MODULE FOR OZONE CURE AND POST-CURE MOISTURE TREATMENT

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a PCT application of U.S. Patent Application No. 13/247,687, filed September 28, 2011, titled "MODULE FOR OZONE CURE AND POST-CURE MOISTURE TREATMENT," and is related to and claims the benefit of U.S. Provisional Patent Application No. 61/389,957, filed October 5, 2010, entitled "MODULE FOR OZONE CURE AND POST-CURE MOISTURE TREATMENT," which are incorporated herein by reference in their entirety for all purposes.

BACKGROUND OF THE INVENTION

Semiconductor device geometries have dramatically decreased in size since their introduction several decades ago. Modern semiconductor fabrication equipment routinely produces devices with 250 nm, 180 nm, and 65 nm feature sizes, and new equipment is being developed and implemented to make devices with even smaller geometries. The decreasing feature sizes result in structural features on the device having decreased spatial dimensions. The reduced dimensions, in turn, require the use of conductive materials having a very low resistivity and insulation materials having a very low dielectric constant.

Low dielectric constant films are particularly desirable for premetal dielectric (PMD) layers and intermetal dielectric (IMD) layers to reduce the RC time delay of the interconnect metalization, to prevent cross-talk between the different levels of metalization, and to reduce device power consumption. Undoped silicon oxide films deposited using early CVD techniques typically had a dielectric constant (κ) in the range of 4.0 to 4.2. In contrast, various carbon-based dielectric layers that are now commonly used in the semiconductor industry have dielectric constants below 3.0. Many of these carbon-based layers are relatively unstable when initially deposited and are subsequently cured in an oxygen environment and/or annealed to increase the film's stability.

BRIEF SUMMARY OF THE INVENTION

A substrate curing and treatment module is described for performing the curing and post-cure treatment of dielectric layers deposited on the substrate. The modules may include a separate curing chamber and treatment chamber. Substrates may be transferred to the curing chamber of the module with uncured layers deposited thereon by an FCVD process. The deposition process may form an uncured silicon-oxygen-carbon containing layer, silicon-oxygen-nitrogen containing layer, and/or silicon-oxygen-nitrogen-carbon containing layer on the substrate. When the substrate is transferred to the curing chamber, the deposited layer or layers may be cured at temperatures of about 150°C to about 200°C in an ozone-containing atmosphere. After the curing, the substrate may be transferred to the treatment chamber of the module an exposed to a water-vapor containing atmosphere at temperatures above the dew point (e.g., about 80°C to about 100°C) to form the treated dielectric film. For some fabrication processes, the cured and treated substrates removed from the module are transferred through a load-lock chamber and factory interface (FI) to a front-opening unified pod (FOUP) that stores the substrate as it is removed from the fabrication system.

Embodiments of the invention include a substrate curing and treatment module. The module may include a curing chamber for curing a dielectric layer in an atmosphere that includes ozone, and a treatment chamber for treating the cured dielectric layer in an atmosphere that includes water vapor. The curing chamber may be vertically positioned with respect to the treatment chamber. The module may also include a heating system operatively coupled to the curing chamber and the treatment chamber. The heating system may be operative to adjust a first temperature of the curing chamber to from about 150°C to about 200°C, and to adjust a second temperature of the treatment chamber to from about 80°C to about 100°C. The module may further include an access door on both the curing chamber and the treatment chamber. Each access door is operable to be moved to an open position to receive a substrate, and operable to be moved to a closed sealed position during while the substrate is being cured or treated.

Embodiments of the invention further include a substrate processing system that has a plurality of deposition chambers, and a first robotic arm operable to move a substrate between one of the deposition chambers and a load-lock substrate holding area. The system may also have a second robotic arm operable to move the substrate between the load-lock substrate holding area and a curing chamber of a substrate curing and treatment module. The substrate curing and treatment module is attached to the load-lock substrate holding area, and may include: The curing chamber for curing a dielectric layer in an atmosphere comprising

ozone, and a treatment chamber for treating the cured dielectric layer in an atmosphere comprising water vapor. The curing chamber may be vertically positioned with respect to the treatment chamber. The module may also include a heating system operatively coupled to the curing chamber and the treatment chamber, where the heating system is operative to adjust a first temperature of the curing chamber to from about 150°C to about 200°C, and to adjust a second temperature of the treatment chamber to from about 80°C to about 100°C. The module may still further include an access door on both the curing chamber and the treatment chamber. Each of the access doors are operable to be moved to an open position to receive a substrate, and operable to be moved to a closed sealed position during while the substrate is being cured or treated.

