process at a temperature range of from 300-500$^0$C. The raw material is an organic silicon compound, represented by formula: (a)$HSi(CH_3)(R^1)(NR^2R^3)$, wherein, $R^1$ represents $NR^4R^5$ or a 1C-5C alkyl group; $R^2$and $R^4$ each represent a 1C-5C alkyl group or hydrogen atom; and $R^3$ and $R^5$ each represent a 1C-5C alkyl group); or (b) $HSiCl(NR^1R^2)(NR^3R^4)$, wherein $R^1$ and $R^3$ independently represent an alkyl group having 1 to 4 carbon atoms, or a hydrogen atom; and $R^2$ and $R^4$ independently represent an alkyl group having 1 to 4 carbon atoms. The organic silicon compounds contained H-Si bonds.

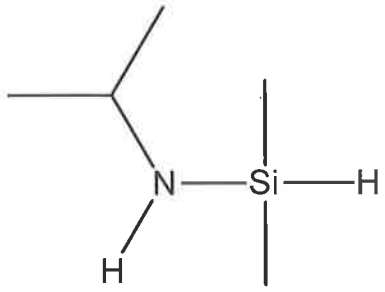
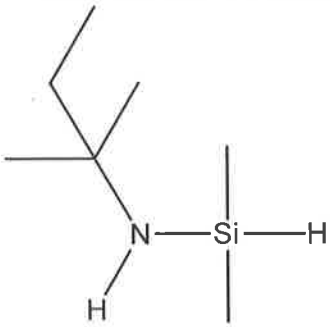
**[0007]** U.S. Pat. No. 5,424,095 describes a method to reduce the rate of coke formation during the industrial pyrolysis of hydrocarbons, the interior surface of a reactor is coated with a uniform layer of a ceramic material, the layer being deposited by thermal decomposition of a non-alkoxylated organosilicon precursor in the vapor phase, in a steam containing gas atmosphere in order to form oxide ceramics.

**[0008]** U. S. Publ. No. ~~2012/0291321~~2010-0291321 describes a PECVD process for forming a high-quality Si carbonitride barrier dielectric film between a dielectric film and a metal interconnect of an integrated circuit substrate, comprising the steps of: providing an integrated circuit substrate having a dielectric film or a metal interconnect; contacting the substrate with a barrier dielectric film precursor comprising: $R_xR_y(NRR')_zSi$ wherein R, R', R and R' are each individually selected from H, linear or branched saturated or unsaturated alkyl, or aromatic group; wherein x+y+z = 4; z = 1 to 3; but R, R' cannot both be H; and where z = 1 or 2 then each of x and y are at least 1; forming the Si carbonitride barrier dielectric film with C/Si ratio>0.8 and a N/Si ratio >0.2 on the integrated circuit substrate.

**[0009]** U. S. Publ. No. 2013/0295779 A describes an atomic layer deposition (ALD) process for forming a silicon oxide film at a deposition temperature > 500°C using silicon precursors having the following formula:

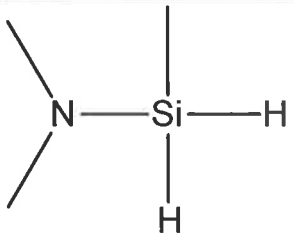
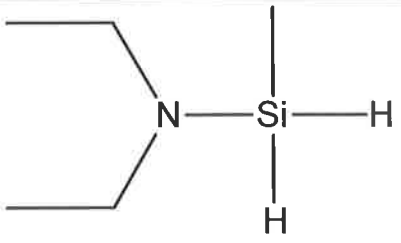
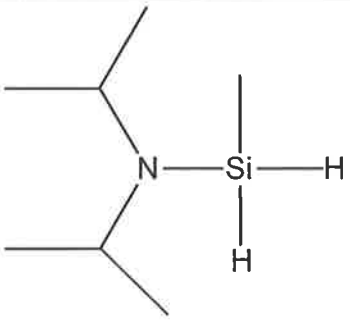
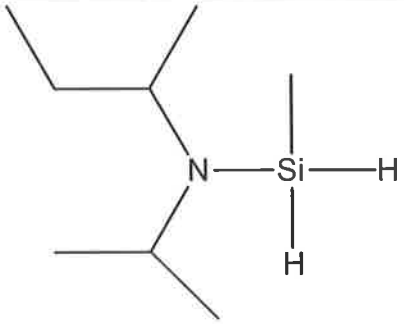
$$\text{I. } R^1R^2{}_mSi(NR^3R^4)_nX_p$$

