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TRIHALOSILANE**(71) Applicant: **Dow Corning Corporation**, Midland,
MI (US)(72) Inventors: **Dimitris Katsoulis**, Midland, MI (US);
Robert Larsen, Midland, MI (US);
Matthew McLaughlin, Midland, MI
(US); **Wendy Sparschu**, Bay City, MI
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(57)

ABSTRACT

A method of preparing a trihalosilane comprising the separate and consecutive steps of (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising at least 0.1% (w/w) of silicon, wherein the copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum; and (ii) contacting the silicon-containing copper catalyst with a hydrogen halide at a temperature of from 100 to 600° C. to form a trihalosilane.

METHOD FOR PREPARING A TRIHALOSILANE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of U.S. patent application Ser. No. 13/809,263, filed on Jan. 9, 2013 and claims priority thereto under 35 U.S.C. §120 and 35 U.S.C. §365(c). U.S. patent application Ser. No. 13/809,263 is hereby incorporated by reference. U.S. patent application Ser. No. 13/809,263 is a U.S. national stage filing under 35 U.S.C. §371 of PCT Application No. PCT/US11/49138 filed on Aug. 25, 2011, currently pending, which claims the benefit of U.S. Provisional Patent Application No. 61/380,744 filed Sep. 8, 2010 under 35 U.S.C. §119 (e). PCT Application No. PCT/US11/49138 and U.S. Provisional Patent Application No. 61/380,744 are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to a method of preparing a trihalosilane comprising the separate and consecutive steps of (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide to form a silicon-containing copper catalyst, and (ii) contacting the silicon-containing copper catalyst with a hydrogen halide to form a trihalosilane.

BACKGROUND OF THE INVENTION

[0003] A number of methods of producing trihalosilane have been disclosed. For example, the reaction of HCl with zero-valent silicon has been described. In addition, trichlorosilane has been produced by passing silicon tetrachloride, hydrogen, and hydrogen chloride over zero-valent silicon at 600° C. Further, trichlorosilane has been produced by passing H₂ and SiCl₄ over silicon particles in a first stage, adding HCl to the effluent from the first stage, and then passing the effluent and HCl over more silicon particles optionally containing a catalyst (i.e., CuCl) in a second stage. Finally, trichlorosilane has been produced by passing H₂, SiCl₄, and HCl over zero-valent silicon containing homogeneously distributed copper silicide.

[0004] While the art describes methods of producing trichlorosilane, these methods have some limitations. Many of these processes employ zero-valent silicon. Since zero-valent silicon is typically produced by the highly energy-intensive carbothermic reduction of silicon dioxide, using zero-valent silicon adds costs to these processes.

[0005] Therefore, there is a need for more economical methods of producing trihalosilanes that avoid the need for using zero-valent silicon.

BRIEF SUMMARY OF THE INVENTION

[0006] The present invention is directed to a method of preparing a trihalosilane comprising the separate and consecutive steps of (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising at least 0.1% (w/w) of silicon, wherein the copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum; and (ii) contacting the silicon-containing copper catalyst with a hydrogen halide at a temperature of from 100 to 600° C. to form a trihalosilane.

[0007] The method of the present invention produces a trihalosilane using silicon tetrahalide. Silicon tetrahalide is a byproduct of industrial processes and may be produced using less energy than required to produce zero-valent silicon. Thus, the method of the invention may be more economical than prior processes for producing trihalosilane.

[0008] The trihalosilane produced by the method of the invention can be used to make high purity polysilicon, which is used in solar cells or electronic chips, or can be hydrolyzed in known processes to produce polysiloxanes, which find use in many industries and applications.

DETAILED DESCRIPTION OF THE INVENTION

[0009] A method of preparing a trihalosilane, the method comprising the following separate and consecutive steps:

[0010] (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising at least 0.1% (w/w) of silicon, wherein the copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum; and

[0011] (ii) contacting the silicon-containing copper catalyst with a hydrogen halide at a temperature of from 100 to 600° C. to form a trihalosilane.

[0012] In step (i), a copper catalyst is contacted with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising at least 0.1% (w/w) of silicon, wherein the copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum.

[0013] The copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum. The mixture typically comprises from 0.1 to less than 100% (w/w), alternatively from 50 to less than 100% (w/w), alternatively, from 70 to less than 100% (w/w), alternatively, from 80 to 99.9% (w/w), of copper, based on the total weight of the mixture, with the balance of the mixture being at least one of the elements described above.

[0014] The copper catalyst may further comprise a support. Examples of supports include, but are not limited to, oxides of aluminum, titanium, zirconium, and silicon; activated carbon; carbon nanotubes; fullerenes; graphene and other allotropic forms of carbon. In one embodiment, the support is activated carbon.

[0015] When the copper catalyst comprises a support, the catalyst typically comprises from 0.1 to less than 100% (w/w), alternatively from 0.1 to 50% (w/w), alternatively from 0.1 to 35% (w/w), of copper or the mixture, based on the combined weight of the support and copper or the mixture.

[0016] The copper catalyst can have a variety of physical forms including, but not limited to, lumps, granules, flakes, and powder.

