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(54) **METHOD OF FORMING A NITROGEN-CONTAINING CARBON FILM AND SYSTEM FOR PERFORMING THE METHOD**

(71) Applicant: **ASM IP Holding B.V.**, Almere (NL)

(72) Inventors: **Hirotugu Sugiura**, Tama (JP);
Yoshiyuki Kikuchi, Tokyo (JP)

(73) Assignee: **ASM IP Holding B.V.**, Almere (NL)

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Primary Examiner — Katherine A Bareford

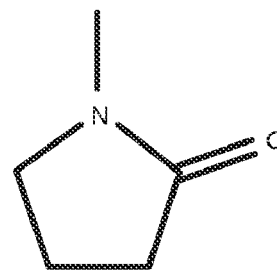
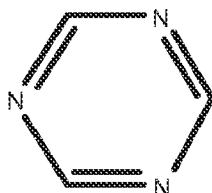
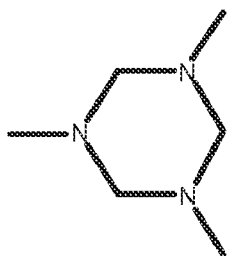
Assistant Examiner — Christina D McClure

(74) *Attorney, Agent, or Firm* — Snell & Wilmer L.L.P.

(57) **ABSTRACT**

Methods and systems for forming a nitrogen-containing carbon film and structures formed using the methods or systems are disclosed. Exemplary methods include providing a precursor with carbon-terminated carbon-nitrogen bonds. The methods can further include providing a reactant to the reaction chamber.

13 Claims, 3 Drawing Sheets



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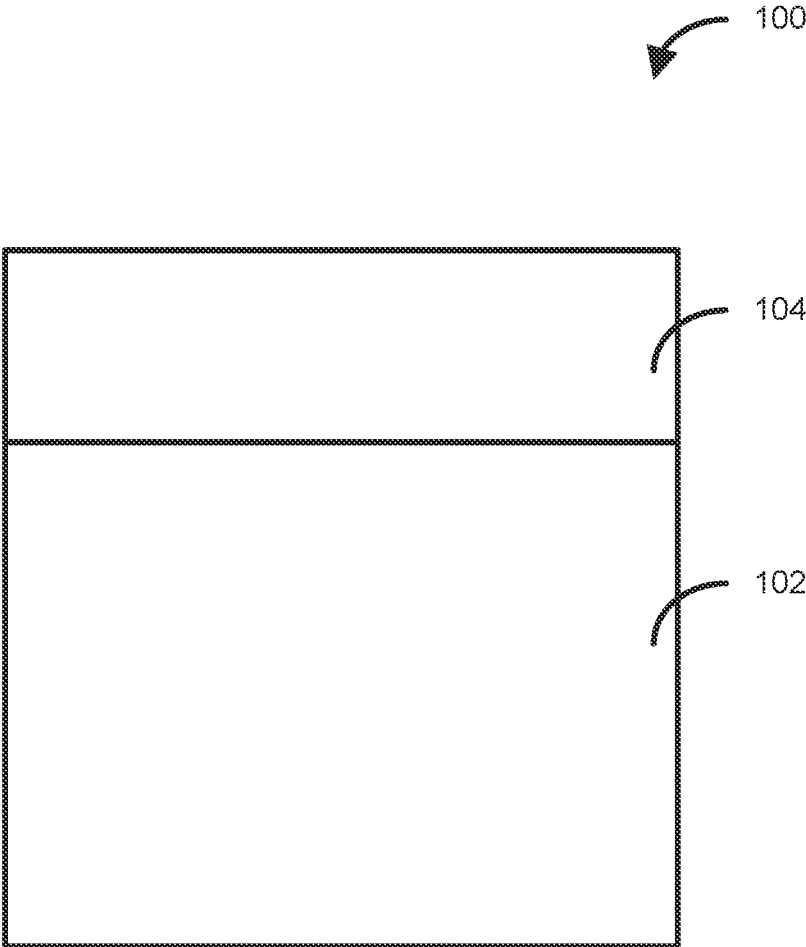