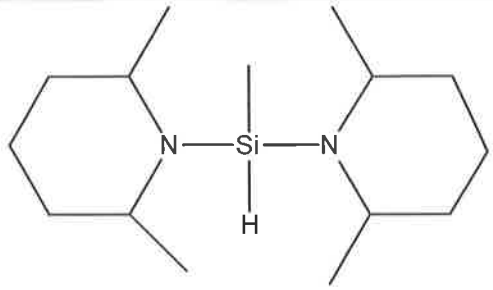
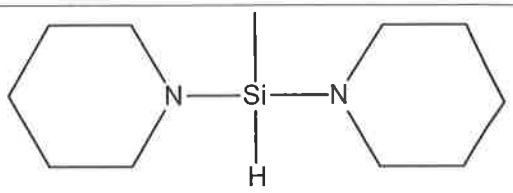
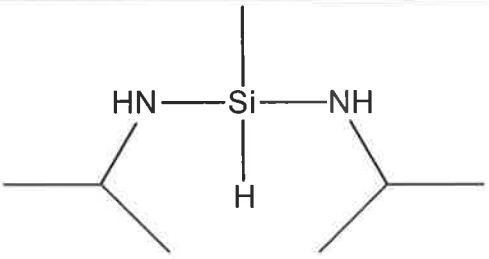
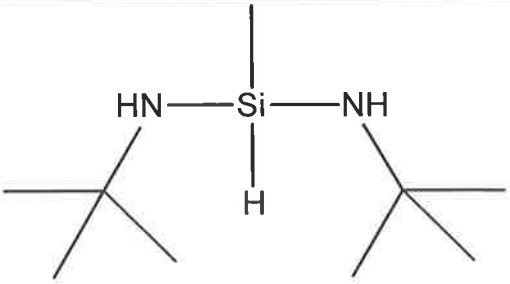
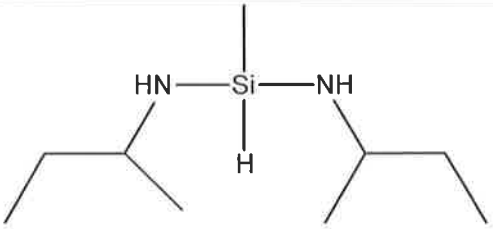
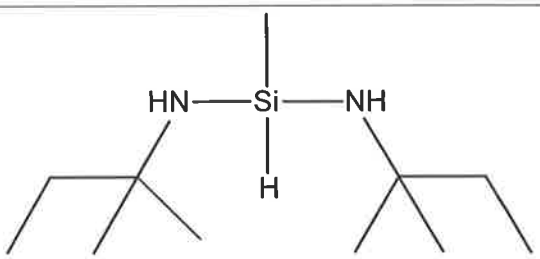
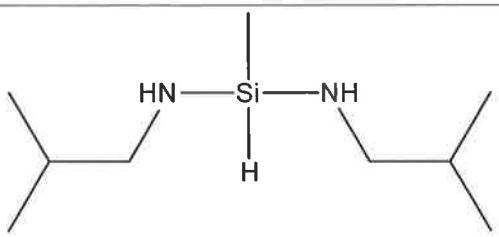
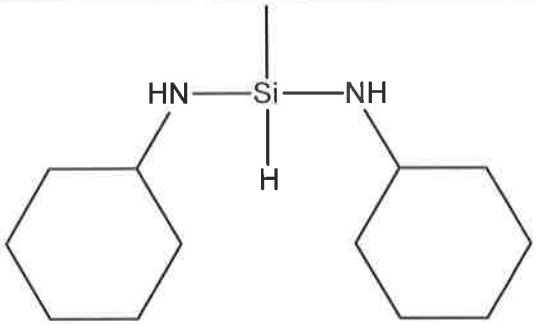
wherein $R^1$, $R^2$, and $R^3$ are each independently selected from hydrogen, a linear or branched $C_1$ to $C_{10}$ alkyl group, and a $C_6$ to $C_{10}$ aryl group; $R^4$ is selected from, a linear or branched $C_1$ to $C_{10}$ alkyl group, and a $C_6$ to $C_{10}$ aryl group, a $C_3$ to $C_{10}$ alkylsilyl group; wherein $R^3$ and $R^4$ are linked to form a cyclic ring structure or $R^3$ and $R^4$ are not linked to

