[0004] It is in this context that embodiments described in the present disclosure arise.

Summary

[0005] Embodiments of the disclosure provide apparatus, methods and computer programs for controlling an impedance of a radio frequency (RF) delivery path. It should be appreciated that the present embodiments can be implemented in numerous ways, e.g., a process, an apparatus, a system, a piece of hardware, or a method on a computer-readable medium. Several embodiments are described below.

[0006] In some embodiments, uniformity is achieved by controlling an impedance of an RF delivery path, e.g., an RF supply path, etc., in a plasma tool. The RF delivery path is formed between an RF generator and a gap of a plasma chamber. The impedance is controlled by controlling a capacitance and/or an inductance between an impedance matching circuit of the plasma tool and a plasma reactor of the plasma tool. When the impedance is controlled, the uniformity is achieved.

[0007] In various embodiments, a plasma system for controlling an impedance of an RF supply path includes an RF generator and a matchbox including an impedance matching circuit, which is coupled to the RF generator via an RF cable. The plasma system includes a chuck and a plasma reactor coupled to the matchbox via an RF line. The RF line forms a portion of an RF supply path, which extends ~~between~~ from the RF generator through the matchbox, and to the chuck. The plasma system further includes a phase adjusting circuit coupled to the RF supply path between the impedance matching circuit and the chuck. The phase adjusting circuit has an end coupled to the RF supply path and another end that is grounded. The plasma system includes a controller coupled to the phase adjusting

circuit. The controller is used for changing a parameter of the phase adjusting circuit to control an impedance of the RF supply path based on a tune recipe.

[0008] In some embodiments, a system for controlling an impedance of an RF supply path includes a filter, which is located between an impedance matching circuit and a plasma chamber. The filter is coupled to ground and is used to control an impedance of an RF delivery path. The RF delivery path is used to transfer an RF signal that is output from the impedance matching circuit towards the plasma ~~reactor~~ chamber.

[0009] In several embodiments, a method for controlling an impedance of an RF supply path includes receiving an RF signal from an impedance matching circuit, which is coupled to an RF generator of a plasma tool. The method further includes modifying an impedance of the RF signal to achieve a measurable factor and sending the modified RF signal via a portion of an RF supply path to a plasma reactor. The plasma reactor is coupled to the impedance matching circuit.

[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 delivery path is controlled by a filter to achieve the uniformity. A capacitance, an inductance, or a combination thereof, of the filter is changed to control the impedance of the RF delivery path. 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 delivery path of a plasma system to achieve a pre-determined uniformity in etch rates or in deposition rates. The pre-determined uniformity is stored within a tune recipe. Moreover, a one-to-one correspondence between the pre-determined uniformity and an inductance, a capacitance, or a combination thereof of a filter is

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.

[0039] Moreover, as shown in the graph 100, at a ~~fourth~~ 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 ~~B4C1~~ B5C1 corresponds to the capacitance value C1, a bar ~~B4C2~~ B5C2 corresponds to the capacitance value C2, and a bar ~~B4C3~~ 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.

[0040] 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.

[0041] Moreover, a table 1 provided below illustrates a decrease in a standing wavelength λ 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)
60	113	28
120	43	11
180	24	6
240	16	4
300	12	3

impedance matching circuit 210. The RF signal that is received from the source by the impedance matching circuit 210 is combined within the impedance matching circuit 210 to generate an RF supply signal 228 that is supplied via the RF rod 216A to the plasma reactor 214.

[0063] Examples of the source include one or more of the x, y, and z MHz RF generators and one or more of RF cable systems that couple the RF generators to the impedance matching circuit 210, and any other circuits coupled between the RF generator and the impedance matching circuit 210. Examples of the load include the RF transmission line 216 and the plasma reactor 214, and any other circuitry, e.g., the filter 218, etc., coupled between the plasma reactor 214 and the impedance matching circuit 210. The RF generator 225 generates an RF supply signal 202 that is supplied, e.g., delivered, etc., via the RF cable 212A to the impedance matching circuit 210. For example, a driver and amplifier system of the RF generator 204 generates the RF supply signal 202. The impedance matching circuit 210 combines the RF supply signal 202 with one or more RF signals that are received from one or more other RF generators to generate the RF supply signal 228, which is supplied to the plasma reactor 214 via the RF rod 216A. The impedance matching circuit 210 combines the RF supply signal 202 with one or more RF signals received from one or more of the other RF generators to match an impedance of the source with that of the load. In some embodiments, the RF supply signal 228 is generated when the impedance of the source matches with that of the load.