Additional embodiments and features are set forth in part in the description that follows, and in part will become apparent to those skilled in the art upon examination of the specification or may be learned by the practice of the invention. The features and advantages of the invention may be realized and attained by means of the instrumentalities, combinations, and methods described in the specification.

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings wherein like reference numerals are used throughout the several drawings to refer to similar components. In some instances, a sublabel is associated with a reference numeral and follows a hyphen to denote one of multiple similar components. When reference is made to a reference numeral without specification to an existing sublabel, it is intended to refer to all such multiple similar components.

Fig. 1 shows a simplified cross-section drawing of a substrate curing and treatment module according to embodiments of the invention;

Fig. 2 shows a simplified drawing of substrate processing system that includes a pair of substrate curing and treatment modules according to embodiments of the invention;

Fig. 3 shows another drawing of a substrate processing system with a pair of substrate curing and treatment modules coupled to a load-lock chamber according to embodiments of the invention;

Fig. 4A shows a simplified front-side perspective drawing of a substrate processing system with a pair of substrate curing and treatment modules positioned on opposite sides of a load-

lock chamber that interfaces with a set of substrate processing chambers according to embodiments of the invention; and

Fig. 4B shows a simplified back-side perspective drawing of a substrate processing system with a pair of substrate curing and treatment modules positioned on opposite sides of a load-lock chamber that interfaces with a set of substrate processing chambers according to embodiments of the invention.

Fig. 5 shows a simplified overhead view of a substrate processing system with a substrate curing and treatment module positioned adjacent to the factory interface.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a substrate curing and treatment module 100 that includes a curing chamber 102 and a treatment chamber 104 vertically positioned with respect to each other. In module 100, the curing chamber is shown vertically positioned above the treatment chamber 102, while additional embodiments may reverse this order and position the treatment chamber above the curing chamber. Module 100 also shows the two chambers separated by a common wall 110 having opposite sides exposed to the interiors of the curing chamber 102 and treatment chamber 104, respectively. Additional embodiments may have two separate walls that define the bottom of the curing chamber 102 and the top of the treatment chamber 104, respectively. The separate walls may be reversibly or permanently attached to each other, or alternatively, they may be separated by a gap which may or may not be filled with and insulating material.

Both chambers include an access door 106a-b that is operable to move to an open position to receive one or more substrates 108a-c, and also operable to move to a closed sealed position while the substrate is being cured or treated. Module 100 shows substrate racks 112a-b that can hold a plurality of substrates 108a-c in the chambers at the same time. This makes module 100 a batch cure and treatment module that can perform curing and treatment steps simultaneously on multiple substrates (*e.g.*, 2 or more substrates, 3 or more substrates, 4 or more substrates, 5 or more substrates, 10 or more substrates, *etc.*). Additional embodiments may include an alternate structure for holding the substrates, such as a platen that may be translatable in a vertical, horizontal, and/or circular direction. These alternate structures may be operable to hold a single substrate or multiple substrates.

The module 100 may receive substrates from a robotic arm 114 that has a positioning arm 116 operable to move a substrate into and out of the curing chamber 102 and transfer chamber 104. The positioning arm 116 may place a substrate 108a-c into the substrate rack

112a of the curing chamber 102, and later remove the cured substrate from the curing chamber. The positing arm 116 may also transfer the cured substrate from the curing chamber 102 to the substrate rack 112b of the treatment chamber 104. The arm 116 may also remove the cured and treated substrate from the treatment chamber 104. In the embodiment shown, the positioning arm 116 may be extended into and retracted from the chambers of module 100, as well as move in a vertical direction between the chambers. The arm 116 may also rotate to receive or place substrates from a substrate holding area near the module 100.

The module 100 may also include a gas distribution system 118 and heating system 122 coupled to the curing and treatment chambers, respectively, to control the atmospheric conditions and temperatures of the chambers. As noted above, substrate curing may include exposing the substrate to an ozone-containing atmosphere at about 150°C to about 200°C, and substrate treatment may include exposing the cured substrate to an water-vapor containing atmosphere at about 80°C to about 100°C.

The gas distribution system 118 is operable to control the flow of gases from a gas source (not shown) into the curing chamber 102 and treatment chamber 104. In module 100, the delivery mechanism includes gas conduits 120a-b that transport gases from the gas delivery system to each of the chambers. The gas delivery system may also include a gas return (not shown) that removes gases from the chambers of module 100. The gas return may be coupled to a vacuum pump and exhaust that are fluidly coupled to the module 100.

