Claims

1. A method of processing a substrate, comprising:

positioning the substrate on a substrate support disposed in a process volume of a process chamber;

flowing a process gas comprising a hydrocarbon gas and a diluent gas into the process volume;

maintaining the process volume at a pressure less than 100 mTorr;

forming a plasma of the process gas by applying a first power to a first electrode of the process chamber and applying a second power to a second electrode of the process chamber, wherein the second power is a first pulsed DC power;

maintaining the substrate support at a temperature less than 100 °C;

exposing a surface of the substrate to the plasma; and

depositing an amorphous carbon layer on the surface of the substrate.

2. The method of claim 1, wherein the amorphous carbon layer has a density of more than 1.8 g/cm^3 and has a Young's modulus of more than 150 GPa.

3. The method of claim 1, wherein the amorphous carbon layer has a film stress of less than 500 MPa.

4. The method of claim 1, wherein the hydrocarbon gas comprises one of CH_4, C_2H_2, C_3H_8, C_4H_{10}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10}, or a combination thereof, and wherein a flowrate ratio of the hydrocarbon gas to the diluent gas is between 1:10 and 10:1.

5. The method of claim 4, wherein the pressure is less than 20 mTorr.

6. The method of claim 5, wherein the diluent gas comprises H_2, and wherein a flowrate ratio of H_2 to the hydrocarbon gas is between 0.5:1 and 1:10.

7. The method of claim 1, wherein the first power is an RF AC power between 500 W and 5 kW, with a frequency between 350 kHz and 100 MHz, and wherein the second power is between 200 W and 15 kW and is pulsed at a frequency of 1 kHz.

8. The method of claim 1, wherein the first electrode is disposed in the substrate support and the second electrode is disposed opposite the substrate support and wherein the second electrode is a showerhead.

9. The method of claim 1, wherein the second electrode is disposed in the substrate support and the first electrode is disposed opposite the substrate support.

10. A method of processing a substrate, comprising:

positioning the substrate on a substrate support, the substrate support disposed in a process volume of a process chamber;

flowing a process gas comprising a hydrocarbon gas and a diluent gas into the process volume;

maintaining the process volume at a pressure less than 20 mTorr;

forming a plasma of the process gas by applying an RF AC power to a first electrode of the process chamber, wherein the RF AC power is between 500 W and 5 kW with a frequency between 350 kHz and 100 MHz and applying a first pulsed DC power to a second electrode of the process chamber, the second_electrode disposed in the substrate support, wherein the first pulsed DC power is between 200 W and 15 kW;

maintaining the substrate support at a temperature less than 100 °C;

exposing a surface of the substrate to the plasma; and

depositing an amorphous carbon layer on the surface of the substrate by plasma enhanced chemical vapor deposition.

11. The method of claim 10, wherein the hydrocarbon gas comprises one of CH_4, C_2H_2, C_3H_8, C_4H_{10}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10}, or a combination thereof.

12. The method of claim 11, wherein the diluent gas comprises H_2, and wherein a flowrate ratio of H_2 to the hydrocarbon gas is between 0.5:1 and 1:10.

13. The method of claim 10, wherein the first electrode is disposed opposite the substrate support.

14. The method of claim 9, wherein:

a lid assembly of the process chamber includes a third electrode; and

the method further comprises:

applying a third power to the third electrode, the third power being a second pulsed DC power.

15. The method of claim 13, wherein:

a lid assembly of the process chamber includes a third electrode; and

the method further comprises:

applying a third power to the third electrode, the third power being a second pulsed DC power.

16. A method of processing a substrate, comprising:

positioning the substrate on a substrate support disposed in a process volume of a process chamber;

flowing a process gas comprising a hydrocarbon gas and a diluent gas into the process volume;

maintaining the process volume at a pressure less than 20 mTorr;

forming a plasma of the process gas by applying an RF AC power to a first electrode of the process chamber, wherein the RF AC power is between 500 W and 5 kW with a frequency between 350 kHz and 100 MHz and applying a pulsed DC power to a second electrode of the process chamber, wherein the pulsed DC power is between 200 W and 15 kW;

maintaining the substrate support at a temperature less than 100 °C;

exposing a surface of the substrate to the plasma; and

depositing an amorphous carbon layer on the surface of the substrate.

17. The method of claim 16, wherein the hydrocarbon gas comprises one of CH_4, C_2H_2, C_3H_8, C_4H_{10}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10}, or a combination thereof.

18. The method of claim 17, wherein the diluent gas comprises H_2, and wherein a flowrate ratio of H_2 to the hydrocarbon gas is between 0.5:1 and 1:10.

19. The method of claim 16, wherein the second electrode is disposed in the substrate support and the first electrode is disposed opposite the substrate support.

20. A method for manufacturing a carbon hardmask comprising an amorphous carbon layer on a surface of a substrate, the method comprising:

positioning the substrate on a substrate support disposed in a process volume of a process chamber;

flowing a process gas comprising a hydrocarbon gas and a diluent gas into the process volume;

maintaining the process volume at a pressure less than 100 mTorr;

forming a plasma of the process gas by applying a first power to a first electrode of the process chamber and applying a second power to a second electrode of the process chamber, wherein the second power is a pulsed DC power;

maintaining the substrate support at a temperature less than 200 °C;

exposing a surface of the substrate to the plasma; and

depositing the amorphous carbon layer on the surface of the substrate;

wherein the amorphous carbon layer has a density of more than 1.8 g/cm^3, a Young's modulus of more than 150 GPa, and a film stress of less than 500 MPa.