FIG. 1

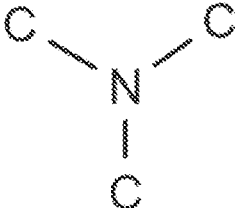
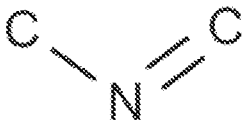


FIG. 2

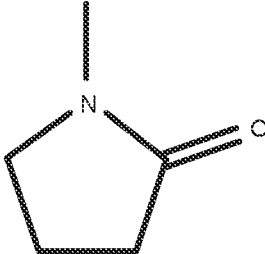
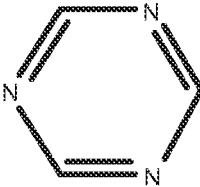
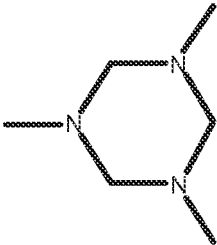


FIG. 3

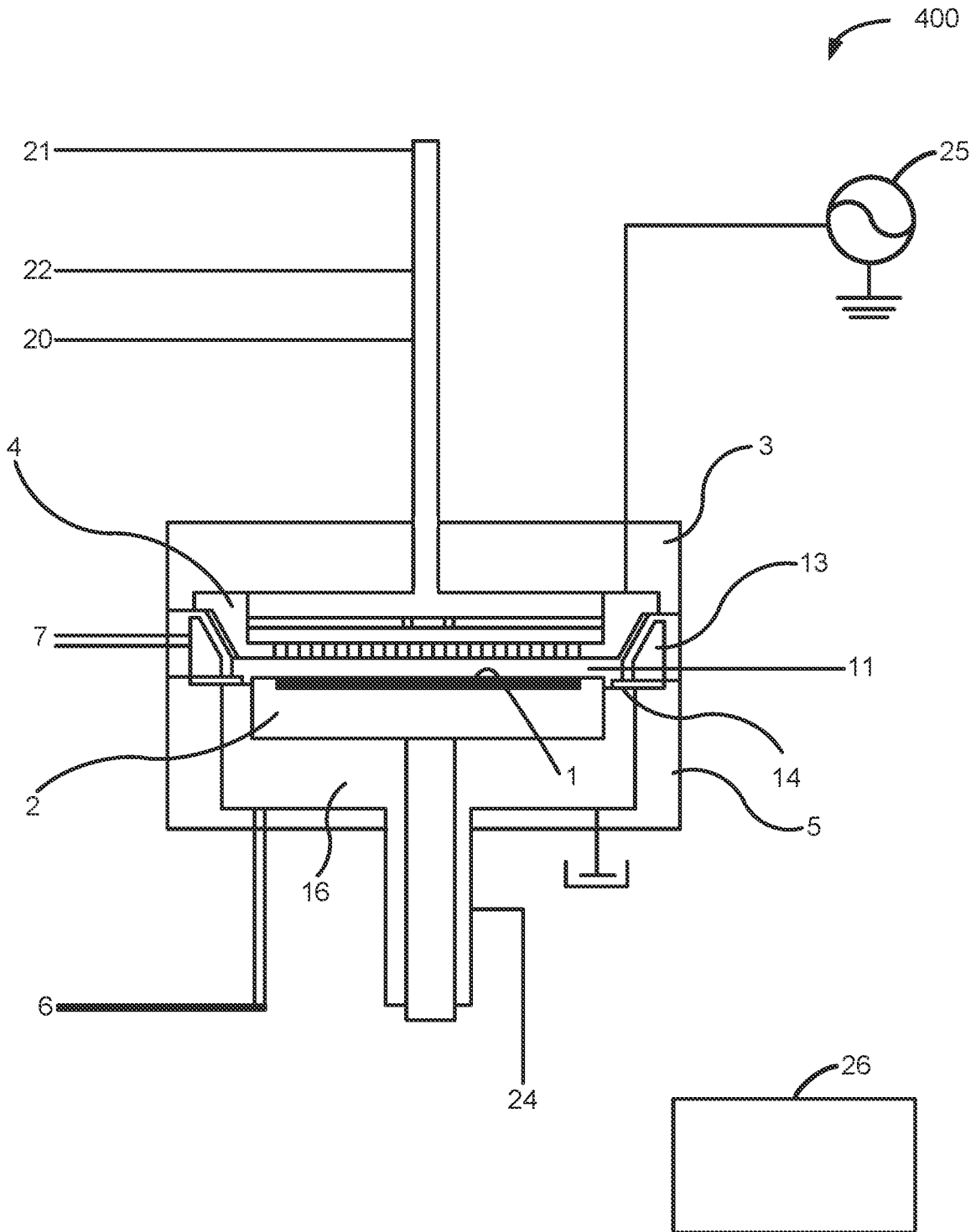


FIG. 4

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**METHOD OF FORMING A
NITROGEN-CONTAINING CARBON FILM
AND SYSTEM FOR PERFORMING THE
METHOD**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application claims the benefit of and priority to U.S. Provisional Application No. 63/009,318, filed on Apr. 13, 2020 in the United States Patent and Trademark Office, the disclosure of which is incorporated herein in its entirety by reference.

FIELD OF INVENTION

The present disclosure generally relates to methods suitable for use in the manufacture of electronic devices. More particularly, examples of the disclosure relate to methods of forming nitrogen-containing carbon films, to methods of forming structures including such films, and to systems for performing the methods and/or forming the structures.

BACKGROUND OF THE DISCLOSURE

Nitrogen-containing carbon films can be used in a variety of applications during the manufacture of electronic devices. For example, nitrogen-containing carbon films can be used as optical films, as etching hard mask films, as a gap-fill film for trench patterns, and the like. For some applications, etching resistance, chemical mechanical planarization (CMP) resistance and/or thermal stability may desirably be relatively high. The incorporation of nitrogen in the nitrogen-containing carbon films can produce carbon-containing films that exhibit superior properties, such as increased etch resistance, increased CMP resistance, and/or thermal stability, compared to films that do not include the nitrogen containing material.

For some applications, the nitrogen-containing carbon films may desirably be formed using a plasma process. Use of a plasma process can allow for lower temperatures during the film deposition and/or increased deposition rates of the nitrogen-containing carbon films, compared to thermal processes.

