includes a controller coupled to the switch circuit, the controller configured to control the switch circuit based on a tune recipe to change an impedance of the RF return path.

**[0008]** In various embodiments, a system for controlling an impedance of an RF return signal includes an RF transmission line further including an RF rod and a grounded RF tunnel. The system includes a plasma reactor and an impedance match circuitry coupled via the RF transmission line to the plasma reactor. The RF transmission line is used for supplying an RF supply signal to the plasma reactor via the RF rod and for receiving the RF return signal from the plasma reactor via the grounded RF tunnel. The system includes a switch circuit coupled between the impedance match circuitry and the plasma reactor for controlling an impedance of the RF return signal.

**[0009]** In several embodiments, a method for controlling an impedance of RF return path includes receiving an RF return signal from a plasma reactor via an RF return path portion of an RF transmission line. The method further includes modifying the impedance of the RF return path including the RF return path portion to achieve a measurable factor and sending the modified RF return signal via an RF cable sheath to an RF generator.

**[0010]** Some advantages of some of the above-described embodiments include a control of uniformity in etch rates or deposition rates applied to a substrate. For example, an impedance of an RF return path is controlled by a switch circuit to achieve the uniformity. A capacitance, an inductance, or a combination thereof, of the switch circuit is changed to control the impedance of the RF return path. The RF return path is formed between a gap of a plasma chamber and an RF generator that is used to generate an RF signal. The control in uniformity reduces non-uniformity in the etch rates or in the deposition rates.

**[0011]** Additional advantages of some of the above-described embodiments include controlling an impedance of an RF return path of a plasma system to achieve a pre-

**[0020]** Figure 5B is a diagram of a capacitor as a parametric element, in accordance with one embodiment described in the present disclosure.

**[0021]** Figure 5C is a diagram of an inductor as a parametric element, in accordance with one embodiment described in the present disclosure.

**[0022]** Figure 5D is a diagram of a combination of the capacitor and the inductor as a parametric element, in accordance with one embodiment described in the present disclosure.

**[0023]** Figure 6 is a diagram of a system for illustrating a portion of an RF return path of an RF signal, in accordance with one embodiment described in the present disclosure.

**[0024]** Figure 7 is a diagram of a system that illustrates a portion of an RF return path of an RF return signal, in accordance with one embodiment described in the present disclosure.

**[0025]** Figure 8 is a diagram of an inductor system that is connected between a matchbox housing and an RF tunnel to modify an impedance of an RF return signal, in accordance with one embodiment described in the present disclosure.

**[0026]** Figure 9 is a graph that plots an etch rate of etching a substrate with respect to a radius of the substrate for different numbers of inductor straps, in accordance with one embodiment described in the present disclosure.

**[0027]** Figure 10 is a graph that shows a relationship between an etch rate of etching a substrate and a radius of the substrate for two different numbers of inductor straps, in accordance with one embodiment described in the present disclosure.

**[0028]** Figure 11 is a graph that plots a phase of an RF return signal versus a frequency of the RF return signal for different numbers of inductor straps, in accordance with one embodiment described in the present disclosure.

are used. For example, a bar B3C1 corresponds to a capacitance value C1 of the filter and a bar B3C2 corresponds to a capacitance value C2 of the filter.

**[0035]** In some embodiments, an output of the upper electrode is at a bottom surface of the upper electrode. The top surface is located opposite to a bottom surface of the upper electrode and is at the input of the upper electrode. The bottom surface of the upper electrode faces a gap within the plasma chamber. The gap is formed between the upper electrode and a chuck, e.g., an electrostatic chuck (ESC), etc. The chuck is located within the plasma chamber and includes a lower electrode that faces the upper electrode. The chuck is disposed on a facility plate that is located below the lower electrode.

**[0036]** Moreover, as shown in the graph 100, at a fifth order harmonic and at a tenth order harmonic of the RF signal, there is non-uniformity in voltage measured at the upper electrode. For example, a bar B5C1 corresponds to the capacitance value C1, a bar B5C2 corresponds to the capacitance value C2, and a bar B5C3 corresponds to a capacitance value C3 of the filter. As another example, at the tenth order harmonic, a bar B10C2 corresponds to the capacitance value C2 and a bar B10C3 corresponds to the capacitance value C3.

**[0037]** Also, shown in the graph 100 is a bar B1C1 that corresponds to the capacitance value C1, a bar B1C2 that corresponds to the capacitance value C2, and a bar B1C3 that corresponds to the capacitance value C3.

