containing species may reduce hydrogen content of the film without etching or with significantly reduce etching of the carbon hardmask. Furthermore, as shown in FIG. 4, above, the mechanical properties of films deposited using a process gas including a halide-containing species may be significantly similar to the mechanical properties of films deposited without such halide-containing species.

[0103] In some examples, a relatively small amount of halide-containing species may significantly reduce hydrogen content. Figures 5 and 6 present FTIR spectra for various ratios of SF_6 to C_2H_2 (FIG. 5) and various ratios of CF_4 to C_2H_2 (FIG. 6). As shown in FIG. 5, a co-flow of SF_6 that is as little as 5% of the flow of C_2H_2 may significantly reduce a C-H peak around 2925, indicating reduced hydrogen content in the film. This peak is further reduced with higher amounts of SF_6, though higher amounts may lead to greater incorporation of sulfur and fluorine in the film. FIG. 6, similarly, illustrates a reduced C-H peak with as little as 5% CF_4 added to the process gas flow.

[0104] Examples can be implemented in a plasma enhanced chemical vapor deposition (PECVD) reactor. Such a reactor may take many different forms. Further, various examples may be implemented on a multi-station or single station tool.

[0105] Generally, the apparatus will include one or more chambers or reactors that each include one or more stations. Chambers will house one or more wafers and are suitable for wafer processing. The one or more chambers maintain the wafer in a defined position or positions, by preventing rotation, vibration, or other agitation. In some example, a wafer undergoing AHM deposition is transferred from one station to another within a chamber during the process. For example, a 2000 Å AHM deposition may occur entirely at one station, or 500 Å of film may be deposited at each of four stations in accordance with various examples. Alternatively, any other fraction of the total film thickness may be deposited at any number of stations. In various examples where more than one AHM is deposited, more than one station may be used to deposit each AHM layer. During processing, each wafer is held in place by a pedestal, wafer chuck, and/or other wafer holding apparatus. For certain operations where the wafer is to be heated, the apparatus may include a heater such as a heating plate.

[0106] FIG. 7 schematically shows an example of a process station 700 that may be used to deposit material using plasma enhanced chemical vapor deposition (PECVD). For simplicity, the process station 700 is depicted as a standalone process station having a processing chamber body 702 for maintaining a low-pressure environment. However, it will be appreciated that a

carbon hardmask can have a stress, a modulus of elasticity, and/or a hydrogen content outside of these ranges.

[0134] In some examples, the annealing time and temperature can be controlled such that an annealed carbon hardmask exhibits a limited change in the grain size as measured by Raman spectroscopy compared to the carbon hardmask prior to annealing. In some examples, the change in an average grain size can be less than or equal to 15 percent after annealing. In addition, annealing can be controlled such that the annealed carbon hardmask exhibits a change in sp^3 carbon content of less than or equal to 10 percent as measured by Raman spectroscopy.

[0135] Referring next to FIG. 9D, the annealed carbon hardmask 907 is patterned. In some examples, a photolithography process can be used. The patterning process removes the hardmask from the region 908. The remaining regions of the annealed carbon hardmask 907 protect underlying regions of the mold stack 900 from etching.

[0136] Referring next to FIG. 9E, a directional etching process is used to form a high aspect ratio feature 910. Any suitable method for directional etching can be used. As mentioned above, examples methods for directional etching include sputtering, ion milling and reactive ion etching (RIE). Comparing FIG. 9D and FIG. 9E, the thickness of the annealed carbon hardmask 907 from FIG. 9C is reduced during etching of high aspect ratio feature 910 as the annealed carbon hardmask 907 is consumed. However, the etch selectivity of the annealed carbon hardmask 907 of FIG. 9 is higher than that of the carbon hardmask 806 of FIG. 8. This allows directional etching to be continued without completely consuming the annealed carbon hardmask 907. Referring next to FIG. 9F, the high aspect ratio feature 910 has been completely etched without fully consuming the annealed carbon hardmask 907.

[0137] FIG. 10 shows a flow diagram depicting an example method 1000 for processing a substrate. Method 1000 comprises, at step 1002, placing a substrate in an annealing tool. The substrate comprises a carbon hardmask with a first stress and a first hydrogen content. Method 1000 further comprises, at step 1004, annealing the substrate to form an annealed hardmask. The annealed carbon hardmask has a second stress that is lower than the first stress. The annealed carbon hardmask also has a second hydrogen content that is lower than the first hydrogen content. Any suitable conditions can be used to anneal the carbon hardmask. In some examples, the substrate can be heated to a temperature within a temperature range of 500-1000ºC, as indicated at 1005. In other examples, annealing can be performed at a temperature outside of this range. Further, the annealing can be performed in any suitable gaseous

described herein. The processing tool 1200 comprises a processing chamber 1202. The processing tool 1200 further comprises a substrate support 1204 within the processing chamber for supporting a substrate 1206. The substrate support 1204 can comprise a pedestal, a chuck, and/or any other suitable structure. The substrate support 1204 further can include a substrate heater 1208. The processing chamber 1202 further comprises a showerhead 1210. In other examples, a nozzle and/or other suitable inlet hardware can be used.

[0149] The processing tool 1200 further comprises one or more processing gas inlets for introducing processing gases into the processing chamber 1202. One example of a processing gas inlet 1214 is shown. In the depicted example, the processing gas inlet 1214 directs processes gases to the showerhead 1210. The processing tool 1200 further comprises flow control hardware 1216 for controlling the introduction of processing gases into the processing chamber 1202. The flow control hardware is connected to a carbon-containing precursor source 1218 and an inert gas source 1220.

[0150] The carbon-containing precursor source 1218 can contain any suitable carbon-containing precursor for depositing a carbon hardmask. Example carbon-containing precursors include can include alkanes having a general formula C_nH_{2n+2} where n is an integer in a range of 1 to 10 (such as methane, ethane, etc.), alkenes having a general formula C_nH_{2n} where n = 2 to 10 (such as ethylene, propylene, etc.), and alkynes having a general formula C_nH_{2n-2} where n = 2 to 10 (such as acetylene, propyne, etc.), that are gas-phase under processing conditions. Other examples of carbon-containing precursors can comprise aliphatic and aromatic cyclic hydrocarbons, nitrogen-containing compounds including alkyl amines, and oxygen-containing compounds including alcohols, ketones, esters, aldehydes, and ethers, that are gas-phase under processing conditions.

[0151] The inert gas source 1220 can comprise any suitable inert gas. Examples include helium, neon, argon, krypton, xenon, and nitrogen.

[0152] The processing tool 1200 further comprises an exhaust system 1222. The exhaust system 1222 is configured to remove gases from the processing chamber 1202. The exhaust system 1222 can comprise any suitable hardware. Example hardware includes one or more low vacuum pumps and one or more high vacuum pumps.

[0153] The substrate heater 1208 can be used to provide thermal energy to facilitate a deposition process. Further, in some examples, a plasma to facilitate the deposition process