US010636705B1

(12) **United States Patent**
Wang et al.

(10) **Patent No.: US 10,636,705 B1**
(45) **Date of Patent: Apr. 28, 2020**

(54) **HIGH PRESSURE ANNEALING OF METAL GATE STRUCTURES**

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Yifei Wang**, Sunnyvale, CA (US); **Kurtis Leschkies**, San Jose, CA (US); **Fei Wang**, Fremont, CA (US); **Xin Liu**, Fremont, CA (US); **Wei Tang**, Santa Clara, CA (US); **Yixiong Yang**, San Jose, CA (US); **Wenyi Liu**, Santa Clara, CA (US); **Ludovic Godet**, Sunnyvale, CA (US)

(73) Assignee: **APPLIED MATERIALS, INC.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/204,560**

(22) Filed: **Nov. 29, 2018**

(51) **Int. Cl.**
H01L 21/768 (2006.01)
H01L 21/02 (2006.01)
H01L 21/28 (2006.01)

(52) **U.S. Cl.**
CPC .. ***H01L 21/76882*** (2013.01); ***H01L 21/02244*** (2013.01); ***H01L 21/76846*** (2013.01); ***H01L 21/76883*** (2013.01); ***H01L 21/76888*** (2013.01); *H01L 21/28079* (2013.01); *H01L 21/28088* (2013.01); *H01L 21/28097* (2013.01); *H01L 21/7685* (2013.01)

(58) **Field of Classification Search**
CPC H01L 21/76864; H01L 21/76843; H01L 21/76846; H01L 21/76868; H01L 21/76873; H01L 21/76882
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,099,904	A	8/2000	Mak et al.	
6,156,382	A	12/2000	Rajagopalan et al.	
6,162,715	A	12/2000	Mak et al.	
6,206,967	B1	3/2001	Mak et al.	
6,249,055	B1 *	6/2001	Dubin	H01L 21/76831 257/751
6,251,190	B1	6/2001	Mak et al.	
6,309,713	B1	10/2001	Mak et al.	
6,528,409	B1 *	3/2003	Lopatin	H01L 21/288 257/E21.174
6,551,929	B1	4/2003	Kori et al.	
6,607,976	B2	8/2003	Chen et al.	
6,620,723	B1	9/2003	Byun et al.	
6,720,027	B2	4/2004	Yang et al.	
6,740,585	B2	5/2004	Yoon et al.	
6,809,026	B2	10/2004	Yoon et al.	
6,827,978	B2	12/2004	Yoon et al.	

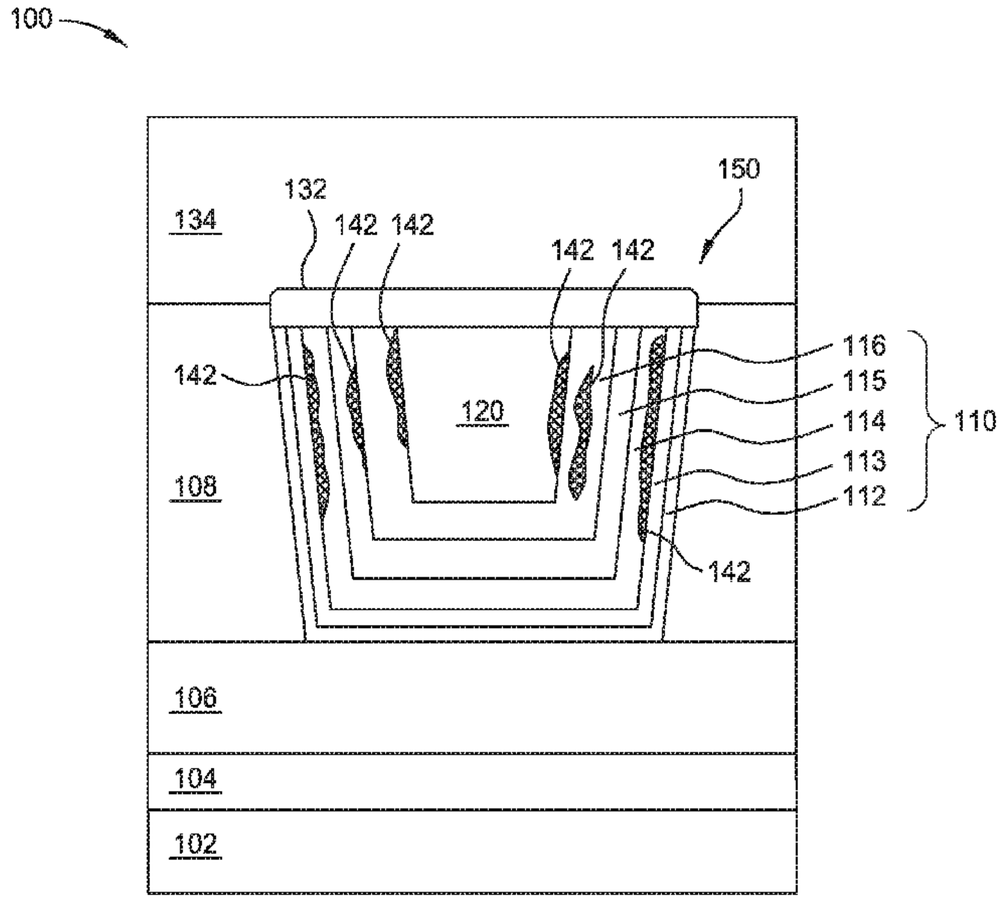
(Continued)

Primary Examiner — Zandra V Smith
Assistant Examiner — John M Parker
(74) *Attorney, Agent, or Firm* — Patterson + Sheridan, LLP

(57) **ABSTRACT**

The method of treating a film stack includes depositing a barrier film containing a metal into a via formed within a dielectric layer disposed on a substrate and depositing a metal contact on the barrier film within the via, where a void is located within the barrier film or between the barrier film and the metal contact. The method also includes exposing the metal contact and the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void.

