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(54) **IMMOBILIZED LEWIS ACID CATALYSTS COATED WITH IONIC LIQUIDS AND USE THEREOF**

MIT IONISCHEN FLÜSSIGKEITEN BESCHICHTETE IMMOBILISIERTE LEWIS-SÄURE-KATALYSATOREN UND VERWENDUNG DAVON

CATALYSEURS ACIDE DE LEWIS IMMOBILISES ENDUITS DE LIQUIDES IONIQUES ET LEUR UTILISATION

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- **GUY. ET AL.: 'A Heterogeneous Silica-Supported Scandium / Ionic Liquid Catalyst System for Organic Reactions in Water' ANGEWANDTE CHEMIE INTERNATIONAL EDISION vol. 45, no. 43, 06 November 2006, pages 7217 - 7220, XP003018102**

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Description

Technical Field

5 **[0001]** The present invention relates to an immobilized Lewis acid catalyst prepared by supporting a Lewis acid on the surface of a solid substance by chemical binding, and coating the surface of the solid substance and the peripheries of the Lewis acid with an ionic liquid, as well as a use of the catalyst and a method for producing a compound using the catalyst.

10 Background Art

[0002] In chemical industries, conversion of reaction solvents from organic solvents to water has been actively investigated for the purpose of cost reduction, safety, reduction of environmental loads and the like. However, there are only few examples of succeeding such conversion because of the problems of solubility of the reaction substrate or catalyst, safety and the like. In recent years, the inventors of the present invention succeeded in developing a Lewis acid catalyst which is stable even in water, and subsequently a Lewis acid catalyst integrated with a surfactant (see Patent Document 1), thereby greatly increased the possibility of carrying out synthesis reactions in water (see Non-Patent Document 1). Furthermore, the inventors of the present invention conducted investigation on the immobilization of a catalyst onto an insoluble support, for the purpose of facilitating the isolation of catalysts from products or the recovery/reuse of catalysts, and found that a Lewis acid catalyst which is bound to a hydrophobic polymer support and is stable in water, accelerates various reactions in water, compared with in an organic solvent (see Non-Patent Document 2, Patent Document 2 and Patent Document 3). Nevertheless, Lewis acid catalysts supported on organic polymers have problems such as that production of such catalysts is relatively difficult and expensive.

[0003] Meanwhile, in recent years, ionic liquids are attracting attention as a new reaction field (see Non-Patent Documents 3 and 4), and a biphasic reaction involving a solution or a gas has been recently developed, in which an ionic liquid is supported on the surface of a porous support so as to use the ionic liquid as an immobilized catalyst (see Non-patent Document 5). In addition, a method of performing a Heck reaction using a Pd/C catalyst in an ionic liquid (see Patent Document 4), a method of performing an aldol reaction using proline as a catalyst in the presence of an ionic liquid, and recovering and reusing the catalyst or solvent (see Patent Document 5), a method of using an ionic liquid as a catalyst in the isomerization of paraffinic hydrocarbons or in the production of high octane gasoline (see Patent Documents 6 and 7) and the like, have been reported. As such, ionic liquids are widely used as reaction solvents or catalysts. Furthermore, numerous improvements are also being added to the ionic liquids themselves, such as in the cases of an immobilized ionic liquid in which either the cations or the anions of the ionic liquid are immobilized (see Patent Document 8), a method for producing an ionic liquid from a Lewis acid having titanium, niobium, tantalum, tin or antimony as the base (see Patent Document 9), and the like. Also, a method of coating an enzyme with an ionic liquid and using the coated enzyme in an enzymatic reaction (see Patent Document 10), a method of using an ionic liquid as a liquid matrix in an organic reaction in a homogeneous phase (see Patent Document 11) and the like, have been reported. However, examples of utilizing an ionic liquid phase as a hydrophobic field in reactions performed in aqueous solutions are yet to be known.

40 **[0004]**

Patent Document 1: JP-A No. 11-244705

Patent Document 2: JP-A No. 2001-137710

Patent Document 3: JP-A No. 2005-254115

45 Patent Document 4: JP-A No. 2002-265394

Patent Document 5: JP-A No. 2002-275118

Patent Document 6: JP-A No. 2004-269846

Patent Document 7: JP-A No. 2005-314500

Patent Document 8: JP-W No. 2003-512926

50 Patent Document 9: JP-A No. 2003-535054

Patent Document 10: JP-A No. 2005-514033

Patent Document 11: JP-A No. 2006-500418

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Non-Patent Document 2: Imura, S.; Manabe, K.; Kobayashi, S., Tetrahedron, 2004, 60, 7673.

55 Non-Patent Document 3: Welton T., et al., Chem. Reviews, 1999, 99, 2071-2083.

Non-Patent Document 4: Wasserscheid P, et al., Angewandte Chemie International Edition, 2000, 39(21), 3772-3787.

Non-Patent document 5: Gruttadauria, M.; Riela, S.; Aprile, C.; Meo, P.L.; D'Anna, F. and Noto, R., Adv. Synth. Catal., 2006, 348, 82.

Non-Patent Document 6: Jones, C.W. ; Tsuji, K; Davis, M.E., Nature, 1998, 393, 52.

Non-Patent Document 7: Huddleston, J.G.; Visser, A.E.; Reichert, W.M.; Willauer, H.D.; Broker, G.A.; Rogers, R.D., Green Chem. 2001, 3, 156.

5 Disclosure of the Invention

Problems to be Solved by the Invention

10 **[0005]** It is an object of the present invention to provide a novel immobilized Lewis acid catalyst which has a high catalytic activity in an aqueous solution, and can be recovered, reused or continuously used for a long time.

Means for Solving the Problems

15 **[0006]** The inventors of the present invention developed a Lewis acid catalyst which is stable even in water, and thus greatly increased the possibility of synthesis reactions in water (see Non-Patent Document 1). The inventors also conducted investigation on the immobilization of a catalyst onto an insoluble support, for the purpose of facilitating the isolation of catalysts from products or the recovery/reuse of catalysts, and found that a Lewis acid catalyst which is bound to a hydrophobic polymer support and is stable in water, accelerates various reactions in water, compared with
20 in an organic solvent (see Non-Patent Document 2, Patent Document 2 and Patent Document 3). Nevertheless, Lewis acid catalysts supported on organic polymers have problems such as that production of such catalysts is relatively difficult and expensive, and thus the inventors continued their investigation. As a result, the inventors found that when an immobilized Lewis acid catalyst is coated with a hydrophobic ionic liquid, a Lewis acid catalyst which does not impair the catalytic activity in water and is reusable, can be obtained.