[0017] As used herein, the term "metal" refers to zero-valent metal, a metal compound, or a combination of zero-valent metal and a metal compound. The oxidation number of the metal can vary, for example, from 0 to an oxidation number equal to the metal's group number in the Periodic Table of Elements, alternatively the oxidation number is from 0 to 2, alternatively the oxidation number is 0 for copper, gold and platinum, and 2 for magnesium.

[0018] Examples of the unsupported copper catalyst include, but are not limited to, zero-valent copper, mixtures of zero-valent copper and metallic gold, mixtures of zero-valent copper, zero-valent gold and magnesium chloride, and mixtures of zero-valent copper and zero-valent platinum.

[0019] Examples of the supported copper catalyst include the unsupported copper catalysts described above on an activated carbon support.

[0020] The unsupported and supported copper catalysts can be made by processes known in the art. For example, to make the unsupported catalyst, metallic copper, metallic gold, magnesium chloride, and metallic platinum may be mixed to form the copper catalysts. Alternatively, metal salts, including, but not limited to, halide, acetate, nitrate, and carboxylate salts of copper, gold, magnesium, and platinum, may be mixed in desired proportions and then reduced with hydrogen at elevated temperature, typically around 500° C. One such reduction process is described below for making the supported copper catalysts. This process may leave some salts, such as magnesium chloride, unreduced, while reducing others.

[0021] The supported copper catalyst may be prepared by, for example, dissolving a copper salt, such as cupric chloride, in a solvent, such as water or acid, applying this copper salt solution to a support, and reducing the copper salt on the surface of the support. For example, CuCl_2 can be dissolved in water or hydrochloric acid and mixed with activated carbon. Excess CuCl_2 solution can then be removed, and the activated carbon- CuCl_2 mixture dried. The CuCl_2 can then be reduced on the activated carbon with hydrogen at high temperature, typically about 500° C., to give the supported copper catalyst. One skilled in the art would understand that the order of addition and reduction and multistep addition of salts and subsequent reduction can also be carried out to prepare the supported catalyst. In addition, it is contemplated that the supported copper catalyst may be prepared by separately reducing separate metals on separate supports and then mixing the separately supported metals to form the copper catalyst. A method of making the supported metallic catalysts is also described in detail in the examples section below. Some of these catalysts are also available commercially.

[0022] The silicon tetrahalide has the formula SiX_4 , where X is chloro, bromo, fluoro, or iodo, alternatively chloro, bromo, or iodo, alternatively chloro.

[0023] Examples of the silicon tetrahalide include, but are not limited, silicon tetrachloride, silicon tetrabromide, silicon tetraiodide, and silicon tetrafluoride. In one embodiment, the silicon tetrahalide is silicon tetrachloride.

[0024] The reactor for step (i) can be any reactor suitable for the combining of gases and solids. For example, the reactor configuration can be a packed bed, stirred bed, vibrating bed, moving bed, re-circulating bed, or a fluidized bed. When using a re-circulating bed, the silicon-containing copper catalyst can be circulated from a bed for conducting step (i) to a separate bed for conducting step (ii). To facilitate reaction, the reactor should have means to control the temperature of the reaction zone.

[0025] The temperature at which the hydrogen and the silicon tetrahalide are contacted with the copper catalyst is typically from 500 to 1400° C.; alternatively from 600 to 1200° C.; alternatively from 650 to 1100° C.

[0026] The pressure at which the hydrogen and the silicon tetrahalide are contacted with the copper catalyst can be sub-atmospheric, atmospheric, or super-atmospheric. For

example, the pressure is typically from atmospheric pressure to 4000 kilopascals gauge (kPag); alternatively from 0 to 2000 kPag; alternatively from 7 to 1000 kPag.

[0027] The mole ratio of hydrogen to silicon tetrahalide contacted with the copper catalyst is typically from 10,000:1 to 0.01:1, alternatively from 100:1 to 1:1, alternatively from 20:1 to 2:1, alternatively from 20:1 to 5:1.

[0028] The residence time for the hydrogen and silicon tetrahalide is sufficient for the hydrogen and silicon tetrahalide to contact the copper catalyst and form the silicon-containing copper catalyst. For example, a sufficient residence time for the hydrogen and silicon tetrahalide is typically at least 0.01 seconds (s); alternatively at least 0.1 s; alternatively from 0.1 s to 10 min; alternatively from 0.1 s to 1 min; alternatively from 1 s to 10 s. As used herein, "residence time" means the time for one reactor volume of reactant gases (i.e., hydrogen and silicon tetrahalide) to pass through a reactor charged with copper catalyst. The desired residence time may be achieved by adjusting the flow rate of the hydrogen and silicon tetrahalide.

[0029] The hydrogen and silicon tetrahalide are typically fed to the reactor simultaneously; however, other methods of combining, such as by separate pulses, are also envisioned.