20 Claims, 2 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,836,017	B2 *	12/2004	Ngo	H01L 21/76831 257/751
6,838,125	B2	1/2005	Chung et al.	
6,849,545	B2	2/2005	Mak et al.	
6,872,429	B1	3/2005	Chen et al.	
6,875,271	B2	4/2005	Glenn et al.	
6,936,538	B2	8/2005	Byun	
6,939,801	B2	9/2005	Chung et al.	
6,958,296	B2	10/2005	Chen et al.	
7,026,238	B2	4/2006	Xi et al.	
7,041,335	B2	5/2006	Chung	
7,211,508	B2	5/2007	Chung et al.	
7,244,683	B2	7/2007	Chung et al.	
7,262,133	B2	8/2007	Chen et al.	
7,504,006	B2 *	3/2009	Gopalraja	C23C 14/345 204/192.12
7,507,660	B2	3/2009	Chen et al.	
7,541,650	B2	6/2009	Hung et al.	
7,547,644	B2	6/2009	Chen et al.	
7,576,002	B2	8/2009	Chen et al.	
7,585,762	B2	9/2009	Shah et al.	
7,595,263	B2	9/2009	Chung et al.	
7,605,083	B2	10/2009	Lai et al.	
7,611,990	B2	11/2009	Yoon et al.	
7,691,742	B2	4/2010	Marcadal et al.	
7,695,563	B2	4/2010	Lu et al.	
7,709,385	B2	5/2010	Xi et al.	
7,732,325	B2	6/2010	Yang et al.	
7,732,327	B2	6/2010	Lee et al.	
7,745,329	B2	6/2010	Wang et al.	
7,745,333	B2	6/2010	Lai et al.	
7,824,743	B2	11/2010	Lee et al.	
7,838,441	B2	11/2010	Khandelwal et al.	
7,846,840	B2	12/2010	Kori et al.	
7,867,896	B2	1/2011	Cao et al.	
7,867,914	B2	1/2011	Xi et al.	
7,892,602	B2	2/2011	Chung et al.	
7,989,339	B2	8/2011	Shah et al.	
8,653,663	B2 *	2/2014	Kao	H01L 23/53238 257/744
8,653,664	B2 *	2/2014	Liu	H01L 21/76831 257/751
2001/0016429	A1	8/2001	Mak et al.	
2002/0086111	A1	7/2002	Byun et al.	
2002/0117399	A1	8/2002	Chen et al.	
2003/0049931	A1	3/2003	Byun et al.	
2003/0057526	A1	3/2003	Chung et al.	
2003/0059538	A1	3/2003	Chung et al.	
2003/0072884	A1	4/2003	Zhang et al.	
2003/0082307	A1	5/2003	Chung et al.	
2003/0123216	A1	7/2003	Yoon et al.	
2003/0124262	A1	7/2003	Chen et al.	
2003/0157760	A1	8/2003	Xi et al.	
2003/0194825	A1	10/2003	Law et al.	
2003/0203616	A1	10/2003	Chung et al.	
2003/0224217	A1	12/2003	Byun et al.	
2004/0009336	A1	1/2004	Marcadal et al.	
2004/0013803	A1	1/2004	Chung et al.	
2004/0247788	A1	12/2004	Fang et al.	
2006/0040052	A1	2/2006	Fang et al.	
2007/0009658	A1	1/2007	Yoo et al.	
2007/0026147	A1	2/2007	Chen et al.	
2007/0099415	A1	5/2007	Chen et al.	
2008/0206987	A1	8/2008	Gelatos et al.	
2009/0085173	A1 *	4/2009	Boemmels	H01L 21/76814 257/635
2010/0062149	A1	3/2010	Ma et al.	
2010/0062614	A1	3/2010	Ma et al.	
2010/0075494	A1	3/2010	Chung et al.	
2010/0075499	A1	3/2010	Olsen	
2010/0102417	A1	4/2010	Ganguli et al.	
2010/0120245	A1	5/2010	Tjandra et al.	
2010/0167527	A1	7/2010	Wu et al.	
2010/0311237	A1	12/2010	Seutter et al.	
2011/0244682	A1	10/2011	Khandelwal et al.	
2011/0256715	A1 *	10/2011	Pan	H01L 21/76831 438/653
2011/0266676	A1 *	11/2011	Isobayashi	H01L 21/76831 257/751

