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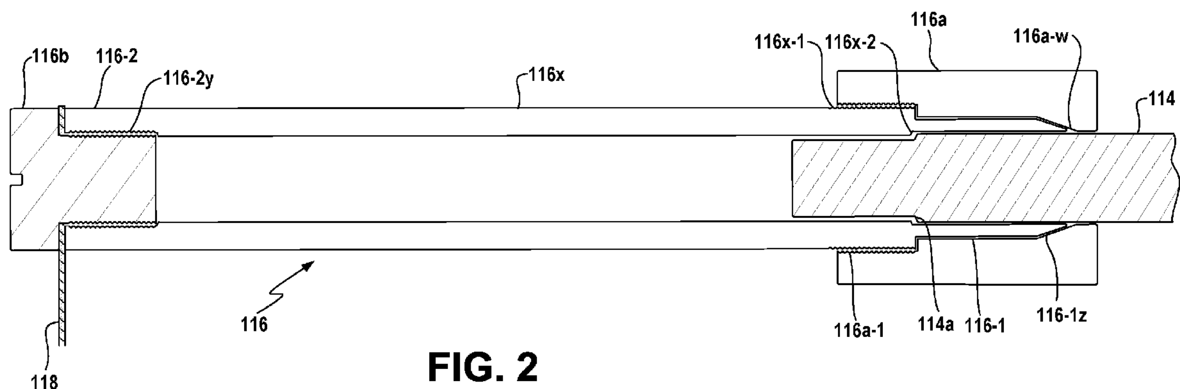

FIG. 2

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(57) Abstract: A thermal choke rod connecting a radio frequency source to a substrate support of a plasma processing system includes a tubular member having a first connector for connecting to an RF rod coupled to the substrate support and a second connector for connecting to an RF strap that couples to the RF source. A tubular segment extends between the first and second connectors. The first connector has a conically-shaped end region that tapers away from the inner surface thereof to an outer surface in a direction toward the tubular segment, and slits that extend for a prescribed distance from a terminal end of the first connector. The outer surface of the tubular segment has a threaded region for threaded engagement with an annular cap that fits over the first connector and reduces an inner diameter of the first connector upon contact with the conically-shaped end region of the first connector.

HIGH TEMPERATURE RF CONNECTION WITH INTEGRAL THERMAL CHOKE

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BACKGROUND

[0001] The latest generation of plasma enhanced chemical vapor deposition (PECVD) processes require increased high frequency electrical power. This increased power requirement exceeds the limits of existing electrical connectors and conductors. High ambient temperatures and heating from electrical current traveling through conductors and connections contribute to create a temperature condition in excess of the capabilities of commonly used components.

[0002] The electrical connections for some current PECVD processes use screw threads and preloaded spring washers. One limitation of threaded electrical connections is that the threads provide a poor, non-repeatable electrical contact area. This causes more electrical resistive heating of the connection. Another limitation of threaded electrical connections is that the threads of the radio frequency (RF) pedestal rod are extremely fragile and can be tightened with just a light torque, otherwise the threads are damaged. This light torque cannot provide the electrical contact needed for a high power electrical connection.

[0003] Other commercially available electrical connectors rely on spring force to make the electrical contact. These connectors can be used at temperatures up to about 150 to 200 degrees Celsius. In PECVD processes requiring increased high frequency power, the environment in which the electrical connector must function can be in the range from 300 to 350 degrees Celsius because a ceramic pedestal is typically used in such processes.

[0004] It is in this context that embodiments arise.

SUMMARY

[0005] In an example embodiment, a thermal choke rod for use in connecting a radio frequency (RF) source to a substrate support of a plasma processing system includes a tubular member having a first connector for connecting to an RF rod that is coupled to the substrate support and a second connector for connecting to an RF strap that couples to the RF source. A tubular segment, which has an inner diameter, extends between the first and second connectors. The first connector has an inner surface that is a continuation of an inner surface of the tubular segment, with the first connector having a conically-shaped end region that tapers away from the inner surface of the first connector to an outer surface of

the first connector in a direction toward the tubular segment. The first connector has a plurality of slits formed through a wall thickness of the first connector along a prescribed distance from a terminal end of the first connector. An outer surface of the tubular segment has a threaded region proximate to the first connector for threaded engagement with an annular cap configured to fit over the first connector and reduce an inner diameter of the first connector upon contact with the conically-shaped end region of the first connector.

[0006] In one embodiment, the annular cap has an inner threaded region for threaded engagement with the threaded region proximate to the first connector, and an inner tapered wall that is configured to mate with the conically-shaped end region of the first connector. In one embodiment, the second connector has an inner threaded region and the thermal choke rod further includes a threaded mechanical fastener that is configured to connect the RF strap to the second connector of the thermal choke rod. In one embodiment, the threaded mechanical fastener is either a bolt or a machine screw.

[0007] In one embodiment, the thermal choke rod is formed of a base material having a low thermal conductivity, and the base material is plated with a highly electrically conductive material. In one embodiment, the base material having a low thermal conductivity comprises stainless steel or a nickel-chromium-based superalloy, and the highly electrically conductive material plated on the base material comprises gold.