Traditional plasma-assisted processes to form nitrogen-containing carbon films include a plasma strike on the carbon film after film formation and addition of N₂ and NH₃ in the gas phase during the film formation process. Such techniques generally result in C—NH₂ bond termination and dangling bonds, as verified with FTIR analysis. Although such techniques can work well for some applications, in other applications, it may be desirable to have or to increase an amount of carbon-terminated carbon-nitrogen bonds, such as C—N—C and C—N=C, in nitrogen-containing carbon films. The inclusion of carbon-terminated carbon-nitrogen bonds can improve desired chemical properties (e.g., etch and CMP resistance) and physical properties (e.g., optical) of nitrogen-containing carbon films.

Accordingly, improved methods for forming nitrogen-containing carbon films, particularly for methods of forming nitrogen-containing carbon films that include carbon-terminated carbon-nitrogen bonds, such as C—N—C and C—N=C, are desired.

Any discussion, including discussion of problems and solutions, set forth in this section, has been included in this disclosure solely for the purpose of providing a context for the present disclosure, and should not be taken as an

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admission that any or all of the discussion was known at the time the invention was made or otherwise constitutes prior art.

SUMMARY OF THE DISCLOSURE

Various embodiments of the present disclosure relate to methods of forming nitrogen-containing carbon films suitable for use in the formation of electronic devices. While the ways in which various embodiments of the present disclosure address drawbacks of prior methods and structures are discussed in more detail below, in general, exemplary embodiments of the disclosure provide improved methods that include improved precursors and techniques for forming nitrogen-containing carbon films.