[0064] The filter 218 changes, e.g., reduces, etc., at the point 258 a power of the RF supply signal 228 by filtering the RF supply signal 228 to generate an RF supply signal 250. For example, the filter 218 provides a capacitance, or an inductance, or a combination thereof, etc., in a path of the RF supply signal 228 to generate the RF supply

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an inductance, or a combination thereof, that is applied to the RF supply signal ~~218~~ to modify an impedance of the RF supply signal 228.

[0079] Figure 5 is a diagram of an embodiment of a system 310 for illustrating different points at which the filter 218 is connected along an RF supply path 312. The system 310 includes a plasma reactor 316, which is an example of the plasma reactor 214 (Figures 4A, 4B).

[0080] The plasma reactor 316 includes a plasma chamber 320 and an RF cylinder 222. The plasma reactor 316 further includes return RF straps 360 and 362, a ground ring 332 and a bottom electrode housing 372. The plasma chamber 320 includes an upper electrode 322, an upper electrode extension 328, a C-shroud 330, the ground ring 332, and a chuck assembly. The chuck assembly includes a chuck 334 and a facility plate 336. A substrate 338, which is an example of the substrate 284 (Figures 4A, 4B), is placed on top of the chuck 334 for processing the substrate 338. Examples of processing the substrate 338 include cleaning the substrate 338, or etching the substrate 338, or etching an oxide on top of the substrate 338, or depositing materials, e.g., oxides, dioxides, photo resist materials, etc., on the substrate 338, or a combination thereof. The upper electrode 322 is an example of the upper electrode 226 (Figures 4A, 4B).

[0081] The C-shroud 330 includes slots that are used to control pressure within the plasma chamber 320. For example, the slots are opened to increase gas flow through the slots to decrease gas pressure in a gap 340 of the plasma chamber 320. The slots are closed to decrease the gas flow to increase gas pressure in the gap 340. The gap 340 is formed between the upper electrode 322 and a lower electrode of the chuck 334.

[0082] In various embodiments, the bottom electrode housing 372 is of any shape, e.g., cylindrical, square, polygonal, etc.

coupling 260, and the RF cylinder 222 to the chuck 334 to generate plasma within the plasma chamber 320.

[0096] Moreover, when the filter 218 is connected to the connection point 242, the RF supply signal 228 that is output from the impedance matching circuit 110 is supplied via the RF strap ~~230~~ 238 to the filter 218. The RF supply signal 228 is modified by the filter 218 at the connection point 242 to generate the RF supply signal 250. The RF supply signal 250 is supplied via the RF strap 244, the RF rod 230, the RF coupling 260, and the RF cylinder 222 to the chuck 334 to generate plasma within the plasma chamber 320.

[0097] When the filter 218 is connected to the connection point 246, the RF supply signal 228 that is output from the impedance matching circuit 110 is supplied via the RF strap 238 and the RF strap 244 to the filter 218. The RF supply signal 228 is modified by the filter 218 at the connection point 246 to generate the RF supply signal 250. The RF supply signal 250 is supplied via the RF rod 230, the RF coupling 260, and the RF cylinder 222 to the chuck 334 to generate plasma within the plasma chamber 320.

[0098] Furthermore, when the filter 218 is connected to the connection point 398, the RF supply signal 228 that is output from the impedance matching circuit 110 is supplied via the RF strap ~~230~~ 238, the RF strap 244, the RF rod 230, and the RF coupling 260 to the filter 218. The RF supply signal 228 is modified by the filter 218 at the connection point 398 to generate the RF supply signal 250. The RF supply signal 250 is supplied via the RF cylinder 222 to the chuck 334 to generate plasma within the plasma chamber 320.

[0099] The end 270A of the filter 218 is connected to the connection point 241, or the connection point 242, or the connection point 246, or the connection point 398. In some embodiments, when the end 270A is connected to the connection point 241 or the connection point 242 or the connection point 246, the end 270B is connected to the housing

252, which is grounded. In various embodiments, when the end 270A is connected to the connection point 246, the end 270B is connected to the grounded RF tunnel 232. In several embodiments, when the end 270A is connected to the connection point 398, the end 270B is connected to the ground shield portion 240A or to the ground shield portion 240B or to the bottom electrode housing portion 372A or to the bottom electrode housing portion 372B or to the bottom electrode housing portion 372C.