| | |
|---|---|
|  Iso-propylaminodimethylsilane |  Tert-pentylaminodimethylaminosilane |

**[0037]** In one or more embodiments, the at least one silicon precursor comprises a ~~bisaminoalkylsilane~~ compound having the formula A described herein and wherein n=1 and m=1. In one particular embodiment, $R^1$ in the formula comprises a $C_1$ linear alkyl group or methyl. Further exemplary precursors are listed in the following Table 3:

Table 3. Monoaminoalkylsilane compounds having the formula A wherein n=1 and m=1

| | |
|---|---|
|  Dimethylaminomethylsilane |  Diethylaminomethylsilane |
|  Di-iso-propylaminomethylsilane |  Iso-propyl-sec-butylaminomethylsilane |

| | |
|---|---|
|  Bis(2,6-dimethylpiperidino)methylsilane |  Bis(piperidino)methylsilane |
|  Bis(iso-propylamino)methylsilane |  Bis(tert-butylamino)methylsilane |
|  Bis(sec-butylamino)methylsilane |  Bis(tert-pentylamino)methylsilane |
|  ~~Bis(iso-butylamino)dimethylsilane~~ Bis(iso-butylamino)methylsilane |  ~~Bis(cyclohexylamino)dmethylsilane~~ Bis(cyclohexylamine) methylisilane |

**[0039]** In one or more embodiments, the at least one silicon precursor comprises a bisaminoalkylsilane compound having the formula A or B described herein and wherein

butyl, sec-butyl, tert-butyl, iso-pentyl, tert-pentyl, iso-hexyl, and neo-hexyl. In certain embodiments, the alkyl group may have one or more functional groups attached thereto such as, but not limited to, an alkoxy group, a dialkylamino group or combinations thereof, attached thereto. In other embodiments, the alkyl group does not have one or more functional groups attached thereto. The alkyl group may be saturated or, alternatively, unsaturated.

**[0041]** In the formulas above and throughout the description, the term "cyclic alkyl" denotes a cyclic functional group having from 4 to 10 carbon atoms. Exemplary cyclic alkyl groups include, but are not limited to, cyclobutyl, cyclopentyl, cyclohexyl, and cyclooctyl groups.

**[0042]** In the formulas above and throughout the description, the term "alkenyl group" denotes a group which has one or more carbon-carbon double bonds and has from 2 to 10 ~~or from 2 to 10~~ or from 2 to 6 carbon atoms.

**[0043]** In the formulas above and throughout the description, the term "alkynyl group" denotes a group which has one or more carbon-carbon triple bonds and has from 3 to 10 or from 2 to 10 or from 2 to 6 carbon atoms.

**[0044]** In the formulas above and throughout the description, the term "aryl" denotes an aromatic cyclic functional group having from 4 to 10 carbon atoms, from 5 to 10 carbon atoms, or from 6 to 10 carbon atoms. Exemplary aryl groups include, but are not limited to, phenyl, benzyl, chlorobenzyl, tolyl, o-xylyl, 1,2,3-triazolyl, ~~pyrrolyl~~pyrrolyl, and furanyl.