[0030] The copper catalyst is in a sufficient amount. As used herein, a "sufficient amount" of copper catalyst is enough catalyst to form the silicon-containing copper catalyst, described below, when the hydrogen and silicon tetrahalide are contacted with the copper catalysts. For example, a sufficient amount of catalyst is at least 0.01 mg catalyst/ cm^3 of reactor volume; alternatively at least 0.5 mg catalyst/ cm^3 of reactor volume; alternatively from 1 to 10,000 mg catalyst/ cm^3 of reactor volume.

[0031] There is no upper limit on the time for which step (i) is conducted. For example, step (i) is usually conducted for at least 0.1 seconds, alternatively from 1 second to 5 hours, alternatively from 1 minute to 1 hour.

[0032] Step (i) produces a silicon-containing copper catalyst comprising, based on the total weight of the silicon-containing copper catalyst including any support, at least 0.1% (w/w), alternatively from 0.1 to 90% (w/w), alternatively 1 to 20% (w/w), alternatively from 1 to 5% (w/w), of silicon. The percentage of silicon in the silicon-containing copper catalyst can be determined using standard analytical tests. For example, the percentage of silicon may be determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES) and ICP mass spectrometry (ICP-MS).

[0033] In step (ii) of the method, the silicon-containing copper catalyst, as described above for step (i), is contacted with a hydrogen halide at a temperature of from 100 to 600° C. to form a trihalosilane.

[0034] The hydrogen halide has the formula HX , where X is as defined above for the silicon tetrahalide and may be the same or different as for the silicon tetrahalide.

[0035] Examples of the hydrogen halide include, but are not limited to, hydrogen chloride, hydrogen bromide, and hydrogen iodide.

[0036] The reactors suitable for use in (ii) are as described for (i). The same reactor may be used for step (i) as used in step (ii); however, separate reactors may also be used.

[0037] The hydrogen halide is typically contacted with the silicon-containing copper catalyst by feeding the hydrogen halide into a reactor containing the silicon-containing copper catalyst produced in step (i).

[0038] The residence time of the hydrogen halide is sufficient for the hydrogen halide to react with the silicon-containing copper catalyst to form a trihalosilane. For example, a sufficient residence time of the hydrogen halide is typically at least 0.01 s, alternatively at least 0.1 s, alternatively from 0.5 s to 10 min, alternatively from 1 to 60 s, alternatively from 1 to 10 s. The desired residence time can be achieved by adjusting the flow rate of the hydrogen halide.

[0039] The temperature at which hydrogen halide is contacted with the silicon-containing copper catalyst is typically from 100 to 600° C.; alternatively from 200 to 500° C.;

[0040] alternatively from 250 to 375° C.

[0041] Step (ii) is typically conducted until the silicon in the silicon-containing copper catalyst falls below a predetermined limit. For example, step (ii) is typically conducted until the silicon in the silicon-containing copper catalyst is below 90% (w/w), alternatively from 1 to 90% (w/w), alternatively from 1 to 40% (w/w), of its initial weight. As used herein, the “initial weight” of silicon in the silicon-containing copper catalyst means the weight of silicon in the silicon-containing copper catalyst before being contacted with the hydrogen halide in step (ii). The amount of silicon in the silicon-containing catalyst contacted with the hydrogen halide in step (ii) may be determined as described for the silicon-containing catalyst for step (i).

[0042] The pressure at which the hydrogen halide is contacted with the silicon-containing copper catalyst in (ii) can be sub-atmospheric, atmospheric, or super-atmospheric. For example, the pressure is typically from atmospheric pressure to 4000 kPag; alternatively from 0 to 2000 kPag; alternatively from 7 to 1000 kPag.

[0043] The silicon-containing copper catalyst is in a sufficient amount. As used herein, a “sufficient amount” of silicon-containing copper catalyst is enough catalyst to form the trihalosilane, described below, when contacted with the hydrogen halide. For example, a sufficient amount of silicon-containing copper catalyst is at least 0.01 mg silicon-containing copper catalyst/cm³ of reactor volume; alternatively at least 0.5 mg silicon-containing copper catalyst/cm³ of reactor volume; alternatively from 1 to 10,000 mg silicon-containing copper catalyst/cm³ of reactor volume.

[0044] In one embodiment, step (ii) is conducted in the presence of hydrogen. When present, the hydrogen and hydrogen halide are in a mole ratio of hydrogen to hydrogen halide of at least 0.05:1, alternatively from 0.05:1 to 50:1, alternatively from 0.25:1 to 20:1, alternatively from 2:1 to 10:1.

[0045] The residence time, pressure, temperature and other parameters for the hydrogen and hydrogen halide together are as described for the hydrogen halide above.

[0046] Step (i) and step (ii) of the method are conducted separately and consecutively. As used herein, “separately” means that the step (i) and step (ii) do not overlap or coincide. As used herein, “consecutively” means that step (ii) is performed after step (i) in the method; however, additional steps may be performed between step (i) and (ii), such as described below.

[0047] The method of the invention may also comprise purging prior to the contacting of the silicon-containing copper catalyst with the hydrogen halide in step (ii) and prior to the contacting of the reformed silicon-containing catalyst with the hydrogen halide in (iv), described below. As used herein, “purging” means to introduce a gas stream to the reactor containing the silicon-containing copper catalyst to

remove unwanted materials. Unwanted materials are, for example, O₂ and H₂O. Purging may be accomplished with an inert gas, such as argon, nitrogen, or helium or with a reactive gas, such as silicon tetrachloride, which reacts with moisture thereby removing it.