[0008] In another example embodiment, a plasma processing system is provided. The plasma processing system includes a radio frequency (RF) input rod having a first end connected to a plasma processing chamber and a second end for receiving RF signals from an RF source. The system also includes a thermal choke rod having a first connector, a second connector, and a tubular segment extending between the first and second connectors. The first connector has an inner surface that is a continuation of an inner surface of the tubular segment. Further, the first connector has a conically-shaped end region that tapers away from the inner surface of the first connector to an outer surface of the first connector in a direction toward the tubular segment. The first connector also has a plurality of slits formed through a wall thickness of the first connector along a prescribed distance from a terminal end of the first connector. An outer surface of the tubular segment has a threaded region proximate to the first connector. The first connector is configured to receive the second end of the RF input rod, and the second connector is configured to connect to an RF strap. An annular cap is configured to fit over the first connector and reduce an inner diameter of the first connector upon contact with the conically-shaped end region of the first

connector. The system also includes an RF source coupled to the RF strap.

[0009] In one embodiment, the plasma processing chamber includes a processing region, and the plasma processing system further includes a substrate support disposed in the chamber below the processing region. In this embodiment, the RF input rod is coupled to the substrate support.

[0010] In one embodiment, the annular cap has an inner threaded region for threaded engagement with the threaded region proximate to the first connector, and an inner tapered wall that is configured to mate with the conically-shaped end region of the first connector. In one embodiment, the second connector has an inner threaded region and the thermal choke rod further includes a threaded mechanical fastener that is configured to connect the RF strap to the second connector of the thermal choke rod. In one embodiment, the threaded mechanical fastener is either a bolt or a machine screw.

[0011] In one embodiment, the thermal choke rod is formed of a base material having a low thermal conductivity, and the base material is plated with a highly electrically conductive material. In one embodiment, the base material having a low thermal conductivity comprises stainless steel or a nickel-chromium-based superalloy, and the highly electrically conductive material plated on the base material comprises gold.

[0012] In yet another example embodiment, a method for connecting a radio frequency (RF) source to a plasma processing chamber is provided. The method includes providing a thermal choke rod having a first connector, a second connector, and a tubular segment extending between the first and second connectors, with the first connector having an inner surface that is a continuation of an inner surface of the tubular segment. The method also includes inserting a first end portion of a radio frequency (RF) input rod into the first connector of the thermal choke rod and positioning the first end portion of the RF input rod at a prescribed location within the thermal choke rod, with the RF input rod having a second end portion coupled to a plasma processing chamber. Further, the method includes compressing the first connector to reduce an inner diameter of the first connector and cause an inner surface of the first connector to contact and press upon an outer surface of the RF input rod so as to be mechanically secured to the RF input rod. The method also includes attaching a radio frequency (RF) strap to the second connector of the thermal choke rod, with the RF strap being coupled to an RF source.

[0013] In one embodiment, the providing of the thermal choke rod includes providing a thermal choke rod comprised of a base material having a low thermal

conductivity, and the base material is plated with a highly electrically conductive material. In one embodiment, the base material having a low thermal conductivity comprises stainless steel or a nickel-chromium-based superalloy, and the highly electrically conductive material plated on the base material comprises gold.

[0014] In one embodiment, the compressing of the first connector to reduce an inner diameter of the first connector includes contacting a tapered surface provided at an end region of the first connector with a tapered surface that is configured to mate with the tapered surface provided at the end region of the first connector. In one embodiment, the tapered surface that is configured to mate with the tapered surface provided at the end region of the first connector is an inner surface of an annular cap configured to fit over the first connector.

[0015] In one embodiment, the prescribed location within the thermal choke rod at which the first end portion of the RF input rod is positioned includes the first connector and a portion of the tubular segment. In one embodiment, the attaching of the RF strap to the second connector of the thermal choke rod includes attaching a mechanical fastener to the second connector of the thermal choke rod.

[0016] Other aspects and advantages of the disclosures herein will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, which illustrate by way of example the principles of the disclosures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figure 1 is a simplified schematic cross-sectional diagram showing a plasma processing system used for deposition operations, in accordance with one embodiment.

[0018] Figure 2 is a cross-sectional view of a thermal choke rod in the process of being connected to an RF input rod, in accordance with one embodiment.

[0019] Figures 3A and 3B are enlarged cross-sectional views that illustrate the process of connecting the thermal choke rod to the RF input rod, in accordance with one embodiment.

[0020] Figure 4A is a partial perspective view of a thermal choke rod, in accordance with one embodiment.

[0021] Figure 4B is a partial perspective view of a thermal choke rod, in accordance with another embodiment.

[0022] Figure 5 is a cutaway perspective view that illustrates an RF input rod connected to the thermal choke rod, in accordance with one embodiment.

[0023] Figure 6 is a flow diagram illustrating the method operations performed in connecting a radio frequency (RF) source to a plasma processing chamber, in accordance with an example embodiment.

DETAILED DESCRIPTION

[0024] In the following description, numerous specific details are set forth in order to provide a thorough understanding of the example embodiments. However, it will be apparent to one skilled in the art that the example embodiments may be practiced without some of these specific details. In other instances, process operations and implementation details have not been described in detail, if already well known.

[0025] Embodiments of the present invention provide a thermal choke rod having a collet connection that provides a strong clamping force for electrically connecting a radio frequency (RF) input rod to an RF source. The thermal choke rod also serves to isolate the high heat generated by the pedestal and electrical current resistive heating from sensitive electrical components located upstream. This thermal functionality is accomplished by forming the thermal choke rod from a base material having a low thermal conductivity and the capability to withstand high temperatures. To provide the thermal choke rod with the electrical conductivity needed to conduct electrical power, the base material is used in conjunction with a highly electrically conductive material, which, in one embodiment, is plated on the base material.