* cited by examiner

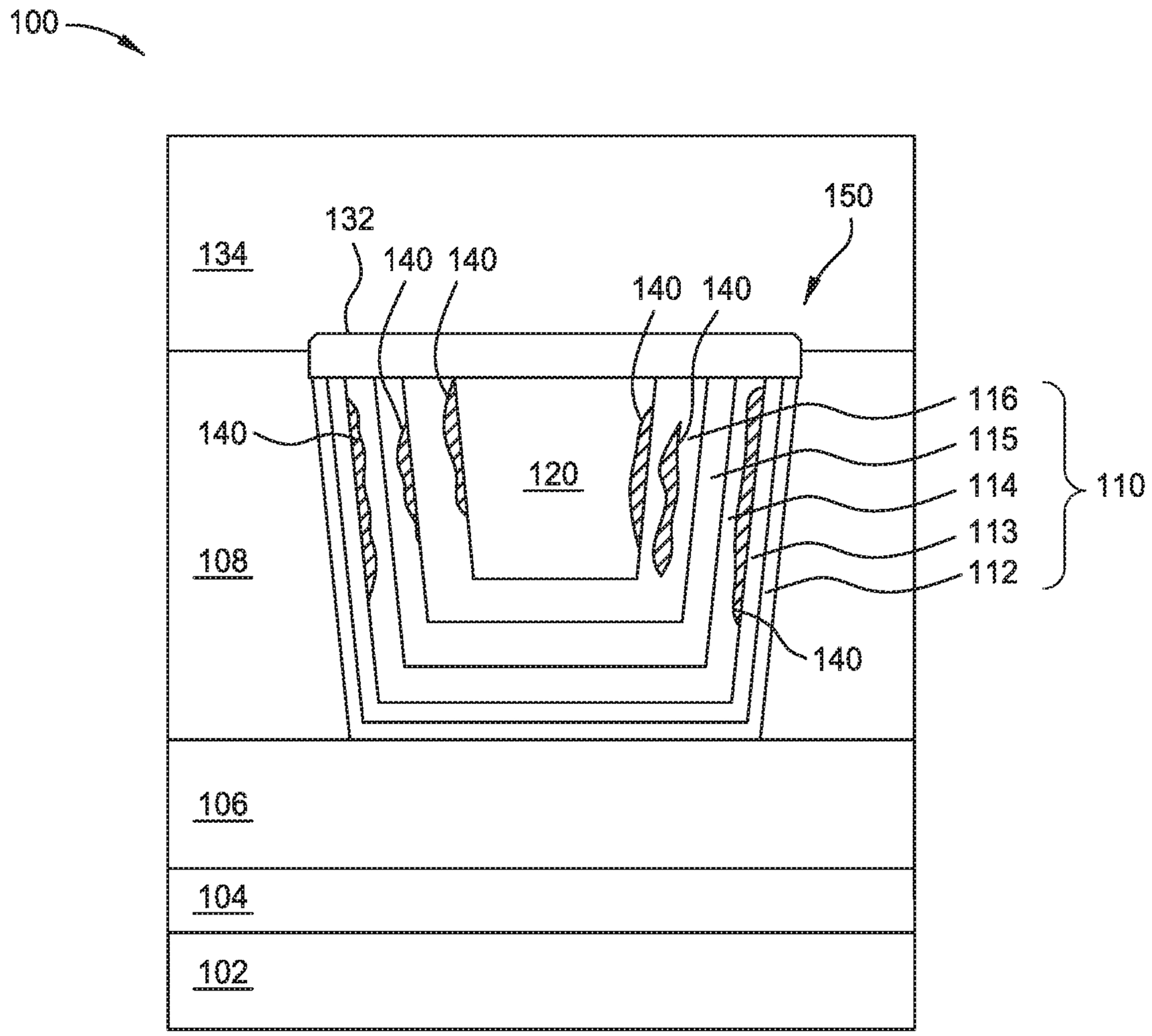

100
150
132
134
140
140
140
140
140
116
115
114
113
112
110
120
108
140
106
104
102

