Claims

1. A microwave plasma reactor for manufacturing synthetic diamond material via chemical vapour deposition, the microwave plasma reactor comprising:

a microwave generator configured to generate microwaves at a frequency f;

a plasma chamber comprising a base, a top plate, and a side wall extending from said base to said top plate defining a resonance cavity for supporting a microwave resonance mode, wherein the resonance cavity has a central rotational axis of symmetry extending from the base to the top plate, and wherein the top plate is mounted across said central rotational axis of symmetry;

a microwave coupling configuration for feeding microwaves from the microwave generator into the plasma chamber;

a gas flow system for feeding process gases into the plasma chamber and removing them therefrom; and

a substrate holder disposed in the plasma chamber and comprising a supporting surface for supporting a substrate on which the synthetic diamond material is to be deposited in use;

wherein the resonance cavity is configured to have a height, as measured from the base to the top plate of the plasma chamber, which supports a TM_{011} resonant mode between the base and the top plate at said frequency f, and

wherein the resonance cavity is further configured to have a diameter, as measured at a height less than 50% of the height of the resonance cavity as measured from the base, which satisfies the condition that a ratio of the resonance cavity height / the resonance cavity diameter is in the range 0.3 to 1.0.

2. A microwave plasma reactor according to any preceding claim, wherein the height of the resonance cavity as measured from the base is selected to support a TM_{011} resonant mode at a microwave frequency f in the range 400 MHz to 500 MHz, 800 MHz to 1000 MHz, or 2300 MHz to 2600 MHz.

3. A microwave plasma reactor according to claim 1 or 2, wherein the ratio of the resonance cavity height / the resonance cavity diameter is in the range 0.4 to 0.9 or 0.5 to 0.8.

4. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity height, as measured from the base to the top plate of the plasma chamber, is in a range:

300 mm to 600 mm, 300 mm to 500 mm, or 400 mm to 500 mm at a microwave frequency f in the range 400 MHz to 500 MHz;

150 mm to 300 mm, 150 mm to 250 mm, or 200 mm to 250 mm at a microwave frequency f in the range 800 MHz to 1000 MHz; or

50 mm to 110 mm, 50 mm to 90 mm, or 70 mm to 90 mm at a microwave frequency f in the range 2300 MHz to 2600 MHz.

5. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity diameter is in the range:

400 mm to 1000 mm, 500 mm to 900 mm, or 600 mm to 800 mm at a microwave frequency f in the range 400 MHz to 500 MHz;

200 mm to 500 mm, 250 mm to 450 mm, or 300 mm to 400 mm at a microwave frequency f in the range 800 MHz to 1000 MHz; or

70 mm to 180 mm, 90 mm to 160 mm, or 110 mm to 150 mm at a microwave frequency f in the range 2300 MHz to 2600 MHz.

6. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity has a volume in a range:

0.018 m^3 to 0.530 m^3, 0.062 m^3 to 0.350 m^3, 0.089 m^3 to 0.270 m^3, or 0.133 m^3 to 0.221 m^3 at a microwave frequency f in the range 400 to 500 MHz;

0.002 m^3 to 0.06 m^3, 0.007 m^3 to 0.04 m^3, 0.01 m^3 to 0.03 m^3, or 0.015 m^3 to 0.025 m^3 at a microwave frequency f in the range 800 MHz to 1000 MHz; or

9.8×10^{-5} m^3 to 2.9×10^{-3} m^3, 3.4×10^{-4} m^3 to 1.96×10^{-3} m^3, 4.9×10^{-4} m^3 to 1.47×10^{-3} m^3, or 7.35×10^{-4} m^3 to 1.23×10^{-3} m^3 at a microwave frequency f in the range 2300 to 2600 MHz.

7. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity is cylindrical.

