catalyst C2

[0142] To prepare catalyst C2, in a nitrogen-filled drybox, ligand L2 (0.150 g, 0.6 mmol) prepared according to Example 2 of this specification was dissolved in 6 mL of toluene, and the solution was mixed with ZrBn_4 (0.137 g, 0.30 mmol). The reaction mixture was stirred overnight, and then the solvent was removed under vacuum, giving an orange oil. The orange oil was subsequently mixed with 20 mL of pentane. Though most of the solid material dissolved, a very small amount of insoluble material was present as a light suspension. The light suspension was filtered, and the filtrate was evaporated to dryness under vacuum, affording the product (catalyst C2) as a sticky orange material in quantitative yield.

[0143] Catalyst C2 was characterized by proton NMR and carbon-13 NMR as follows:
 ^1H NMR (400 MHz, C_6D_6) δ 7.18 (m, 4H), 7.10 (d, $J = 7.2$ Hz, 4H), 6.88 (m, 2H), 6.83 (s, 6H), 3.24 (m, 4H), 2.70 (s, 4H), 2.20 (s, 12H), 1.39 (m, 4H), 1.34 (s, 6H), 1.22 (m, 4H), 0.88 (t, $J = 7.3$ Hz, 6H). ^{13}C NMR (101 MHz, C_6D_6) δ 179.69, 148.06, 144.84, 133.48, 129.67, 129.13, 128.90, 128.87, 127.27, 126.03, 124.77, 121.82, 76.29, 49.23, 34.70, 21.31, 20.48, 14.50, 14.37.

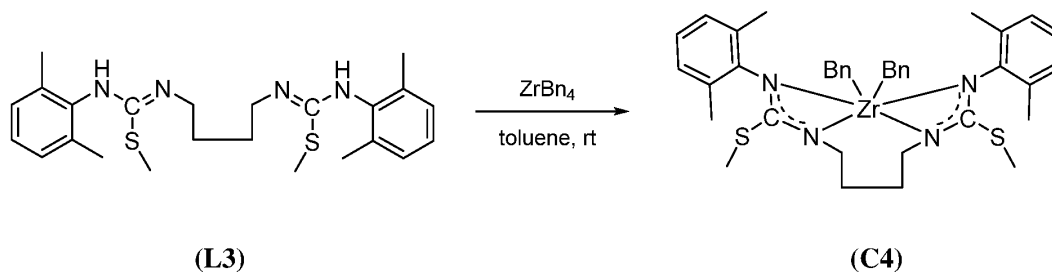
EXAMPLE 7

Preparation of Catalyst C3

[0144] To prepare catalyst C3, in a nitrogen-filled drybox, ligand L1 (0.100 g, 0.37 mmol) prepared according to Example 1 of this specification was dissolved in 6 mL of toluene, and the solution was mixed with ZrBn₄ (0.084 g, 0.18 mmol). The reaction mixture was stirred overnight and then concentrated to about 2 mL under vacuum. Pentane (20 mL) was added and the vial was cooled to −30 °C for several hours. The resulting light suspension was filtered, and the filtrate was evaporated to dryness under vacuum, affording the product (catalyst C3) in quantitative yield.

[0145] Catalyst C3 was characterized by proton NMR and carbon-13 NMR as follows:
¹H NMR (400 MHz, C₆D₆) δ 7.07 (m, 10H), 6.94 (s, 6H), 6.89 (m, 10H), 2.80 (s, 4H), 2.11 (s, 12H), 1.29 (s, 6H). ¹³C NMR (101 MHz, C₆D₆) δ 179.35, 147.45, 145.87, 144.36, 134.26, 129.67, 129.42, 128.98, 128.81, 127.70, 126.09, 82.20, 19.97, 15.27.