In accordance with various embodiments of the disclosure, a method of forming a nitrogen-containing carbon film is provided. Exemplary methods can include providing a precursor to a reaction chamber and forming the nitrogen-containing film on a surface of a substrate using the precursor. Suitable precursors include compounds including carbon-terminated carbon-nitrogen bonds, such as one or more compounds (1) represented by (C—N—C)_a and/or (C—N=C)_{a1}, wherein a and a1 are integers that are independently selected and that are greater than or equal to 1 and (2) cyclic compounds having a cyclic structure comprising C, H, O, and N. Exemplary cyclic compounds can include a cyclic skeleton, including, for example, between 5 and 7 atoms. The cyclic skeleton can include nitrogen. In some cases, the cyclic skeleton can consist of one or more of C, O, and N, such as C and N or O, C, and N. A cyclic compound can consist of C, H, O, and N. The cyclic compound can include a cyclic skeleton and one or more atoms (e.g., hydrogen and/or oxygen), groups, and/or side chains attached to the cyclic skeleton. At least one of the one or more sidechains can include C_wH_xN_yO_z, wherein w, x, y and z are each individually selected and are each a natural number (including zero). Exemplary methods can further include a step of providing a reactant to the reaction chamber. Exemplary reactants include one or more of hydrogen, nitrogen, a compound comprising hydrogen and nitrogen, and a hydrocarbon.

In accordance with yet further exemplary embodiments of the disclosure, a structure is formed, at least in part, by forming a nitrogen-containing carbon film as described herein.

In accordance with yet further exemplary embodiments of the disclosure, a system is provided for performing a method and/or for forming a structure as described herein.

These and other embodiments will become readily apparent to those skilled in the art from the following detailed description of certain embodiments having reference to the attached figures; the invention not being limited to any particular embodiment(s) disclosed.

BRIEF DESCRIPTION OF THE DRAWING
FIGURES

A more complete understanding of exemplary embodiments of the present disclosure can be derived by referring to the detailed description and claims when considered in connection with the following illustrative figures.

FIG. 1 illustrates a structure including a nitrogen-containing carbon film in accordance with exemplary embodiments of the disclosure.

FIGS. 2 and 3 illustrate molecules including carbon-terminated carbon-nitrogen bonds.

FIG. 4 illustrates a system in accordance with exemplary embodiments of the disclosure.

It will be appreciated that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help improve understanding of illustrated embodiments of the present disclosure.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Although certain embodiments and examples are disclosed below, it will be understood by those in the art that the invention extends beyond the specifically disclosed embodiments and/or uses of the invention and obvious modifications and equivalents thereof. Thus, it is intended that the scope of the invention disclosed should not be limited by the particular disclosed embodiments described below.

The present disclosure generally relates to methods of forming a nitrogen-containing carbon film, to methods of forming structures including such films, to film structures formed using the methods, and to systems for performing the methods and/or forming the film structures.

Exemplary methods described herein can be used to form nitrogen-containing carbon films with carbon-terminated carbon-nitrogen bonds or form nitrogen-containing carbon films with an increased number of carbon-terminated carbon-nitrogen bonds, particularly C—N—C or C—NC. Such films can exhibit desired properties, such as optical properties, increased (e.g., dry) etch resistance, and/or increased CMP resistance. As set forth in more detail below, films including C—N—C or C—N=C can be obtained by using one or more precursors that include C—N—C or C—N=C bonds.

In this disclosure, “gas” can refer to material that is a gas at normal temperature and pressure, a vaporized solid and/or a vaporized liquid, and may be constituted by a single gas or a mixture of gases, depending on the context. A gas other than a process gas, i.e., a gas introduced without passing through a gas distribution assembly, such as a showerhead, other gas distribution device, or the like, may be used for, e.g., sealing a reaction space, which includes a seal gas, such as a rare gas. In some cases, such as in the context of deposition of material, the term “precursor” can refer to a compound that participates in the chemical reaction that produces another compound, and particularly to a compound that constitutes a film matrix or a main skeleton of a film, whereas the term “reactant” can refer to a compound, in some cases other than a precursor, that activates a precursor, modifies a precursor, or catalyzes a reaction of a precursor; a reactant may provide an element (such as O, H, N, C) to a film matrix and become a part of the film matrix when, for example, power (e.g., radio frequency (RF) or microwave power) is applied. In some cases, the terms precursor and reactant can be used interchangeably. The term “inert gas” refers to a gas that does not take part in a chemical reaction to an appreciable extent and/or a gas that excites a precursor (e.g., to facilitate polymerization of the precursor) when, for example, power (e.g., RF power) is applied, but unlike a reactant, it may not become a part of a film matrix to an appreciable extent.