8. A microwave plasma reactor according to any one of claims 1 to 6, wherein an upper portion of the resonance cavity has a larger diameter than a lower portion of the resonance cavity, the upper portion of the resonance cavity being configured to support at least one secondary microwave mode which at least partially eliminates a high electric-field anti-node in the upper portion of the resonance cavity in use.

9. A microwave plasma reactor according to claim 8, wherein a ratio of a lower diameter / an upper diameter of the resonance cavity is greater than 0.4 and less than 1, wherein the lower diameter is measured at a height less than 50% of the height of the resonance cavity as measured from the base and the upper diameter is measured at a height greater than 50% of the height of the resonance cavity as measured from the base.

10. A microwave plasma reactor according to claim 9, wherein said ratio is in a range 0.5 to 0.9, 0.6 to 0.9, or 0.7 to 0.8.

11. A microwave plasma reactor according to claim 9 or 10, wherein:

at a microwave frequency f in the range 400 to 500 MHz the lower diameter lies in a range 400 mm to 900 mm, 500 mm to 900 mm, 600 mm to 800 mm, or 650 mm to 800 mm, and the upper diameter may lie in a range 600 mm to 1000 mm, 700 mm to 1000 mm, 700 mm to 900 mm, or 800 mm to 900 mm;

at a microwave frequency f in the range 800 MHz to 1000 MHz the lower diameter lies in a range 200 mm to 450 mm, 250 mm to 450 mm, 300 mm to 400 mm, or 330 mm to 400 mm, and the upper diameter lies in a range 300 mm to 500 mm, 350 mm to 500 mm, 350 mm to 450 mm, or 400 mm to 450mm; or

at a microwave frequency f in the range 2300 to 2600 MHz the lower diameter lies in a range 70 mm to 160 mm, 90 mm to 160 mm, 100 mm to 150 mm, or 120 mm to 150 mm, and the upper diameter may lie in a range 100 mm to 200 mm, 120 mm to 200 mm, 130 mm to 170 mm, or 150 mm to 170 mm.

12. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity comprises internal walls configured to be exposed to a plasma formed within the resonance cavity in use, said internal walls comprising metallic

surfaces forming at least 75%, 80%, 85%, 90% or 95% of a total surface area of said internal walls within the resonance cavity.

13. A microwave plasma reactor according to claim 12, wherein said metallic surfaces are made of aluminium or an alloy thereof comprising at least 80%, 90%, 95%, or 98% by weight of aluminium.

14. A microwave plasma reactor according to claim 12 or 13, wherein a portion of said internal walls is formed by an annular dielectric window, formed in one or several sections, said annular dielectric window forming no more than 25%, 20%, 15%, 10%, or 5% of the total surface area of the internal walls within the resonance cavity.

15. A microwave plasma reactor according to any preceding claim, wherein the microwave plasma reactor further comprises an electrically conductive surface located within the plasma chamber over a high electric field anti-node region which would exist in a corresponding plasma chamber which did not comprise the conductive surface.

16. A microwave plasma reactor according to claim 15, wherein the conductive surface is cone-shaped.

17. A microwave plasma reactor according to claim 16, wherein the cone-shaped conductive surface comprises a rounded tip.

18. A microwave plasma reactor according to claim 16 or 17, wherein the cone-shaped conductive surface forms an annular recess in the plasma chamber and an annular dielectric window is disposed in said recess.

19. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity is configured to have a Q factor not more than 1000, 500, 200, 100, 80, 50, 30, or 20 in use.

20. A microwave plasma reactor according to any preceding claim, wherein the microwave coupling configuration is arranged to inductively couple microwaves into the plasma chamber.

21. A microwave plasma reactor according to any preceding claim, wherein the gas flow system comprises one or more inlet nozzles disposed opposite the substrate holder for injecting process gas towards the substrate in use.