**[0038]** Furthermore, a table 1 provided below illustrates a decrease in a standing wavelength $\lambda$ in plasma with an increase in frequency of the RF signal.

| Frequency (MHz) | Standing Wavelength (centimeters) | Standing Quarter Wavelength (centimeters) (pattern radius on a substrate) |
|---|---|---|

**[0045]** It should be noted that the graph 121 is generated for a process condition, which includes a value of the gap, or a pressure within the plasma chamber, or a combination of one or more process gases supplied to the plasma chamber, or a time for which the process gases are supplied, or an identity of an RF generator that is on, or a combination thereof, etc. The RF generator is on when the RF generated is powered on and is supplying power.

**[0046]** Examples of the RF generator include an x MHz RF generator, a y MHz RF generator, and a z MHz RF generator. Examples of x, y, and z include 2, 27, and 60. It should be noted that a frequency of operation of an RF generator is not limiting and encompasses other frequencies that are within a pre-determined operating range of the frequency. For example, although a generator is referred to herein as a 2 MHz RF generator, the generator operates between 1 and 3 MHz. As another example, although a generator is referred to herein as a 27 MHz RF generator, the generator operates between 25 and 29 MHz. As yet another example, although a generator is referred to herein as a 60 MHz RF generator, the generator operates between 57 and 63 MHz.

**[0047]** Figure 4A is a diagram of an embodiment of a system 200 for controlling an impedance of an RF return path of the system 200. The system 200 includes an RF generator 204, an RF cable system 283, a matchbox 202, an RF transmission line 282, a plasma reactor 218, and a controller 253. The RF cable system 283 couples the RF generator 204 to the matchbox 202 and the RF transmission line 282 couples the matchbox 202 to the plasma reactor 218.

**[0048]** A controller, as used herein, includes a processor and a memory device. As used herein, a processor refers to a central processing unit, or a microprocessor, or an application specific integrated circuit, or a digital signal processor, or a programmable logic device. Examples of a memory device include a random access memory

closed and the remaining of the switches S1 thru S8 are open to modify an impedance of the RF return signal 210.

**[0061]** When a switch of the switch circuit 216 is closed, a parametric element (P), e.g., an inductor, a capacitor, or a combination thereof, etc., is coupled via the switch to the RF tunnel 240 and modifies an impedance of the RF return signal 210. For example, when a switch of the switch circuit 216 is closed, an impedance of a parametric element coupled to the switch is added to or subtracted from an impedance of the RF return signal 210 received from the plasma reactor 218. Moreover, when the switch of the switch circuit 216 is closed, the parametric element is coupled via the connection 225 to a portion of the housing 224, which is grounded. On the other hand, when the switch of the switch circuit 216 is open, the parameter element coupled to the switch is decoupled from the RF tunnel 240.

**[0062]** The RF return signal 263 is transferred via the connection 225 and a grounded portion, of the housing 224, connected to the connection 225, and via the RF cable sheath 238 to the RF generator 204. For example, the RF return signal 263 is reflected towards the RF driver and amplifier system of the RF generator 204 via the RF cable sheath 238.

**[0063]** In some embodiments, an RF supply path 219 includes a first portion 219A, circuit elements of the match circuitry 214, a second portion 219B, and a connection between the RF rod 234 and an RF rod of the plasma reactor 218. The RF supply path 219 is indicated by dots traveling from the RF generator 204 to the plasma reactor 218 in Figure 4A. The first portion 219A of the RF supply path includes the RF cable 232 and the second portion 219B includes the RF rod 234. The RF rod of the plasma reactor 218 is coupled to the lower electrode of the chuck. Examples of the circuit elements of the match circuitry 214

include inductors, or capacitors, a conductor coupling an inductor with another inductor or capacitor, or a combination thereof.

**[0064]** In various embodiments, at least a portion of an RF return path 221 is grounded, e.g., coupled to a ground voltage, or coupled to a reference voltage, or coupled to a zero voltage, etc. The RF return path 221 includes a first portion 221A and a second portion 221B. The RF return path 221 lies along dots traveling from the plasma reactor 214 to the RF generator 204 in Figure 4A. The first portion 221A of the RF return path includes the RF cable sheath 238 and the second portion 221B of the RF return path includes the RF tunnel 240.

**[0065]** In some embodiments, the RF return path 221 includes a C-shroud of the plasma chamber, a ground ring of the plasma reactor 218, RF straps of the plasma reactor 218, a bottom electrode housing of the plasma reactor 218, a ground shield of the plasma reactor 218, the second portion 221B, the switch circuit 216, the connection 225, a grounded portion 221C of the housing 224 connecting the connection 225 with the first portion 221A, and the first portion 221A.