[0026] Figure 1 is a simplified schematic cross-sectional diagram showing a plasma processing system used for deposition operations, in accordance with one embodiment. The plasma processing system 100 includes a chamber 102 in which a gas distribution showerhead 104, which has a plurality of openings 104a through which process gases can flow, and a substrate support 106 are disposed. The chamber 102 has a processing region 108 that is located between the showerhead 104 and the substrate support 106. For a plasma enhanced chemical vapor deposition (PECVD) process, the substrate support 106 can be a pedestal for supporting a substrate, e.g., a wafer, during deposition. Heaters 110 are provided in the substrate support 106 to heat the substrate, with each heater being coupled to an alternating current (AC) generator. One end portion of radio frequency (RF) input rod 114 is coupled to substrate support 106 to provide RF power to an electrode that forms part of the substrate support, e.g., pedestal. The other end portion of RF input rod 114 is connected to a thermal choke rod 116, which includes an annular cap 116a. Additional details regarding the thermal choke rod are described below with reference to Figures 2, 3A-

B, 4A-B, and 5.

[0027] A radio frequency (RF) strap 118 is also connected to thermal choke rod 116. The RF strap 118 is coupled to impedance matching network 120 via a suitable wire connector. Radio frequency (RF) generator system 122, which includes one or more RF generators, is coupled to impedance matching network 120 via a suitable wire connector. In operation, RF generator system 122 generates an RF signal that is transmitted to an input of impedance matching network 120. The impedance matching network 120 matches the impedance of a load coupled to an output of the matching network with the impedance of a source coupled to an input of the matching network and generates a modified RF signal. The modified RF signal is transmitted from the impedance matching network 120 to the thermal choke rod 116 via the wire connector and the RF strap 118. The modified RF signal (RF current) is then conducted, for the most part, along the outer surface of the thermal choke rod 116 and is transmitted to the RF input rod 114 via the electrical connection created where the thermal choke rod contacts the RF input rod, as will be explained in more detail below with reference to Figures 2, 3A, and 3B.

[0028] Figure 2 is a cross-sectional view of a thermal choke rod in the process of being connected to an RF input rod, in accordance with one embodiment. As shown in Figure 2, thermal choke rod 116 includes a first connector 116-1, a second connector 116-2, and a tubular segment 116x that extends between the first and second connectors. The tubular segment 116x has an inner diameter. In one embodiment, the inner diameter is in the range from about 0.125 inch to about 0.156 inch. As used herein, the terms “about” and “approximately” mean that the specified parameter can be varied within a reasonable tolerance, e.g., ± 20%. The inner surface of the first connector 116-1 is a continuation of the inner surface of the tubular segment 116x. In one embodiment, the inner diameter of the first connector 116-1 is smaller than the inner diameter of the tubular segment 116x. This allows for a tight tolerance, locally-machined area in the interface zone, and also provides for a step that indicates when the thermal choke rod is fully slid onto the RF input rod, as described in more detail below. The wall thickness of the first connector 116-1 is reduced relative to the wall thickness of the tubular segment 116x. In one embodiment, the wall thickness of the tubular segment 116x is approximately 0.250 inch and the wall thickness of the first connector 116-1 is approximately 0.205 inch. The reduced wall thickness of the first connector 116-1 enables the inner diameter of the first connector to be reduced by the application of a compressive force, as will be described in more detail below.

[0029] The end region of the first connector 116-1 has a conical shape that tapers away from the inner surface of the first connector to an outer surface of the first connector in a direction toward the tubular segment 116x. In one embodiment, the surface 116-1z of the conically-shaped end region is disposed at an angle of about 10 degrees to about 30 degrees relative to a horizontal reference line. To enable threaded engagement with annular cap 116a, the outer surface of the tubular segment 116x is provided with a threaded region 116x-1 proximate or near to the first connector 116-1. In the example of Figure 2, the threaded region 116x-1 is adjacent to the first connector 116-1. In other embodiments, the threaded region 116x-1 can be separated from the first connector 116-1 by a prescribed distance.

[0030] The annular cap 116a is configured to fit over the first connector 116-1 and reduce the inner diameter thereof to create a firm connection between the first connector and the RF input rod 114. The annular cap 116a has an inner threaded region 116a-1 for threaded engagement with the threaded region 116x-1 on the outer surface of tubular segment 116x. The annular cap 116a also has an inner tapered wall 116a-w that is configured to mate with the surface 116-1z of the conically-shaped end region of the first connector 116-1. In one embodiment, the inner tapered wall 116a-w is disposed at an angle of about 10 degrees to about 30 degrees relative to a horizontal reference line.

[0031] To connect the RF input rod 114 to the thermal choke rod 116, the RF input rod is inserted through the central opening of the annular cap 116a while the annular cap is either separated from the thermal choke rod or is loosely threaded over the first connector 116-1. An end portion of the RF input rod 114 is then inserted into the first connector 116-1 and positioned at a prescribed location within the thermal choke rod. In the example shown in Figure 2, the prescribed location of the end portion of the RF input rod 114 includes the first connector 116-1 and a portion of the tubular segment 116x. In one embodiment, there is a step 114a in the outer diameter of the end portion of the RF input rod 114 and a step 116x-2 in the inner diameter of the tubular segment 116x. In this embodiment, the step 116x-2 acts as a locating stop for the insertion depth of the RF input rod 114. With the RF input rod 114 disposed at the prescribed location within the thermal choke rod 116, the annular cap 116a is then threaded onto the threaded region 116x-1 on the outer surface of tubular segment 116x. As the annular cap 116a is moved from an initial engagement position to a fully engaged position, the inner tapered wall 116a-w of the annular cap contacts the surface 116-1z of the conically-shaped end region of the first

connector 116-1. This contact causes a compressive force to be exerted on the first connector 116-1 that reduces the inner diameter of the first connector. As the inner diameter of the first connector 116-1 is reduced, a portion of the inner surface of the first connector is brought into contact with and pressed upon the outer surface of the RF input rod 114 to mechanically secure the first connector to the RF input rod. Additional details regarding the process of connecting the RF input rod to the thermal choke rod are described below with reference to Figures 3A, 3B, 5, and 6.

