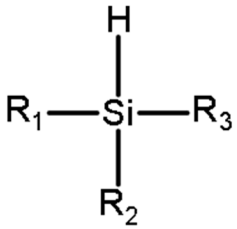
[0053] The term “radiofrequency (RF) power source” generally represents a component of a processing tool configured to apply power to a pair of electrodes in a processing chamber to form a plasma between the electrodes.

[0054] The term “silicon-containing precursor” generally represents any material that can be introduced into a processing chamber in a gas phase to form a silicon oxide film on the substrate. Example silicon-containing precursors for forming silicon oxide films can comprise materials having the general structure:



where R_1, R_2 and R_3 can be the same or different substituents, and can include silanes, siloxy groups, amines, halides, hydrogen, or organic groups, such as alkylamines, alkoxy, alkyl, alkenyl, alkynyl and aromatic groups.

[0055] Example silicon-containing precursors include polysilanes (H_3Si-$(SiH_2)_n$-SiH_3), where n ≥1, such as silane, disilane, trisilane, tetrasilane, and trisilylamine.

[0056] In some examples, the silicon-containing precursor is an alkoxysilane. Alkoxysilanes that can be used include the following:

H_x-Si-$(OR)_y$, where x = 1-3, x+y = 4 and each R is a substituted or unsubstituted alkyl, alkenyl, alkynyl or aromatic group; and

$H_x(RO)_y$,-Si-Si-$(OR)_yH_x$, where each R is a substituted or unsubstituted alkyl, alkenyl, alkynyl or aromatic group.

[0057] Examples of silicon-containing precursors include tetraethyl orthosilicate (TEOS), tetramethoxysilane (TMOS), methylsilane, trimethylsilane (3MS), ethylsilane, butasilanes, pentasilanes, octasilanes, heptasilane, hexasilane, cyclobutasilane, cycloheptasilane, cyclohexasilane, cyclooctasilane, cyclopentasilane, l,4-dioxa-2,3,5,6-tetrasilacyclohexane, diethoxymethylsilane (DEMS), diethoxysilane (DES), dimethoxymethylsilane, dimethoxysilane (DMOS), methyl-diethoxysilane (MDES), methyl-dimethoxysilane (MDMS), t-butoxydisilane, triethoxysilane (TES), and trimethoxysilane (TMS or TriMOS).

(PH_3) and alkyl phosphines such as trimethylphosphine, triethylphosphine, and tributylphosphine. One example of a boron-containing precursor is diborane (B_2H_6). Examples of carbon-containing precursors include carbon monoxide (CO), alkanes, alkenes, alkynes, cyclic hydrocarbons, aromatics, alcohols, aldehydes, esters, ethers, ketones, alkyl amines, alkyl diamines, and organosilicon precursors (e.g., methylsilane, dimethylsilane, trimethylsilane, and siloxanes). One example of an arsenic-containing precursor is arsine (AsH_3).

[0080] Inert gas source 220 can comprise any suitable inert gas, such as one or more of helium, neon, argon, krypton, xenon, or nitrogen.

[0081] Flow control hardware 214 can be controlled to flow gas from the various gas sources into processing chamber 202 via gas inlet 212. Flow control hardware 214 can comprise one or more valves controllable to place a selected gas source in fluid connection with gas inlet 212.

[0082] Processing tool 200 further comprises an exhaust system 224. Exhaust system 224 is configured to receive gas outflowing from processing chamber 202. In some examples, exhaust system 224 is configured to actively remove gas from processing chamber 202 and/or apply a partial vacuum. Exhaust system 224 can comprise any suitable hardware, including one or more pumps.

[0083] Processing tool 200 further comprises a radiofrequency power source 228 that is electrically connected to substrate support 204. Radiofrequency power source 228 is configured to form a plasma comprising the oxygen-containing gas. Processing tool 200 also comprises a matching network 229 for impedance matching of the radiofrequency power source 228. The plasma also can comprise an inert diluent gas from inert gas source 220. Radiofrequency power source 228 can be configured for any suitable frequency (e.g., 400 kHz or 13.56 MHz as examples) and power (e.g., between 0 and 6500 watts). In some examples, radiofrequency power source 228 is configured to operate at a plurality of different frequencies and/or powers.

[0084] Controller 230 is operatively coupled to substrate heater 208, flow control hardware 214, exhaust system 224, and radiofrequency power source 228. Controller 230 is configured to control various functions of processing tool 200, such as operating substrate heater 208 to heat to a desired temperature. Controller 230 is further configured to operate flow control hardware 214 to flow selected gases into processing chamber 202. Controller 230 is further configured to operate exhaust system 224. Controller 230 is further configured to operate radiofrequency power source 228

to form a plasma. Controller 230 can comprise any suitable computing system, examples of which are described below with reference to FIG. 11.