22. A microwave plasma reactor for manufacturing synthetic diamond material via chemical vapour deposition, the microwave plasma reactor comprising:

a plasma chamber comprising a base, a top plate, and a side wall extending from said base to said top plate defining a resonance cavity for supporting a microwave resonance mode, wherein the resonance cavity has a central rotational axis of symmetry extending from the base to the top plate, and wherein the top plate is mounted across said central rotational axis of symmetry;

a microwave coupling configuration for feeding microwaves from a microwave generator into the plasma chamber;

a gas flow system for feeding process gases into the plasma chamber and removing them therefrom; and

a substrate holder disposed in the plasma chamber and comprising a supporting surface for supporting a substrate on which the synthetic diamond material is to be deposited in use;

wherein the resonance cavity is configured to have a height, as measured from the base to the top plate of the plasma chamber, which supports a TM_{011} resonant mode between the base and the top plate at a frequency in the range 400 to 500 MHz, 800 to 1000 MHz, or 2300 MHz to 2600Mz, and

wherein the resonance cavity is further configured to have a diameter, as measured at a height less than 50% of the height of the resonance cavity as measured from the base, which satisfies the condition that a ratio of the resonance cavity height / the resonance cavity diameter is in the range 0.3 to 1.0.

23. A method of manufacturing synthetic diamond material using a chemical vapour deposition process, the method comprising:

providing a microwave plasma reactor according to any preceding claim;

locating a substrate over the substrate holder;

feeding microwaves into the plasma chamber;

feeding process gases into the plasma chamber; and

forming synthetic diamond material on the substrate.

24. A method according to claim 23, wherein a ratio of a resonance cavity diameter / substrate diameter is in the range 1.5 to 5, 2.0 to 4.5, or 2.5 to 4.0, wherein the resonance cavity diameter is measured at a height less than 50%, 40%, 30%, or 20% of a height of the resonance cavity.

25. A method according to claim 24, wherein the substrate diameter is in the range:

165 mm to 415 mm, 185 mm to 375 mm, 205 mm to 375 mm, 205 mm to 330 mm, or 240 mm to 330 mm for a microwave frequency f in the range 400 to 500 MHz;

80 mm to 200 mm, 90 mm to 180 mm, 100 mm to 180 mm, 100 mm to 160, or 115 mm to 160 mm for a microwave frequency f in the range 800 to 1000 MHz; or

30 mm to 75 mm, 33 mm to 65 mm, 37 mm to 65 mm, 37 mm to 58 mm, or 42 mm to 58 mm for a microwave frequency f in the range 2300 to 2600 MHz.

26. A method according to any one of claims 23 to 25, wherein the microwave plasma reactor is inverted whereby a base of the plasma chamber supporting the substrate forms an upper wall of the plasma chamber relative to earth.

Claims

1. A microwave plasma reactor for manufacturing synthetic diamond material via chemical vapour deposition, the microwave plasma reactor comprising:

a plasma chamber comprising a base, a top plate, and a side wall extending from said base to said top plate defining a resonance cavity for supporting a microwave resonance mode, wherein the resonance cavity has a central rotational axis of symmetry extending from the base to the top plate, and wherein the top plate is mounted across said central rotational axis of symmetry;

a microwave coupling configuration for feeding microwaves from a microwave generator into the plasma chamber;

a gas flow system for feeding process gases into the plasma chamber and removing them therefrom; and

a substrate holder disposed in the plasma chamber and comprising a supporting surface for supporting a substrate on which the synthetic diamond material is to be deposited in use;

wherein the resonance cavity is configured to have a height, as measured from the base to the top plate of the plasma chamber, which supports a TM_{011} resonant mode between the base and the top plate at a frequency in the range 400 to 500 MHz, 800 to 1000 MHz, or 2300 MHz to 2600Mz,

wherein the resonance cavity is further configured to have a diameter, as measured at a height less than 50% of the height of the resonance cavity as measured from the base, which satisfies the condition that a ratio of the resonance cavity height / the resonance cavity diameter is in the range 0.3 to 1.0,

wherein the resonance cavity comprises internal walls configured to be exposed to a plasma formed within the resonance cavity in use, said internal walls comprising metallic surfaces forming at least 75% of a total surface area of said internal walls within the resonance cavity, and

wherein a portion of said internal walls is formed by an annular dielectric window, formed in one or several sections, said annular dielectric window forming no more than 25% of the total surface area of the internal walls within the resonance cavity.