FIG. 1A

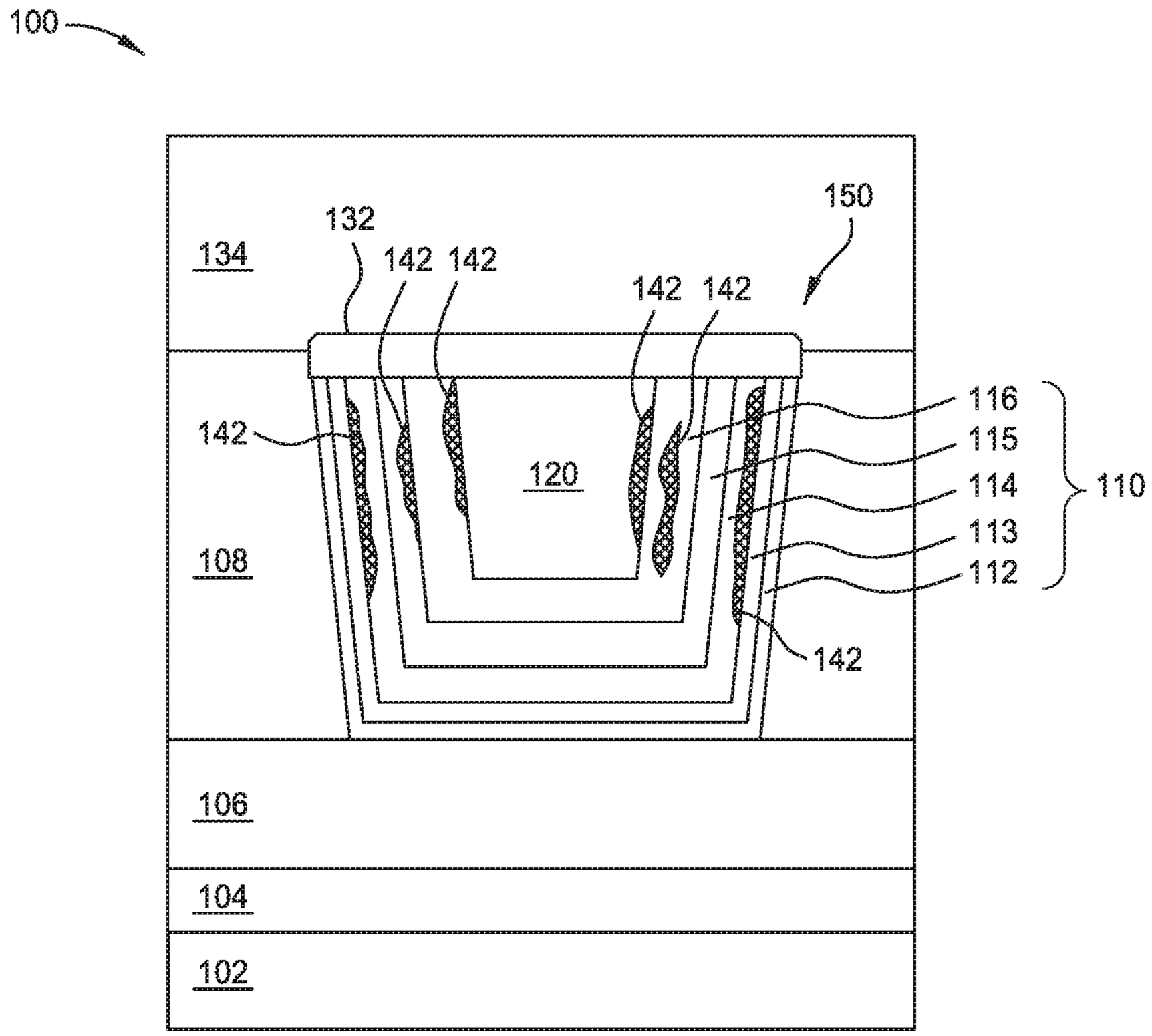

100
150
132
134
142
142
142
142
142
116
115
114
113
112
110
120
108
142
106
104
102

FIG. 1B

HIGH PRESSURE ANNEALING OF METAL GATE STRUCTURES

BACKGROUND

Field

Embodiments described herein generally relate to methods for processing substrates, and more specifically to methods for reducing or eliminating gaps or voids within a film stack.

Description of the Related Art

In advanced semiconductor devices, the film stack structures have become smaller and more complicated than previous generations of semiconductor devices. For these advanced semiconductor devices with high aspect ratio trenches, it is quite a challenge to fill the desired materials (e.g., TiN) into such trenches without any voids or seams by conventional technologies (e.g., vapor deposition—including CVD and ALD), because the trench will be closed before completely filling. Such voids or gaps can damage the device performance significantly.

Currently, no mature technologies achieve void-free, high-aspect-ratio trenches efficiently and cost-effectively. The methods of tuning various vapor deposition recipes are unable to provide perfectly void-free trench filling when manufacturing film stacks. An alternative method is to open up the voids via etch and subsequently deposit material into the voids. However, the etching process can damage the device. Also, such method requires many steps and is not cost-effective. Other methods, such as materials reflow, are limited by the process thermal budgets.

Thus, there is a need for improved methods for reducing or eliminating gaps or voids within a film stack.

SUMMARY

In one or more embodiments, a method of treating a film stack, such as in a metal gate structure, includes depositing a barrier film containing a metal into a via formed within a dielectric layer disposed on a substrate and depositing a metal contact on the barrier film within the via, where a void is located within the barrier film or between the barrier film and the metal contact. The method also includes exposing the metal contact and the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void.

In some embodiments, a method of treating a film stack includes depositing a barrier film containing a metal into a via located on a substrate and depositing a metal contact on the barrier film within the via, where a void is located within the barrier film or between the barrier film and the metal contact. The method also includes exposing the metal contact and the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void, and then exposing the metal contact and the barrier film to an annealing gas a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within the process chamber, where the annealing gas can be or include nitrogen gas (N_2), ammonia, hydrogen gas (H_2), or a mixture thereof. In some examples, the void is disposed between two layers contained in the barrier film.

In other embodiments, a method of treating a film stack includes depositing a barrier film containing a metal into a via formed within a dielectric layer disposed on a substrate, where the void is disposed within the barrier film. The method also includes exposing the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void. The oxidizing agent can be or include water, steam, oxygen gas (O_2), oxygen plasma, ozone, hydrogen peroxide, or any combination thereof. The method further includes filling the void with the metal oxide to produce a sealed seam within the film stack.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, may admit to other equally effective embodiments.

FIGS. **1**A and **1**B depict cross-sectional views of a film stack during various stages of fabrication, as discussed and described in one or more embodiments herein.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

Embodiments discussed and described herein provide methods for reducing or eliminating open seams, gaps, or voids within a film stack, such as a metal gate structure. These various types of voids can occur in and around barrier films and metal contacts within the film stack. Such voids reduce the electrical conductivity of the film stack and can cause delamination issues. The methods described and discussed herein are used to at least reduce the size of the voids and/or completely eliminate the voids by exposing the film stacks to a high pressure, thermal oxidation process. During the oxidation process, an oxidizing gas is exposed to the inner surfaces of the voids to generate metal oxide that fills the voids while producing sealed seams within the film stack. Subsequently, in some examples, the film stack with the sealed seams is exposed to a high pressure, thermal process that includes an annealing gas.

FIG. **1**A depicts cross-sectional view of a film stack **100** containing a damascene structure **150** that includes one or more open seams, gaps, and/or voids **140** (six voids **140** are shown) therein, as discussed and described in one or more embodiments herein. The damascene structure **150** is a metal gate structure. The film stack **100** includes a substrate **102** containing dielectric layers **104** and **108** separated by an etch-stop layer **106** disposed therebetween. In one or more examples, the dielectric layer **104** can be or include silicon oxide or polysilicon and be disposed on the substrate **102**, the etch-stop layer **106** can be or include silicon nitride, silicon carbide, or silicon carbide nitride and be disposed on

the dielectric layer **104**, and the dielectric layer **108** can be or include silicon oxide or polysilicon and be disposed on the etch-stop layer **106**.