[0048] In one embodiment, the method further comprises step (iii) contacting the silicon-containing copper catalyst contacted with the hydrogen halide in step (ii) with the mixture comprising hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to reform the silicon-containing copper catalyst comprising at least 0.1% (w/w) silicon; and step (iv) contacting the reformed silicon-containing copper catalyst with the hydrogen halide at a temperature of from 100 to 600° C. to form the trihalosilane.

[0049] In another embodiment, the method of the invention further comprises repeating steps (iii) and (iv) at least 1 time, alternatively from 1 to 10⁵ times, alternatively from 1 to 1000 times, alternatively from 1 to 100 times, alternatively from 1 to 10 times.

[0050] The method may further comprise pre-heating and gasifying the silicon tetrahalide by known methods prior to contacting with the copper catalyst in steps (i) and (iii). Alternatively, the process may further comprise bubbling the hydrogen through the silicon tetrahalide to vaporize the silicon tetrahalide prior to contacting with the copper catalysts in step (i) and the silicon-containing copper catalyst in step (iii).

[0051] The process may further comprise recovering the trihalosilane produced. The trihalosilane may be recovered by, for example, removing gaseous trihalosilane and any other gases from the reactor followed by isolation of the trihalosilane by distillation.

[0052] The trihalosilane produced by the process described and exemplified above has the formula HSiX₃, wherein X is as defined and exemplified for the silicon tetrahalide.

[0053] Examples of trihalosilanes prepared according to the present process include, but are not limited to, HSiCl₃, HSiBr₃, and HSiI₃.

[0054] The method of the present invention produces a trihalosilane from silicon tetrahalide. Since silicon tetrahalide, such as silicon tetrachloride, is a byproduct of other industrial processes and may be produced using less energy than required to produce zero-valent silicon, the method of the invention may be more economical than methods of producing trihalosilane using zero-valent silicon.

[0055] The process of the present invention produces a trihalosilane that can be used to make high purity polysilicon or that can be hydrolyzed in known processes for producing polysiloxanes. High purity polysilicon finds use in, for example, solar cells and computer chips, and polysiloxanes find use in many industries and applications.

EXAMPLES

[0056] The following examples are presented to better illustrate the method of the present invention, but are not to be considered as limiting the invention, which is delineated in the appended claims. Unless otherwise noted, all parts and percentages reported in the examples are by weight. The following table describes the abbreviations and terms used in the

Examples

[0057]

TABLE 1

List of abbreviations and terms used in the examples.	
Abbreviation	Word
g	gram
mg	milligram
Me	methyl
wt	weight
%	percent
mol	mole
hr	hour
° C.	degrees Celsius
NA	not applicable
mL	milliliters
cm	centimeter
sccm	standard cubic centimeters per minute
TCD	thermal conductivity detector
Sel.	selectivity
Selectivity	mole % of product, based on weight of product and all other silicon-containing products
GC	gas chromatography
ND	none detected
Temp.	temperature
P	pressure
kPag	kilopascals (gauge)
min	minutes
s	seconds

Method of Producing Copper Catalyst Comprising Copper, Gold, and Magnesium

[0058] $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (99+%, 1.0526 g), 0.0192 g AuCl_3 (99%), and 0.0357 g $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ (99.995%) were dissolved in 2.1 mL of deionized H_2O and 0.1 mL concentrated HCl to form a metal salt mixture. This metal salt mixture was then added to 1.1734 g of activated carbon. Excess liquid not absorbed by the activated carbon was dabbed away, and then the activated carbon was dried at 175° C. The dried activated carbon had a final dry weight of 1.9355 g. Based on the starting weight of the activated carbon and metal solution loading, the metal loading on the activated carbon was calculated to be 22.3% (w/w) Cu, 0.71% (w/w) Au, and 0.24% (w/w) Mg. The metal loaded activated carbon (0.77 g) was charged into a quartz glass tube and placed into a flow reactor. Activation and reduction of the catalyst was performed by flowing H_2 at 100 sccm (controlled via MKS 1179A mass flow controller) into the glass tube containing the catalyst in the reactor at 600° C. for 5 hours. The heating was accomplished using a Lindberg/Blue Minimite 1 inch tube furnace.

Reaction Apparatus

[0059] The reaction apparatus comprised a 4.8 mm inner diameter quartz glass tube in a flow reactor. The reactor tube was heated using a Lindberg/Blue Minimite 2.54 cm tube furnace. MKS 1179A mass flow controllers were used to control gas flow rates. A stainless steel SiCl_4 bubbler was used to introduce SiCl_4 into the H_2 gas stream. The amount of SiCl_4 in the H_2 gas stream was adjusted by changing the temperature of the SiCl_4 in the bubbler according to calculations using well-known thermodynamic principles. For reactions run at pressures above atmospheric pressure, a back pressure regulator (GO type Hastelloy® rated for 0-500 psig) was intro-

duced at the back end of the reactor. The reactor effluent passed through an actuated 6-way valve from Vici.