[0085] FIG. 3 schematically shows an example etching tool 300 configured to perform cryogenic dry etching processes, also referred to as reduced temperature etching processes herein. Etching tool 300 comprises a processing chamber 302 and a substrate support 304 within the processing chamber. Substrate support 304 is configured to support a substrate 306 disposed within processing chamber 302. Substrate support 304 can comprise a pedestal, a chuck, and/or any other suitable structure.

[0086] Etching tool 300 further comprises a gas inlet 312 and flow control hardware 314. Flow control hardware 314 is connected to an etchant gas source 316 and an inert gas source 320. Etchant gas source 316 can comprise any suitable etchant chemical. Examples include fluorine-containing etchants. Suitable fluorine-containing etchants include HF, NF_3, CF_4, and C_2F_6. Inert gas source 320 can comprise any suitable inert gas, such as one or more of helium, neon, argon, krypton, xenon, or nitrogen.

[0087] Flow control hardware 314 is controllable to flow gas from etchant gas source 316 and inert gas source 320 into processing chamber 302 via gas inlet 312. Flow control hardware 314 comprises one or more valves controllable to place a selected gas source in fluid connection with gas inlet 312.

[0088] Etching tool 300 further comprises an exhaust system 324. Exhaust system 324 is configured to receive gas outflowing from processing chamber 302. In some examples, exhaust system 324 is configured to actively remove gas from processing chamber 302 and/or apply a partial vacuum. Exhaust system 324 can comprise any suitable hardware, including one or more pumps.

[0089] Etching tool 300 further comprises a radiofrequency power source 328 that is electrically connected to substrate support 304. Thus, substrate support 304 forms a first electrode. Etching tool 300 further comprises a second electrode 350. Radiofrequency power source 328 is configured to form a plasma comprising the etchant gas. Etching tool 300 can include a matching network 329 for impedance matching of the radiofrequency power source 328. The plasma also can comprise an inert diluent gas from inert gas source 320. Radiofrequency power source 328 can be configured for any suitable frequency and power. In some examples, radiofrequency power source 328 is configured to operate at a plurality of different frequencies and/or powers.

3D NAND memory structure. In other examples, the feature comprises a contact hole in a 3D NOR memory structure. Further, in some examples, the substrate comprises a first substrate structure comprising alternating layers in a mold stack for a 3D NAND structure, and a second substrate structure comprising the dielectric material. In such examples, the method further comprises controlling the processing tool to simultaneously etch the hole in the second substrate structure and at least a portion of a channel hole in the first substrate structure, as indicated at 422.

[0096] FIGS. 5A and 5B show an example high aspect ratio feature etched through a hard mask layer and into a silicon oxide layer, compared to an example high aspect ratio feature etched through a hard mask layer and into a nitrogen-doped silicon oxide layer.

[0097] More particularly, FIGS. 5A schematically shows a feature 500 etched, using a reduced temperature etching process, into a gapfill material 502 comprising undoped silicon oxide. The feature is defined by a hard mask 504. As shown, the relatively slower dry etch rate of the undoped silicon oxide in some examples can lead to bowing. This is shown by the increase and then decrease in width of feature 500 at the interface of gapfill material 502 and hard mask 504. As a result, a width (e.g. diameter) dimension of feature 500 at this interface is larger than the width (e.g. diameter) of the corresponding opening in hard mask 504. Further, the bowing and wider dimensions can be evident prior to etching feature 500 to its full depth.

[0098] FIG. 5B schematically shows a feature 550 etched, using a reduced temperature etching process, into a gapfill material 552 comprising silicon oxide doped with an etch rate-modifying dopant under similar etching conditions as feature 500. As mentioned above, the use of the etch rate-modifying dopant can provide for faster etch rates compared to etching undoped silicon oxide. Any suitable dopant concentration can be used. In some examples, an N-doped silicon oxide film comprising a nitrogen concentration between 16 to 20 atomic percent can have an etch rate of ~180 nm/min. An undoped oxide film can have an etch rate of ~100 nm/min under similar etching conditions.

[0099] In contrast with feature 500, feature 550 has less bowing, and a width more closely matched to the width of the corresponding opening in hard mask 554 compared to feature 500 and hard mask 504. Feature 550 can have any suitable aspect ratio. In some examples, feature 550 can have an aspect ratio of 10:1 or greater. For