The damascene structure **150** is formed or otherwise produced within the dielectric layer **108** and on top of the etch-stop layer **106**. The damascene structure **150** is a film stack and includes a barrier film **110** and a metal contact **120**. The barrier film **110** can be or include one or more barrier layers **112**, **113**, **114**, **115**, and **116** which are each independently the same or different. Although the barrier film **110** is shown in FIG. **1**A with five barrier layers (e.g., barrier layers **112**, **113**, **114**, **115**, and **116**), the barrier film **110** can have one, two, three, four, five, six, or more barrier layers. As such, any of the barrier layers **112**, **113**, **114**, **115**, and **116** shown in FIG. **1**A can be present or absent within the barrier film **110**. The barrier film **110** is deposited, formed, or otherwise produced in one or more trenches or vias formed within the dielectric layer **108**.

Each of the barrier layers **112**, **113**, **114**, **115**, and **116** can independently have a thickness of about 0.5 nm, about 1 nm, about 1.5 nm, about 2 nm, or about 2.5 nm to about 3 nm, about 4 nm, about 5 nm, about 8 nm, about 10 nm, or thicker. For example, each of the barrier layers **112**, **113**, **114**, **115**, and **116** can independently have a thickness of about 0.5 nm to about 10 nm, about 1 nm to about 10 nm, about 1.5 nm to about 10 nm, about 2 nm to about 10 nm, about 3 nm to about 10 nm, or about 5 nm to about 10 nm.

Each of the barrier layers **112**, **113**, **114**, **115**, and **116** can independently contain titanium, titanium nitride, titanium silicide nitride, titanium aluminum alloy, titanium aluminide, tantalum, tantalum nitride, tantalum silicide nitride, tungsten, tungsten nitride, tungsten silicide nitride, alloys thereof, or any combination thereof. In some examples, the barrier film **110** includes two or more different barrier layers and each of the barrier layers contains different compositions. In one or more examples, the barrier layer **112** contains titanium silicon nitride, the barrier layer **113** contains tantalum nitride, the barrier layer **114** contains titanium nitride, the barrier layer **115** contains titanium aluminum alloy (e.g., titanium aluminate), and the barrier layer **116** contains titanium nitride. Each of the barrier layers **112**, **113**, **114**, **115**, and **116** can independently be deposited, plated, formed, or otherwise prepared by chemical vapor deposition (CVD), plasma enhanced CVD (PE-CVD), atomic layer deposition (ALD), plasma enhanced ALD (PE-ALD), physical vapor deposition (PVD), or any combination thereof.

The metal contact **120** is deposited, formed, or otherwise produced on the upper layer (e.g., barrier layer **116**) of the barrier film **110** so to fill the remaining trenches or vias formed within the dielectric layer **108**. The metal contact **120** can be or include one or more metal seed layers, a bulk layer, a metal fill layer, or any combination thereof. In some examples, one or more metal seed layers are first deposited on the barrier film **110** and then a bulk or fill metal layer is deposited thereover filling the remaining trenches or vias.

The metal contact **120** can be or include one or more of tungsten, copper, aluminum, cobalt, ruthenium, palladium, alloys thereof, or any combination thereof. The metal contact **120** can be deposited, plated, formed, or otherwise prepared by chemical vapor deposition (CVD), plasma enhanced CVD (PE-CVD), atomic layer deposition (ALD), plasma enhanced ALD (PE-ALD), physical vapor deposition (PVD), electrochemical plating, electroless plating, or any combination thereof. In one or more embodiments, each of the layers within the barrier film **110** and the metal contact **120** can independently be deposited by the Trillium®, Producer®, or Centura® chamber, commercially available from Applied Materials, Inc.

The film stack **100** also includes a capping layer **132** disposed on or over the damascene structure **150** and an oxide layer **134** disposed on or over the capping layer **132** and the dielectric layer **108**. The capping layer **132** can include a cobalt material, such as cobalt, cobalt phosphide, cobalt boride, cobalt phosphide boride, or combinations thereof and has a thickness of about 0.5 nm to about 5 nm. The oxide layer **134** can include silicon oxide or silicon oxynitride and has a thickness of about 50 nm to about 300 nm, such as about 100 nm to about 200 nm. In one or more examples, the capping layer **132** can be deposited by electroplating, electroless deposition, ALD, or CVD and the oxide layer **134** can be deposited by CVD or plasma enhanced-CVD.

The damascene structures **150**, as well as the respective trenches or vias which the damascene structure **150** was formed within, have relatively high aspect ratios. The damascene structures **150** is depicted in FIG. **1**A with a relatively low aspect ratio in order to easier illustrate all the various layers, films, and other features in the drawing. The damascene structures **150** generally have a much greater aspect ratio than illustrated in FIG. **1**A. The damascene structures **150** can have an aspect ratio (depth over width) of greater than 1, such as about 2, about 3, about 5, about 8, or about 10 to about 12, about 15, about 20, about 30, about 40, about 50, about 60, about 80, or about 100. For example, the damascene structures **150** can have an aspect ratio of about 2 to about 100, about 2 to about 80, about 2 to about 60, about 2 to about 60, about 2 to about 50, about 2 to about 40, about 2 to about 35, about 2 to about 30, about 2 to about 20, about 10 to about 100, about 10 to about 80, about 10 to about 60, about 10 to about 60, about 10 to about 50, about 10 to about 40, about 10 to about 35, about 10 to about 30, or about 10 to about 20.