2. A microwave plasma reactor according to claim 1, wherein the ratio of the resonance cavity height / the resonance cavity diameter is in the range 0.4 to 0.9 or 0.5 to 0.8.

3. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity height, as measured from the base to the top plate of the plasma chamber, is in a range:

300 mm to 600 mm, 300 mm to 500 mm, or 400 mm to 500 mm at a microwave frequency f in the range 400 MHz to 500 MHz;

150 mm to 300 mm, 150 mm to 250 mm, or 200 mm to 250 mm at a microwave frequency f in the range 800 MHz to 1000 MHz; or

50 mm to 110 mm, 50 mm to 90 mm, or 70 mm to 90 mm at a microwave frequency f in the range 2300 MHz to 2600 MHz.

4. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity diameter is in the range:

400 mm to 1000 mm, 500 mm to 900 mm, or 600 mm to 800 mm at a microwave frequency f in the range 400 MHz to 500 MHz;

200 mm to 500 mm, 250 mm to 450 mm, or 300 mm to 400 mm at a microwave frequency f in the range 800 MHz to 1000 MHz; or

70 mm to 180 mm, 90 mm to 160 mm, or 110 mm to 150 mm at a microwave frequency f in the range 2300 MHz to 2600 MHz.

5. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity has a volume in a range:

0.018 m^3 to 0.530 m^3, 0.062 m^3 to 0.350 m^3, 0.089 m^3 to 0.270 m^3, or 0.133 m^3 to 0.221 m^3 at a microwave frequency f in the range 400 to 500 MHz;

0.002 m^3 to 0.06 m^3, 0.007 m^3 to 0.04 m^3, 0.01 m^3 to 0.03 m^3, or 0.015 m^3 to 0.025 m^3 at a microwave frequency f in the range 800 MHz to 1000 MHz; or

9.8×10^{-5} m^3 to 2.9×10^{-3} m^3, 3.4×10^{-4} m^3 to 1.96×10^{-3} m^3, 4.9×10^{-4} m^3 to 1.47×10^{-3} m^3, or 7.35×10^{-4} m^3 to 1.23×10^{-3} m^3 at a microwave frequency f in the range 2300 to 2600 MHz.

6. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity is cylindrical.

7. A microwave plasma reactor according to any one of claims 1 to 5, wherein an upper portion of the resonance cavity has a larger diameter than a lower portion of the resonance cavity, the upper portion of the resonance cavity being configured to support at least one secondary microwave mode which at least partially eliminates a high electric-field anti-node in the upper portion of the resonance cavity in use.

8. A microwave plasma reactor according to claim 7, wherein a ratio of a lower diameter / an upper diameter of the resonance cavity is greater than 0.4 and less than 1, wherein the lower diameter is measured at a height less than 50% of the height of the resonance cavity as measured from the base and the upper diameter is measured at a height greater than 50% of the height of the resonance cavity as measured from the base.

9. A microwave plasma reactor according to claim 8, wherein said ratio is in a range 0.5 to 0.9, 0.6 to 0.9, or 0.7 to 0.8.