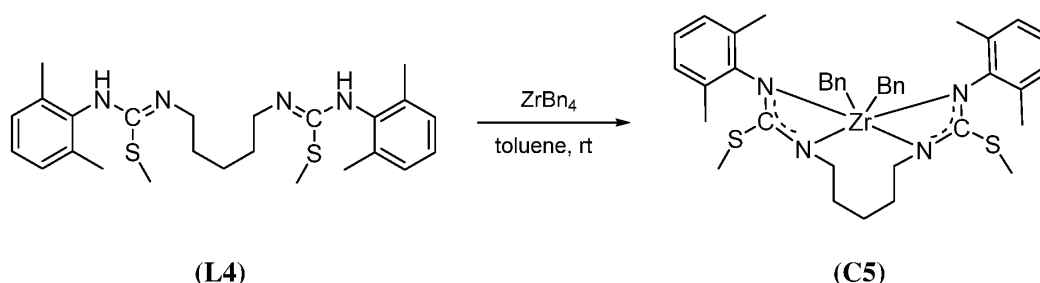
EXAMPLE 8

Preparation of Catalyst C4

[0146] To prepare catalyst C4, ligand L3 (0.150 g, 0.34 mmol) prepared according to Example 3 of this specification was dissolved in 10 mL of toluene, and the solution was mixed with ZrBn_4 (0.154 g, 0.34 mmol). The reaction mixture was stirred for 2 hours, then was concentrated to about 1 mL under vacuum. To the concentrated mixture, 10 mL of pentane was added, causing a small amount of precipitate that was subsequently filtered off and discarded. The filtrate was evaporated to dryness under vacuum to afford catalyst C4 as an orange residue. The yield of catalyst C4 was 215 mg (89%).

[0147] Catalyst C4 was characterized by proton NMR and carbon-13 NMR as follows: ^1H NMR (400 MHz, C_6D_6) δ 7.07 (t, $J = 7.7$ Hz, 4H), 6.96 (m, 6H), 6.84 (m, 2H), 6.69 (d, $J = 7.1$ Hz, 4H), 3.35 (m, 4H), 2.55 (s, 4H), 2.36 (s, 12H), 1.53 (m, 4H), 1.42 (s, 6H). ^{13}C NMR (101 MHz, C_6D_6) δ 176.41, 147.76, 147.59, 145.20, 145.08, 134.32, 129.66, 129.49, 129.19, 128.80, 128.63, 128.39, 128.27, 128.15, 127.36, 127.22, 127.17, 125.31, 121.78, 79.23, 77.53, 48.26, 30.44, 28.46, 20.58, 20.32, 20.03, 14.70.

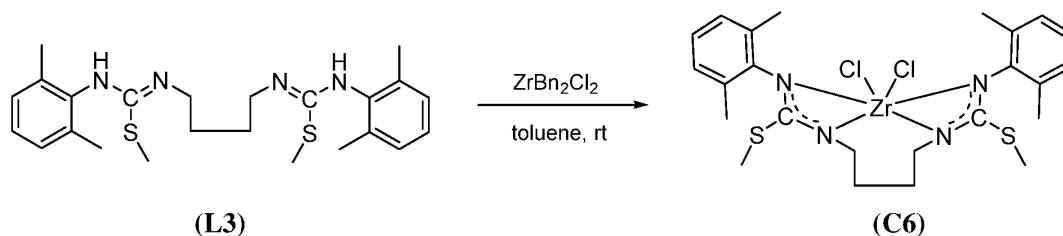
EXAMPLE 9

Preparation of Catalyst C5

[0148] To prepare catalyst C5, ligand L4 (0.075 g, 0.16 mmol) prepared according to Example 4 of this specification was dissolved in 5 mL of toluene, and the solution was mixed with ZrBn_4 (0.075 g, 0.16 mmol). The reaction mixture was stirred for 10 minutes at room temperature ($25\text{ }^\circ\text{C} \pm 2\text{ }^\circ\text{C}$). Excess pentane (20 mL) was added, causing a small amount of an orange precipitate to form. The vial was cooled to $-30\text{ }^\circ\text{C}$, and the precipitate was filtered off and discarded. The filtrate was concentrated to about 2 mL under vacuum. Solvent was removed from the filtrate under vacuum to afford catalyst C5 as an orange residue. The yield of catalyst C5 was 0.055 g (46%).

[0149] Catalyst C5 was characterized by proton NMR and carbon-13 NMR as follows:
 $^1\text{H NMR}$ (400 MHz, C_6D_6) δ 7.09 (t, $J = 7.5\text{ Hz}$, 4H), 6.96 (m, 6H), 6.82 (t, $J = 7.3\text{ Hz}$, 2H), 6.73 (d, $J = 7.1\text{ Hz}$, 4H), 3.16 (m, 4H), 2.68 (s, 4H), 2.44 (s, 12H), 1.49 (m, 4H), 1.47 (s, 6H), 1.33 (m, 2H). $^{13}\text{C NMR}$ (101 MHz, C_6D_6) δ 178.33, 147.27, 145.55, 134.00, 128.90, 128.44, 127.15, 125.09, 121.64, 77.35, 49.79, 29.18, 26.88, 21.20, 14.77.