25 **[0007]** Thus, the present invention relates to an immobilized Lewis acid catalyst wherein a trifluoromethanesulfonate of rare earth metal or a trifluoromethanesulfonate of bismuth is immobilized on the surface of silica gel through a sulfonic acid group of a low molecular weight organic compound which is chemically bound to the surface of silica gel, and the surface of silica gel and the peripheries (more particularly, the entire or a part of the peripheries) of the Lewis acid are coated with a hydrophobic ionic liquid; wherein the low molecular weight organic compound is a spacer group selected from the group consisting of benzenesulfonic acid and alkylbenzenesulfonic acid.

30 The present invention also relates to a method for producing an immobilized Lewis acid coated with a hydrophobic ionic liquid, the method comprising mixing an immobilized Lewis acid wherein a trifluoromethanesulfonate of rare earth metal or a trifluoromethanesulfonate of bismuth is immobilized on the surface of a silica gel via a sulfonic acid group of a low molecular weight organic compound which is chemically bound to the surface of silica gel, with a solution of a hydrophobic ionic liquid dissolved in an organic solvent, and then removing the organic solvent; wherein the low molecular weight
35 organic compound is a spacer group selected from the group consisting of benzenesulfonic acid and alkylbenzenesulfonic acid.

Moreover, the present invention relates to a use of the immobilized Lewis acid catalyst coated with an ionic liquid according to the present invention, and a method for producing a chemical product by a chemical reaction using the catalyst.

40 **[0008]** The present invention may be described in more detail, as follows.

(1) An immobilized Lewis acid catalyst wherein a trifluoromethanesulfonate of rare earth metal or a trifluoromethanesulfonate of bismuth is immobilized on the surface of silica gel through a sulfonic acid group of a low molecular weight organic compound which is chemically bound to the surface of silica gel, and the surface of silica gel and the peripheries of the Lewis acid are coated with a hydrophobic ionic liquid; wherein the low molecular weight organic compound is a spacer group selected from the group consisting of benzenesulfonic acid and alkylbenzenesulfonic acid.

45 (2) The immobilized Lewis acid catalyst according to (1) above, wherein the ionic liquid is an ionic liquid containing any of imidazolium, pyridinium, quaternary ammonium and quaternary phosphonium, as a cation.

(3) The immobilized Lewis acid catalyst according to any one of (1) to (2) above, wherein the ionic liquid is an ionic liquid containing any of a halide ion, trifluoromethanesulfonate, tetrafluoroborate, hexafluoroantimonate, hexafluorophosphate and bis(trifluoromethanesulfonamide) ions, as an anion.

55 (4) The immobilized Lewis acid catalyst according to any one of (1) to (3) above, wherein the ionic liquid is an imidazolium salt.

(5) The immobilized Lewis acid catalyst according to any one of (1) to (4) above, wherein the ionic liquid is an imidazolium salt, and is an ionic liquid in which a hydrocarbon group having 6 or more carbon atoms is bound to at least one of the two nitrogen atoms present in the imidazole ring of the imidazolium salt.

5 (6) The immobilized Lewis acid catalyst according to (1) above, wherein the rare earth metal is any of scandium, yttrium and ytterbium.

(7) The immobilized Lewis acid catalyst according to any one of (1) to (6) above, wherein the silica gel is bound through a siloxane bond (Si-O-Si) to the low molecular weight organic compound having a sulfonic acid group.

10 (8) A method for producing an immobilized Lewis acid coated with a hydrophobic ionic liquid, the method comprising mixing an immobilized Lewis acid wherein a trifluoromethanesulfonate of rare earth metal or a trifluoromethanesulfonate of bismuth is immobilized on the surface of a silica gel via a sulfonic acid group of a low molecular weight organic compound which is chemically bound to the surface of silica gel, with a solution of a hydrophobic ionic liquid dissolved in an organic solvent, and then removing the organic solvent; wherein the low molecular weight organic compound is a spacer group selected from the group consisting of benzenesulfonic acid and alkylbenzenesulfonic acid.

15 (9) Use of the immobilized Lewis acid catalyst according to any one of (1) to (7) above, in a Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent.

(10) The use according to (9) above, wherein the Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent is any chemical reaction selected from the group consisting of an aldol reaction, a Mannich type reaction, a Diels-Alder reaction, an allylation reaction and a Michael reaction.

25 (11) A method for producing a chemical substance by a Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent, in the presence of the immobilized Lewis acid catalyst according to any one of (1) to (7) above.

30 (12) The method according to (11) above, wherein the Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent is any chemical reaction selected from the group consisting of an aldol reaction, a Mannich type reaction, a Diels-Alder reaction, an allylation reaction and a Michael reaction.

[0009] As the immobilized Lewis acid, supported on the surface of silica gel according to the present invention, the Lewis acid is bound to the surface of the silica gel through a spacer group having a functional group.

35 As the Lewis acid of the present invention, a conventional Lewis acid such as a metal Lewis acid formed from a salt of Bi or a rare earth metal may be favorable, but in the case where a reaction in water is intended, a Lewis acid which is stable even in water is preferred. Such Lewis acid which is stable even in water includes a Lewis acid represented by the following formula:



wherein M represents a rare earth metal or bismuth; X represents an anion; and n represents an integer corresponding to the valence of M. The rare earth metal is preferably selected from the group of rare earth elements including elements such as, for example, Sc, Yb, Sm, Y and Nd, and Sc is particularly preferred. Therefore, the metal element of the Lewis acid according to the present invention is preferably a metal element selected from the group consisting of Sc, Yb, Sm, Y, Nd and Bi, and Sc or Bi is particularly preferred. The anion is a trifluoromethanesulfonic acid ion (CF₃SO₃⁻(OTf)). Specific examples of the Lewis acid according to the present invention include, for example, trifluoromethanesulfonates of scandium, yttrium, ytterbium, bismuth and the like. A particularly preferred Lewis acid includes a trifluoromethanesulfonate of scandium or bismuth and the like.