[00100] In various embodiments, the filter 218 is located within and is coupled to the grounded RF tunnel 232 or is located within the enclosure 390 surrounded by the bottom electrode housing 372 and the facility plate 336 (Figure 5).

[00101] In some embodiments, four filters, e.g., four of the filters 218, etc., are connected to the connection point 241, the connection point 242, the connection point 246, and the connection point 398. For example, the filter 218 is connected to the connection point 241, another one of the filter 218 is connected to the connection point 242, yet another one of the filter 218 is connected to the connection point 246, and still another one of the filter 218 is connected to the connection point 398. As another example, the filter 218, e.g., a first filter, etc., is connected to the connection point 241, a second filter is connected to the connection point 242, a third filter is connected to the connection point 246, and a fourth filter is connected to the connection point 398. Any of the second, third, and fourth filters has an impedance that is same or different from an impedance of the first filter. In some embodiments, two or more of the second, third, and fourth filters have impedances that are different from an impedance of the first filter. In some embodiments, an impedance of a filter is based on a capacitance and/or an inductance of the filter.

[00102] In various embodiments, the filter 218 is connected to any point along an RF supply path 312, which extends via the RF strap ~~328~~ 238, the RF strap 244, the RF rod 230,

[00107] In various embodiments, a portion of an RF return signal, which is generated by plasma within the plasma chamber 320 passes from the bottom surface 380, along the bottom surface portion 383B ~~338B~~ of the upper electrode extension 328, further along the C-shroud portion 330B, further along the ground ring portion 332B, further along the return RF strap 362, further along the bottom electrode housing portion 372B, further along the ground shield portion 240B, to the grounded RF tunnel 232.

[00108] It should be noted that a portion of an RF return path of the RF return signal 290 extends from the bottom surface 380 of the upper electrode 322, along the bottom surface portion 383A ~~338A~~ of the upper electrode extension 328, further along the C-shroud portion 330A, further along the ground ring portion 332A, further along the return RF strap 360, further along the bottom electrode housing portion 372A, further along the ground shield portion 240A, further along the bottom electrode housing portion 372C, further along the bottom electrode housing portion 372B, to the grounded RF tunnel 232.

[00109] Moreover, a portion of an RF return path of the RF return signal 290 extends from the bottom surface 380 of the upper electrode 322, along the bottom surface portion 383B ~~338B~~ of the upper electrode extension 328, further along the C-shroud portion 330B, further along the ground ring portion 332B, further along to the return RF strap 362, further along the bottom electrode housing portion 372B, further along the ground shield portion 240B, to the grounded RF tunnel 232.

[00110] In various embodiments, the filter 218 that is grounded sinks at least a portion of a current of the RF signal 228 to ground.

[00111] In some embodiments, instead of the RF strap 238, any number of RF straps is connected to the output of the impedance matching circuit 210. Moreover, in

parameter T1, a deposition rate D2 corresponds to the tuning parameter T2, etc. Moreover, in these embodiments, the uniformities U1 thru U4 are uniformities in deposition rates and each uniformity has a one-to-one correspondence with a tuning parameter. For example, the uniformity U1 in deposition rates is mapped to the tuning parameter T1, the uniformity U2 in deposition rates is mapped to the tuning parameter T2, and so on. In some embodiments, each curve that plots an oxide deposition rate of depositing an oxide on a substrate versus a radius of the wafer represents a uniformity in deposition on the substrate. In some embodiments, a uniformity in deposition rates includes deposition rates that lie within a pre-determined standard deviation of a deposition rate.

[00121] The processor 412 is programmed to achieve an etch rate or a uniformity by achieving a corresponding tuning parameter. For example, the processor 412 is programmed to achieve the etch rate E2 or the uniformity U2 by achieving the tuning parameter T2. The processor 412 sends a signal ~~410~~ 414 to the driver 408 to generate one or more amounts of current to achieve an etch rate or a uniformity. Upon receiving the signal ~~410~~ 414, the driver 408 generates one or more amounts of current ~~412~~ 416 to provide to the movement mechanism 410. Upon receiving the current ~~412~~ 416, the movement mechanism 410 performs one or more rotational motions or one or more translation motions to move the filter 218 to achieve a tuning parameter to generate the RF supply signal 250. For example, the movement mechanism 410 changes a distance between plates of a capacitor of the filter 218 or changes a length of an inductor of the filter 218. The generation of the RF supply signal 250 helps achieve an etch rate or uniformity.