Open seams, gaps, and/or voids **140** can be inadvertently formed in the damascene structure **150** during the processes of depositing each of the different layers or films that make up the barrier film **110** and/or the metal contact **120**. The term "voids"—as used herein—includes voids, open seams, gaps, and any other open or hollow defect contained within the damascene structure **150** including between layers and/or films. The voids **140** can be located between two of the barrier layers **112-116** contained within the barrier film **110**, as well as located between the barrier film **110** and the metal contact **120**. The voids **140** negatively affect the damascene structure **150** by decreasing the electrical resistivity due to the lack of conductive material from the barrier film **110** and/or the metal contact **120**. The voids **140** can also increase the probability of failure due to delamination of the various layers within the damascene structure **150**. Therefore, the methods described and discussed herein are used to at least reduce the size of the voids **140** and/or eliminate the voids **140**.

In one or more embodiments, the method includes exposing at least the barrier film **110** to one or more oxidizing agents. The barrier film **110** can be exposed to the oxidizing agent before or after the deposition of the metal contact **120**, before or after the deposition of the capping layer **132**, and/or before or after the deposition of the oxide layer **134**. In many examples discussed and described herein, the barrier film **110** is exposed to the oxidizing agent before or after the deposition of the metal contact **120**.

In some embodiments, the method includes exposing the damascene structure **150**, including the metal contact **120**

and the barrier film **110**, to one or more oxidizing agents. The oxidizing agent diffuses through holes within the barrier film **110** and/or the metal contact **120** to reach the voids **140**. The oxidizing agent reacts with the metal and/or metal nitride within the barrier film **110** and/or the metal contact **120** to produce metal oxides within the voids **140**. The voids **140** are at least partially filled, substantially filled, or completely filled with the metal oxide during the oxidation process. Since the metal oxide is derived from the barrier film **110** and/or the metal contact **120**, the metal oxide includes one or more metals contained within the barrier film **110** and/or the metal contact **120**. The oxidizing agent can be or include water, steam or water vapor, oxygen gas (O_2), oxygen plasma, ozone, hydrogen peroxide, or any combination thereof. The metal oxide can be or include one or more metal oxides and/or one or more metal oxynitrides, such as titanium oxide, tantalum oxide, tungsten oxide, titanium oxynitride, tantalum oxynitride, tungsten oxynitrides thereof, oxysilicides thereof, alloys thereof, or any combination thereof.

The damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to one or more oxidizing agents at a temperature of less than 400° C. and at a relatively high pressure (e.g., greater than 18 bar) to produce the metal oxide within the void **140**. The relatively low temperature of less than 400° C. provides more flexible thermal limits to avoid damaging the damascene structure **150** or even the overall electronic device. The relatively high pressure during the process helps diffuse the reagents (e.g., oxidizing agents) into the voids **140**. The metal contact **120** and the barrier film **110** are exposed to the oxidizing agent at the desired temperature and pressure for about 5 minutes, about 10 minutes, about 20 minutes, about 30 minutes, or about 45 minutes to about 1 hour, about 1.25 hours, about 1.5 hours, about 2 hours, about 2.5 hours, or about 3 hours.

The damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the oxidizing agent at a temperature of less than 400° C., such as about 20° C., about 25° C., about 30° C., about 50° C., about 75° C., about 90° C., or about 100° C. to about 125° C., about 150° C., about 200° C., about 250° C., about 300° C., about 325° C., about 340° C., about 350° C., about 370° C., about 380° C., about 390° C., or 395° C. within the process chamber. For example, the damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the oxidizing agent at a temperature of about 25° C. to about 390° C., about 25° C. to about 380° C., about 25° C. to about 350° C., about 25° C. to about 300° C., about 25° C. to about 275° C., about 25° C. to about 250° C., about 25° C. to about 200° C., about 25° C. to about 150° C., about 25° C. to about 125° C., about 25° C. to about 100° C., about 100° C. to about 390° C., about 100° C. to about 380° C., about 100° C. to about 350° C., about 100° C. to about 300° C., about 100° C. to about 275° C., about 100° C. to about 250° C., about 100° C. to about 200° C., about 100° C. to about 150° C., or about 100° C. to about 125° C.

The damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the oxidizing agent at a pressure of greater than 18 bar, such as about 20 bar, about 25 bar, about 30 bar, or about 35 bar to about 40 bar, about 45 bar, about 50 bar, about 60 bar, about 70 bar, about 80 bar, about 90 bar, or about 100 bar within the process chamber. For example, the damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the oxidizing agent at a pressure of about 20 bar to about 100 bar, about 20 bar to about 80 bar, about 20 bar to about 60 bar, about 20 bar to about 50 bar, about 20 bar to about 40 bar, about 25 bar to about 100 bar, about 25 bar to about 80 bar, about 25 bar to about 60 bar, about 20 bar to about 30 bar, about 30 bar to about 100 bar, about 30 bar to about 80 bar, about 30 bar to about 60 bar, about 30 bar to about 50 bar, or about 30 bar to about 40 bar.

In one or more examples, the metal contact **120** and the barrier film **110** are exposed to the oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within the process chamber to produce the metal oxide within the void **140**. In some examples, the metal contact **120** and the barrier film **110** are exposed to the oxidizing agent at a temperature of about 25° C. to about 380° C. and at a pressure of about 25 bar to about 80 bar within the process chamber to produce the metal oxide within the void **140**. In other examples, the metal contact **120** and the barrier film **110** are exposed to the oxidizing agent at a temperature of about 100° C. to about 350° C. and at a pressure of about 30 bar to about 60 bar within the process chamber to produce the metal oxide within the void **140**.

FIG. **1**B depicts a cross-sectional view of the film stack **100** containing the damascene structure **150** in which the voids **140** (as depicted in FIG. **1**A) have been at least partially filled and/or closed, if not completely filled and/or closed, with the metal oxide to produce sealed seams **142**, as discussed and described in one or more embodiments herein. The formation of the metal oxide from the oxidized surfaces within the voids **140** leads to volume expansion which pushes the voids **140** to narrower until the voids at least partially filled and/or closed thereby producing the sealed seams **142**.