[0010] The silica gel for immobilizing the Lewis acid according to the present invention is stable in water and insoluble in water, and has a functional group capable of chemical bonding, on the surface.

The method of immobilizing the above-described Lewis acid onto the silica gel according to the present invention is not particularly limited, as long as it is a method based on chemical bonding such as covalent bonding, ionic bonding or coordinate bonding. For binding the Lewis acid to the surface of the silica gel a method of binding the Lewis acid through a spacer group formed from an appropriate low molecular weight organic compound is used. The appropriate low molecular weight organic compound is benzenesulfonic acid or alkylbenzenesulfonic acid.

55 Such low molecular weight organic compound can be reacted with the functional group at the surface of the silica gel

to form chemical bonding.

In the case of using silica gel as the solid substance, chemical bonding can be formed with the silanol group at the surface of the silica gel. For example, when a silyl compound such as alkyl or aryltrialkoxysilane is used, a Si-O-Si-alkyl or aryl bond can be formed at the surface of the silica gel.

5 Furthermore, such binding of the Lewis acid of the present invention with the low molecular weight organic compound as a spacer, can be achieved through ionic bonding with an acidic group carried by the low molecular weight organic compound. The acidic group carried by the low molecular weight organic compound is a sulfonic acid group, and binding can be achieved by neutralizing the acidic group with a base, and then mixing the resultant with the Lewis acid of the present invention.

10 These methods can be carried out in an appropriate organic solvent.

The amount of immobilization of the Lewis acid to the silica gel is not particularly limited, but the amount may be usually 0.01 mmol to 1 mmol, and preferably 0.05 mmol to 0.5 mmol, of the Lewis acid based on 1 g of the silica gel.

[0011] The ionic liquid according to the present invention is a salt composed of an organic cation species and an anion species, and may be exemplified by a compound having a lower melting point than conventional salts, and maintaining the liquid state at a melting point of 150°C or below, preferably 80°C or below, and more preferably 0°C. Examples of such ionic liquid include alkyl-substituted imidazolium salts, alkyl-substituted pyridinium salts, quaternary ammonium salts, quaternary phosphonium salts, tertiary sulfonium salts, and the like, and as the ionic liquid of the present invention, alkyl-substituted imidazolium salts, alkyl-substituted pyridinium salts and quaternary ammonium salts are preferred, while among them, alkyl-substituted imidazolium salts are preferred.

20 The organic cation species of the ionic liquid of the present invention includes, an imidazolium cation in which two nitrogen atoms of an imidazole ring are bound to the same alkyl group or to different alkyl groups, a pyridinium cation in which a nitrogen atom on a pyridine ring is bound to an alkyl group, an ammonium cation in which identical or different four alkyl groups are bound to a nitrogen atom, a phosphonium cation in which identical or different four alkyl groups are bound to a phosphorus atom, a sulfonium cation in which identical or different three alkyl groups are bound to a sulfur atom, and the like. The cationic species which are preferable as the ionic liquid of the present invention includes, an imidazolium cation in which two nitrogen atoms of an imidazole ring are bound to the same alkyl group or to different alkyl groups, a pyridinium cation in which a nitrogen atom on a pyridine ring is bound to an alkyl group, an ammonium cation in which identical or different four alkyl groups are bound to a nitrogen atom and the like, while a more preferred cation species may be exemplified by an imidazolium cation in which two nitrogen atoms of an imidazole ring are bound to the same alkyl group or to different alkyl groups.

The alkyl group in these cation species includes, a straight-chained or branched alkyl group having 1 to 12 carbon atoms, and preferably a straight-chained alkyl group having 1 to 10 carbon atoms. Specifically, for example, a methyl group, an ethyl group, an n-propyl group, an n-butyl group, an n-pentyl group, an n-hexyl group, an n-heptyl group, an n-octyl group, an n-decyl group and the like may be included.

35 **[0012]** The anion species of the ionic liquid of the present invention includes, a hexafluoroantimonate anion, a hexafluorophosphate anion, a tetrafluoroborate anion, a chlorine anion, a bromine anion, an iodine anion, an alkanesulfonate anion, a perfluoroalkanesulfonate anion and the like.

The ionic liquid of the present invention is obtained by appropriately combining these anion species and the above-mentioned cation species. For example, imidazolium hexafluoroantimonate, imidazolium hexafluorophosphate, imidazolium tetrafluoroborate, imidazolium chloride, imidazolium bromide, imidazolium iodide, imidazolium alkanesulfonate; pyridinium hexafluoroantimonate, pyridinium hexafluorophosphate, pyridiniumtetrafluoroborate, pyridinium chloride, pyridinium bromide, pyridinium iodide, pyridinium alkanesulfonate; ammonium hexafluoroantimonate, ammonium hexafluorophosphate, ammonium tetrafluoroborate, ammonium chloride, ammonium bromide, ammonium iodide, ammonium alkanesulfonate; phosphonium hexafluoroantimonate, phosphonium hexafluorophosphate, phosphonium tetrafluoroborate, phosphonium chloride, phosphonium bromide, phosphonium iodide, phosphonium alkanesulfonate and the like may be included.

[0013] The ionic liquid of the present invention that has been described so far can be produced by a known method, or a commercially available product may be used. Furthermore, the ionic liquid can also be produced according to the method described in Non-Patent Document 7.

50 As the coating method of the present invention, production can be achieved by dissolving an ionic liquid in an organic solvent, mixing this solution with the immobilized Lewis acid catalyst of the present invention described above, and then removing the organic solvent.

The organic solvent in this method is not particularly limited as long as the solvent is volatile and can dissolve an ionic liquid, and for example, ester-based solvents such as ethyl acetate, ether-based solvents such as dimethoxyethane and THF, ketone-based solvents such as acetone, halogenated hydrocarbons such as dichloroethane, and the like may be included.