[00122] Figure 6B is a diagram of an embodiment of the filter 218 as a capacitive element and/or an inductive element. The filter 218 includes a number of capacitors and/or a number of inductors. The capacitors are in series with each other and the

[00126] In some embodiments, different RF straps are used to vary inductances of the RF straps. For example, when the RF strap 430 is replaced with another RF strap, an inductance of the RF strap 430 is changed to change an impedance of the RF supply signal 228.

[00127] Figure 7 is an embodiment of a graph 480 that plots an etch rate of etching a substrate with respect to a radius of the substrate for different amounts of capacitances. As a capacitance of the filter 218 is increased from C11 to C15, there is an increase in uniformity in the etch rates. By controlling capacitance of the filter 218, a control, e.g., reduction, etc., in non-uniformity in the etch rates is achieved. Also, it is shown in graph 480 that when the filter 218 is not used, there is a non-uniformity in etch rates.

[00128] In some embodiments, a non-uniformity in etch rates is measured close to the center of the substrate, e.g., within a pre-determined range, from the center of the substrate, etc.

[00129] Figure 8 is an embodiment of a graph 490 that plots an impedance at an output of the matchbox 208 (Figure 4A), e.g., match impedance, etc., versus frequencies close to a third harmonic of an RF supply signal measured at the output when the output of the matchbox 208 is connected to a network analyzer. The network analyzer is coupled to the output of the matchbox 208 after the output is decoupled from the plasma chamber 215 (Figure 4A). It should be noted that the graph 490 plots impedances for various values of capacitances C of the filter 218 (Figures 6A-6E).

[00130] As the capacitance C increases, a phase of a curve that plots the match impedance changes in a range close to the third harmonic of the RF supply signal measured at the output of the matchbox ~~209~~ 208. The matchbox ~~209~~ 208 impedance decreases to corresponding minimum values at resonance points. In some embodiments, the filter 218 (Figures 4A, 4B)

is referred to herein as a phase adjusting circuit that changes a phase of the RF supply signal 228 to generate the RF supply signal 250 (Figures 4A, 4B). In various embodiments, the phase of the RF supply signal 228 is adjusted to achieve the measurable factor. The change in phase is used to control an impedance of the RF supply signal 228 to reduce non-uniformity in etch rates or to achieve an etch rate.

[00131] Figure 9 is an embodiment of a graph 500 that plots the match impedance versus frequencies close to a fundamental frequency of the RF supply signal measured at the output of the matchbox 208 to illustrate a lack of change in phase and a resonance condition where matchbox impedance is close to zero. As shown in the graph 500, as values of capacitances C of the filter 218 and/or various turns of different RF straps, e.g., RF straps similar to the RF strap 430 (Figures 6A-6E), etc., change, there is no change in phase of a curve that plots the match impedance in a range close to the fundamental frequency of the RF supply signal measured at the output of the matchbox ~~209~~ 208. Hence, the fundamental frequency is minimally affected by a change in the capacitance C and/or change in the turns of different RF straps.

[00132] Figure 10A is an embodiment of a graph 502 that plots an impedance at an output of the filter 218 (Figure 4A), e.g., filter impedance, etc., versus frequencies close to a third harmonic of an RF supply signal calculated at the output. As shown in graph 502, there is a change in phase of the filter impedance, e.g., when the filter impedance is close to zero, etc., with a change in the capacitance C.

[00133] Figure 10B is an embodiment of a graph 506 that plots the filter impedance versus a frequency of a third harmonic of an RF supply signal calculated at the output of the filter 218. As shown in graph 506, there is a change in phase of the filter impedance, e.g., when the filter impedance is close to zero, etc., with a change in an inductance of an RF strap, e.g., an RF strap similar to the RF strap 430, etc.

CLAIMS

1. A plasma system comprising:

a radio frequency (RF) generator;

a matchbox including an impedance matching circuit, the impedance matching circuit coupled to the RF generator via an RF cable;

a plasma reactor coupled to the matchbox via an RF line, the plasma reactor including a chuck, wherein the RF line forms a portion of an RF supply path, the RF supply path extending ~~between~~ from the RF generator through the matchbox, and to the chuck; and

a phase adjusting circuit coupled to the RF supply path between the impedance matching circuit and the chuck, the phase adjusting circuit having a first end coupled to the RF supply path and a second end that is grounded; and

a controller coupled to the phase adjusting circuit, the controller for changing a parameter of the phase adjusting circuit to control an impedance of the RF supply path based on a tune recipe.