Reagents

[0060] The activated carbon, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, AuCl_3 , and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ and other reagents used in the examples were purchased from Sigma Aldrich (Milwaukee, Wis.).

Product Analysis

[0061] The effluent of the reactor containing the products and byproducts was passed through an actuated 6-way valve (Vici) with constant 100 μL injection loop before being discarded. Samples were taken from the reaction stream by actuating the injection valve and the 100 μL sample passed directly into the injection port of a 6890A Agilent GC for analysis with a split ratio at the injection port of 5:1. The GC contained a single 30 m Rtx-DCA column (Restek, 320 μm inner diameter, 1 μm thick film), which was split at the outlet. One path went to a TCD for quantization of the reaction products and the other path went to a Flame Ionization Detector.

Flow Rates

[0062] Flow rate ratios were determined using known thermodynamic principles and the flow rates of hydrogen and SiCl_4 at standard temperature and pressure.

Example 1

[0063] A copper catalyst (0.6085 g) comprising an activated carbon supported mixture of 22.3% (w/w) Cu, 0.71% (w/w) Au, and 0.24% (w/w) Mg was prepared as described above. The copper catalyst was then treated with H_2 and SiCl_4 at a mole ratio of H_2 to SiCl_4 of 16:1 for 30 min by bubbling H_2 (100 sccm) through a stainless steel bubbler containing liquid SiCl_4 at about 0° C. and into a flow reactor containing the copper catalyst at 750° C. to form a silicon-containing copper catalyst comprising about 4% (w/w) Si. After 30 minutes, the SiCl_4 flow was ceased, and the hydrogen flow was maintained for about 1 hr. while cooling the reactor to 300° C.

[0064] The reactor containing the silicon-containing copper catalyst was then purged with a 50 sccm argon flow for 15 min. After the purging, HCl was fed through the reactor at a flow rate of 5 sccm. The reaction effluent was periodically analyzed by GC to determine the HSiCl_3 selectivity. After the silane production rate declined, the HCl feed was ceased, and the silicon-containing copper catalyst was contacted again with H_2 and SiCl_4 for 30 min at 750° C. to reform the silicon-containing copper catalyst. The reformed silicon-containing copper catalyst was then purged with argon and contacted again with HCl as described above.

[0065] This cycle of treating the copper catalyst with H_2 and SiCl_4 to form the silicon-containing copper catalyst (step (i)) and exposing the silicon-containing catalyst formed to HCl (step (ii)) was repeated six times. In some cycles, hydrogen or argon were co-fed with the HCl to the catalyst. Each cycle's conditions and the selectivity results are shown in Table 2. This example shows that HSiCl_3 can be produced with good selectivity, the benefits of adding hydrogen with the hydrogen halide, and that the silicon-containing copper catalyst can be regenerated repeatedly.

TABLE 2

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu, Au, and Mg on activated carbon.						
Cycle #	Flow Rates and Conditions		Time (min.)	Selectivity (mol % Si products)		
	Step 1	Step 2		HSiCl ₃	H ₂ SiCl ₂	SiCl ₄
1	H ₂ : 100 sccm SiCl ₄ : 7.2 sccm P: 49.6 kPag	HCl: 5 sccm T: 300° C. P: 9.65 kPag	9	22.4	ND	77.6
			30	0.4	ND	99.6
			51	ND	ND	100.0
			73	ND	ND	100.0
			99	ND	ND	100.0
2	H ₂ Flow: 100 sccm SiCl ₄ : 10.7 sccm P: 22.1 kPag	HCl: 5 sccm Ar: 5 sccm T: 300° C. P: 7.6 kPag	9	28.6	ND	71.2*
			33	4.4	ND	95.6
			56	ND	ND	100.0
			83	ND	ND	100.0
			104	ND	ND	100.0
			125	ND	ND	100.0
			151	ND	ND	100.0
			172	ND	ND	43.9*
3	H ₂ : 100 sccm SiCl ₄ : 3.5 sccm P: 213 kPag	HCl: 5 sccm H ₂ : 5 sccm Temp.: 300° C. P: 7.6 kPag	8	58.5	0.1	41.4
			31	4.6	ND	95.4
			52	ND	ND	69.7*
			73	ND	ND	58.6*
			94	ND	ND	54.4*
4	H ₂ : 100 sccm SiCl ₄ : 6.8 sccm P: 75.2 kPag	HCl: 5 sccm H ₂ : 5 sccm Temp.: 400° C. P: 11.0 kPag	8	58.5	1.3	40.2*
			30	ND	ND	100.0
			55	ND	ND	100.0
			76	ND	ND	100.0
5	H ₂ : 100 sccm SiCl ₄ : 4.3 sccm P: 153 kPag	HCl: 5 sccm H ₂ : 5 sccm Temp: 200° C. P: 13-48 kPag	5	45.1	ND	54.9
			31	50.7	ND	49.3
			56	73.8	ND	26.2
			85	76.2	ND	23.8
			120	60.4	ND	39.6
6	H ₂ : 100 sccm SiCl ₄ : 3.6 sccm P: 213 kPag	HCl: 5 sccm H ₂ : 5 sccm Temp.: 300° C. P: 744-848 kPag	8	47.4	0.8	51.8*
			30	9.4	ND	90.6
			68	ND	ND	100.0

*balance of material is methylated silicon-containing products.