The ionic liquid is dissolved in these organic solvents, and to this solution, the immobilized Lewis acid catalyst of the present invention is added and mixed with stirring. This operation is usually performed at room temperature, but the

system may be appropriately cooled or may also be heated. The amount of the ionic liquid used may be 10 to 200% by mass, preferably 10 to 100% by mass, 10 to 80% by mass, 30 to 100% by mass, or 30 to 80% by mass, based on the mass of the immobilized Lewis acid catalyst of the present invention. These are sufficiently mixed, and then the organic solvent is removed. The method of removing the organic solvent is performed by distilling off the solvent at normal
5 pressure or under reduced pressure. When the organic solvent is completely distilled off, a solid dried immobilized Lewis acid catalyst of the present invention is obtained. The obtained immobilized Lewis acid catalyst of the present invention is coated with the added ionic liquid. If surplus ionic liquid, that is, ionic liquid that is not used in the coating, is present, the coated immobilized Lewis acid catalyst of the present invention can be obtained by eliminating the excess ionic liquid.

[0014] The immobilized Lewis acid catalyst coated with an ionic liquid of the present invention not only has a catalytic
10 activity as a Lewis acid in a non-homogeneous reaction system, but also has a good catalyst recovery rate, and can be reused. Even if the immobilized Lewis acid catalyst were expensive, the catalyst can be repeatedly used, and thus can be used as a practical catalyst.

In the reaction using the immobilized Lewis acid catalyst coated with an ionic liquid of the present invention, the solvent
15 is not particularly limited as long as the solvent does not dissolve an ionic liquid, but water or a water-containing organic solvent is particularly suitable.

Furthermore, the present invention is to provide a use of the immobilized Lewis acid catalyst coated with an ionic liquid
of the present invention, as a Lewis acid catalyst for various chemical reactions.

Examples of such chemical reactions include an aldol reaction, a Mannich type reaction, a Diels-Alder reaction, an
allylation reaction, a Michael reaction, and the like.

[0015] In addition, the present invention is to provide a method for producing chemical substances by various chemical reactions
20 using the immobilized Lewis acid catalyst coated with an ionic liquid of the present invention. This method of the present invention can be applied to, for example, an aldol reaction, a Mannich type reaction, a Diels-Alder reaction, an allylation reaction, a Michael reaction, and the like, and the present invention is to provide a method for producing chemical substances that can be produced by these reactions.

Effects of the Invention

[0015] The present invention is to provide a practical immobilized Lewis catalyst which can be easily recovered after
30 use, and can be repeatedly used in various chemical reactions, by coating an immobilized Lewis acid catalyst, which is difficult to produce and expensive, with an ionic liquid. The immobilized Lewis acid catalyst coated with an ionic liquid of the present invention can be applied to various chemical reactions that are carried out in the presence of a Lewis acid catalyst, is stable against water, and is effective in Lewis acid catalyzed reactions that are performed in water or a water-containing organic solvent, thus making it possible to perform environmentally friendly chemical reactions.

Brief Description of the Drawings

[0016] Fig. 1 shows a graph plotted, in the case where scandium triflate is used as a Lewis acid in the immobilized
40 Lewis acid catalyst coated with an ionic liquid of the present invention, for the ratio of added scandium triflate (ratio with respect to sodium salt) (horizontal axis) and the loading rate (ratio) of scandium in a silica gel supporting scandium (vertical axis).

[0017] The present invention is illustrated in more detail by the following Examples, but should not be construed to be
limited thereto.

In these Examples, silica gel used was Davisil™ 643. For water, distilled water was used after deaeration, and reactions
45 were performed in argon. Silicon enolate was synthesized according to the literature (see Non-Patent Document 6). The ionic liquid was synthesized according to an existing method (see Non-Patent Document 7). As for reagents other than those, commercial products were purchased and used after purification as necessary.

Production Example 1: Immobilization of scandium onto silica gel

[0018] Scandium was immobilized onto silica gel according to the reaction scheme shown in the following.

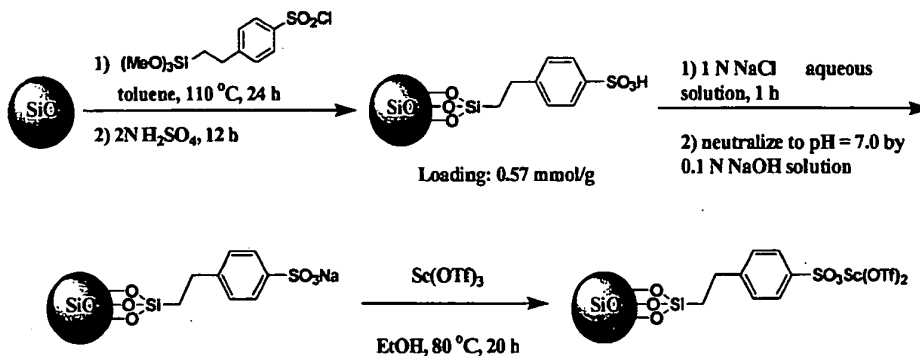
[0019]

[Chemical Formula 1]

5

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15



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[0020] (Chlorosulfonylphenyl)ethyltriethoxysilane (5 g) was refluxed together with silica gel (6.2 g) in toluene (30 ml) for 24 hours. The insoluble was collected by filtration and washed with toluene, and then the solvent was distilled off under reduced pressure. Subsequently, the resultant was treated in a 2 M aqueous solution of sulfuric acid at 80°C for 12 hours. The insoluble was collected by filtration and dried under reduced pressure, to obtain 6.2 g of sulfonic acid group-bound silica gel. 1 g of this silica gel had 0.57 millimoles of sulfonic acid groups incorporated. This (6.2 g) was suspended in 1 M saline (200 ml), and the suspension was neutralized by adding a 0.1 M sodium hydroxide solution dropwise. The reaction product was filtered, and the insoluble was washed with water and then dried under reduced pressure. The obtained silica gel having sodium arylsulfonate immobilized (0.52 g) and scandium triflate (68.5 mg) were added to ethanol (6.2 ml), and the mixture was refluxed for 20 hours. The reaction product was filtered, and the insoluble was washed with ethanol and then dried under reduced pressure, to obtain a silica gel having scandium bis(trifluoromethanesulfonate) bound through arylsulfonic acid. The yield was 0.52 g, and the scandium loading amount was 0.28 mmol/g.