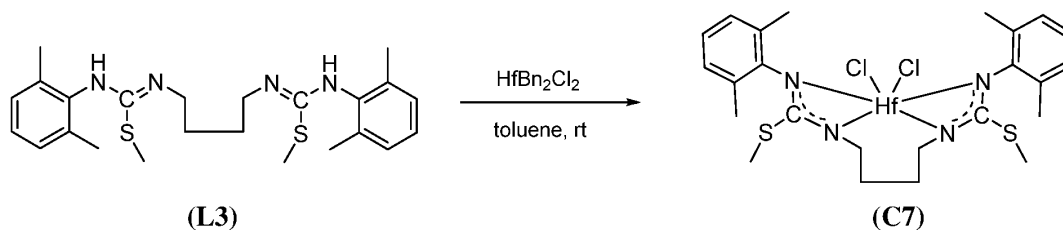
EXAMPLE 10

Preparation of Catalyst C6

[0150] To prepare catalyst C6, ligand L3 (0.100 g, 0.23 mmol) prepared according to Example 3 of this specification was dissolved in 5 mL toluene, and the solution was mixed with $\text{ZrBn}_2\text{Cl}_2 \cdot 2.18\text{Et}_2\text{O}$ (0.114 g, 0.23 mmol). The reaction mixture was stirred overnight at room temperature. Solvent was removed under vacuum. The crude product was triturated with pentane (10 mL) and filtered. The filtrate was evaporated to dryness under vacuum to afford 11 mg of solid material. The mostly pentane-insoluble material was triturated again with pentane (3×30 mL), affording another 55 mg of the pentane-soluble desired product (catalyst C6). Overall, the yield of catalyst C6 was 66 mg (49%). Catalyst C6 was determined by x-ray diffraction analysis to have a dimeric structure. The molecular structure of catalyst C6, as determined by x-ray diffraction analysis, is provided in the FIGURE.

[0151] Catalyst C6 was characterized by proton NMR and carbon-13 NMR as follows: ^1H NMR (400 MHz, C_6D_6) δ 6.85 (s, 6H), 3.56 (m, 4H), 2.35 (s, 12H), 1.74 (s, 4H), 1.28 (s, 6H). ^{13}C NMR (101 MHz, C_6D_6) δ 179.05, 143.63, 134.41, 128.91, 126.33, 51.33, 29.05, 19.90, 14.36.

EXAMPLE 11

Preparation of Catalyst C7

[0152] To prepare catalyst C7, ligand L3 (0.100 g, 0.23 mmol) prepared according to Example 3 of this specification was dissolved in 5 mL toluene, and the solution was mixed with

HfBn₂Cl₂·2.34Et₂O (0.137 g, 0.23 mmol). The reaction mixture was stirred overnight at room temperature. Solvent was removed under vacuum. The crude product was triturated with pentane (10 mL) and filtered. The filtrate was evaporated to dryness under vacuum to afford 5 mg of solid material. The mostly pentane-insoluble material was triturated again with pentane (3 × 30 mL), affording another 41 mg of the pentane-soluble desired product (catalyst C7). The overall yield of catalyst C7 was 46 mg (30%).

[0153] Catalyst C7 was characterized by proton NMR and carbon-13 NMR as follows: ¹H NMR (400 MHz, C₆D₆) δ 6.86 (s, 6H), 3.61 (m, 4H), 2.35 (s, 12H), 1.74 (m, 4H), 1.30 (s, 6H). ¹³C NMR (101 MHz, C₆D₆) δ 179.00, 142.99, 134.77, 128.85, 126.39, 50.93, 28.95, 19.82, 14.33.

EXAMPLE 12

Batch Copolymerization of Ethylene and 1-Octene

[0154] To determine the effectiveness of various catalysts according to embodiments of this specification, ethylene and 1-octene were batch copolymerized in the presence of catalysts C1, C2, C3, C4, and C5.

[0155] The copolymerizations were conducted in a 1G Autoclave batch reactor designed for ethylene homopolymerizations and ethylene/α-olefin copolymerizations. The reactor was heated by electrical heating bands and cooled by an internal serpentine cooling coil containing chilled glycol. Both the reactor and the heating/cooling system were controlled and monitored by a Camile TG process computer. The bottom of the reactor was fitted with a dump valve that emptied the reactor contents into a glass dump pot for runs that were saved or to a plastic dump drum for waste. The dump pot was vented to the atmosphere with both the drum and glass kettle under a nitrogen purge. All chemicals used for polymerization or catalyst makeup (including solvents and monomers) were run through purification columns to remove any impurities that could affect the polymerization. High-pressure nitrogen and high-pressure hydrogen were ultra-high purity grade, supplied by Airgas.