As used herein, the term “substrate” can refer to any underlying material or materials that may be used to form, or upon which, a device, a circuit, or a film may be formed. A substrate can include a bulk material, such as silicon (e.g.,

single-crystal silicon), other Group IV materials, such as germanium, or compound semiconductor materials, such as Group III-V or Group II-VI semiconductors, and can include one or more layers overlying or underlying the bulk material. Further, the substrate can include various features, such as gaps (e.g., recesses or vias), lines or protrusions, such as lines having gaps formed therebetween, and the like formed on or within or on at least a portion of a layer or bulk material of the substrate. By way of examples, one or more features can have a width of about 10 nm to about 100 nm, a depth or height of about 30 nm to about 1,000 nm, and/or an aspect ratio of about 3.0 to 100.0.

In some embodiments, “film” refers to a layer extending in a direction perpendicular to a thickness direction. In some embodiments, “layer” refers to a material having a certain thickness formed on a surface and can be a synonym of a film or a non-film structure. A film or layer may be constituted by a discrete single film or layer having certain characteristics or multiple films or layers, and a boundary between adjacent films or layers may or may not be clear and may or may not be established based on physical, chemical, and/or any other characteristics, formation processes or sequence, and/or functions or purposes of the adjacent films or layers. The layer or film can be continuous—or not. Further, a single film or layer can be formed using multiple deposition cycles.

As used herein, the term “nitrogen-containing carbon layer” or “nitrogen-containing carbon material” can refer to a layer whose chemical formula can be represented as including carbon and nitrogen. Layers comprising nitrogen-containing carbon material can include other elements, such as one or more of oxygen and hydrogen. Nitrogen-containing carbon layers desirably include one or more of C—N—C and C—N=C.

As used herein, the term “structure” can refer to a partially or completely fabricated device structure. By way of examples, a structure can be a substrate or include a substrate with one or more layers and/or features formed thereon.

As used herein, the term “cyclic deposition process” can refer to a vapor deposition process in which deposition cycles, typically a plurality of consecutive deposition cycles, are conducted in a process chamber. Cyclic deposition processes can include cyclic chemical vapor deposition (CVD) and atomic layer deposition processes. A cyclic deposition process can include one or more cycles that include plasma activation of a precursor, a reactant, and/or an inert gas.

In this disclosure, “continuously” can refer to without breaking a vacuum, without interruption as a timeline, without any material intervening step, immediately thereafter, as a next step, or without an intervening discrete physical or chemical structure between two structures other than the two structures in some embodiments and depending on the context.

In this disclosure, any two numbers of a variable can constitute a workable range of the variable, and any ranges indicated may include or exclude the endpoints. Additionally, any values of variables indicated (regardless of whether they are indicated with “about” or not) may refer to precise values or approximate values and include equivalents, and may refer to average, median, representative, majority, etc. in some embodiments. Further, in this disclosure, the terms “including,” “constituted by” and “having” can refer independently to “typically or broadly comprising,” “comprising,” “consisting essentially of,” or “consisting of” in some

embodiments. In this disclosure, any defined meanings do not necessarily exclude ordinary and customary meanings in some embodiments.

FIG. 1 illustrates a structure **100** including a substrate **102** and a nitrogen-containing film **104** deposited overlying the substrate. In accordance with examples of the disclosure, nitrogen-containing film **104** can be formed using a method as described herein. Additionally or alternatively, nitrogen-containing film **104** can include carbon-terminated carbon-nitrogen bonds. For example, all nitrogen-carbon bonds can be terminated with a carbon-nitrogen bond.

Methods in accordance with exemplary embodiments of the disclosure include providing a precursor to a reaction chamber and forming the nitrogen-containing film on a surface of a substrate using the precursor. The methods can also include steps of providing a substrate to a reaction chamber and, in accordance with some examples, providing a reactant to the reaction chamber. The step of forming can be thermally activated or plasma activated.