35

[0021] The ratio of scandium triflate with respect to sodium arylsulfonate on the silica gel was changed as indicated in the following Table 1, and the same treatment as described in the above Production Example 1 was performed. As a result, silica gels supporting scandium with different loading rates of scandium triflate were produced.

The ratio of added scandium triflate (ratio with respect to sodium salt) and the loading rate of scandium in the produced silica gel supporting scandium are presented in the following Table 1. Furthermore, a graph summarizing these results is shown in Fig. 1. The horizontal axis of Fig. 1 represents the ratio of added scandium triflate (ratio with respect to sodium salt), while the vertical axis represents the loading rate (ratio) of scandium in the silica gel supporting scandium.

[0022]

40

[Table 1]

Sc/Na (M/M)	Sc Loading (mmol/g)
0.99	0.08
0.21	0.17
0.26	0.20
0.30	0.23
0.47	0.28
1.05	0.31
3.00	0.37

50

Production Example 2: Immobilization of bismuth onto silica gel

55

[0023] The same operation as in Production Example 1 was performed, except that bismuth triflate (0.33 mmol) was used instead of the scandium triflate in Production Example 1, and the amount of use of the sodium arylsulfonate-immobilized silica gel was set to 0.58 g, and thus a bismuth-bound silica gel was obtained. The yield was 0.58 g, and the bismuth loading amount was 0.25 mmol/g.

EXAMPLE 1

Coating of surface of silica gel supporting scandium with ionic liquid

5 [0024] The silica gel supporting scandium (50 mg) produced in Production Example 1 was mixed with an ethyl acetate solution (0.25 ml) of 1-butyl-3-decylimidazolium hexafluoroantimonate (25 mg) for 10 minutes at room temperature. Ethyl acetate was distilled off under reduced pressure, and dried under reduced pressure for 20 minutes, to thus obtain a silica gel-supported scandium catalyst coated with an ionic liquid as a dry powder. Yield 65 mg. The amount of supported scandium was 0.21 mmol/g.

10

EXAMPLE 2

Coating of surface of silica gel supporting bismuth with ionic liquid

15 [0025] The same operation as in Example 1 was performed using the silica gel supporting bismuth produced in Production Example 2 in place of the silica gel supporting scandium of Example 1, and thus a silica gel-supported bismuth catalyst coated with an ionic liquid was obtained. Yield 75 mg. The amount of supported bismuth was 0.17 mmol/g.

EXAMPLE 3

20

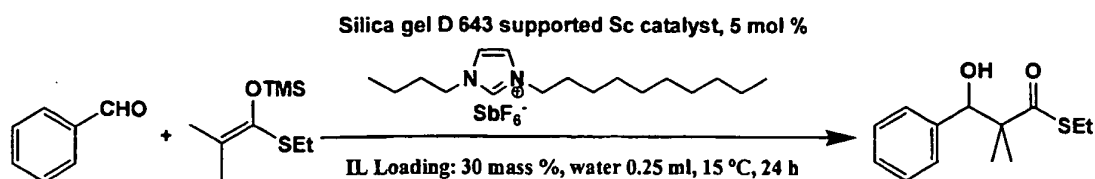
[0026] Mukaiyama-aldol reaction represented by following reaction scheme, using silica gel-supported scandium catalyst coated with ionic liquid

[0027]

25

[Chemical Formula 2]

30



35 [0028] Water (0.25 ml) was added to the silica gel supporting scandium produced in Example 1 (65 mg), and while stirring, benzaldehyde (0.25 mmol) and 1-ethylthio-1-trimethylsilyloxy-2-methyl-1-propene (0.38 mmol) were continuously added. The mixture was stirred at 15°C for 24 hours. The mixture was extracted four times by a decantation method using hexane, the solvent was distilled off under reduced pressure, and then the residue was purified by silica gel thin layer chromatography, to obtain the target product, 3-hydroxy-2,2-dimethyl-3-phenylthiopropionate, as a colorless oil. Yield 97%.

40

¹H NMR (CDCl₃) δ;

1.12 (3H, s), 1.22 (3H, s), 1.26 (3H, t, J=7.4 Hz), 2.89 (2H, q, J=7.4 Hz), 2.96 (1H, brs), 4.94 (1H, s), 7.27-7.35 (5H, m);

¹³C NMR (CDCl₃) δ;

14.4, 19.0, 23.3, 23.7, 54.3, 78.9, 127.78, 127.80, 139.9, 208.0

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The same reaction was performed using a recovered silica gel supporting scandium, and the same target product was obtained at a yield of 95%.

COMPARATIVE EXAMPLE 1

50 [0029] The method described in Example 3 was carried out in the same manner as in Example 3, using a catalyst produced by mechanically coating silica gel with an ionic liquid and scandium triflate, in place of the silica gel supporting scandium.

As a result, the target product was obtained at a yield of 78%, but the catalyst could not be recovered.

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From this, it has been demonstrated that since the immobilized Lewis acid catalyst of the present invention is supported by covalent bonding, there is a measurable improvement in the yield, and also, the catalyst is excellent even from the viewpoints of recovery and reuse of the catalyst. Moreover, since a sufficient catalytic activity is maintained even after reuse, the immobilized Lewis acid catalyst of the present invention can be said to be very stable.

EXAMPLE 4

Mukaiyama-aldol reaction using silica gel-supported bismuth catalyst coated with ionic liquid

5 [0030] The same operation as in Example 3 was performed, except that the silica gel supporting bismuth produced in Example 2 (50 mg) was used instead of the silica gel supporting scandium, and thus 3-hydroxy-2,2-dimethyl-3-phenylthiopropionate was obtained. Yield 84%.

