the other stations. This requires the auto-match circuits for the stations to have larger tuning ranges to compensate for this loading imbalance of the stations.

[0057] The examples set forth herein overcome the disadvantages described above and provide substrate processing systems including RF distribution circuits including one or more transformers and/or transformer coupled combiners. The transformers and/or transformer coupled combiners minimize input impedance variation as a result of changes in load impedances. Some of the disclosed RF distribution circuits include efficient combiner circuits. As used herein a “combiner circuit” combines two or more RF signals into a single RF signal.

[0058] The RF distribution circuits provide station-to-load, station-to-station and input-to-output isolation to minimize effects on certain stations due to a variation in load impedance at another station. The RF distribution circuits provide self-sustaining systems that: exhibit decreased sensitivity to load impedance variation; allow for a broad range of recipes for substrate processing with a large range of corresponding load impedances; experience minimal input impedance variation due to loading and unloading of substrates in and out of a processing chamber; and allow for each leg (or RF signal path to each station) to be at or near resonance for fast and smooth ignition associated with plasma generation. In certain embodiments, the RF combiner and distribution circuits combine two or more RF frequency signals and supply signals having two or more frequencies to one or more stations. The RF distribution circuits allow for impedance matching for both LF and HF signals. Other advantages and aspects of the RF distribution circuits set forth herein are further described below.

[0059] FIG. 2 is a functional block diagram of an example of a substrate processing system 200 incorporating a RF distribution circuit 201 including a transformer 202. The RF distribution circuit 201 may be configured the same or similarly as any of the RF distribution circuits disclosed herein. The transformer 202 may be configured as any transformer and/or transformer coupled combiner disclosed herein. Although FIG. 2 shows a capacitive coupled plasma (CCP) system, the embodiments disclosed herein are applicable to other plasma processing systems. The embodiments are applicable to deposition, etch, and other substrate treatment processes including plasma enhanced atomic layer deposition (PEALD) and plasma enhanced chemical vapor deposition (PECVD) processes.

[0064] A gas delivery system 230 includes one or more gas sources 232-1, 232-2,…, and 232-N (collectively gas sources 232), where N is an integer greater than zero. The gas sources 232 supply one or more precursors and gas mixtures thereof. The gas sources 232 may also supply etch gas, carrier gas and/or purge gas. Vaporized precursor may also be used. The gas sources 232 are connected by valves 234-1, 234-2, …, and 234-N (collectively valves 234) and mass flow controllers 236-1, 236-2, …, and 236-N (collectively mass flow controllers 236) to a manifold 240. An output of the manifold 240 is fed to the processing chamber 204. For example only, the output of the manifold 240 is fed to the showerhead 210.

[0065] The substrate processing system 200 further includes a cooling system 241 that includes a temperature controller 242, which may be connected to the TCEs. Although shown separately from a system controller 260, the temperature controller 242 may be implemented as part of the system controller 260. One or more of the plates 206, 207 may include multiple temperature controlled zones (e.g., 4 zones, where each of the zones includes 4 temperature sensors).

[0066] The temperature controller 242 may control operation and thus temperatures of the TCEs to control temperatures of the plates 206, 207 and a substrate (e.g., the substrate 209). The temperature controller 242 and/or the system controller 260 may control flow rate of backside gas (e.g., helium) to the gas channels in the ESC 204 for cooling the substrate by controlling flow from one or more of the gas sources 232 to the gas channels. The temperature controller 242 may also communicate with a coolant assembly 246 to control flow of a first coolant (pressures and flow rates of a cooling fluid) through channels in the ESC 204. The first coolant assembly 246 may receive a cooling fluid from a reservoir (not shown). For example, the coolant assembly 246 may include a coolant pump and reservoir. The temperature controller 242 operates the coolant assembly 246 to flow the coolant through the channels 216 to cool the baseplate 207. The temperature controller 242 may control the rate at which the coolant flows and a temperature of the coolant. The temperature controller 242 controls current supplied to the TCEs and pressure and flow rates of gas and/or coolant supplied to channels based on detected parameters from sensors 243 within the processing chamber 205. The temperature sensors 243 may include resistive temperature devices, thermocouples, digital temperature sensors, and/or other suitable temperature sensors. During an etch process, the substrate 209 may be heated up by a predetermined temperature (e.g., 120 degrees Celsius (˚C)) in presence of high-power plasma. Flow of

channels, where n is an integer greater than or equal to two. The outputs of the n channels are isolated from each other, such that change in one of the channels does not affect or minimally affects change in the other channels. The inputs of the channels are isolated from the input of the transformer 712. The RF combiner circuits provide fast and smooth ignition for plasma generation.