Example 2

[0066] A catalyst comprising 16.5% Cu, 0.7% Au, and 0.2% Mg on activated carbon was prepared and treated as described in example 1, except the stainless steel bubbler was at 23° C. to give a mole ratio of H₂ to SiCl₄ of 10:1 and the time was varied as indicated in Table 3, to form a silicon-

containing copper catalyst comprising about 4% (w/w) Si. The silicon-containing copper catalyst was reacted in step 2 as in example 1 but with the parameters listed in Table 3 and at 300° C. in every cycle. This example shows that HSiCl₃ can be produced with good selectivity, the benefits of adding hydrogen with the hydrogen halide, and that the silicon-containing copper catalyst can be regenerated repeatedly.

TABLE 3

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu, Au, and Mg on activated carbon.						
Cycle #	Flow Rates and Conditions		Time (min)	Selectivity (mol % Si products)		
	Step 1	Step 2		H ₂ SiCl ₂	HSiCl ₃	SiCl ₄
1	H ₂ : 100 sccm Temp: 750° C. P: 82 kPag SiCl ₄ : 19.3 sccm	HCl: 2 sccm H ₂ : 20 sccm P: 14 kPag	22	ND	42.2	57.8
			42	ND	29.9	70.2
2	H ₂ : 100 sccm Temp: 750° C. P: 28 kPag SiCl ₄ : 28.5 sccm	HCl: 5 sccm H ₂ : 10 sccm P: 14 kPag	20	ND	15.8	84.3
			39	ND	16.7	83.3
			59	ND	19.0	81.0
			80	ND	22.3	77.8
			100	ND	24.5	75.5
			119	ND	23.4	76.6

TABLE 3-continued

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu, Au, and Mg on activated carbon.						
Cycle #	Flow Rates and Conditions		Time (min)	Selectivity (mol % Si products)		
	Step 1	Step 2		H ₂ SiCl ₂	HSiCl ₃	SiCl ₄
3	H ₂ : 100 sccm Temp: 750° C. P: 165 kPag SiCl ₄ : 30.3 sccm	HCl: 3 sccm	20	ND	32.3	67.7
		H ₂ : 15 sccm	40	ND	21.3	78.8
		P: 14 kPag	60	ND	18.7	81.3
4	H ₂ : 100 sccm Temp: 850° C. P: 34 kPag SiCl ₄ : 28.3 sccm	HCl: 5 sccm	14	ND	24.3	75.7
		Ar: 10 sccm	31	ND	15.4	84.6
		P: 14 kPag	55	ND	ND	100.0
			79	ND	ND	100.0
5	H ₂ : 100 sccm Temp: 850° C. P: 28 kPag SiCl ₄ : 29.9 sccm	HCl: 5 sccm	14	ND	35.4	64.6
		H ₂ : 10 sccm	31	ND	24.1	75.9
		P: 14 kPag	51	ND	22.1	77.9
6	H ₂ : 100 sccm Temp: 850° C. P: 159 kPag SiCl ₄ : 5.0 sccm	HCl: 5 sccm	17	ND	22.9	77.1
		Ar: 10 sccm	36	ND	15.1	84.9
		P: 14 kPag	53	ND	13.0	87.0
			72	ND	ND	100.0
			91	ND	ND	100.0
7	H ₂ : 100 sccm Temp: 850° C. P: 28 kPag Time: 60 min SiCl ₄ : 30.7 sccm	HCl: 2 sccm	18	4.5	85.7	9.8
		H ₂ : 20 sccm	36	ND	17.8	82.2
		P: 345 kPag	53	ND	11.9	88.1
8	H ₂ : 100 sccm Temp: 850° C. P: 28 kPag Time: 60 min SiCl ₄ : 29.6 sccm	HCl: 2 sccm	18	2.4	84.9	12.7
		Ar: 20 sccm	35	ND	23.6	76.4
		P: 345 kPag	53	ND	8.1	91.9
			71	ND	7.2	92.9

Example 3

[0067] A catalyst comprising 15.2% (w/w) Pt and 1.4% (w/w) Cu on activated carbon was prepared contacted as in example 1 with the conditions listed in Table 4, and the products analyzed by GC-MS. No other silanes, other than those listed in Table 4, were detected in the effluent after the second step. This example shows that HSiCl₃ can be produced with good selectivity and that the silicon-containing copper catalyst can be regenerated.