EXAMPLE 5

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[0031] Three-component Mannich type reaction represented by following reaction scheme, using silica gel-supported scandium catalyst coated with ionic liquid

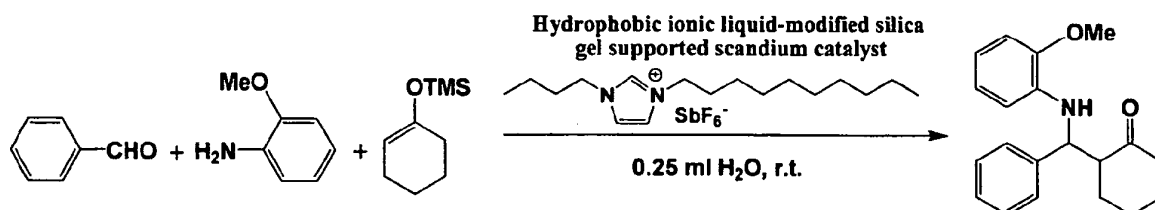
[0032]

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[Chemical Formula 3]

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[0033] Water (0.25 ml) was added to the silica gel supporting scandium produced in Example 1 (75 mg), and while stirring, benzaldehyde (0.125 mmol) and o-anisidine (0.125 mmol) and 1-cyclohexenyloxytrimethylsilane (0.25 mmol) were continuously added. The mixture was stirred at room temperature for 24 hours. The mixture was extracted four times by a decantation method using a mixture of ethyl acetate-hexane (1:1), the solvent was distilled off under reduced pressure, and then the residue was purified by silica gel thin layer chromatography, to obtain the target product, 2-(phenyl-N-(2-methoxyphenyl)aminomethyl)cyclohexanone at a syn/anti ratio of 53/47. Yield 92%.

¹H NMR (CDCl₃) δ;

35

1.55-2.10 (m, 6H), 2.24-2.44 (m, 2H), 2.76-2.81 (m, 1H), 3.84 (s, 3H), 4.70 (minor, d, 1H, J=7.6 Hz), 4.87 (d, major, 1H, J=4.4 Hz), 4.80-5.20 (brs, 1H), 6.38-6.79 (m, 4H), 7.16-7.39 (m, 5H);

¹³C NMR (CDCl₃) δ;

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23.6, 24.8, 27.0, 27.8, 28.4, 30.9, 41.6, 42.0, 42.3, 53.70, 55.4, 55.5, 56.4, 57.0, 57.3, 57.5, 109.3, 109.4, 110.4, 110.9, 111.4, 115.0, 116.6, 118.4, 121.0, 121.1, 126.9, 127.1, 127.3, 128.3, 128.4, 128.9, 137.0, 137.3, 141.7, 142.0, 147.1, 210.7, 212.2.

EXAMPLE 6

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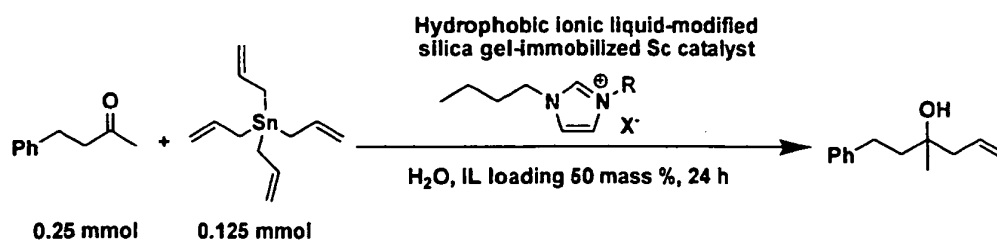
[0034] Allylation reaction represented by following reaction scheme, using silica gel-supported scandium catalyst coated with ionic liquid

[0035]

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[Chemical Formula 4]

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[0036] The same method as in Example 1 was carried out using 1-butyl-3-methylimidazolium hexafluorophosphate (25 mg) was used instead of 1-butyl-3-decylpyridinium hexafluoroantimonate (25 mg), and thus a silica gel-supported scandium catalyst coated with an ionic liquid was obtained. Yield 75 mg. The amount of supported scandium was 0.23 mmol/g.

5 Water (0.25 ml) was added to this silica gel supporting scandium (75 mg), and while stirring, 4-phenyl-2-butanone (0.25 mmol) and tetraallyltin (0.125 mmol) were continuously added. The mixture was stirred at 40°C for 24 hours. The mixture was returned to room temperature, and then was extracted four times by a decantation method using hexane. The solvent was distilled off under reduced pressure, and then the residue was purified by silica gel thin layer chromatography, to obtain the target product, 1-phenyl-3-buten-1-ol. Yield 98%.

10 Industrial Applicability

[0037] The present invention provides an immobilized Lewis acid catalyst coated with an ionic liquid, which catalyst is stable in water, has a good recovery rate, and can be reused, and provides a Lewis acid catalyst which not only maintains the activity as a Lewis acid, but also can be repeatedly used and is practical. Furthermore, since the catalyst can be used in those chemical reactions using water as the solvent, industrial usage thereof is possible without generating waste organic solvent, and thus the catalyst is useful in various chemical industries.

15 Therefore, the present invention has industrial applicability in chemical industries, particularly in various industries concerning organic compounds, such as organic synthesis industry, pharmaceutical industry or agrochemical industry.

20 Claims

- 25 1. An immobilized Lewis acid catalyst wherein a trifluoromethanesulfonate of rare earth metal or a trifluoromethanesulfonate of bismuth is immobilized on the surface of silica gel through a sulfonic acid group of a low molecular weight organic compound which is chemically bound to the surface of silica gel, and the surface of silica gel and the peripheries of the Lewis acid are coated with a hydrophobic ionic liquid; wherein the low molecular weight organic compound is a spacer group selected from the group consisting of benzenesulfonic acid and alkylbenzenesulfonic acid.
- 30 2. The immobilized Lewis acid catalyst according to claim 1, wherein the ionic liquid is an ionic liquid containing any of imidazolium, pyridinium, quaternary ammonium and quaternary phosphonium, as a cation.
- 35 3. The immobilized Lewis acid catalyst according to any one of claims 1 to 2, wherein the ionic liquid is an ionic liquid containing any of a halide ion, trifluoromethanesulfonate, tetrafluoroborate, hexafluoroantimonate, hexafluorophosphate and bis(trifluoromethanesulfonamide) ions, as an anion.
- 40 4. The immobilized Lewis acid catalyst according to any one of claims 1 to 3, wherein the ionic liquid is an imidazolium salt.
- 45 5. The immobilized Lewis acid catalyst according to any one of claims 1 to 4, wherein the ionic liquid is an imidazolium salt, and is an ionic liquid in which a hydrocarbon group having 6 or more carbon atoms is bound to at least one of the two nitrogen atoms present in the imidazole ring of the imidazolium salt.
- 50 6. The immobilized Lewis acid catalyst according to claim 1, wherein the rare earth metal is any of scandium, yttrium and ytterbium.
- 55 7. The immobilized Lewis acid catalyst according to any one of claims 1 to 6, wherein the silica gel is bound through a siloxane bond (Si-O-Si) to the low molecular weight organic compound having a sulfonic acid group.
8. A method for producing an immobilized Lewis acid coated with a hydrophobic ionic liquid, the method comprising mixing an immobilized Lewis acid wherein a trifluoromethanesulfonate of rare earth metal or a trifluoromethanesulfonate of bismuth is immobilized on the surface of a silica gel via a sulfonic acid group of a low molecular weight organic compound which is chemically bound to the surface of silica gel, with a solution of a hydrophobic ionic liquid dissolved in an organic solvent, and then removing the organic solvent; wherein the low molecular weight organic compound is a spacer group selected from the group consisting of benzenesulfonic acid and alkylbenzenesulfonic acid.