[0032] With continuing reference to Figure 2, second connector 116-2 has an inner threaded region 116-2y for threaded engagement with a threaded mechanical fastener 116b. The threaded mechanical fastener 116b can be any suitable fastener such as, for example, a bolt or a machine screw. The RF strap 118 can be attached to the second connector 116-2 of the thermal choke rod 116 by inserting the threaded mechanical fastener 116b through an opening in the RF strap and then threading the fastener into a fully engaged position in the threaded region 116-2y to firmly attach the RF strap to the second connector.

[0033] Figures 3A and 3B are enlarged cross-sectional views that illustrate the process of connecting the thermal choke rod to the RF input rod, in accordance with one embodiment. Figure 3A shows the relative positions of the first connector 116-1, the annular cap 116a, and the RF input rod 114 before the annular cap reaches the fully engaged position. As shown in Figure 3A, the inner tapered wall 116a-w of annular cap 116a has yet to contact the surface 116-1z of the conically-shaped end region of the first connector 116-1. In this state, there is a gap, G_1, between the outer surface of the RF input rod 114 and the inner surface of the first connector 116-1. Figure 3B shows the relative positions of the first connector 116-1, the annular cap 116a, and the RF input rod 114 once the annular cap reaches the fully engaged position. As shown in Figure 3B, the annular cap 116a has been moved by a distance, X, in the direction toward the first connector 116-1 (i.e., from right to left on the page) relative to the position of the annular cap shown in Figure 3A, to bring the annular cap into the fully engaged position. In the fully engaged position, the inner tapered wall 116a-w contacts the surface 116-1z of the conically-shaped end region of the first connector 116-1 and exerts a compressive force on the first connector. This compressive force reduces the inner diameter of the first connector 116-1 and causes a portion of the inner surface of the first connector to contact and press upon the outer surface of the RF input rod 114. In the embodiment shown in Figure 3B, the region in which the inner surface of first connector 116-1 and the outer surface of the RF input rod 114 are pressed into

contact is labeled as CR_1, and in contact region CR_1 there is no gap between the inner surface of the first connector and the outer surface of the RF input rod. As such, as indicated in Figure 3B, G_2 equals zero.

[0034] The length of the contact region in which the inner surface of the first connector 116-1 and the outer surface of the RF input rod 114 are pressed into contact can be varied by changing the size and shape of the conically-shaped end region of the first connector and making corresponding changes to the angle of the inner tapered wall 116a-w of the annular cap 116a. Thus, in other embodiments, the length of the contact region can be longer than the length of contact region CR_1 shown in Figure 3B. For example, contact region CR_2 shown in Figure 3B extends beyond the conically-shaped end region of the first connector 116-1.

[0035] Figure 4A is a partial perspective view of a thermal choke rod, in accordance with one embodiment. The portion of the thermal choke rod 116 shown in Figure 4A includes tubular segment 116x and first connector 116-1. For ease of illustration, the threaded portion 116x-1 on the outer surface of tubular segment 116x has been omitted from Figure 4A. In the embodiment of Figure 4A, a plurality of slits 140 is formed in first connector 116-1 to define axial fingers 116-11, 116-12, 116-13, and 116-14. The slits 140 extend for the length of first connector 116-1 but the slit length can be varied, as will be described below with reference to Figure 4B. The axial fingers 116-11, 116-12, 116-13, and 116-14 are radially compressed when that annular cap is attached to the thermal choke rod, in the manner described above, to exert a strong clamping force against the RF input rod when the RF input rod is disposed with the first connector. In this manner, the axial fingers of the first connector function as a collet to hold the RF input rod securely within the thermal choke rod. The strong clamping force provided by radial compression of the axial fingers provides for improved electrical contact between the first connector of the thermal choke rod and the RF input rod.

[0036] Figure 4B is a partial perspective view of a thermal choke rod, in accordance with another embodiment. The portion of the thermal choke rod 116 shown in Figure 4B includes tubular segment 116x and first connector 116-1. For ease of illustration, the threaded portion 116x-1 on the outer surface of tubular segment 116x has been omitted from Figure 4B. The embodiment shown in Figure 4B is the same as the embodiment shown in Figure 4A, except for the length of the slits formed in the first connector. As shown in Figure 4B, the slits 140' extend for a portion of the length of the first connector

116-1, as opposed to extending for the length of the first connector as shown in Figure 4A. In one embodiment, the slits 140' extend for about one quarter (25%) to about one third (33%) of the length of the first connector 116-1. In other embodiments, the slits 140' can extend for a longer distance, e.g., about 40%, 50%, 60%, etc. of the length of the first connector, or a shorter distance, e.g., about 10%, 20%, etc. of the length of the first connector. The slits 140' formed in the first connector 116-1 should extend for a length that is sufficient to enable the axial fingers 116-11, 116-12, 116-13, and 116-14 to be radially compressed against the RF input rod when the annular cap is attached to the thermal choke rod. On the other hand, the length of the slits should not be so long that the axial fingers defined by the slits are prone to bending or other deformation that might limit the lifetime of the thermal choke rod.