During the step of providing a precursor to a reaction chamber, one or more precursors are flowed into a reaction chamber of a gas-phase reactor. In accordance with examples of the disclosure, the reaction chamber can form part of a cyclical deposition reactor, such as an atomic layer deposition (ALD) (e.g., PEALD) reactor or chemical vapor deposition (CVD) (e.g., PECVD) reactor. Various steps of methods described herein can be performed within a single reaction chamber or can be performed in multiple reaction chambers, such as reaction chambers of a cluster tool.

During the step of providing a substrate within a reaction chamber, before the step of providing the precursor to the reaction chamber, or during the step of providing the precursor to the reaction chamber, the substrate can be brought to a desired temperature and/or the reaction chamber can be brought to a desired pressure, such as a temperature and/or pressure suitable for subsequent steps. By way of examples, a temperature (e.g., of a substrate or a substrate support) within a reaction chamber can be less than or equal to 400° C. or between about 550° C. and about 650° C. In accordance with particular examples of the disclosure, the substrate includes one or more features, such as recesses.

In accordance with examples of the disclosure, the precursor includes one or more compounds in which one or more nitrogen atoms are bonded to a carbon atom, wherein the carbon atom is a terminal atom.

FIG. 2 illustrates molecules/compounds (N-methyl methanimine and trimethylamine) that include a carbon-terminated carbon-nitrogen bond. Although such compounds may work well for some applications, gases composed of such molecules can exhibit an unfavorable odor and therefore may desirably be avoided in some applications.

FIG. 3 illustrates exemplary cyclic structures that include cyclic skeletons (e.g., the ring portion of the compound/structure) in accordance with examples of the disclosure. Use of cyclic compounds that include one or more carbon-terminated carbon-nitrogen bonds (e.g., within the skeleton of the molecule) may be desirable over linear or non-cyclic compounds that include carbon-terminated carbon-nitrogen bonds, because the cyclic compounds with the skeleton including the one or more carbon-terminated carbon-nitrogen bonds may not exhibit as offensive of an odor as the linear compounds with the one or more carbon-terminated carbon-nitrogen bonds. In accordance with further examples of the disclosure, the precursor does not include a halogen, such as fluorine (F), chlorine (Cl), bromine (Br), iodine (I), or astatine (At).

In accordance with examples of the disclosure, a chemical formula of the precursor comprises one or more of (1) $(C-N-C)_a$ and/or $(C-N=C)_{a1}$, wherein a and $a1$ are integers that are independently selected and that are greater than or equal to 1 and (2) a cyclic compound, such as a cyclic compound having a cyclic structure comprising C, H, O, and N. A can range from, for example, about 3 to about 6. $A1$ can range from about 3 to about 6.

In accordance with examples of the disclosure, a cyclic skeleton of a cyclic compound can include between 5 and 7 atoms. The cyclic skeleton can include one or more nitrogen atoms. A nitrogen atom in the cyclic skeleton can form a single bond or a double bond with carbon in the cyclic skeleton. In addition to carbon and/or nitrogen, a cyclic skeleton can include one or more oxygen atoms. In some cases, the cyclic skeleton can consist of one or more of C, O, and N—for example, C and N or C, N and O. In accordance with further examples, the cyclic compound, including the cyclic skeleton, can consist of one or more of C, H, O, and N—e.g., C, H, and N or C, H, N, and O.

A cyclic compound can include one or more atoms, molecules, groups, and/or sidechains attached to the cyclic skeleton. The atoms can include, for example, N, C, O, and H. The molecules or groups can include, for example, methyl groups, ethyl groups, other hydrocarbon groups, hydroxy groups, or the like.

The side chains can include molecules or groups that are represented by the chemical formula $C_wH_xN_yO_z$, wherein w , x , y and z are each individually selected and are each a natural number, and wherein a natural number can be zero. X can range from 0 to 9 or 15, Y can range from 0 to 3 or 6, and Z can range from 0 to 3.