[0156] The reactor was charged with Isopar E and 1-octene via independent Micromotion Flow Meters. The reactor was heated to the polymerization setpoint. Ethylene was added to the reactor at the reaction temperature to maintain the reaction pressure setpoint. Ethylene addition amounts were monitored by a Micromotion Flow Meter.

[0157] An MMAO-3A scavenger, an RIBS-II activator ($[\text{HNMe}(\text{C}_{18}\text{H}_{37})_2][\text{B}(\text{C}_6\text{F}_5)_4]$), and a catalyst (one of catalysts C1, C2, C3, C4, or C5) were mixed with an appropriate amount of toluene in an inert-atmosphere glove box to achieve a desired molarity solution. The mixture was drawn into a syringe and transferred into the catalyst shot tank located outside the glove box. The mixture was added via high-pressure N_2 injection when the reactor pressure setpoint was achieved.

[0158] Immediately after catalyst addition, the run timer was started. Usually within the first minute of successful catalyst runs, an exotherm was observed, as well as decreasing reactor pressure. Then, ethylene was added by the Camile utilizing a Bronkhorst pressure controller to maintain the pressure setpoint in the reactor. The polymerizations were run for up to 10 minutes (or less than 10 minutes if a target ethylene uptake was observed), then the agitator was stopped and the bottom dump valve was opened to empty the reactor contents to the kettle. The kettle contents were poured into trays and placed in a lab hood, where the solvent was evaporated off overnight. The trays containing the remaining polymer were then transferred to a vacuum oven, where they were heated at 100 °C under vacuum to remove any remaining solvent. After the trays cooled to ambient temperature, the polymers were weighed for yields and efficiencies and were submitted for polymer testing.

[0159] Two runs of 10 minutes, one at 120 °C and another at 150 °C, were conducted for each of the catalysts C1, C2, C3, C4, and C5. Pertinent data for each of the runs are provided in Table 1.

Table 1—Batch Polymerizations of Ethylene and 1-Octene Using Exemplary Catalysts

Catalyst	Temp (°C)	Efficiency (g poly/ g metal)	M _w (g/mol)	M _n (g/mol)	PDI	Octene Content (mol.%)	T _m (°C)	ΔH _m (J/g)
C1	120	109,625	214,367	7,817	27.4	5.3		
C1	150	19,489	82,191	7,292	11.3	4.4		
C2	120	54,813	245,641	22,883	10.7	4.1	120	112
C2	150	20,359	93,266	15,439	6.0	4.2	121	122
C3	120	95,008	126,123	11,482	11.0	3.6		
C3	150	25,794	80,833	7,339	11.0	4.2		
C4	120	70,160	199,161	36,553	5.4	5.7	103	97
C4	150	16,865	84,694	20,565	4.1	5.5	101	97
C4 in situ*	120	79,727	171,428	57,843	3.0	4.0	104	92
C4 in situ*	150	21,925	68,320	21,806	3.1	5.4	104	93
C5	120	102,317	326,665	109,497	3.0	4.1	105	94
C5	150	31,669	118,005	32,400	3.6	4.2	107	95

*Catalyst C4 in situ prepared by mixing toluene solutions of ligand L4 and ZrBn₄ (1:1) shortly before each run.

Polymerization conditions:

Activator [HNMe(C₁₈H₃₇)₂][B(C₆F₅)₄] (1.2 equiv); MMAO-3A (10 equiv).

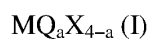
Runs at Temperature = 120 °C: 1180 g of Isopar E; 570 g of 1-octene; no H₂; 280 psi of ethylene; 10 min run time.

Runs at Temperature = 150 °C: 1045 g of Isopar E; 570 g of 1-octene; no H₂; 317 psi of ethylene; 10 min run time.

[0160] It should be apparent to those skilled in the art that various modifications and variations can be made to the embodiments described herein without departing from the spirit and scope of the claimed subject matter. Thus it is intended that the specification cover the modifications and variations of the various embodiments described herein provided such modification and variations come within the scope of the appended claims and their equivalents.