[0037] Figure 5 is a cutaway perspective view that illustrates an RF input rod connected to the thermal choke rod, in accordance with one embodiment. As shown in Figure 5, RF input rod 114 extends through the annular opening in annular cap 116a and into the thermal choke rod 116 so that an end portion of the RF input rod is situated within tubular segment 116x. The annular cap 116a has been fit over first connector 116-1 and the inner threaded region 116a-1 has been brought into threaded engagement with threaded region 116x-1 on the outer surface of tubular segment 116x so that the annular cap is in the fully engaged position. With the annular cap 116a in the fully engaged position, the inner tapered wall 116a-w contacts the surface 116-1z of the conically-shaped end region of the first connector 116-1 and exerts a compressive force on the first connector. This compressive force causes a portion of the inner surface of the first connector 116-1 to contact and press upon the outer surface of the RF input rod 114, as described above with reference to Figures 3A and 3B. The strong clamping force provided by radial compression of the first connector 116-1 provides for improved electrical contact between the first connector of the thermal choke rod 116 and the RF input rod 114.

[0038] The brackets shown on the left side of Figure 5 indicate the various sections of the thermal choke rod 116. These sections include the first connector 116-1, the second connector 116-2, and the tubular segment 116x that extends between the first and second connectors. The second connector 116-2 includes an inner threaded region 116-2y for threaded engagement with a threaded mechanical fastener (see, for example, threaded mechanical fastener 116b shown in Figure 2) that secures an RF strap to the second connector.

[0039] In addition to providing improved electrical contact with the RF input rod, the thermal choke rod also serves to isolate the high heat generated by the pedestal and electrical current resistive heating from sensitive electrical components located upstream. This thermal functionality is accomplished by forming the thermal choke rod from a base material which has a low thermal conductivity and is capable of withstanding high temperatures. In one embodiment, the base material having a low thermal conductivity is formed of stainless steel or a nickel-chromium-based superalloy. Examples of these materials include Type 316L stainless steel and superalloys commercially available under the trade names INCONEL®, HAYNES®, and HASTELLOY®. In one embodiment, the base material is chosen to match the thermal mechanical properties, e.g., coefficient of thermal expansion, of the RF input rod. By matching the coefficients of thermal expansion, the risk of the connection between the thermal choke rod and the RF input rod becoming loosened at high temperatures is minimized. To further reduce heat transfer, the thermal choke rod is configured to minimize the cross-sectional area of the component.

[0040] The electrically conductive components typically used in electrical power delivery are also highly thermally conductive. To provide the thermal choke rod with the electrical conductivity needed to conduct electrical power, the base material is used in conjunction with a highly electrically conductive material, e.g., gold. In one embodiment, the highly electrically conductive material is plated on the base material. As RF current is conducted largely on the surface of a conductor, the use of a plating material provides the thermal choke rod with the needed RF conductivity, while maintaining the desirable thermal properties of the base material. With regard to the ability to withstand high temperatures, the conductive plating is the limiting factor because the base material can withstand extremely high temperatures. A conductive plating of gold is believed to be able to withstand high temperatures up to about 400 degrees Celsius, which exceeds the temperature range of 300 to 350 degrees Celsius at which the thermal choke rod must function when used in conjunction with ceramic pedestals in high frequency power environments.

[0041] Figure 6 is a flow diagram illustrating the method operations performed in connecting a radio frequency (RF) source to a plasma processing chamber, in accordance with an example embodiment. In operation 600, a thermal choke rod having a first connector, a second connector, and tubular segment extending between the first and second connectors is provided. In one embodiment, the thermal choke rod has the configuration of

thermal choke rod 116 shown in, for example, Figure 2. In one embodiment, the thermal choke rod is formed of a base material having low thermal conductivity and the base material is plated with a highly electrically conductive material. By way of example, the base material having a low thermal conductivity can be comprised of stainless steel or a nickel-chromium-based superalloy, as described above. In one embodiment, the highly electrically conductive material plated on the base material is comprised of gold.

[0042] In operation 602, a first end portion of an RF input rod is inserted into the first connector of the thermal choke rod and positioned at a prescribed location within the thermal choke rod. The second end portion of the RF input rod is coupled to a plasma processing chamber, e.g., a plasma enhanced chemical vapor deposition (PECVD) chamber. In one embodiment,, the prescribed location within the thermal choke rod at which the first end portion of the RF input rod is positioned includes the first connector and a portion of the tubular segment, as shown in, for example, Figures 2 and 5.

[0043] Once the first end portion of the RF input rod is positioned within the thermal choke rod, in operation 604, the first connector is compressed to reduce the inner diameter of the first connector and cause the inner surface of the first connector to contact and press upon the outer surface of the RF input so as to be mechanically secured to the RF input rod. In one embodiment, the compressing of the first connector to reduce an inner diameter of the first connector includes contacting a tapered surface provided at an end region of the first connector with a tapered surface that is configured to mate with the tapered surface provided at the end region of the first connector. By way of example, the tapered surface provided at an end region of the first connector can be the surface 116-1z of the conically-shaped end region of first connector 116-1 (see, for example, Figure 2). In one embodiment, the tapered surface that is configured to mate with the tapered surface provided at the end region of the first connector is tapered inner wall 116a-w of annular cap 116a (see, for example, Figures 2 and 5).

[0044] In operation 606, an RF strap is connected to the second connector of the thermal choke rod. The RF strap is coupled to an RF source such as, for example, RF generator system 122 shown in Figure 1. In one embodiment, the attaching of the RF strap to the second connector of the thermal choke rod includes attaching a mechanical fastener to the second connector of the thermal choke rod. By way of example, the mechanical fastener can be a threaded mechanical fastener such as a bolt or a machine screw. In one embodiment, as shown in Figure 2, the RF strap 118 can be attached to the second

connector 116-2 of the thermal choke rod 116 by inserting the threaded mechanical fastener 116b through an opening in the RF strap and then threading the fastener into a fully engaged position in the threaded region 116-2y to firmly attach the RF strap to the second connector.