**[0045]** In the formulas above and throughout the description, the term "amino" denotes an organoamino group having from 1 to 10 carbon atoms derived from an organoamines with formula of $HNR^2R^3$. Exemplary amino groups include, but are not limited to, secondary amino groups derived from secondary amines such as dimethylamino($Me_2N$-), diethyamino($Et_2N$-), di-iso-propylamino($^iPr_2N$-); primary amino groups derived from primary amines such as methylamino(MeNH-), ethylamine(EtNH-), iso-propylamino($^iPrNH$-), sec-butylamino ($^sBuNH$-), tert-butylamino($^tBuNH$-),.

**[0046]** In certain embodiments, substituents $R^2$ and $R^3$ in the formula can be linked together to form a ring structure. As the skilled person will understand, where $R^2$ and $R^3$ are linked together to form a ring and $R^2$ would include a bond for linking to $R^3$ and vice versa. In these embodiments, the ring structure can be ~~unsaturated~~saturated such as,

for example, a cyclic alkyl ring, or ~~saturated~~unsaturated, for example, an aryl ring. Further, in these

**[0066]** The deposited films have applications, which include, but are not limited to, computer chips, optical devices, magnetic information storages, coatings on a supporting material or substrate, microelectromechanical systems (MEMS), nanoelectromechanical systems, thin film transistor (TFT), light emitting diodes (LED), organic light emitting diodes (OLED), IGZO, and liquid crystal displays (LCD). Potential use of resulting solid silicon oxide or carbon doped silicon oxide include, but not limited to, shallow trench insulation, inter layer dielectric, passivation layer, an etch stop layer, part of a dual spacer, and sacrificial layer for patterning.

**[0067]** The methods described herein provide a high quality silicon oxide or carbon-doped silicon oxide film. The term "high quality" means a film that exhibits one or more of the following characteristics: a density of about 2.1 g/cc or greater; a wet etch rate that is less than <2.5 Å/s as measured in a solution of 1:100 dilute HF (dHF) acid; an electrical leakage of about 1 or less ~~e-8~~e$^{-8}$ A/cm$^2$ up to 6 MV/cm~~)~~; a hydrogen impurity of about 5 e20 at/cc or less as measured by SIMS; and combinations thereof. With regard to the etch rate, a thermally grown silicon oxide film has 0.5 Å/s etch rate in 1:100 dHF.

**[0068]** In certain embodiments, one or more silicon precursors having Formulae A and B described herein can be used to form silicon oxide films that are solid and are non-porous or are substantially free of pores.

**[0069]** The following examples illustrate the method for depositing silicon oxide films described herein and are not intended to limit it in any way.

## EXAMPLES

**[0070]** Unless stated otherwise, in the examples below all plasma enhanced ALD (PEALD) depositions were performed on a commercial style lateral flow reactor (300 mm PEALD tool manufactured by ASM International) equipped with 27.1 MHz direct plasma capability with 3.5 millimeters (mm) fixed spacing between electrodes. The design utilizes outer and inner chambers which have independent pressure settings. The inner chamber is the deposition reactor in which all reactant gases (e.g. silicon precursor, Ar) are mixed in the manifold and delivered to the process reactor. Argon (Ar) gas is used to maintain reactor pressure in the outer chamber. All precursors were liquids maintained at room temperature in stainless steel bubblers and delivered to the chamber with Ar carrier gas, typically set at 200 standard cubic centimeters (sccm) flow. Precursor

20. A silicon precursor for depositing a film comprising silicon and oxide, the silicon precursor comprising at least one selected from the group consisting of bis(sec-butylamino)methylsilane, bis(tert-butylamino)methylsilane, and bis(cyclohexylamino)methylsilane.