2. The plasma system of claim 1, wherein the impedance matching circuit matches an impedance of the RF generator and an RF cable system with an impedance of the plasma reactor and an RF transmission line, the RF transmission line coupling the impedance matching circuit to the plasma reactor, the RF transmission line including the RF line and a grounded RF tunnel, the RF cable system including the RF cable and an RF cable sheath.

3. The plasma system of claim 1, wherein the plasma reactor includes a lower electrode and an upper electrode, the upper electrode faces the lower electrode, the impedance

9. The plasma system of claim 1, wherein the plasma reactor includes an RF cylinder that is connected to the chuck, wherein the phase adjusting circuit is coupled to the RF supply path via a connection of the RF cylinder, the RF cylinder coupled to the RF line via an RF coupling.

10. The plasma system of claim 1, wherein the matchbox has a housing, the phase adjusting circuit is located outside the housing and is coupled to the RF line.

11. The plasma system of claim 1, wherein the matchbox has a housing, the phase adjusting circuit is located within the housing and is coupled to an RF strap located within the housing, the RF strap coupling the impedance matching circuit to the RF line.

12. The plasma system of claim 1, wherein the RF supply path includes one or more RF straps coupled to the impedance matching circuit, wherein the plasma reactor includes an RF cylinder wherein the RF line is coupled to the RF cylinder via an RF coupling, wherein the RF supply path further includes the RF line, the RF coupling, and the RF cylinder, wherein the RF cylinder is coupled to the chuck.

13. The plasma system of claim 1, wherein the impedance is dependent on a capacitance, or an inductance, or a combination thereof of the phase adjusting circuit.

14. The plasma system of claim 1, wherein the impedance is controlled to achieve an etch rate, or a deposition rate, or a uniformity in etch rates, or a uniformity in deposition rates, wherein the etch rate, or the deposition rate, or the uniformity in etch rates, or the uniformity in deposition rates are specified within the tune recipe.

15. The plasma system of claim 1, wherein the controller is configured to control the phase adjusting circuit based on a value of a parameter measured on the RF supply path.

16. The plasma system of claim 1, wherein the phase adjusting circuit includes a filter for filtering an RF supply signal received from the impedance matching circuit and sending the filtered signal to the chuck.

17. The plasma system of claim 16, wherein the filter includes a variable capacitor that is coupled in series with a variable inductor or fixed inductor, wherein the variable inductor or fixed inductor is coupled to ground, wherein the variable capacitor is coupled to the RF supply path.

18. A system comprising a filter, the filter located between an impedance matching circuit and a plasma chamber, wherein the filter is coupled to ground, the filter used to control an impedance of a radio frequency (RF) signal to be delivered to the plasma chamber, the RF signal output from the impedance matching circuit towards the plasma ~~reactor~~ chamber.

19. The system of claim 18, wherein the filter includes a capacitor, an inductor, or a combination thereof.

20. The system of claim 18, wherein the impedance matching circuit is configured to match an impedance of an RF generator and an RF cable system with an impedance of a plasma reactor and an RF transmission line, wherein the RF transmission line couples the impedance matching circuit to the plasma reactor, wherein the impedance matching circuit is

located within a matchbox, wherein the matchbox is coupled to the RF generator via the RF cable system, wherein the plasma reactor includes the plasma chamber.

21. The system of claim 18, wherein the plasma chamber includes a lower electrode and an upper electrode, the upper electrode faces the lower electrode.

22. The system of claim 18, wherein the impedance is dependent on a capacitance, or an inductance, or a combination thereof of the filter.

23. A method ~~comprising:~~ for controlling an impedance of an RF supply path, comprising:

receiving a radio frequency (RF) signal from an impedance matching circuit, the impedance matching circuit coupled to an RF generator of a plasma tool;

modifying an impedance of the RF signal to achieve a measurable factor; and

sending the modified RF signal via a portion of an RF supply path to a plasma reactor, the plasma reactor coupled to the impedance matching circuit.

24. The method of claim 23, wherein the RF signal received from the impedance matching circuit is generated when the impedance matching circuit matches an impedance of the RF generator and an RF cable system coupled to the RF generator with an impedance of the plasma reactor and an RF transmission line, the RF transmission line coupling the plasma reactor to the impedance matching circuit.

25. The method of claim 23, wherein the measurable factor includes an etch rate of etching a wafer when present within a plasma chamber of the plasma reactor, a deposition rate of depositing materials on the wafer when present within the plasma chamber, or