[0045] In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform or platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the "controller," which may control various components or subparts of the system or systems. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0046] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0047] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system,

or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0048] Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0049] As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller,

or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

[0050] With the above embodiments in mind, it should be understood that the embodiments can employ various computer-implemented operations involving data stored in computer systems. These operations are those requiring physical manipulation of physical quantities. Any of the operations described herein that form part of the embodiments are useful machine operations. The embodiments also relates to a device or an apparatus for performing these operations. The apparatus may be specially constructed for the required purpose, such as a special purpose computer. When defined as a special purpose computer, the computer can also perform other processing, program execution or routines that are not part of the special purpose, while still being capable of operating for the special purpose. Alternatively, the operations may be processed by a general purpose computer selectively activated or configured by one or more computer programs stored in the computer memory, cache, or obtained over a network. When data is obtained over a network the data may be processed by other computers on the network, e.g., a cloud of computing resources.

[0051] One or more embodiments can also be fabricated as computer readable code on a computer readable medium. The computer readable medium is any data storage device that can store data, which can be thereafter be read by a computer system. Examples of the computer readable medium include hard drives, network attached storage (NAS), read-only memory, random-access memory, CD-ROMs, CD-Rs, CD-RWs, magnetic tapes and other optical and non-optical data storage devices. The computer readable medium can include computer readable tangible medium distributed over a network-coupled computer system so that the computer readable code is stored and executed in a distributed fashion.

[0052] Although the method operations were described in a specific order, it should be understood that other housekeeping operations may be performed in between operations, or operations may be adjusted so that they occur at slightly different times, or may be distributed in a system which allows the occurrence of the processing operations at various intervals associated with the processing, as long as the processing of the overlay operations are performed in the desired way.

[0053] Accordingly, the disclosure of the example embodiments is intended to be illustrative, but not limiting, of the scope of the disclosures, which are set forth in the following claims and their equivalents. Although example embodiments of the disclosures

have been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications can be practiced within the scope of the following claims. In the following claims, elements and/or steps do not imply any particular order of operation, unless explicitly stated in the claims or implicitly required by the disclosure.

CLAIMS

1. A thermal choke rod for use in connecting a radio frequency (RF) source to a substrate support of a plasma processing system, comprising,

a tubular member having a first connector for connecting to an RF rod that is coupled to the substrate support and a second connector for connecting to an RF strap that couples to the RF source, and a tubular segment extending between the first and second connectors, the tubular segment having an inner diameter, the first connector having an inner surface that is a continuation of an inner surface of the tubular segment, the first connector having a conically-shaped end region that tapers away from the inner surface of the first connector to an outer surface of the first connector in a direction toward the tubular segment, the first connector having a plurality of slits formed through a wall thickness of the first connector along a prescribed distance from a terminal end of the first connector, an outer surface of the tubular segment having a threaded region proximate to the first connector for threaded engagement with an annular cap configured to fit over the first connector and reduce an inner diameter of the first connector upon contact with the conically-shaped end region of the first connector.

2. The thermal choke rod of claim 1, wherein the annular cap has an inner threaded region for threaded engagement with the threaded region proximate to the first connector, and an inner tapered wall that is configured to mate with the conically-shaped end region of the first connector.

3. The thermal choke rod of claim 1, wherein the second connector has an inner threaded region and the thermal choke rod further includes a threaded mechanical fastener that is configured to connect the RF strap to the second connector of the thermal choke rod.

4. The thermal choke rod of claim 3, wherein the threaded mechanical fastener is either a bolt or a machine screw.

5. The thermal choke rod of claim 1, wherein the thermal choke rod is formed of a base material having a low thermal conductivity, and the base material is plated with a highly electrically conductive material.

6. The thermal choke rod of claim 5, wherein the base material having a low thermal conductivity comprises stainless steel or a nickel-chromium-based superalloy, and the highly electrically conductive material plated on the base material comprises gold.

7. A plasma processing system, comprising:

a radio frequency (RF) input rod having a first end connected to a plasma processing chamber and a second end for receiving RF signals from an RF source;

a thermal choke rod having a first connector, a second connector, and a tubular segment extending between the first and second connectors, the first connector having an inner surface that is a continuation of an inner surface of the tubular segment, the first connector having a conically-shaped end region that tapers away from the inner surface of the first connector to an outer surface of the first connector in a direction toward the tubular segment, the first connector having a plurality of slits formed through a wall thickness of the first connector along a prescribed distance from a terminal end of the first connector, an outer surface of the tubular segment having a threaded region proximate to the first connector, the first connector configured to receive the second end of the RF input rod, the second connector configured to connect to an RF strap, and an annular cap configured to fit over the first connector and reduce an inner diameter of the first connector upon contact with the conically-shaped end region of the first connector; and

an RF source coupled to the RF strap.

8. The plasma processing system of claim 7, wherein the plasma processing chamber includes a processing region, and the plasma processing system further comprises:

a substrate support disposed in the chamber below the processing region, wherein the RF input rod is coupled to the substrate support.

9. The plasma processing system of claim 7, wherein the annular cap has an inner threaded region for threaded engagement with the threaded region proximate to the first connector, and an inner tapered wall that is configured to mate with the conically-shaped end region of the first connector.

10. The plasma processing system of claim 7, wherein the second connector has an inner threaded region and the thermal choke rod further includes a threaded mechanical fastener

that is configured to connect the RF strap to the second connector of the thermal choke rod.