CLAIMS

1. A composition comprising at least one thioguanidine complex according to Formula (I):

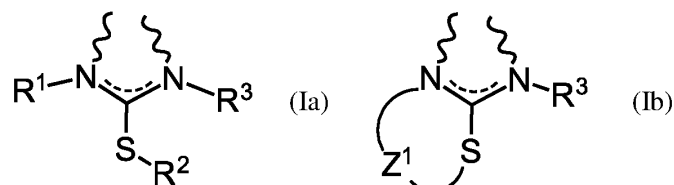


where:

M is a metal center chosen from Ti, Zr, or Hf;

a is 1 or 2;

each group Q of the at least one thioguanidine complex is a bidentate thioguanidine ligand bound to the metal center, the thioguanidine ligand having Formula (Ia) or Formula (Ib):



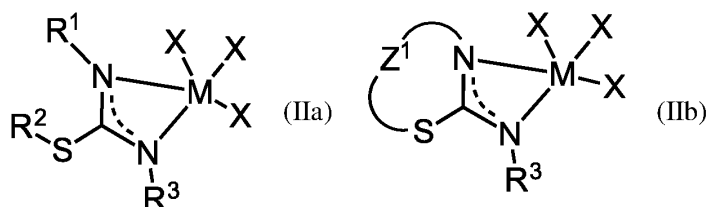
each group R^1 , R^2 , and R^3 in the at least one thioguanidine complex is independently chosen from alkyl groups or aryl groups;

each group Z^1 in the at least one thioguanidine complex is independently chosen from alkylene groups;

if $a = 2$, groups R^3 of the two groups Q are optionally linked to each other through at least one covalent bond; and

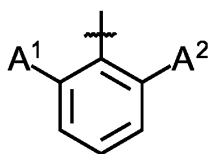
each X is covalently bonded or coordinated to the metal center and is independently chosen from alkyl groups, halides, or amides.

2. The composition of claim 1, wherein a is 1, and the at least one thioguanidine complex has Formula (IIa) or Formula (IIb):



where M, R^1 , R^2 , R^3 , Z^1 , and X are as defined in Formula (I).

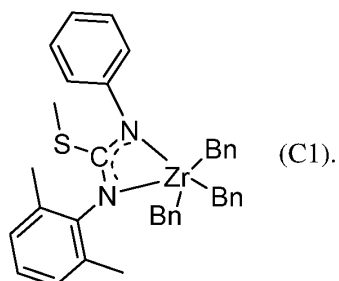
3. The composition of claim 2, wherein R^1 of Formula (IIa) and R^3 of Formulas (IIa) and (IIb) are independently chosen from groups according to the formula



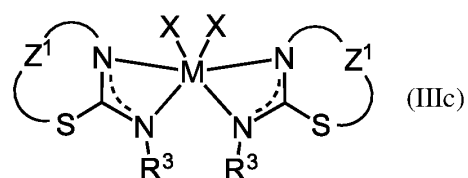
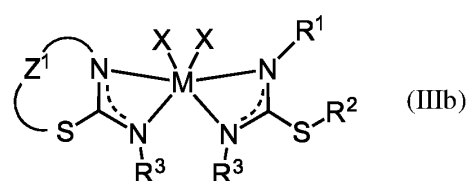
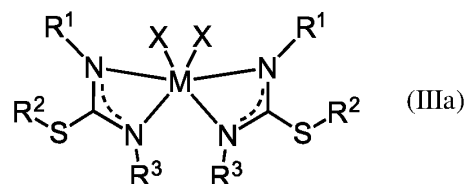
where A^1 and A^2 are independently hydrogen or a (C_1-C_{10}) alkyl group.

4. The composition of claim 3, wherein A^1 and A^2 are independently hydrogen or methyl.
5. The composition of claim 3, wherein both A^1 and A^2 are methyl.
6. The composition of claim 2, wherein R^2 is a (C_1-C_{10}) alkyl group.
7. The composition of claim 2, wherein R^2 is methyl.
8. The composition of claim 2, wherein all groups X are identical.
9. The composition of claim 2, wherein each X is a benzyl group coordinated to the metal center.
10. The composition of claim 2, wherein each X is chloride.

11. The composition of claim 2, wherein the at least one thioguanidine complex comprises compound C1:



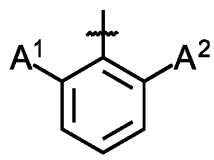
12. The composition of claim 1, wherein a is 2 and the at least one thioguanidine complex has Formula (IIIa), Formula (IIIb), or Formula (IIIc):



where M, R¹, R², R³, Z¹, and X are as defined in Formula (I).

13. The composition of claim 12, wherein each R¹ is independently chosen from phenyl or a (C₁–C₁₀) alkyl group.
14. The composition of claim 12, wherein each R¹ is independently chosen from phenyl or a (C₁–C₄) alkyl group.

