Claims

1. A microwave power delivery system for supplying microwave power to a plurality of microwave plasma reactors, the microwave power delivery system comprising:

a tuner configured to be coupled to a microwave source and configured to match impedance of the plurality of microwave plasma reactors to that of the microwave source; and

a waveguide junction coupled to the tuner and configured to guide microwaves to and from the plurality of microwave plasma reactors,

wherein the waveguide junction comprises four waveguide ports including a first port coupled to the tuner, second and third ports configured to be coupled to respective microwave plasma reactors, and a fourth port coupled to a microwave sink,

wherein the waveguide junction is configured to evenly split microwave power input from the tuner through the first port between the second and third ports for providing microwave power to respective microwave plasma reactors,

wherein the waveguide junction is configured to decouple the second and third ports thereby preventing any reflected microwaves from one of the microwave plasma reactors from feeding across the waveguide junction directly into another microwave plasma reactor causing an imbalance,

wherein the waveguide junction is further configured to feed reflected microwaves received back through the second and third ports which are balanced in terms of magnitude and phase to the tuner such that they can be reflected by the tuner and re-used, and

wherein the waveguide junction is further configured to feed excess reflected power which is not balanced through the fourth port into the microwave sink.

2. A microwave power delivery system according to claim 1, further comprising a microwave isolator for coupling the tuner to the microwave source.

3. A microwave power delivery system according to claim 1 or 2, wherein the tuner is a stub tuner.

4. A microwave power delivery system according to claim 3, wherein the stub tuner comprises a plurality of stubs.

5. A microwave power delivery system according to claim 4, wherein the plurality of stubs are separated by a quarter guided wavelength.

6. A microwave power delivery system according to claim 4 or 5, wherein the stub tuner is a three stub tuner.

7. A microwave power delivery system according to any preceding claim, wherein the waveguide junction is one of a hybrid tee junction, a hybrid ring junction, and a two-hole directional coupler.

8. A microwave power delivery system according to any preceding claim, wherein the first, second, third and fourth ports are formed by rectangular waveguides.

9. A microwave power delivery system according to any preceding claim, wherein the waveguide junction is a hybrid tee junction in which the first, second and third ports lie in a plane with the first port disposed at a 90° angle relative to the second and third ports which are disposed in a straight line, and wherein the fourth port is coupled at a junction between the first, second and third ports and lies in a plane perpendicular to the first, second and third ports.

10. A microwave power delivery system according to any preceding claim, wherein the waveguide junction is configured to decouple the second and third ports when operating within a frequency band width in the range 400 MHz to 500 MHz, 800 MHz to 1000 MHz, or 2300 MHz to 2600 MHz.

11. A microwave power delivery system according to any preceding claim, wherein the second and third ports are equal in length or have a difference in length which is a multiple of $\frac{1}{2}\ \lambda_g$, where λ_g is an operating guided wavelength for the waveguide junction.

12. A microwave power delivery system according to claim 11, wherein the lengths of the second and third ports are configured to a design tolerance within 10 mm, 5 mm, 3 mm, 1mm, 0.5 mm, or 0.1 mm and/or within 4%, 2%, 1%, 0.5%, 0.2%, 0.1% or 0.06% of a target port length.

13. A microwave power delivery system according to any preceding claim, further comprising a power measuring device configured to measure the magnitude of reflected power back to the microwave source.

14. A microwave power delivery system according to any preceding claim, wherein the system comprises a plurality of said waveguide junctions.

15. A microwave power delivery system according to any preceding claim, wherein the second and third ports are coupled to respective coaxial waveguides for providing microwave power to respective microwave plasma reactors.

16. A microwave power delivery system according to claim 15, wherein each coaxial waveguide comprises a floating post central conductor.

17. A microwave plasma reactor system comprising:

a microwave source;

a microwave power delivery system according to any preceding claim coupled to the microwave source; and

a plurality of microwave plasma reactors coupled to the microwave power delivery system.

18. A microwave plasma reactor system according to claim 17, wherein the microwave source is configured to generate a power equal to or greater than a sum of operating powers of the plurality of microwave plasma reactors coupled to the microwave source.

19. A microwave plasma reactor system according to claim 18, wherein available power from the microwave source exceeds the sum of the operating powers of the

plurality of microwave plasma reactors coupled to the microwave source by no more than 50%, 40%, 30%, 20%, 10% or 5%.

20. A microwave plasma reactor system according to any one of claims 17 to 19, wherein the microwave source is configured to generate microwaves at a frequency in the range 400 to 500 MHz, 800 to 1000 MHz, or 2300 to 2600 MHz.

21. A microwave plasma reactor system according to any one of claims 17 to 20, wherein each microwave plasma reactor comprises a resonance cavity having 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 for an operating frequency of 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 for an operating frequency 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 for an operating frequency of 2300 to 2600 MHz.

22. A microwave plasma reactor system according to any one of claims 17 to 21, wherein each microwave plasma reactor coupled to the microwave delivery system has a Q factor resonance cavity equal to or less than 1000, 500, 200, 100, 80, 50, 30, or 20 in use.