Subsequent to the oxidation process described and discussed above, the substrate can be exposed to a post treatment process. The post treatment process can include further assist in forming the sealed seams **142** and also increases the electrical conductivity of the damascene structure **150**. In some instances, the metal contact **120** and the barrier film **110** are exposed to reducing gas under relatively high pressure and low temperature. For example, the post treatment process can include exposing the metal contact **120** and the barrier film **110** to an annealing gas a temperature of less than 400° C. and at a pressure of about 20 bar to about 60 bar within the process chamber. The annealing gas can be or include nitrogen gas (N_2), ammonia, hydrazine, hydrogen gas (H_2), forming gas, or any combination thereof.

During the post treatment process, the damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the annealing gas at a temperature of less than 400° C., such as about 20° C., about 25° C., about 30° C., about 50° C., about 75° C., about 90° C., or about 100° C. to about 125° C., about 150° C., about 200° C., about 250° C., about 300° C., about 325° C., about 340° C., about 350° C., about 370° C., about 380° C., about 390° C., or 395° C. within the process chamber. For example, the damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the annealing gas at a temperature of about 25° C. to about 390° C., about 25° C. to about 380° C., about 25° C. to about 350° C., about 25° C. to about 300° C., about 25° C. to about 275° C., about 25° C. to about 250° C., about 25° C. to about 200° C., about 25° C. to about 150° C., about 25° C. to about 125° C., about 25° C. to about 100° C., about 100° C. to about 390° C., about 100° C. to about 380° C., about 100° C. to about 350° C., about 100° C. to about 300° C., about 100° C. to about 275° C., about 100° C. to about 250° C., about 100° C. to about 200° C., about 100° C. to about 150° C., or about 100° C. to about 125° C. during the post treatment process.

During the post treatment process, the damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the annealing gas at a pressure of greater than 18 bar, such as about 20 bar, about 25 bar, about 30 bar, or about 35 bar to about 40 bar, about 45 bar, about 50 bar, about 60 bar, about 70 bar, about 80 bar, about 90 bar, or about 100 bar within the process chamber. For example, the damascene structure **150**, including the metal contact **120** and the barrier film **110**, is exposed to the annealing gas at a pressure of about 20 bar to about 100 bar, about 20 bar to about 80 bar, about 20 bar to about 60 bar, about 20 bar to about 50 bar, about 20 bar to about 40 bar, about 25 bar to about 100 bar, about 25 bar to about 80 bar, about 25 bar to about 60 bar, about 20 bar to about 30 bar, about 30 bar to about 100 bar, about 30 bar to about 80 bar, about 30 bar to about 60 bar, about 30 bar to about 50 bar, or about 30 bar to about 40 bar during the post treatment process.

The damascene structure **150** with the voids **140** containing metal oxides and/or the sealed seams **142** is exposed to the annealing gas at the desired temperature and pressure during the post treatment process for about 1 minute, about 2 minutes, about 5 minutes, about 10 minutes, about 20 minutes, about 30 minutes, or about 45 minutes to about 1 hour, about 1.25 hours, about 1.5 hours, about 2 hours, about 2.5 hours, or about 3 hours.

The oxidation process and/or the post treatment process can be conducted in the same process or deposition chamber as any of the deposition processes (e.g., the barrier film **110** and/or the metal contact **120**) or in different process chambers. In some examples, the oxidation process and/or the post treatment process can independently be conducted in a high pressure anneal or thermal process chamber or system. For example, the oxidation process and/or the post treatment process can independently be conducted in a pressurized annealing chamber, such as the Centura®, Radiance®, or WXZ™ chambers or systems, commercially available from Applied Materials, Inc.

In one or more embodiments, a method of treating a film stack **100** includes depositing a barrier film **110** containing one or more metals and/or metal nitrides into one or more trenches or vias formed within a dielectric layer **108** disposed on a substrate **102** and depositing a metal contact **120** on the barrier film **110** within the vias, where one or more voids **140** are located within the barrier film **110** or between the barrier film **110** and the metal contact **120**. The method also includes exposing the metal contact **120** and the barrier film **110** to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the voids **140**.

In some embodiments, a method of treating a film stack **100** includes depositing a barrier film **110** containing one or more metals and/or metal nitrides into one or more trenches or vias located on a substrate **102** and depositing a metal contact **120** on the barrier film **110** within the vias, where one or more voids **140** are located within the barrier film **110** or between the barrier film **110** and the metal contact **120**. The method also includes exposing the metal contact **120** and the barrier film **110** to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the voids **140**, and then exposing the metal contact **120** and the barrier film **110** to an annealing gas a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within the process chamber, where the annealing gas can be or include nitrogen gas (N_2), ammonia, hydrogen gas (H_2), or a mixture thereof. In some examples, the voids **140** are disposed between two layers contained in the barrier film **110**.

In other embodiments, a method of treating a film stack **100** includes depositing a barrier film **110** containing one or more metals and/or metal nitrides into one or more trenches or vias formed within a dielectric layer **108** disposed on a substrate **102**, where the voids **140** are disposed within the barrier film **110**. The method also includes exposing the barrier film **110** to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the voids **140**. The oxidizing agent can be or include water, steam, oxygen gas (O_2), oxygen plasma, ozone, hydrogen peroxide, or any combination thereof. The method further includes filling the voids **140** with the metal oxide to produce a sealed seam **142** within the film stack **100**.

