various processing stages including development and treatment of photoresist. As shown in **FIG. 2A**, a wafer 200 includes a substrate 202 and a substrate layer 204 to be etched. The patterning structure can include any useful substrate. For instance, an incoming wafer can be prepared with a substrate surface of a desired material, with the uppermost material being the layer into which the resist pattern is transferred. While the material selection may vary depending on integration, it is generally desired to select a material which can be etched with high selectivity to (i.e., much faster than) the EUV resist or imaging layer.

[0075] In some embodiments, the substrate is a hardmask, which is used in lithographic etching of an underlying semiconductor material. The hardmask may comprise any of a variety of materials, including amorphous carbon (a-C), tin oxide (e.g., SnO_x), silicon oxide (e.g., SiO_x, including SiO_2), silicon oxynitride (e.g., SiO_xN_y), silicon oxycarbide (e.g., SiO_xC_y), silicon nitride (e.g., Si_3N_4), titanium oxide (e.g., TiO_2), titanium nitride (e.g., TiN), tungsten (e.g., W), doped carbon (e.g., W-doped C), tungsten oxide (e.g., WO_x), hafnium oxide (e.g., HfO_2), zirconium oxide (e.g., ZrO_2), and aluminum oxide (e.g., Al_2O_3). Suitable substrate materials can include various carbon-based films (e.g., ashable hardmask (AHM), silicon-based films (e.g., SiO_x, SiC_x, SiO_xC_y, SiO_xN_y, $SiO_xC_yN_z$), a-Si:H, poly-Si, or SiN), or any other (generally sacrificial) film applied to facilitate the patterning process). For example, the substrate may preferably comprise SnO_x, such as SnO_2. In various embodiments, the layer may be from 1 nm to 100 nm thick, or from 2 nm to 10 nm thick.

[0076] In some embodiments, the substrate layer 204 includes an ashable hard mask such as amorphous carbon, spin-on carbon, or other material, e.g., silicon, silicon oxide, silicon nitride, silicon carbide, etc. In some embodiments, the substrate layer 204 may be a layer stack disposed on the substrate 202. The wafer 200 further includes a photopatterned metal-containing EUV resist film 206. For example, the photopatterned metal-containing EUV resist film 206 may be an organometal-containing layer disposed on the substrate layer 204 to be etched. The photopatterned metal-containing EUV resist film 206 may have a thickness between about 5 nm and about 50 nm or between about 10 nm and about 30 nm. The photopatterned metal-containing EUV resist film 206 may be provided in a process chamber after photopatterning in an EUV scanner and/or after a PEB treatment. The photopatterned metal-containing EUV resist film 206 includes non-EUV exposed regions 206a and EUV exposed regions 206b.

[0077] As shown in **FIG. 2B**, the non-EUV exposed regions 206a of the photopatterned metal-containing EUV resist film 206 is removed in a development process. The development may use a wet development chemistry or dry development chemistry. Where dry development chemistry

CLAIMS

1. A method for processing a semiconductor substrate, the method comprising:

providing a patterned photoresist on a semiconductor substrate in a process chamber;

thermally dry developing the photopatterned photoresist with a process gas at a first pressure to form a thermally dry developed patterned resist; and

plasma dry developing the thermally dry developed patterned resist with an etchant at a second pressure, wherein thermally dry developing and plasma dry developing occur in the same process chamber, wherein the photopatterned photoresist comprises a metal-containing photoresist.

2. The method of claim 1, wherein the process chamber is transitioned from the first pressure to the second pressure in ten seconds or less.

3. The method of claim 1, wherein the first pressure is from about 200 to 500 mTorr and the second pressure is from about 20 to 50 mTorr.

4. The method of claim 1, wherein the metal-containing photoresist comprises a photopatterned EUV-sensitive organo-metal oxide, a photopatterned EUV-sensitive metal oxide, or an organo-metal-containing thin film EUV resist.

5. The method of claim 4, wherein the photopatterned EUV-sensitive metal oxide comprises tin oxide.

6. The method of claim 1, further comprising:

etching the thermally dry developed patterned resist after plasma dry developing the thermally dry developed patterned resist to form a patterned substrate, wherein the etching is performed in the same process chamber as thermally dry developing and plasma dry developing.

7. The method of claim 6, wherein the process chamber is returned to the first pressure after etching in twenty seconds or less.

8. The method of claim 1, further comprising:

modulating from the first pressure to the second pressure in the process chamber using a throttle valve and/or pump.

9. The method of claim 1, wherein the process gas comprises a halide and the etchant comprises oxygen.

10. The method of claim 1, wherein each of the process gas and the etchant comprises a halide.

11. An apparatus for integrating dry development and plasma dry development, the apparatus comprising:

a process chamber;

one or more pressure-regulating devices;

one or more pumps fluidly coupled with the one or more pressure-regulating devices;

a controller having at least one processor and a memory, wherein the controller is configured with instructions to perform the following operations:

perform thermal dry development at a first pressure in a process chamber;

transition pressure in the same process chamber from the first pressure to the second pressure; and

perform plasma dry development at a second pressure in the same process chamber.

12. The apparatus of claim 11, wherein the controller configured with instructions to transition the pressure in the same process chamber from the first pressure to the second pressure is configured with instructions to transition the pressure in the same process chamber from the first pressure to the second pressure in ten seconds or less.

13. The apparatus of claim 11, wherein the one or more pressure-regulating devices comprises a pressure control valve assembly.

14. The apparatus of claim 11, wherein the one or more pumps comprise a roughing pump and a turbomolecular pump.

15. The apparatus of claim 11, wherein the first pressure is from five to fifty times higher than the second pressure.

16. The apparatus of claim 11, wherein the process chamber comprises a substrate support configured to support a semiconductor substrate in the process chamber, wherein the semiconductor substrate comprises a patterned photoresist, wherein the patterned photoresist is a metal-containing photoresist.

17. The apparatus of claim 11, wherein the controller is further configured with instructions to perform the following operations: maintain one or more process parameters uniformly in the process chamber.

18. The apparatus of claim 17, wherein the one or more process parameters comprise pumping, gas delivery or pumping and gas delivery.

19. The apparatus of claim 11, wherein the controller is further configured with instructions to perform the following operations:

return pressure in the same process chamber from the second pressure back to the first pressure in twenty seconds or less.

20. The apparatus of claim 11, wherein the first pressure is from about 200 to 500 mTorr and the second pressure is from about 20 to 50 mTorr.