[0092] The Examples of FIGs. 3, 5, and 7 are configured such that each of the RF distribution circuits 300, 500, 700 may be used for multiple different substrate processes. The processes may include etching, depositing and/or other substrate treatment processes.

[0093] FIG. 8 shows a side view of an example transformer 800 that may be used for a high-frequency RF signal in a RF distribution circuit. As an example, the transformers 308, 512 of FIGs. 3 and 5 may each be replaced with the transformer 800. The transformer 800 is a coaxial transformer and may include a primary coil 802 and a secondary coil 804. The primary coil 802 includes (i) conductive shields 822, 832 of two coaxial cables 806, 810, and (ii) a conductive interconnector 808. The conductive interconnector 808 extends through non-conductive sheaths 820, 830 of the coaxial cables 806, 810 and is connected to the conductive shields 822, 832. The conductive interconnector may be a conductive plate, or other suitable interconnector that maintains position of the second coaxial cable 810 relative to the first coaxial cable 806.

[0094] The coaxial cables 806, 810 extend parallel to each other and further include conductive cores 825, 835 that are isolated from the conductive shields 822, 832 by inner dielectric insulators 824, 834. The conductive cores 825, 835 are connected in a series loop by conductive lines 826A, 826B. The conductive line 826A connects a first end of the first coaxial cable 806 to a first end of the second coaxial cable 810. The first end of the second coaxial cable 810 is at an opposite end of the conductive interconnector 808 than the first end of the first coaxial cable 806. The conductive line 826B connects a second end of the first coaxial cable 806 to a second end of the second coaxial cable 810. The second end of the second coaxial cable 810 is at an opposite end of the conductive interconnector 808 than the second end of the first coaxial cable 806.

[0095] As an example, the conductive shields 822, 832, the conductive cores 825, 835, and the conductive lines 826A, 826B may be formed of copper and/or other suitable material that exhibits a minimal amount of heating during use. The non-

CLAIMS

1. A transformer comprising:

a primary coil comprising

a first shield of a first coaxial cable,

a second shield of a second coaxial cable, and

a conductive interconnector connecting the first shield to the second shield; and

a secondary coil comprising

a first core of the first coaxial cable,

a second core of the second coaxial cable, and

a pair of conductive lines connecting the first core to the second core.

2. The transformer of claim 1, wherein the first coaxial cable extends parallel to the second coaxial cable.

3. The transformer of claim 1, wherein a sum of lengths of the first core, the second core and the pair of conductive lines is at least one of based or equal to a multiple of a length of each of the first coaxial cable and the second coaxial cable.

4. The transformer of claim 1, wherein a length of each of the first coaxial cable and the second coaxial cable is at least one of based on or equal to a fraction multiple of a wavelength of a radio frequency signal transmitted by the transformer.

5. A radio frequency distribution circuit comprising:

a radio frequency generator to generate a first radio frequency signal including a frequency component at a radio frequency; and

the transformer of claim 1, wherein the transformer is to convert the first radio frequency signal to a second radio frequency signal, the second radio frequency signal includes a frequency component at the radio frequency.

6. A substrate processing system comprising:

the radio frequency distribution circuit of claim 5;

a process chamber;

a showerhead comprising an electrode and implemented in the process chamber; and

a substrate support implemented in the process chamber adjacent the showerhead,

wherein the transformer is to supply the second radio frequency signal to the electrode.