The gases delivered by gas distribution system 118 to the curing chamber 102 may include molecular oxygen, ozone, argon, and molecular nitrogen, among other gases. The gases may be mixed and sent to the curing chamber 102 in a single stream, or provided separately and first mixed in the chamber. The gases delivered to the treatment chamber 104 by distribution system 118 may include water vapor, argon, and molecular nitrogen, among other gases.

The heating system 122 is operatively coupled to heating elements (not shown) in both the curing chamber 102 and the treatment chamber 104. These heating elements are independently controlled by the heating system 122 to permit the temperature of the curing chamber 102 to be different than the temperature of the treatment chamber 104. Independent temperature sensors (not shown) may be present in the chambers to monitor the chamber temperature and provide feedback to the heating system 122 for adjusting and/or maintaining the temperature in the chamber.

Referring now to Figs. 2 and 3, a substrate processing system 200 is shown that includes a pair of substrate curing and treatment modules 202a-b, according to embodiments of the

invention. Commercial examples of system 200 may include specific configurations of the Centura™, Producer™, and Eterna™ systems manufactured by Applied Materials of Santa Clara California.

As shown in Fig. 2, the modules 202a-b are positioned at opposite ends of a load-lock chamber 204, and behind the factory interface (FI) 206 of the system 200. In the configuration of system 200 shown, this positioning places the modules 202a-b behind the FI 206 without increasing the overall width of the system, and without displacing two of the four FOUPs 208a-b reversibly coupled to the front side of the system.

The modules 202a-b may be reversibly, and substantially leak-tightly coupled to the load-lock chamber 204. The coupling mechanism may include reversible fasteners (e.g., threaded bolts, screws, etc.) and gaskets that leak-tightly couple the modules 202a-b to the load-lock chamber. The load-lock chamber 204 includes openings aligned with the access doors of the curing and treatment chambers of the modules 202a-b, to permit a robot arm to transfer substrates between the load-lock chamber and the modules.

Substrate wafers may be provided to the system through the FOUPs 208a-d, which may sealingly couple to the FI 206. The substrates may pass through the FI 206 and into the load-lock chamber 204 with the aid of a robotic arm (not shown) positioned in the FI. Another robotic arm may then transfer the substrate from the load-lock chamber 204 to one of the processing chambers 210a-f that deposit one or more uncured dielectric layers on the substrate.

After the deposition, the robotic arm may transfer the substrate from the processing chamber 210a-f back to the load-lock chamber 204, where the initial robotic arm may place the substrate into a curing chamber of one of the modules 202a-b through an open access door in the chamber. As noted in the description of Fig. 1 above, after the robot arm has placed the uncured substrate in the curing chamber, the access door may be placed in a closed-sealed position while the gas distribution system and heating system adjust the environment in the curing chamber to a curing state. Once the dielectric layer(s) on the substrate has been cured, the access door may be opened, and the robot arm may take the cured substrate and transfer it to the treatment chamber of the same module 210a-b. The access door of the treatment chamber may be placed in a closed-sealed position while the gas distribution system and heating system adjust the environment of the chamber to a treatment state to produce a cured and treated substrate. At the end of the treatment process, the access door may be opened, and the robot arm may remove the cured, treated substrate from the module 210a-b and return

it to a FOUP 208a-d while the substrate awaits removal from system 200. Alternatively, the cured, treated substrate may be transferred back to one or more of the processing chambers 210a-f for additional deposition, etching, CMP, *etc.*, before finally being transferred to one of the FOUPs 208a-d.

Figs. 4A&B show simplified front and back-side perspective drawings, respectively, of a substrate processing system 400 where a pair of substrate curing and treatment modules 402a-b are positioned on opposite sides of a load-lock chamber 404 that interfaces with a set of substrate processing chambers 406a-f according to embodiments of the invention. These figures show the modules 402a-b attached on opposite sides of the load-lock chamber as substantially planar to a front side of the load-lock chamber that attached to the factory interface (not shown). As noted above, this configuration of the modules 402a-b permit them to be integrated with the overall substrate processing system 400 without increasing the width of the system 400, or interfering with the coupling of the load-lock chamber 406 with the FI.