10. A microwave plasma reactor according to claim 8 or 9, wherein:

at a microwave frequency f in the range 400 to 500 MHz the lower diameter lies in a range 400 mm to 900 mm, 500 mm to 900 mm, 600 mm to 800 mm, or 650 mm to 800 mm, and the upper diameter may lie in a range 600 mm to 1000 mm, 700 mm to 1000 mm, 700 mm to 900 mm, or 800 mm to 900 mm;

at a microwave frequency f in the range 800 MHz to 1000 MHz the lower diameter lies in a range 200 mm to 450 mm, 250 mm to 450 mm, 300 mm to 400 mm, or 330 mm to 400 mm, and the upper diameter lies in a range 300 mm to 500 mm, 350 mm to 500 mm, 350 mm to 450 mm, or 400 mm to 450mm; or

at a microwave frequency f in the range 2300 to 2600 MHz the lower diameter lies in a range 70 mm to 160 mm, 90 mm to 160 mm, 100 mm to 150 mm, or 120 mm to 150 mm, and the upper diameter may lie in a range 100 mm to 200 mm, 120 mm to 200 mm, 130 mm to 170 mm, or 150 mm to 170 mm.

11. A microwave plasma reactor according to any preceding claim, wherein the metallic surfaces of the internal walls of the resonance cavity form at least 80%, 85%, 90% or 95% of the total surface area of said internal walls within the resonance cavity.

12. A microwave plasma reactor according to claim 11, wherein said metallic surfaces are made of aluminium or an alloy thereof comprising at least 80%, 90%, 95%, or 98% by weight of aluminium.

13. A microwave plasma reactor according to any preceding claim, wherein the annular dielectric window forms no more than 20%, 15%, 10%, or 5% of the total surface area of the internal walls within the resonance cavity.

14. A microwave plasma reactor according to any preceding claim, wherein the microwave plasma reactor further comprises an electrically conductive surface located within the plasma chamber over a high electric field anti-node region which would exist in a corresponding plasma chamber which did not comprise the conductive surface.

15. A microwave plasma reactor according to claim 14, wherein the conductive surface is cone-shaped.

16. A microwave plasma reactor according to claim 15, wherein the cone-shaped conductive surface comprises a rounded tip.

17. A microwave plasma reactor according to claim 15 or 16, wherein the cone-shaped conductive surface forms an annular recess in the plasma chamber and an annular dielectric window is disposed in said recess.

18. A microwave plasma reactor according to any preceding claim, wherein the resonance cavity is configured to have a Q factor not more than 1000, 500, 200, 100, 80, 50, 30, or 20 in use.

19. A microwave plasma reactor according to any preceding claim, wherein the microwave coupling configuration is arranged to inductively couple microwaves into the plasma chamber.

20. A microwave plasma reactor according to any preceding claim, wherein the gas flow system comprises one or more inlet nozzles disposed opposite the substrate holder for injecting process gas towards the substrate in use.

21. A method of manufacturing synthetic diamond material using a chemical vapour deposition process, the method comprising:

providing a microwave plasma reactor according to any preceding claim;

locating a substrate over the substrate holder;

feeding microwaves into the plasma chamber;

feeding process gases into the plasma chamber; and

forming synthetic diamond material on the substrate.

22. A method according to claim 21, wherein a ratio of a resonance cavity diameter / substrate diameter is in the range 1.5 to 5, 2.0 to 4.5, or 2.5 to 4.0, wherein the resonance cavity diameter is measured at a height less than 50%, 40%, 30%, or 20% of a height of the resonance cavity.

23. A method according to claim 22, wherein the substrate diameter is in the range:

165 mm to 415 mm, 185 mm to 375 mm, 205 mm to 375 mm, 205 mm to 330 mm, or 240 mm to 330 mm for a microwave frequency f in the range 400 to 500 MHz;

80 mm to 200 mm, 90 mm to 180 mm, 100 mm to 180 mm, 100 mm to 160, or 115 mm to 160 mm for a microwave frequency f in the range 800 to 1000 MHz; or

30 mm to 75 mm, 33 mm to 65 mm, 37 mm to 65 mm, 37 mm to 58 mm, or 42 mm to 58 mm for a microwave frequency f in the range 2300 to 2600 MHz.

24. A method according to any one of claims 21 to 23, wherein the microwave plasma reactor is inverted whereby a base of the plasma chamber supporting the substrate forms an upper wall of the plasma chamber relative to earth.