7. A radio frequency distribution circuit comprising:

a first filter to receive a first radio frequency signal and a second radio frequency signal from at least one radio frequency generator and filter out the first radio frequency signal, the first radio frequency signal is at a first frequency and the second radio frequency signal is at a second frequency, and the second frequency is less than the first frequency;

a second filter to receive the first radio frequency signal and the second radio frequency signal from the at least one radio frequency generator and filter out the first radio frequency signal;

a first match network to match an output of the at least one radio frequency generator to an input of the first filter;

a second match network to match an output of the at least one radio frequency generator to an input of the second filter; and

a transformer coupled combiner to convert the first radio frequency signal to a third radio frequency signal, convert the second radio frequency signal to a fourth radio frequency signal, and combine either the first radio frequency signal with the second radio frequency signal or the third radio frequency signal with the fourth radio frequency signal, the third radio frequency signal includes a frequency component at the first frequency, and the fourth radio frequency signal includes a frequency component at the second frequency.

8. The radio frequency distribution circuit of claim 7, wherein the transformer coupled combiner comprises:

a first transformer to receive an output of the first filter; and

a second transformer to receive an output of the second filter.

9. The radio frequency distribution circuit of claim 8, wherein:

the first transformer comprises

a primary coil connected to the first filter, and

a secondary coil; and

the second transformer comprises

a primary coil connected to the second filter and the primary coil of the first transformer, and

a secondary coil connected to the secondary coil of the first transformer.

10. The radio frequency distribution circuit of claim 9, wherein:

the primary coil and the secondary coil of the first transformer are connected to a ground reference, and

the primary coil and the secondary coil of the second transformer are connected to the ground reference.

11. The radio frequency distribution circuit of claim 9, wherein the first transformer comprises:

the primary coil comprising

a first shield of a first coaxial cable,

a second shield of a second coaxial cable, and

a conductive interconnector connecting the first shield to the second shield; and

the secondary coil comprising

a first core of the first coaxial cable,

a second core of the second coaxial cable, and

a pair of conductive lines connecting the first core to the second core.

12. The radio frequency distribution circuit of claim 11, wherein the first coaxial cable extends parallel to the second coaxial cable.

13. The radio frequency distribution circuit of claim 11, wherein a sum of lengths of the first core, the second core and the pair of conductive lines is at least one of based on or equal to a multiple of a length of each of the first coaxial cable and the second coaxial cable.

14. The radio frequency distribution circuit of claim 11, wherein a length of each of the first coaxial cable and the second coaxial cable is at least one of based on or equal to a fraction multiple of a wavelength of the first radio frequency signal.

15. The radio frequency distribution circuit of claim 7, wherein:

the transformer coupled combiner comprises a first transformer; and

the first transformer comprises

a first primary coil connected to the first filter,

a second primary coil connected to the second filter,

a first secondary coil connected to receive the third radio frequency signal, and

a second secondary coil connected to receive the fourth radio frequency signal.

16. The radio frequency distribution circuit of claim 15, wherein:

the first transformer comprises a third secondary coil;

the third secondary coil is to receive a fifth radio frequency signal; and

the fifth radio frequency signal includes a frequency component at the first frequency and a frequency component at the second frequency.

17. The radio frequency distribution circuit of claim 7, wherein the transformer coupled combiner comprises:

a first primary coil connected to the first filter;

a second primary coil connected to the second filter;

a first secondary coil outputting the third radio frequency signal, the third radio frequency signal includes frequency components respectively at the first frequency and the second frequency; and

a second secondary coil outputting the fourth radio frequency signal, the fourth radio frequency signal includes frequency components respectively at the first frequency and the second frequency.

18. The radio frequency distribution circuit of claim 17, wherein the transformer coupled combiner comprises:

a third secondary coil outputting a fifth radio frequency signal, the fifth radio frequency signal includes frequency components respectively at the first frequency and the second frequency; and

a fourth secondary coil outputting a sixth radio frequency signal, the sixth radio frequency signal includes frequency components respectively at the first frequency and the second frequency.

19. A substrate processing system comprising:

the radio frequency distribution circuit of claim 7;

a process chamber;

a showerhead comprising an electrode and implemented in the process chamber; and

a substrate support implemented in the process chamber adjacent the showerhead.

20. A radio frequency distribution circuit to supply radio frequency power to an electrode in a substrate processing system, the radio frequency distribution circuit comprising:

a radio frequency generator to generate a first radio frequency signal;

a transformer to convert the first radio frequency signal to a second radio frequency signal and supply the second radio frequency signal to the electrode to adjust plasma ionization density and ionization energy within a process chamber of the substrate processing system; and

a match network to match an output of the radio frequency generator to an input of the transformer.