Figs. 5 shows a simplified overhead view of a substrate processing system 500 having a substrate curing and treatment module 502 positioned adjacent to the FI 504. Positioning of the curing and treatment module 502 adjacent to the FI may allow reduced movement of substrates from the deposition chambers on the backside of the FI (not shown), as well as delivery of the substrates from the curing and treatment module 502 to the FOUPs 506a-d located on the front side of the FI. The curing and treatment modules may be located on one or both sides of the FI.

Having described several embodiments, it will be recognized by those of skill in the art that various modifications, alternative constructions, and equivalents may be used without departing from the spirit of the invention. Additionally, a number of well-known processes and elements have not been described in order to avoid unnecessarily obscuring the present invention. Accordingly, the above description should not be taken as limiting the scope of the invention.

Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limits of that range is also specifically disclosed. Each smaller range between any stated value or intervening value in a stated range and any other stated or intervening value in that stated range is encompassed. The upper and lower limits of these smaller ranges may independently be included or excluded in the range, and each range where either, neither or both limits are included in the smaller ranges is also encompassed within the invention,

subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included.

As used herein and in the appended claims, the singular forms "a", "an", and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a process" includes a plurality of such processes and reference to "the substrate" includes reference to one or more substrates and equivalents thereof known to those skilled in the art, and so forth.

Also, the words "comprise," "comprising," "include," "including," and "includes" when used in this specification and in the following claims are intended to specify the presence of stated features, integers, components, or steps, but they do not preclude the presence or addition of one or more other features, integers, components, steps, acts, or groups.

WHAT IS CLAIMED IS:

1. A substrate curing and treatment module comprising:

a curing chamber for curing a dielectric layer in an atmosphere comprising ozone, and a treatment chamber for treating the cured dielectric layer in an atmosphere comprising water vapor, wherein the curing chamber is vertically positioned with respect to the treatment chamber;

a heating system operatively coupled to the curing chamber and the treatment chamber, wherein the heating system is operative to adjust a first temperature of the curing chamber to from about 150°C to about 200°C, and to adjust a second temperature of the treatment chamber to from about 80°C to about 100°C; and

an access door on both the curing chamber and the treatment chamber, wherein each of the access doors are operable to be moved to an open position to receive a substrate, and operable to be moved to a closed sealed position while the substrate is being cured or treated.

2. The module of claim 1, wherein the curing chamber and the treatment chamber can receive a plurality of substrates at the same time.

3. The module of claim 2, wherein the plurality of substrates are vertically positioned with respect to each other in the curing chamber or the treatment chamber.

4. The module of claim 2, wherein the module is a batch substrate curing and treatment module.

5. The module of claim 1, wherein the module further comprises a gas distribution system coupled to the curing chamber and the treatment chamber, wherein the gas distribution system is operable to introduce a curing gas comprising ozone to the curing chamber, and a treatment gas comprising water vapor to the treatment chamber.

6. The module of claim 5, wherein the module further comprises a gas exhaust system configured to exhaust the curing gas from the curing chamber and the treatment gas from the treatment chamber.

7. A substrate processing system comprising:

a plurality of deposition chambers;

a first robotic arm operable to move a substrate between one of the deposition chambers and a load-lock substrate holding area;

a second robotic arm operable to move the substrate between the load-lock substrate holding area and a curing chamber of a substrate curing and treatment module, wherein the substrate curing and treatment module is attached to the load-lock substrate holding area, and wherein the substrate curing and treatment module comprises:

the curing chamber for curing a dielectric layer in an atmosphere comprising ozone, and a treatment chamber for treating the cured dielectric layer in an atmosphere comprising water vapor, wherein the curing chamber is vertically positioned with respect to the treatment chamber;

a heating system operatively coupled to the curing chamber and the treatment chamber, wherein the heating system is operative to adjust a first temperature of the curing chamber to from about 150°C to about 200°C, and to adjust a second temperature of the treatment chamber to from about 80°C to about 100°C; and

an access door on both the curing chamber and the treatment chamber, wherein each of the access doors are operable to be moved to an open position to receive a substrate, and operable to be moved to a closed sealed position during while the substrate is being cured or treated.

8. The system of claim 7, wherein the second robotic arm is operable to remove the substrate from the curing chamber and deliver the substrate to the treatment chamber.

9. The system of claim 7, wherein the system comprises a plurality of substrate curing and treatment modules, wherein each module is attached to the load-lock substrate holding area.

10. The system of claim 7, wherein the curing chamber and the treatment chamber can receive a plurality of substrates at the same time.