**[0066]** In various embodiments, the controller 253 is coupled to the switch circuit 216. The controller 253 includes a switch select circuitry 287, e.g., a processor, etc. The switch select circuitry 287 selects one or more of switches S1 thru S8 to couple one or more corresponding ones of parametric elements P1 thru P8 of the switch circuit 216 to the RF tunnel 240 or deselects one or more of switches S1 thru S8 to decoupled one or more corresponding ones of parametric elements P1 thru P8 from the switches S1 thru S8 to achieve an etch rate and/or a uniformity. When the one or more of switches S1 thru S8 are coupled to or decoupled from one or more corresponding ones of parametric elements P1 thru P8, an impedance, an inductance, a capacitance, or a combination thereof, of the RF return signal 210 is controlled to achieve an etch rate of etching the substrate and/or a uniformity in etch rates of etching the substrate.

218, a bottom electrode housing of the plasma reactor 218, a ground shield of the plasma reactor 218, the second portion 221B, the switch circuit 216, the connection 304, a grounded portion 212A of the housing 226 connecting the connection 304 with the first portion 221A, and the first portion 221A. The RF return path 212 lies along dots in Figure 4B.

**[0079]** In various embodiments, any number of RF straps are included within the system 200 or the system 300.

**[0080]** Figure 5A is a diagram of an embodiment of the switch circuit 216. The switch circuit 216 includes a series connection between a switch and a parametric element. For example, the switch circuit 216 includes a series connection between the switch S1 and the parametric element P1, a series connection between the switch S2 and the parametric element P2, a series connection between the switch S3 and the parametric element P3, a series connection between the switch S4 and the parametric element P4, a series connection between the switch S5 and the parametric element P5, a series connection between the switch S6 and the parametric element P6, a series connection between the switch S7 and the parametric element P7, and a series connection between the switch S8 and the parametric element P8.

**[0081]** Each combination of a switch and a parametric element of the switch circuit 216 is coupled in parallel to a combination of another switch and another parametric element of the switch circuit 216. For example, a combination of the switch S1 and the parametric element P1 is coupled in parallel to a combination of the switch S2 and the parametric element P2. As another example, a combination of the switch S2 and the parametric element P2 is coupled in parallel to a combination of the switch S3 and the parametric element P3.

**[0082]** The switches S1 thru S8 are coupled to the RF tunnel 240 and the parametric elements P1 thru P8 are coupled to a connection 310, which is an example of the connection 255 (Figure 4A) or the connection 304 (Figure 4B).

**[0083]** In some embodiments, each switch is a relay, e.g., a solid-state relay, or an electromagnetic relay, or a vacuum relay, etc. In various embodiments, power of the RF return signal 210 is divided equally between closed switches of the switch circuit 216.

**[0084]** A portion of an RF return path 231, which is an example of the RF return path 221 or 212 (Figures 4A, 4B), is illustrated as dots in Figure 5A.

**[0085]** Figure 5B is a diagram of an embodiment of a capacitor 250 as a parametric element. The capacitor 250 is coupled in series with a switch 252. The capacitor 250 is an example of any of the parametric elements P1 thru P8 and the switch 252 is an example of any of the switches S1 thru S8.

**[0086]** Figure 5C is a diagram of an embodiment of an inductor 254 as a parametric element. The inductor 254 is coupled in series with the switch 252. The inductor 254 is an example of any of the parametric elements P1 thru P8. In some embodiments, each inductor 254 is an RF strap.

**[0087]** Figure 5D is a diagram of an embodiment of a combination of the capacitor 250 and the inductor 254 as a parametric element. The inductor 254 is coupled in series with the capacitor 254 and the capacitor 254 is coupled in series with the switch 252.

**[0088]** Figure 6 is a diagram of an embodiment of a system for illustrating a portion of a return path of an RF signal. The system includes a plasma reactor 320 and an RF transmission line 324. The RF transmission line 324 is connected to the plasma reactor 320.

**[0089]** The plasma reactor 320 is an example of the plasma reactor 218 (Figures 4A and 4B). Moreover, the RF transmission line 324 is an example of the RF

transmission line 282 (Figures 4A and 4B). The RF transmission line 324 includes an RF rod 261 and a grounded RF tunnel 262. As an example, the RF tunnel 262 is coupled to a ground potential or a reference potential or a zero potential. The grounded RF tunnel 262 is an example of the RF tunnel 240 (Figures 4A, 4B) and the RF rod 261 is an example of the RF rod 234 (Figures 4A, 4B).

**[0090]** The plasma reactor 320 includes a plasma chamber 326 and an RF cylinder 360, which is connected to the RF rod 261 via an RF strap 368. The plasma reactor 320 further includes return RF straps 274 and 277, a ground shield 280 and a bottom electrode housing 276. Examples of a C-shroud, a ground shield, and a return RF strap are provided in Application No. 13/684,098, filed on November 21, 2012, and having U.S. Publication No. 2013-0133834, which is incorporated by reference herein in its entirety.