23. A microwave plasma reactor system according to any one of claims 17 to 22, wherein each microwave plasma reactor is coupled to the waveguide junction of the microwave power delivery system via a coaxial waveguide.

24. A microwave plasma reactor system according to any one of claims 17 to 23, wherein two or four microwave plasma reactors are coupled to the microwave power delivery system.

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

providing a microwave plasma reactor system according to any one of claims 17 to 24; and

forming synthetic diamond material using said microwave plasma reactor system.

26. A method according to claim 25, wherein power is delivered equally to each of the plurality of microwave plasma reactors within ±25%, 20%, 15%, 10%, or 5% of a mean power delivered to each microwave plasma reactor.

27. A method according to claim 25 or claim 26, wherein power delivered to each of the plurality of microwave plasma reactors is stable within ±10%, 8%, 6%, 4%, or 2% of a mean power delivered to each microwave plasma reactor over a time period equal to or greater than 1 hour, 2 hours, 5 hours, 10 hours, 15 hours, 24 hours, 48 hours, 7 days, 14 days, 21 days, or 28 days.

28. A method according to any one of claims 25 to 27, wherein power absorbed by the microwave sink connected to the waveguide junction is equal to or less than 5 kW, 3 kW, 1kW, or 0.5 kW.

Claims

1. A microwave power delivery system for supplying microwave power to a plurality of microwave plasma reactors, the microwave power delivery system comprising:

a tuner configured to be coupled to a microwave source and configured to match impedance of the plurality of microwave plasma reactors to that of the microwave source; and

a waveguide junction coupled to the tuner and configured to guide microwaves to and from the plurality of microwave plasma reactors,

wherein the waveguide junction comprises four waveguide ports including a first port coupled to the tuner, second and third ports configured to be coupled to respective microwave plasma reactors, and a fourth port coupled to a microwave sink,

wherein the waveguide junction is configured to evenly split microwave power input from the tuner through the first port between the second and third ports for providing microwave power to respective microwave plasma reactors,

wherein the waveguide junction is configured to decouple the second and third ports thereby preventing any reflected microwaves from one of the microwave plasma reactors from feeding across the waveguide junction directly into another microwave plasma reactor causing an imbalance,

wherein the waveguide junction is further configured to feed reflected microwaves received back through the second and third ports which are balanced in terms of magnitude and phase to the tuner such that they can be reflected by the tuner and re-used, and

wherein the waveguide junction is further configured to feed excess reflected power which is not balanced through the fourth port into the microwave sink.

2. A microwave power delivery system according to claim 1, further comprising a microwave isolator for coupling the tuner to the microwave source.

3. A microwave power delivery system according to claim 1 or 2, wherein the tuner is a stub tuner.

4. A microwave power delivery system according to claim 3, wherein the stub tuner comprises a plurality of stubs.

5. A microwave power delivery system according to claim 4, wherein the plurality of stubs are separated by a quarter guided wavelength.

6. A microwave power delivery system according to any preceding claim, wherein the waveguide junction is one of a hybrid tee junction, a hybrid ring junction, and a two-hole directional coupler.

7. A microwave power delivery system according to any preceding claim, wherein the first, second, third and fourth ports are formed by rectangular waveguides.

8. A microwave power delivery system according to any preceding claim, wherein the waveguide junction is a hybrid tee junction in which the first, second and third ports lie in a plane with the first port disposed at a 90° angle relative to the second and third ports which are disposed in a straight line, and wherein the fourth port is coupled at a junction between the first, second and third ports and lies in a plane perpendicular to the first, second and third ports.

9. A microwave power delivery system according to any preceding claim, wherein the waveguide junction is configured to decouple the second and third ports when operating within a frequency band width in the range 400 MHz to 500 MHz, 800 MHz to 1000 MHz, or 2300 MHz to 2600 MHz.

10. A microwave power delivery system according to any preceding claim, wherein the second and third ports are equal in length or have a difference in length which is a multiple of $\frac{1}{2}\ \lambda_g$, where λ_g is an operating guided wavelength for the waveguide junction.

11. A microwave power delivery system according to claim 10, wherein the lengths of the second and third ports are configured to a design tolerance within 10

mm, 5 mm, 3 mm, 1mm, 0.5 mm, or 0.1 mm and/or within 4%, 2%, 1%, 0.5%, 0.2%, 0.1% or 0.06% of a target port length.

12. A microwave power delivery system according to any preceding claim, further comprising a power measuring device configured to measure the magnitude of reflected power back to the microwave source.

13. A microwave power delivery system according to any preceding claim, wherein the system comprises a plurality of said waveguide junctions.

14. A microwave power delivery system according to any preceding claim, wherein the second and third ports are coupled to respective coaxial waveguides for providing microwave power to respective microwave plasma reactors.

15. A microwave power delivery system according to claim 14, wherein each coaxial waveguide comprises a floating post central conductor.