TABLE 4

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu and Pt on activated carbon.					
Cycle	Flow Rates and Conditions		Time	Selectivity (mol % Si products)	
	Step 1	Step 2		HSiCl ₃	SiCl ₄
#	Step 1	Step 2	(min.)	HSiCl ₃	SiCl ₄
	H ₂ : 100 sccm	HCl: 2.5	20	ND	100
	Temp: 750° C.	sccm	46	8.0	91.8
	P: 19 kPag	H ₂ : 5	74	1.1	98.9
	SiCl ₄ : 7.7	sccm	99	ND	100
	sccm	Temp: 300° C. P: 75 kPag			

TABLE 4-continued

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu and Pt on activated carbon.					
Cycle	Flow Rates and Conditions		Time	Selectivity (mol % Si products)	
	Step 1	Step 2		HSiCl ₃	SiCl ₄
#	Step 1	Step 2	(min.)	HSiCl ₃	SiCl ₄
	H ₂ : 100 sccm	HCl: 2.5	21	11.7	88.3
	Temp: 750° C.	sccm	41	ND	100
	P: 79 kPag	H ₂ : 5	61	ND	100
	SiCl ₄ : 4.4	sccm			
	sccm	Temp: 450° C. P: 63 kPag			

Example 4

[0068] A catalyst comprising 16.3% (w/w) Cu, 0.7% (w/w) Au, and 0.2% (w/w) Mg on activated carbon was prepared and treated as described in example 1, except the stainless steel bubbler was at 22° C. to give a mole ratio of H₂ to SiCl₄ of 10:1 and the time was varied as indicated in Table 3, to form a silicon-containing copper catalyst comprising about 4% (w/w) Si. The silicon-containing copper catalyst was reacted in step 2 as in example 1 but with the parameters listed in Table 5 and at 300° C. in every cycle.

TABLE 5

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu, Au, and Mg on activated carbon (16.3% (w/w) Cu, 0.7% (w/w) Au, 0.2% (w/w) Mg on activated carbon).						
Flow Rates and Conditions			Selectivity (mol % Si products)			
Cycle #	Step 1	Step 2	Time (min.)	H ₂ SiCl ₂	HSiCl ₃	SiCl ₄
1	H ₂ : 100 sccm	HCl: 2 sccm	19	ND	65	35
	SiCl ₄ : 21.3 sccm	T: 300° C.	41	ND	52	48
	P: 63 kPag	P: 10 kPag	72	ND	36	64
2	H ₂ : 100 sccm	HCl: 2 sccm	19	1	80	19
	SiCl ₄ : 26.9 sccm	T: 300° C.	38	ND	22	78
	P: 26 kPag	P: 276 kPag	60	ND	14	86
3	H ₂ : 100 sccm	HCl: 2 sccm	20	3	80	17
	SiCl ₄ : 26.9 sccm	T: 300° C.	44	ND	20	80
	P: 28 kPag	P: 349 kPag	63	ND	16	84
4	H ₂ : 100 sccm	HCl: 2 sccm	20	ND	65	35
	SiCl ₄ : 27.7 sccm	T: 300° C.	40	ND	22	78
	P: 29 kPag	P: 352 kPag	61	ND	20	80
5	H ₂ : 100 sccm	HCl: 2 sccm	20	4	83	13
	SiCl ₄ : 27.8 sccm	T: 300° C.	42	ND	24	76
	P: 23 kPag	P: 345 kPag	62	ND	21	79
6	H ₂ : 100 sccm	HCl: 2 sccm	19	6	88	5
	SiCl ₄ : 26.6 sccm	T: 300° C.	39	ND	28	72
	P: 28 kPag	P: 346 kPag	61	ND	22	78
7	H ₂ : 100 sccm	HCl: 2 sccm	23	2	85	13
	SiCl ₄ : 26.3 sccm	T: 300° C.	42	ND	24	76
	P: 26 kPag	P: 358 kPag	65	ND	20	80
8	H ₂ : 100 sccm	HCl: 2 sccm	11	ND	94	6
	SiCl ₄ : 27.5 sccm	T: 300° C.	29	ND	64	36
	P: 24 kPag	P: 301 kPag	50	ND	22	78
9	H ₂ : 100 sccm	HCl: 2 sccm	20	ND	78	22
	SiCl ₄ : 26.6 sccm	T: 300° C.	44	ND	26	74
	P: 26 kPag	P: 531 kPag				

Example 5

[0069] A catalyst comprising 17.3% (w/w) Cu, 0.7% (w/w) Au, and 0.2% (w/w) Mg on activated carbon was prepared and treated as described in example 1, except the stainless steel bubbler was at 23° C. to give a mole ratio of H₂ to SiCl₄

of 10:1 and the time was varied as indicated in Table 6, to form a silicon-containing copper catalyst comprising about 4% (w/w) Si. The silicon-containing copper catalyst was reacted in step 2 as in example 1 but with the parameters listed in Table 6 and at 300° C. in every cycle.