By way of particular examples, the precursor can be selected from one or more of the group consisting of 1,3,5-trimethylhexahydro-1,3,5-triazine; 1,3,5-triazine; 2,4,6-trimethyl-s-triazene; and 1-methyl-2-pyrrolidinone.

The precursor can be a gas, a liquid, or a solid at normal temperature and pressure. In the cases of liquid or solid precursors, the precursor can be heated to a temperature sufficient to form a gas phase of the precursor.

As noted above, methods in accordance with the disclosure can include providing a reactant to the reaction chamber. The reactant can be flowed to the reaction chamber during or overlapping in time with the step of providing a precursor to a reaction chamber. In some cases, the reactant can be pulsed to the reaction chamber. In some cases, the method of forming a nitrogen-containing carbon film includes a cyclic deposition process, where the step of providing a precursor to a reaction and providing a reactant to the reaction chamber can be separated by a purge step. The purge step can include providing a vacuum and/or a purge gas to the reaction chamber.

In accordance with embodiments of the disclosure, a reactant comprises a compound comprising one or more of H, N, and C. In some cases, the compound can consist of one or more of H, N, and C. By way of examples, the reactant can include one or more of hydrogen, nitrogen, a compound comprising hydrogen and nitrogen (e.g., ammonia, hydrazine, or the like), and a hydrocarbon (e.g., comprising only C and H).

In accordance with further examples of the disclosure, although a precursor can include nitrogen, an amount of nitrogen in the nitrogen-containing carbon film can be manipulated by changing a (e.g., volumetric) ratio of a flowrate of the precursor to a flowrate of the reactant.

One or more of the reactant and the precursor can be exposed to a plasma to create an activated species. The

plasma can be generated using a direct plasma, as discussed in more detail below, and/or using a remote plasma. In some cases, the reactant can be exposed to a plasma to generate reactant activated species. In some cases, both the precursor and the reactant are exposed to the plasma (e.g., at the same time or during an overlap period). The activated species can be formed using a continuous plasma or a pulsed plasma. In some cases, an inert gas can be continuously flowed to the reaction chamber and activated species can be periodically formed by cycling the power used to form the plasma.

The plasma can be formed using, for example, a capacitively couple plasma (CCP), and inductively coupled plasma (ICP), or a surface plasma, such as a microwave plasma.

A power (e.g., applied to electrodes) to form or maintain the plasma can range from about 50 W to about 600 W. A frequency of the power can range from about 10 kHz to about 100 MHz.

FIG. 4 illustrates a reactor system 400 in accordance with exemplary embodiments of the disclosure. Reactor system 400 can be used to perform one or more steps or sub steps as described herein and/or to form one or more structures or portions thereof as described herein. For example, reactor system 400 can be used to generate a direct plasma for use in methods disclosed herein.

Reactor system 400 includes a pair of electrically conductive flat-plate electrodes 4, 2 in parallel and facing each other in the interior 11 (reaction zone) of a reaction chamber 3. A plasma can be excited within reaction chamber 3 by applying, for example, HRF power (e.g., 13.56 MHz, 27 MHz, microwave frequencies, or the like) from power source 25 to one electrode (e.g., electrode 4) and electrically grounding the other electrode (e.g., electrode 2). A temperature regulator can be provided in a lower stage 2 (the lower electrode), and a temperature of a substrate 1 placed thereon can be kept at a desired temperature. Electrode 4 can serve as a gas distribution device, such as a shower plate. Reactant gas, dilution gas, if any, precursor gas, and/or the like can be introduced into reaction chamber 3 using one or more of a gas line 20, a gas line 21, and a gas line 22, respectively, and through the shower plate 4. Although illustrated with three gas lines, reactor system 400 can include any suitable number of gas lines.