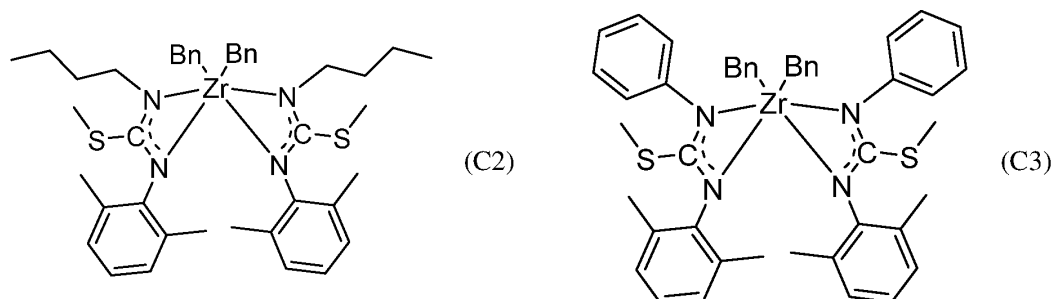
15. The composition of claim 12, wherein each R^1 is independently chosen from phenyl or *n*-butyl.
16. The composition of claim 12, wherein each R^1 is phenyl or each R^1 is *n*-butyl.
17. The composition of claim 12, wherein each R^2 is a (C_1 – C_{10}) alkyl group.
18. The composition of claim 12, wherein each R^2 is methyl.
19. The composition of claim 12, wherein each R^3 is independently chosen from groups according to the formula



where A^1 and A^2 are independently a (C_1 – C_{10}) alkyl group.

20. The composition of claim 19, wherein both A^1 and A^2 are methyl.
21. The composition of claim 12, wherein each X is a benzyl group coordinated to the metal center.
22. The composition of claim 12, wherein each X is chloride.
23. The composition of claim 12, wherein both groups Q are identical and all groups X are identical.

24. The composition of claim 12, wherein the at least one thioguanidine complex is chosen from compounds C2 or C3 or combinations thereof:



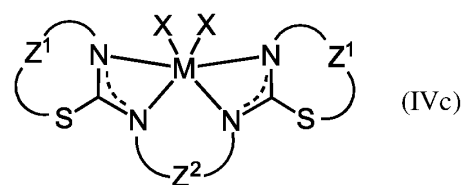
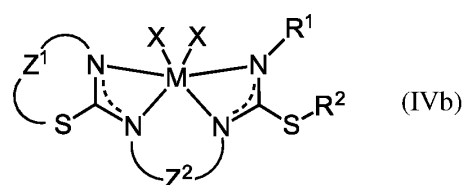
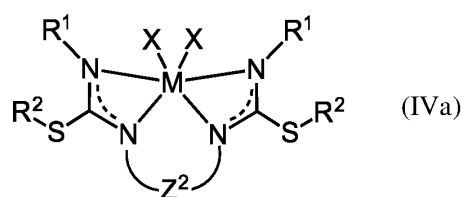
25. The composition of claim 1, wherein:

a is 2;

R^3 of the two groups Q are linked to each other as a bridging group Z^2 ; and

the at least one thioguanidine complex has Formula (IVa), Formula (IVb), or

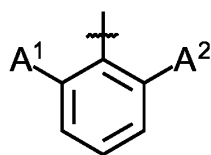
Formula (IVc):



where M, R^1 , R^2 , Z^1 , and X are as defined in Formula (I) and Z^2 is an alkylene group.

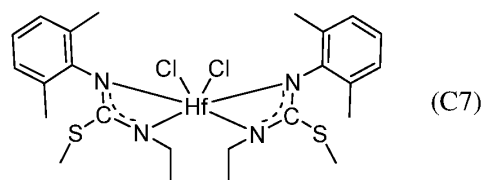
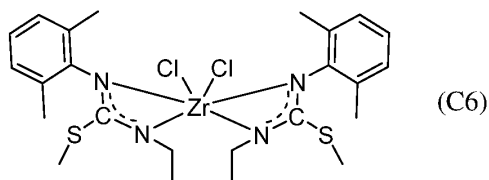
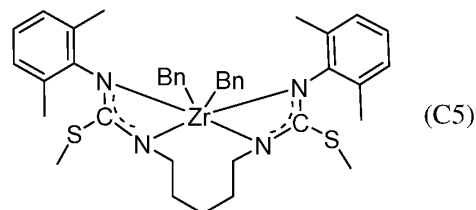
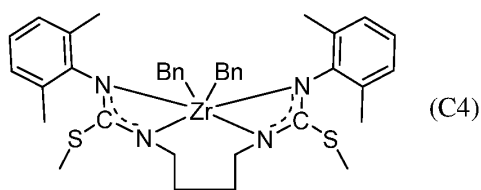
26. The composition of claim 25, wherein Z^2 is $-(CH_2)_n-$, where n is from 4 to 10.
27. The composition of claim 25, wherein Z^2 is $-(CH_2)_n-$, where n is 4 or 5.