TABLE 6

Production of HSiCl ₃ at various temperatures and pressures with catalyst comprising Cu, Au, and Mg on activated carbon (17.3% Cu, 0.7% Au, and 0.2% Mg on C).						
Flow Rates and Conditions			Selectivity (mol % Si products)			
Cycle #	Step 1	Step 2	Time (min.)	H ₂ SiCl ₂	HSiCl ₃	SiCl ₄
1	H ₂ : 100 sccm	HCl: 2 sccm	10	ND	81	19
	SiCl ₄ : 27.6 sccm	T: 300° C.	28	ND	58	42
	P: 31 kPag	P: 10 kPag	47	ND	46	54
2	H ₂ : 100 sccm	HCl: 2 sccm	9	ND	78	22
	SiCl ₄ : 28.4 sccm	T: 300° C.	23	5	78	16
	P: 28 kPag	P: 342 kPag	40	ND	17	83
3	H ₂ : 100 sccm	HCl: 2 sccm	18	6	86	8
	SiCl ₄ : 27.3 sccm	T: 300° C.	25	2	76	22
	P: 32 kPag	P: 355 kPag	32	ND	39	61
4	H ₂ : 100 sccm	HCl: 2 sccm	39	ND	20	80
	SiCl ₄ : 28.6 sccm	T: 300° C.	10	6	78	17
	P: 28 kPag	P: 354 kPag	17	5	86	9
5	H ₂ : 100 sccm	HCl: 2 sccm	23	2	76	23
	SiCl ₄ : 28.3 sccm	T: 300° C.	30	ND	42	58
	P: 296 kPag	P: 363 kPag	10	8	81	12
			17	5	83	12
			23	3	75	22
			30	ND	41	59

1. A method of preparing a trihalosilane, the method comprising the following separate and consecutive steps:

- (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising at least 0.1% (w/w) of silicon, wherein the copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum; and
- (ii) contacting the silicon-containing copper catalyst with a hydrogen halide at from 100 to 600° C. to form a trihalosilane.

2. The method according to claim 1, further comprising (iii) contacting the silicon-containing copper catalyst contacted with the hydrogen halide in step (ii) with the hydrogen gas and the silicon tetrahalide at a temperature of from 500 to 1400° C. to reform the silicon-containing copper catalyst comprising at least 0.1% (w/w) silicon; and (iv) contacting the reformed silicon-containing copper catalyst with the hydrogen halide at a temperature of from 100 to 600° C. to form a trihalosilane.

3. The method according to claim 2, further comprising repeating steps (iii) and (iv) at least 1 time.

4. The method according to claim 2, further comprising purging prior to the contacting of the reformed silicon-containing copper catalyst with the hydrogen halide in step (iv).

5. The method according to claim 4, wherein the purging is conducted with argon or silicon tetrachloride.

6. The method according to claim 1, further comprising purging prior to contacting the silicon-containing copper catalyst with the hydrogen halide in step (ii).

7. The method according to claim 6, wherein the purging is conducted with argon or silicon tetrachloride.

8. The method according to claim 1, wherein the copper catalyst further comprises a support.

9. The method according to claim 8, wherein the support is activated carbon.

10. The method according to claim 1, wherein the copper catalyst comprises from 0.1 to 35% (w/w) of the mixture and the mixture comprises copper, gold and magnesium.

11. The method according to claim 1, wherein the silicon-containing copper catalyst comprises from 1 to 5% (w/w) of silicon.

12. The method according to claim 1, wherein the mole ratio of hydrogen to silicon tetrahalide in step (i) is from 20:1 to 5:1.

13. The method according to claim 1, wherein step (ii) is conducted in the presence of hydrogen.

14. The method according to claim 1, wherein the trihalosilane has the formula HSiX_3 , where X is fluoro, chloro, bromo, or iodo.

15. The method according to claim 1, wherein the hydrogen halide is has formula HX , where X is chloro, and the silicon tetrahalide is silicon tetrachloride.

16. The method according to claim 1, further comprising recovering the trihalosilane.

17. A method of preparing a trihalosilane, the method comprising the following separate and consecutive steps:

- (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising 1 to 20% (w/w) of silicon, wherein the copper catalyst comprises a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum; and
- (ii) contacting the silicon-containing copper catalyst with a hydrogen halide at from 100 to 600° C. to form a trihalosilane.

18. The method according to claim 17, further comprising (iii) contacting the silicon-containing copper catalyst contacted with the hydrogen halide in step (ii) with the hydrogen gas and the silicon tetrahalide at a temperature of from 500 to 1400° C. to reform the silicon-containing copper catalyst comprising at least 0.1% (w/w) silicon; and (iv) contacting the reformed silicon-containing copper catalyst with the hydrogen halide at a temperature of from 100 to 600° C. to form a trihalosilane, and optionally further comprising repeating steps (iii) and (iv) at least 1 time, and optionally further comprising recovering the trihalosilane.

19. The method according to claim 18, wherein the hydrogen halide is has formula HX , where X is chloro, and the silicon tetrahalide is silicon tetrachloride.

20. A method of preparing a trihalosilane, the method comprising the following separate and consecutive steps:

- (i) contacting a copper catalyst with hydrogen gas and a silicon tetrahalide at a temperature of from 500 to 1400° C. to form a silicon-containing copper catalyst comprising at least 0.1% (w/w) of silicon, wherein the copper catalyst comprises a support and a metal selected from copper and a mixture comprising copper and at least one element selected from gold, magnesium, and platinum; and
- (ii) contacting the silicon-containing copper catalyst with a hydrogen halide at from 100 to 600° C. to form a trihalosilane.

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