9. Use of the immobilized Lewis acid catalyst according to any one of claims 1 to 7, in a Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent.
- 5 10. The use according to claim 9, wherein the Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent is any chemical reaction selected from the group consisting of an aldol reaction, a Mannich type reaction, a Diels-Alder reaction, an allylation reaction and a Michael reaction.
- 10 11. A method for producing a chemical substance by a Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent, in the presence of the immobilized Lewis acid catalyst according to any one of claims 1 to 7.
- 15 12. The method according to claim 11, wherein the Lewis acid-catalyzed chemical reaction performed in water or a water-containing organic solvent is any chemical reaction selected from the group consisting of an aldol reaction, a Mannich type reaction, a Diels-Alder reaction, an allylation reaction and a Michael reaction.

Patentansprüche

- 20 1. Immobilisierter Lewis-Säure-Katalysator, in dem ein Seltenerdmetall-trifluormethansulfonat oder ein Bismut-trifluormethansulfonat an der Oberfläche von Silicagel durch eine Sulfonsäuregruppe einer niedermolekulargewichtigen organischen Verbindung, die chemisch an die Oberfläche von Silicagel gebunden ist, immobilisiert ist, und die Oberfläche von Silicagel und die Peripherien der Lewis-Säure mit einer hydrophoben ionischen Flüssigkeit beschichtet sind; wobei die niedermolekulargewichtige organische Verbindung eine Spacer-Gruppe, ausgewählt aus der Gruppe, bestehend aus Benzolsulfonsäure und Alkylbenzolsulfonsäure, ist.
- 25 2. Immobilisierter Lewis-Säure-Katalysator gemäß Anspruch 1, wobei die ionische Flüssigkeit eine ionische Flüssigkeit ist, die eines von Imidazolium, Pyridinium, quaternärem Ammonium und quaternärem Phosphonium als Kation enthält.
- 30 3. Immobilisierter Lewis-Säure-Katalysator gemäß einem der Ansprüche 1 bis 2, wobei die ionische Flüssigkeit eine ionische Flüssigkeit ist, die eines von einem Halogenidion, Trifluormethansulfonat-, Tetrafluorborat-, Hexafluorantimonat-, Hexafluorphosphat- und Bis(trifluormethansulfonamid)-Ionen als Anion enthält.
- 35 4. Immobilisierter Lewis-Säure-Katalysator gemäß einem der Ansprüche 1 bis 3, wobei die ionische Flüssigkeit ein Imidazoliumsalz ist.
- 40 5. Immobilisierter Lewis-Säure-Katalysator gemäß einem der Ansprüche 1 bis 4, wobei die ionische Flüssigkeit ein Imidazoliumsalz ist und eine ionische Flüssigkeit ist, in welcher eine Kohlenwasserstoffgruppe mit 6 oder mehr Kohlenstoffatomen an wenigstens eins der zwei Stickstoffatome, die in dem Imidazolring des Imidazoliumsalzes vorliegen, gebunden ist.
- 45 6. Immobilisierter Lewis-Säure-Katalysator gemäß Anspruch 1, wobei das Seltenerdmetall ein beliebiges von Scandium, Yttrium und Ytterbium ist.
- 50 7. Immobilisierter Lewis-Säure-Katalysator gemäß einem der Ansprüche 1 bis 6, wobei das Silicagel durch eine Siloxanbindung (Si-O-Si) an die niedermolekulargewichtige organische Verbindung, die eine Sulfonsäuregruppe hat, gebunden ist.
- 55 8. Verfahren zur Herstellung einer immobilisierten Lewis-Säure, die mit einer hydrophoben ionischen Flüssigkeit beschichtet ist, wobei das Verfahren Mischen einer immobilisierten Lewis-Säure, in der ein Seltenerdmetalltrifluormethansulfonat oder ein Bismut-trifluormethansulfonat an der Oberfläche eines Silicagels durch eine Sulfonsäuregruppe einer niedermolekulargewichtigen organischen Verbindung, die chemisch an die Oberfläche von Silicagel gebunden ist, immobilisiert ist, mit einer Lösung einer hydrophoben ionischen Flüssigkeit, gelöst in einem organischen Lösungsmittel, und danach Entfernen des organischen Lösungsmittels umfasst; wobei die niedermolekulargewichtige organische Verbindung eine Spacer-Gruppe, ausgewählt aus der Gruppe, bestehend aus Benzolsulfonsäure und Alkylbenzolsulfonsäure, ist.
9. Verwendung des immobilisierten Lewis-Säure-Katalysators gemäß einem der Ansprüche 1 bis 7 in einer Lewis-

Säurekatalysierten chemischen Reaktion, die in Wasser oder einem wasserhaltigen organischen Lösungsmittel durchgeführt wird.