28. The composition of claim 25, wherein each R^2 is a (C_1-C_{10}) alkyl group.
29. The composition of claim 25, wherein each R^2 is methyl.
30. The composition of claim 25, wherein each R^1 is independently chosen from groups having the formula:



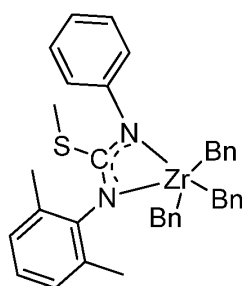
where A^1 and A^2 are independently a (C_1-C_{10}) alkyl group.

31. The composition of claim 30, wherein both A^1 and A^2 are methyl.
32. The composition of claim 25, wherein each X is a benzyl group coordinated to the metal center.
33. The composition of claim 25, wherein each X is chloride.
34. The composition of claim 25, wherein all groups R^1 are identical, all groups R^2 are identical, and all groups X are identical.
35. The composition of claim 25, wherein the at least one thioguanidine complex is chosen from compounds C4, C5, C6, or C7, or combinations thereof:

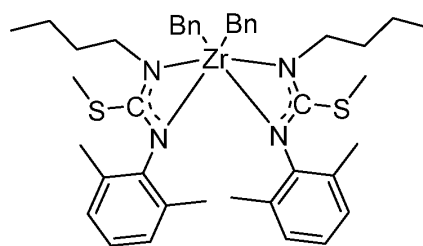


36. A polymerization catalyst system configured to copolymerize ethylene and an α -olefin comonomer in the presence of a catalytic amount of the composition of claim 1.

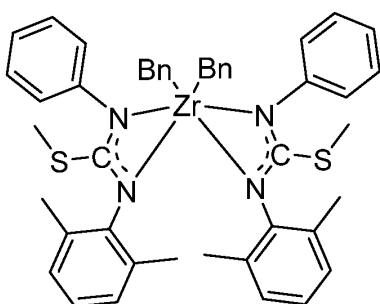
37. The polymerization catalyst system of claim 36, wherein the composition comprises at least one thioguanidine complex chosen from compounds C1, C2, C3, C4, C5, C6, C7, or combinations thereof:



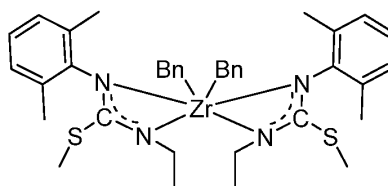
(C1)



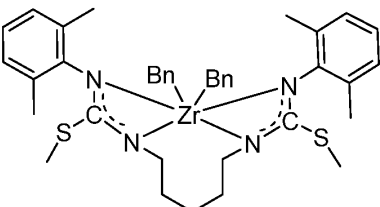
(C2)



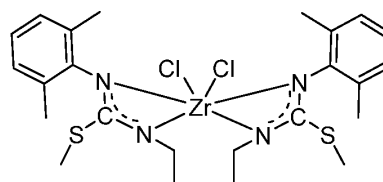
(C3)



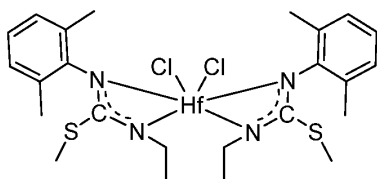
(C4)



(C5)



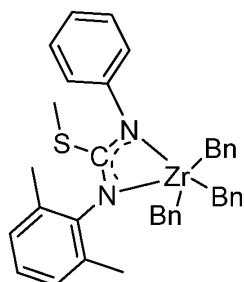
(C6)



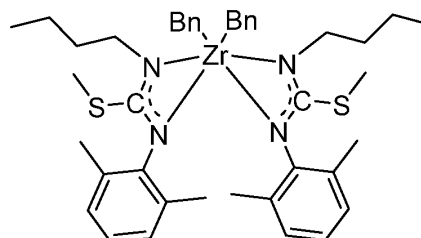
(C7)

38. An ethylene-co-alkylene copolymer produced from the polymerization system of claim 36, wherein the α -olefin comonomer comprises at least one C₃-C₁₂ α -olefin.