In other embodiments, a method of treating a film stack **100** includes depositing a barrier film **110** containing one or more metals and/or metal nitrides into one or more trenches or vias formed within a dielectric layer **108** disposed on a substrate **102** and depositing a metal contact **120** on the barrier film **110** within the vias, where the voids **140** are disposed within the barrier film **110** or between the barrier film **110** and the metal contact **120**. The method also includes exposing the metal contact **120** and the barrier film **110** to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the voids **140**. The oxidizing agent can be or include water, steam, oxygen gas (O_2), oxygen plasma, ozone, hydrogen peroxide, or any combination thereof. The method further includes filling the voids **140** with the metal oxide to produce a sealed seam **142** within the film stack **100**.

While the foregoing is directed to embodiments of the disclosure, other and further embodiments may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow. All documents described herein are incorporated by reference herein, including any priority documents and/or testing procedures to the extent they are not inconsistent with this text. As is apparent from the foregoing general description and the specific embodiments, while forms of the present disclosure have been illustrated and described, various modifications can be made without departing from the spirit and scope of the present disclosure. Accordingly, it is not intended that the present disclosure be limited thereby. Likewise, the term "comprising" is considered synonymous with the term "including" for purposes of United States law. Likewise whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition or group of elements with transitional phrases "consisting essentially of," "consisting of", "selected from the group of consisting of," or "is" preceding the recitation of the composition, element, or elements and vice versa.

Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, e.g., the combination of any lower value with any upper value, the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated. Certain lower limits, upper limits and ranges appear in one or more claims below.

What is claimed is:

1. A method of treating a film stack, comprising:

depositing a barrier film comprising a metal into a via formed within a dielectric layer disposed on a substrate;

depositing a metal contact on the barrier film within the via, wherein a void is located between two barrier layers contained within the barrier film; and

exposing the metal contact and the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void.

2. The method of claim **1**, wherein the oxidizing agent diffuses through holes within the barrier film to reach the void.

3. The method of claim **1**, wherein the void is filled with the metal oxide to produce a sealed seam.

4. The method of claim **1**, wherein the metal oxide comprises the metal contained in the barrier film.

5. The method of claim **4**, wherein the metal oxide comprises titanium oxide, tantalum oxide, tungsten oxide, titanium oxynitride, tantalum oxynitride, tungsten oxynitride, alloys thereof, or any combination thereof.

6. The method of claim **1**, wherein the temperature of the process chamber is about 25° C. to about 380° C. when the metal contact and the barrier film are exposed to the oxidizing agent.

7. The method of claim **1**, wherein the temperature of the process chamber is about 100° C. to about 350° C. when the metal contact and the barrier film are exposed to the oxidizing agent.

8. The method of claim **1**, wherein the pressure of the process chamber is about 25 bar to about 80 bar when the metal contact and the barrier film are exposed to the oxidizing agent.

9. The method of claim **8**, wherein the pressure of the process chamber is about 30 bar to about 60 bar.

10. The method of claim **1**, wherein the oxidizing agent comprises water, steam, oxygen gas (O_2), oxygen plasma, ozone, hydrogen peroxide, or any combination thereof.

11. The method of claim **1**, wherein the barrier film comprises one layer of titanium, titanium nitride, titanium silicide nitride, titanium aluminum alloy, titanium aluminide, tantalum, tantalum nitride, tantalum silicide nitride, tungsten, tungsten nitride, tungsten silicide nitride, alloys thereof, or any combination thereof.

12. The method of claim **1**, wherein the metal contact comprises tungsten, copper, cobalt, alloys thereof, or any combination thereof.

13. The method of claim **1**, wherein a damascene structure comprising the barrier film and the metal contact has an aspect ratio of about 2 to about 100.

14. A method of treating a film stack, comprising:

depositing a barrier film comprising a metal into a via located on a substrate;

depositing a metal contact on the barrier film within the via, wherein a void is located within the barrier film or between the barrier film and the metal contact;

exposing the metal contact and the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void; and then

exposing the metal contact and the barrier film to an annealing gas a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within the process chamber, wherein the annealing gas comprises nitrogen gas (N_2), ammonia, hydrogen gas (H_2), or a mixture thereof.

15. The method of claim **14**, wherein the temperature of the process chamber is about 25° C. to about 380° C. and at a pressure of about 25 bar to about 80 bar when the metal contact and the barrier film are exposed to the oxidizing agent.

16. The method of claim **14**, wherein the temperature of the process chamber is about 100° C. to about 350° C. and at a pressure of about 30 bar to about 60 bar when the metal contact and the barrier film are exposed to the oxidizing agent.

17. A method of treating a film stack, comprising:

depositing a barrier film comprising a metal into a via formed within a dielectric layer disposed on a substrate;

depositing a metal contact on the barrier film within the via, wherein a void is located within the barrier film or between the barrier film and the metal contact; and

exposing the metal contact and the barrier film to an oxidizing agent at a temperature of less than 400° C. and at a pressure of about 20 bar to about 100 bar within a process chamber to produce a metal oxide within the void; and then

exposing the metal contact and the barrier film to an annealing gas at a temperature of less than 400° C. and at a pressure of about 20 bar to about 60 bar within the process chamber, wherein the annealing gas comprises nitrogen gas (N_2), ammonia, hydrazine, hydrogen gas (H_2), forming gas, or any combination thereof.

18. The method of claim **17**, wherein the metal oxide comprises the metal contained in the barrier film.

19. The method of claim **18**, wherein the metal oxide comprises titanium oxide, tantalum oxide, tungsten oxide, titanium oxynitride, tantalum oxynitride, tungsten oxynitride, alloys thereof, or any combination thereof.

20. The method of claim **17**, wherein the temperature of the process chamber is about 100° C. to about 350° C. when the metal contact and the barrier film are exposed to the oxidizing agent.

* * * * *