- 5 10. Verwendung gemäß Anspruch 9, wobei die Lewis-Säure-katalysierte chemische Reaktion, die in Wasser oder einem wasserhaltigen organischen Lösungsmittel durchgeführt wird, eine chemische Reaktion ist, die aus der Gruppe, bestehend aus einer Aldol-Reaktion, einer Reaktion des Mannich-Typs, einer Diels-Alder-Reaktion, einer Allylierungs-Reaktion und einer Michael-Reaktion, ausgewählt ist.
- 10 11. Verfahren zur Herstellung einer chemischen Substanz durch eine Lewis-Säure-katalysierte chemische Reaktion, die in Wasser oder einem wasserhaltigen organischen Lösungsmittel in Gegenwart des immobilisierten Lewis-Säure-Katalysators gemäß einem der Ansprüche 1 bis 7 durchgeführt wird.
- 15 12. Verfahren gemäß Anspruch 11, wobei die Lewis-Säure-katalysierte chemische Reaktion, die in Wasser oder einem wasserhaltigen organischen Lösungsmittel durchgeführt wird, eine beliebige chemische Reaktion ist, die aus der Gruppe, bestehend aus einer Aldol-Reaktion, einer Reaktion des Mannich-Typs, einer Diels-Alder-Reaktion, eine Allylierungs-Reaktion und einer Michael-Reaktion, ausgewählt ist.

Revendications

- 20 1. Un catalyseur d'acide Lewis immobilisé, dans lequel un trifluorométhanesulfonate d'un métal de terre rare ou un trifluorométhanesulfonate de bismuth est immobilisé sur la surface d'un gel de silice par un groupe acide sulfonique d'un composé organique de faible poids moléculaire qui est lié chimiquement à la surface du gel de silice, et la surface du gel de silice et les périphéries de l'acide Lewis sont revêtues avec un liquide ionique hydrophobe; dans lequel ledit composé organique de faible poids moléculaire est un groupe espaceur choisi parmi le groupe consistant en acide benzène-sulfonique et alkylbenzène-sulfonique.
- 25 2. Le catalyseur d'acide Lewis immobilisé selon la revendication 1, dans lequel le liquide ionique est un liquide ionique contenant l'un des ions d'imidazolium, de pyridinium, d'ammonium quaternaire et de phosphonium quaternaire, en tant que cation.
- 30 3. Le catalyseur d'acide Lewis immobilisé selon l'une quelconque des revendications 1 à 2, dans lequel le liquide ionique est un liquide ionique contenant l'un des ions d'halogène, de trifluorométhanesulfonate, de tétrafluoroborate, d'hexafluoroantimoniate, d'hexafluorophosphate et de bis(trifluorométhane-sulfonamide), en tant qu'anion.
- 35 4. Le catalyseur d'acide Lewis immobilisé selon l'une quelconque des revendications 1 à 3, dans lequel le liquide ionique est un sel d'imidazolium.
- 40 5. Le catalyseur d'acide Lewis immobilisé selon l'une quelconque des revendications 1 à 4, dans lequel le liquide ionique est un sel d'imidazolium et est un liquide ionique, dans lequel un groupe hydrocarboné ayant 6 ou plus atomes de carbone est lié à au moins l'un des deux atomes d'azote présents dans le noyau d'imidazole du sel d'imidazolium.
- 45 6. Le catalyseur d'acide Lewis immobilisé selon la revendication 1, dans lequel le métal de terre rare est l'un parmi le groupe consistant en scandium, yttrium et ytterbium.
- 50 7. Le catalyseur d'acide Lewis immobilisé selon l'une quelconque des revendications 1 à 6, dans lequel le gel de silice est lié au composé organique de faible poids moléculaire ayant un groupe d'acide sulfonique par une liaison siloxane (Si-O-Si).
- 55 8. Un procédé de production d'un acide de Lewis immobilisé revêtu d'un liquide ionique, le procédé comprenant le mélange d'un acide de Lewis immobilisé, dans lequel un trifluorométhanesulfonate de métal de terre rare ou un trifluorométhanesulfonate de bismuth est immobilisé sur la surface d'un gel de silice par un groupe acide sulfonique d'un composé organique de faible poids moléculaire qui est lié chimiquement à la surface du gel de silice, et après l'élimination du solvant organique; dans lequel ledit composé organique de faible poids moléculaire est un groupe espaceur choisi parmi le groupe consistant en acide benzène-sulfonique et alkylbenzène-sulfonique.
9. Une utilisation d'un catalyseur d'acide Lewis immobilisé selon l'une quelconque des revendications 1 à 7 dans une

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réaction chimique catalysée par un acide de Lewis effectuée dans l'eau ou un solvant organique contenant de l'eau.

5 10. L'utilisation selon la revendication 9, dans laquelle la réaction chimique catalysée par un acide de Lewis effectuée dans l'eau ou un solvant organique contenant de l'eau est une réaction chimique choisie dans le groupe constitué par une réaction d'aldol, une réaction de type Mannich, une réaction de Diels-Alder, une réaction d'allylation et une réaction de Michael.

10 11. Un procédé de production d'une substance chimique par une réaction chimique catalysée par un acide de Lewis effectuée dans l'eau ou un solvant organique contenant de l'eau en présence du catalyseur d'acide de Lewis immobilisé selon l'une quelconque des revendications 1 à 7.

15 12. Le procédé selon la revendication 11, dans lequel la réaction chimique catalysée par un acide de Lewis effectuée dans l'eau ou un solvant organique contenant de l'eau est une réaction chimique choisie dans le groupe constitué par une réaction d'aldol, une réaction de type Mannich, une réaction de Diels-Alder, une réaction d'allylation ou une réaction de Michael.

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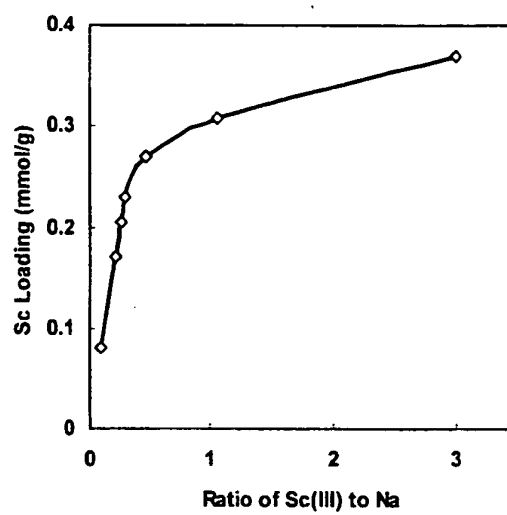
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[FIG.1]



REFERENCES CITED IN THE DESCRIPTION

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