11. The plasma processing system of claim 10, wherein the threaded mechanical fastener is either a bolt or a machine screw.

12. The plasma processing system of claim 7, wherein the thermal choke rod is formed of a base material having a low thermal conductivity, and the base material is plated with a highly electrically conductive material.

13. The plasma processing system of claim 12, wherein the base material having a low thermal conductivity comprises stainless steel or a nickel-chromium-based superalloy, and the highly electrically conductive material plated on the base material comprises gold.

14. A method for connecting a radio frequency (RF) source to a plasma processing chamber, comprising:

providing a thermal choke rod having a first connector, a second connector, and a tubular segment extending between the first and second connectors, the first connector having an inner surface that is a continuation of an inner surface of the tubular segment;

inserting a first end portion of a radio frequency (RF) input rod into the first connector of the thermal choke rod and positioning the first end portion of the RF input rod at a prescribed location within the thermal choke rod, the RF input rod having a second end portion coupled to a plasma processing chamber;

compressing the first connector to reduce an inner diameter of the first connector and cause an inner surface of the first connector to contact and press upon an outer surface of the RF input rod so as to be mechanically secured to the RF input rod; and

attaching a radio frequency (RF) strap to the second connector of the thermal choke rod, the RF strap being coupled to an RF source.

15. The method of claim 14, wherein the providing of the thermal choke rod includes providing a thermal choke rod comprised of a base material having a low thermal conductivity, and the base material is plated with a highly electrically conductive material.

16. The method of claim 15, wherein the base material having a low thermal conductivity comprises stainless steel or a nickel-chromium-based superalloy, and the highly electrically conductive material plated on the base material comprises gold.

17. The method of claim 14, wherein the compressing of the first connector to reduce an inner diameter of the first connector includes contacting a tapered surface provided at an end region of the first connector with a tapered surface that is configured to mate with the tapered surface provided at the end region of the first connector.

18. The method of claim 17, wherein the tapered surface that is configured to mate with the tapered surface provided at the end region of the first connector is an inner surface of an annular cap configured to fit over the first connector.

19. The method of claim 14, wherein the prescribed location within the thermal choke rod at which the first end portion of the RF input rod is positioned includes the first connector and a portion of the tubular segment.

20. The method of claim 14, wherein the attaching of the RF strap to the second connector of the thermal choke rod includes attaching a mechanical fastener to the second connector of the thermal choke rod.