**[0091]** The plasma chamber 326 includes an upper electrode 260, an upper electrode extension 328, a C-shroud 270, a ground ring 272, and a chuck assembly. The chuck assembly includes a chuck 258 and a facility plate 330. A substrate 291 is placed on top of the chuck 258 for processing the substrate 291. Examples of processing the substrate 291 include cleaning the substrate 291, or etching the substrate 291, or etching an oxide on top of the substrate 291, or depositing materials, e.g., oxides, dioxides, photo resist materials, etc., on the substrate 291, or a combination thereof.

**[0092]** The C-shroud 270 includes slots that are used to control pressure within the plasma chamber 326. For example, the slots are opened to increase gas flow through the slots to decrease gas pressure in a gap 370 of the plasma chamber 326. The plates are closed to decrease the gas flow to increase gas pressure in the gap 370.

**[0093]** In various embodiments, the bottom electrode housing 276 is of any shape, e.g., cylindrical, square, polygonal, etc.

4B), etc., is connected to a motor that is connected to a valve. The valve is connected via a tubing to a gas supply, which stores one or more gases. The processor sends a signal to a motor driver to operate a rotor of the motor to open or close the valve. The valve is opened and closed to control, e.g., increase, or decrease, etc., an amount of flow of the one or more gases into the gap, within the plasma chamber, between upper and lower electrodes. An increase in the amount of flow increases pressure in the chamber and a decrease in the amount of flow decreases the pressure. The pressure is used to reduce the non-uniformity in addition to using the switch circuit 216 (Figures 4A, 4B). In some embodiments, the processor controls the pressure in the gap simultaneously with controlling the switch circuit 216 to reduce the non-uniformity.

**[00121]** Figure 12 is a diagram of an embodiment of a system 450 for using a feedback loop for controlling uniformity in etch rates, or uniformity in deposition rates, or achieving an etch rate, or achieving a deposition rate. The system 450 includes a plasma reactor 452, which is an example of the plasma reactor 218 (Figures 4A, 4B). The plasma reactor 452 includes a plasma chamber 454, which is an example of the plasma chamber 326 (Figure 6). The plasma reactor 452 further includes a bottom electrode housing 456, which is an example of the bottom electrode housing 276 (Figure 6).

**[00122]** The bottom electrode housing 456 is connected to the RF tunnel 240. A sensor 458, e.g., a voltage and current probe, a voltage probe, etc., is coupled to the RF tunnel 240. The sensor 458 measures a parameter, e.g., voltage or a complex voltage and current, etc., of the RF return signal 210.

**[00123]** In some embodiments, the sensor 458 is connected to any point along the RF return path 212 or 221 (Figures 4A, 4B). For example, the sensor 458 is connected to any point on the RF tunnel 240.

**[00124]** In some embodiments, the sensor 458 is connected to any point along the RF delivery path 219 (Figures 4A, 4B). For example, the sensor 458 is connected to any point on the RF rod 234.

**[00125]** The sensor 458 provides the measured parameter to the switch select circuitry 287. The switch select circuitry 287 determines whether the measured parameter is similar to, e.g., is equal to or is within a pre-determined range of, etc., a tuning parameter within the tune recipe 289 (Figures 4A, 4B). The tuning parameter corresponds to a uniformity in etch rates or uniformity in deposition rates or a deposition rate or an etch rate. Upon determining that the measured parameter is not similar to the tuning parameter, the switch select circuitry 287 sends a signal to the switch circuit 216 to open or close one or more of the switches S1 thru S8 to disconnect or connect corresponding one or more of the parametric elements P1 thru P8 to a grounded matchbox housing, e.g., the housing 224 or the housing 226 (Figures 4A, 4B). The signal is sent to achieve the tuning parameter that was used to determine whether the measured parameter is similar to the tuning parameter. On the other hand, upon determining that the measured parameter is similar to the tuning parameter, the switch select circuitry 287 does not send a signal that allows to open or close one or more of the switches S1 thru S8 to the switch circuit 216.

**[00126]** It is noted that although the above-described operations are described with reference to a parallel plate plasma chamber, e.g., a capacitively coupled plasma chamber, etc., in some embodiments, the above-described operations apply to other types of plasma chambers, e.g., a plasma chamber including an inductively coupled plasma (ICP) reactor, a transformer coupled plasma (TCP) reactor, conductor tools, dielectric tools, a plasma chamber including an electron-cyclotron resonance (ECR) reactor, etc. For example, the x MHz RF generator, the y MHz RF generator, and/or the z MHz RF generator are coupled to an inductor within the ICP plasma chamber.