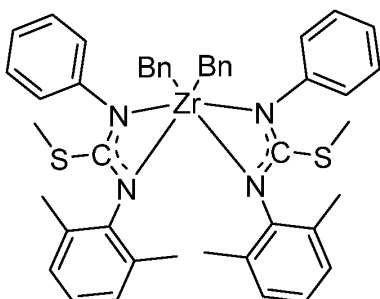
39. The ethylene-co-alkylene copolymer of claim 38, wherein the composition comprises at least one thioguanidine complex chosen from compounds C1, C2, C3, C4, C5, C6, C7, or combinations thereof:



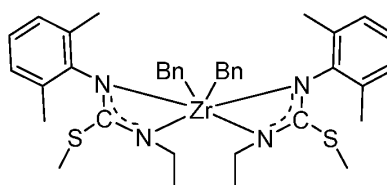
(C1)



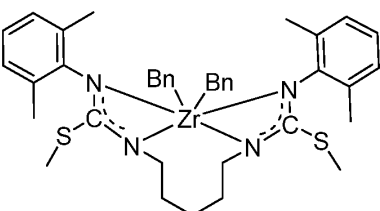
(C2)



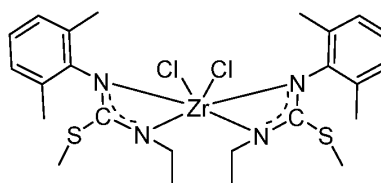
(C3)



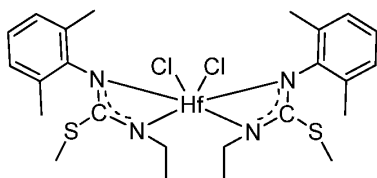
(C4)



(C5)



(C6)



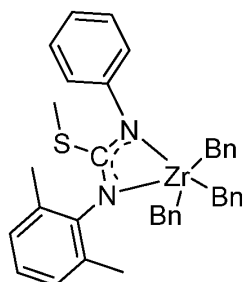
(C7)

40. The ethylene-co-alkylene copolymer of claim 38, wherein the α -olefin comonomer is 1-octene.

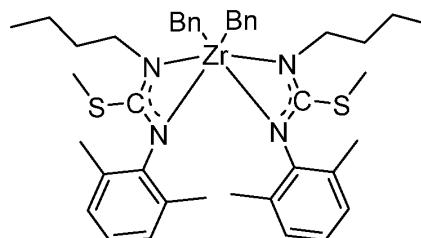
41. A polymerization method comprising:

reacting ethylene and an α -olefin comonomer in the presence of a catalytic amount of the composition of claim 1 to form an ethylene-co-alkylene copolymer, wherein the α -olefin comonomer comprises at least one C_3 - C_{12} α -olefin.

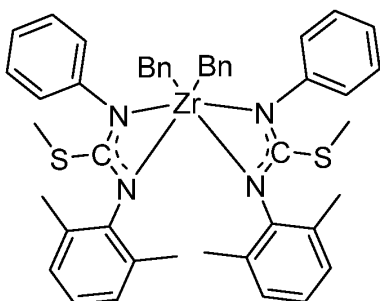
42. The polymerization method of claim 41, wherein the composition comprises at least one thioguanidine complex chosen from compounds C1, C2, C3, C4, C5, C6, C7, or combinations thereof:



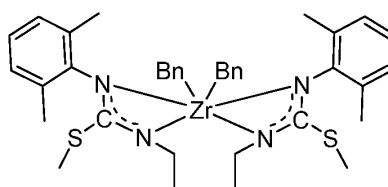
(C1)



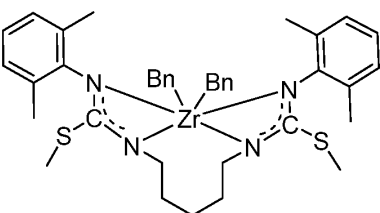
(C2)



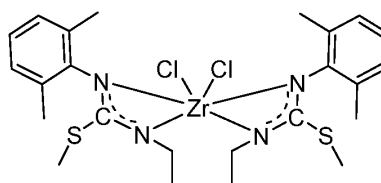
(C3)



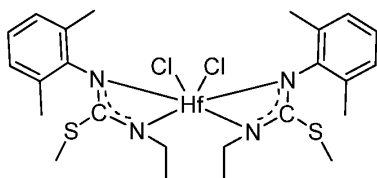
(C4)



(C5)



(C6)



(C7)

43. The polymerization method of claim 42, wherein the α -olefin comonomer is 1-octene.