In reaction chamber 3, a circular duct 13 with an exhaust line 7 is provided, through which gas in the interior 11 of the reaction chamber 3 can be exhausted. Additionally, a transfer chamber 5, disposed below the reaction chamber 3, is provided with a seal gas line 24 to introduce seal gas into the interior 11 of the reaction chamber 3 via the interior 16 (transfer zone) of the transfer chamber 5, wherein a separation plate 14 for separating the reaction zone and the transfer zone is provided (a gate valve through which a wafer is transferred into or from the transfer chamber 5 is omitted from this figure). The transfer chamber is also provided with an exhaust line 6. In some embodiments, the deposition and treatment steps are performed in the same reaction space, so that two or more (e.g., all) of the steps can be continuously conducted without exposing the substrate to air or other oxygen-containing atmosphere.

In some embodiments, continuous flow of an inert or carrier gas to reaction chamber 3 can be accomplished using a flow-pass system (FPS), wherein a carrier gas line is provided with a detour line having a precursor reservoir (bottle), and the main line and the detour line are switched, wherein when only a carrier gas is intended to be fed to a reaction chamber, the detour line is closed, whereas when both the carrier gas and a precursor gas are intended to be fed to the reaction chamber, the main line is closed and the

carrier gas flows through the detour line and flows out from the bottle together with the precursor gas. In this way, the carrier gas can continuously flow into the reaction chamber and can carry the precursor gas in pulses by switching between the main line and the detour line, without substantially fluctuating pressure of the reaction chamber.

A skilled artisan will appreciate that the apparatus includes one or more controller(s) 26 programmed or otherwise configured to cause one or more method steps as described herein to be conducted. The controller(s) are communicated with the various power sources, heating systems, pumps, robotics and gas flow controllers, or valves of the reactor, as will be appreciated by the skilled artisan.

In some embodiments, a dual chamber reactor (two sections or compartments for processing wafers disposed close to each other) can be used, wherein a reactant gas and a noble gas can be supplied through a shared line, whereas a precursor gas is supplied through unshared lines.

The example embodiments of the disclosure described above do not limit the scope of the invention, since these embodiments are merely examples of the embodiments of the invention. Any equivalent embodiments are intended to be within the scope of this invention. Indeed, various modifications of the disclosure, in addition to those shown and described herein, such as alternative useful combinations of the elements described, may become apparent to those skilled in the art from the description. Such modifications and embodiments are also intended to fall within the scope of the appended claims.

What is claimed is:

1. A method of forming a nitrogen-containing carbon film, the method comprising the steps of:
 - providing a precursor to a reaction chamber, wherein a chemical formula of the precursor comprises a cyclic compound having a cyclic structure comprising C, H, and N; and
 - forming the nitrogen-containing film on a surface of a substrate using the precursor, wherein the precursor comprises a carbon-terminated carbon-nitrogen bond and wherein the precursor is selected from one or more of the group consisting of 1,3,5-trimethylhexahydro-1,3,5-triazine, 2,4,6-trimethyl-s-triazene, and 1-methyl-2-pyrrolidinone.
2. The method of claim 1, further comprising a step of providing a reactant to the reaction chamber.
3. The method of claim 2, wherein the reactant comprises a compound comprising C.
4. The method of claim 2, wherein the reactant comprise a hydrocarbon.
5. The method of claim 2, further comprising a step of manipulating an amount of nitrogen in the nitrogen-containing carbon film by changing a ratio of a flowrate of the precursor to a flowrate of the reactant.
6. The method of claim 2, wherein the reactant comprises a compound comprising one or more of H, N, and C.
7. The method of claim 2, wherein the reactant comprises one or more of hydrogen, nitrogen, a compound comprising hydrogen and nitrogen, and a hydrocarbon.
8. The method of claim 1, wherein a temperature of the substrate is between about 550° C. and about 650° C.
9. The method of claim 1, wherein the step of forming the nitrogen-containing carbon film comprises a plasma process.
10. The method of claim 9, wherein the plasma process comprises a direct plasma.

11. The method of claim **9**, wherein the plasma process comprises use of one or more of a capacitively-coupled plasma, an inductively-coupled plasma, and a microwave plasma.

12. The method of claim **1**, wherein the nitrogen-containing carbon film is deposited using a plasma-enhanced atomic layer deposition process. 5

13. A method of forming a structure comprising a method of claim **1**, wherein the nitrogen-containing carbon film comprises carbon-terminated carbon-nitrogen bonds. 10

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