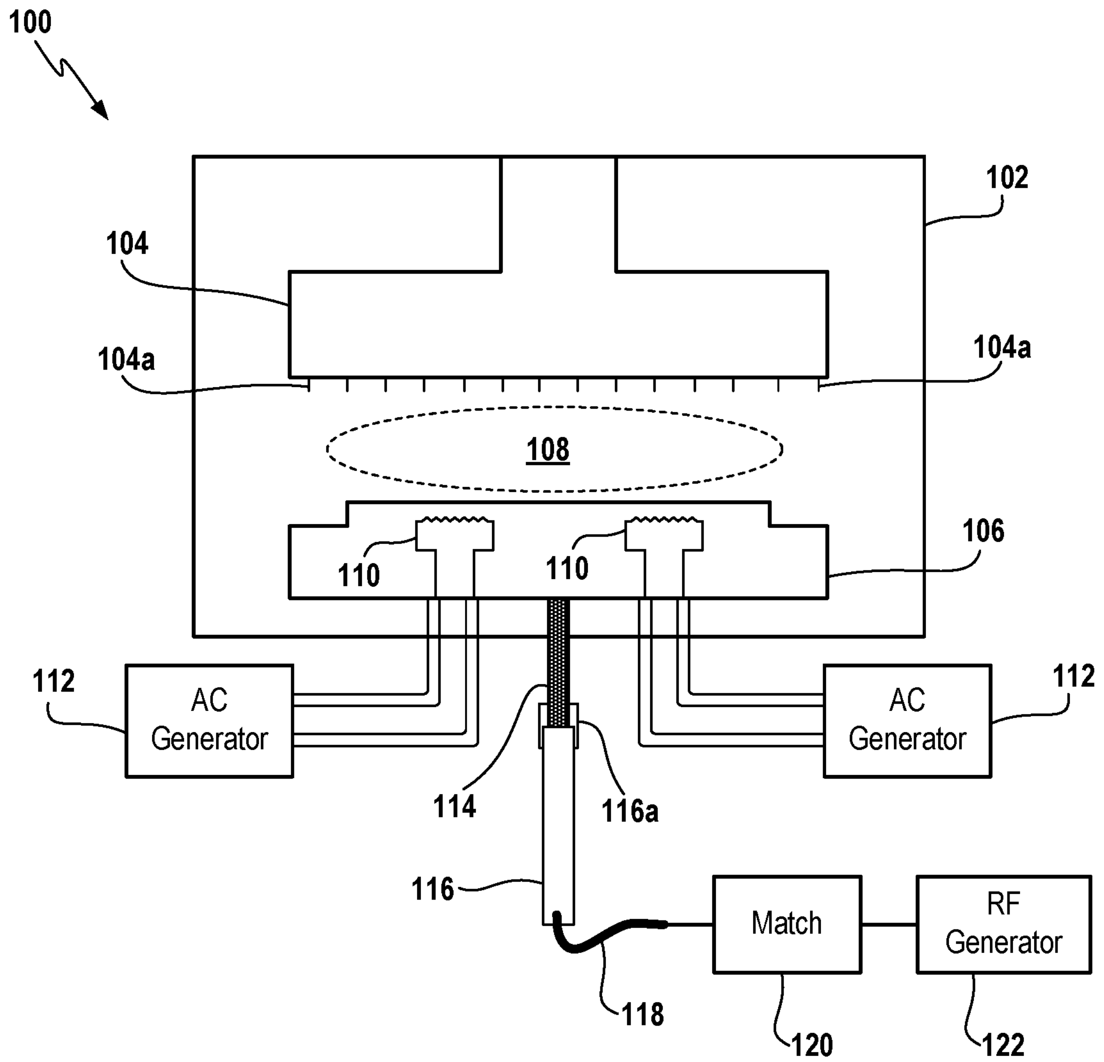

FIG. 1

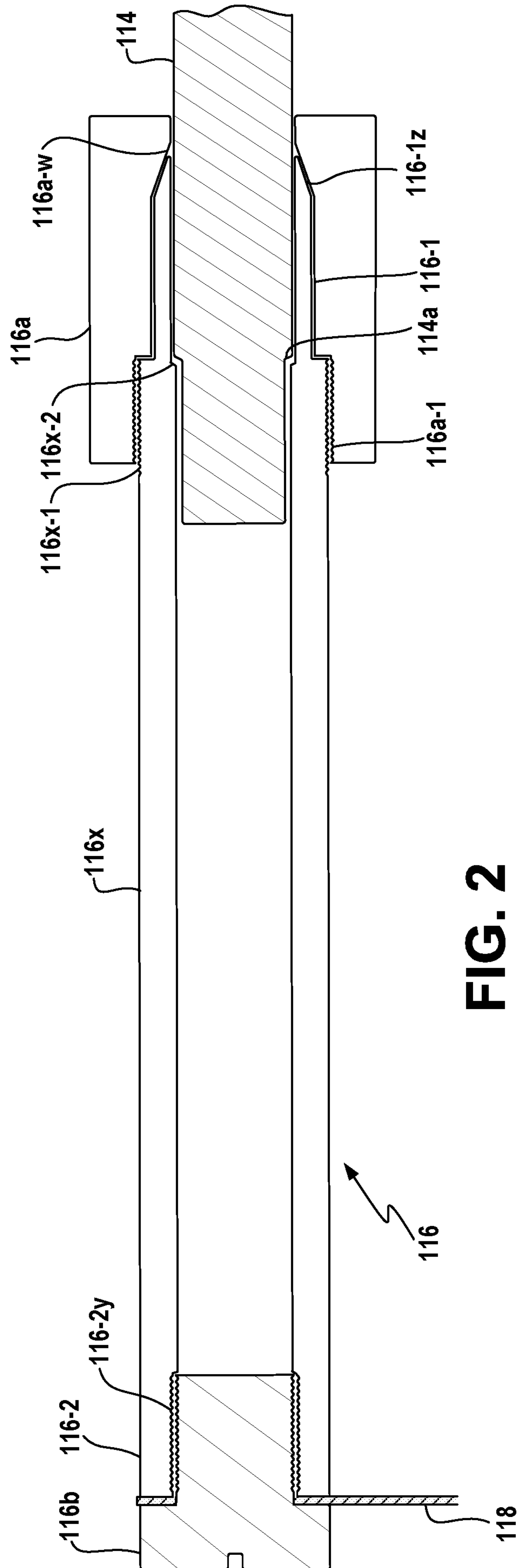

FIG. 2

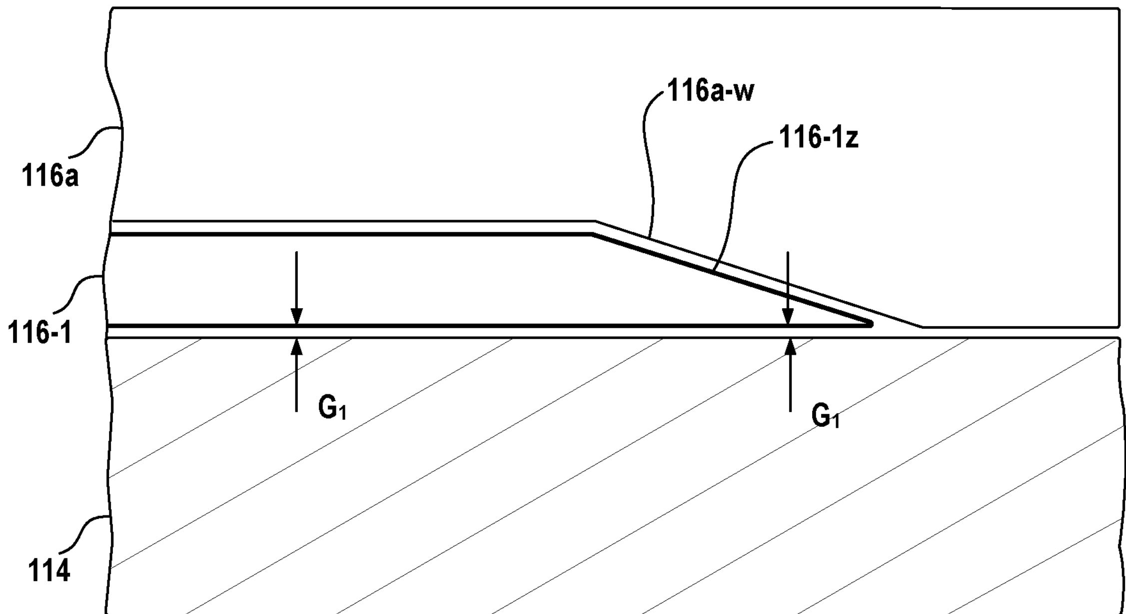

FIG. 3A

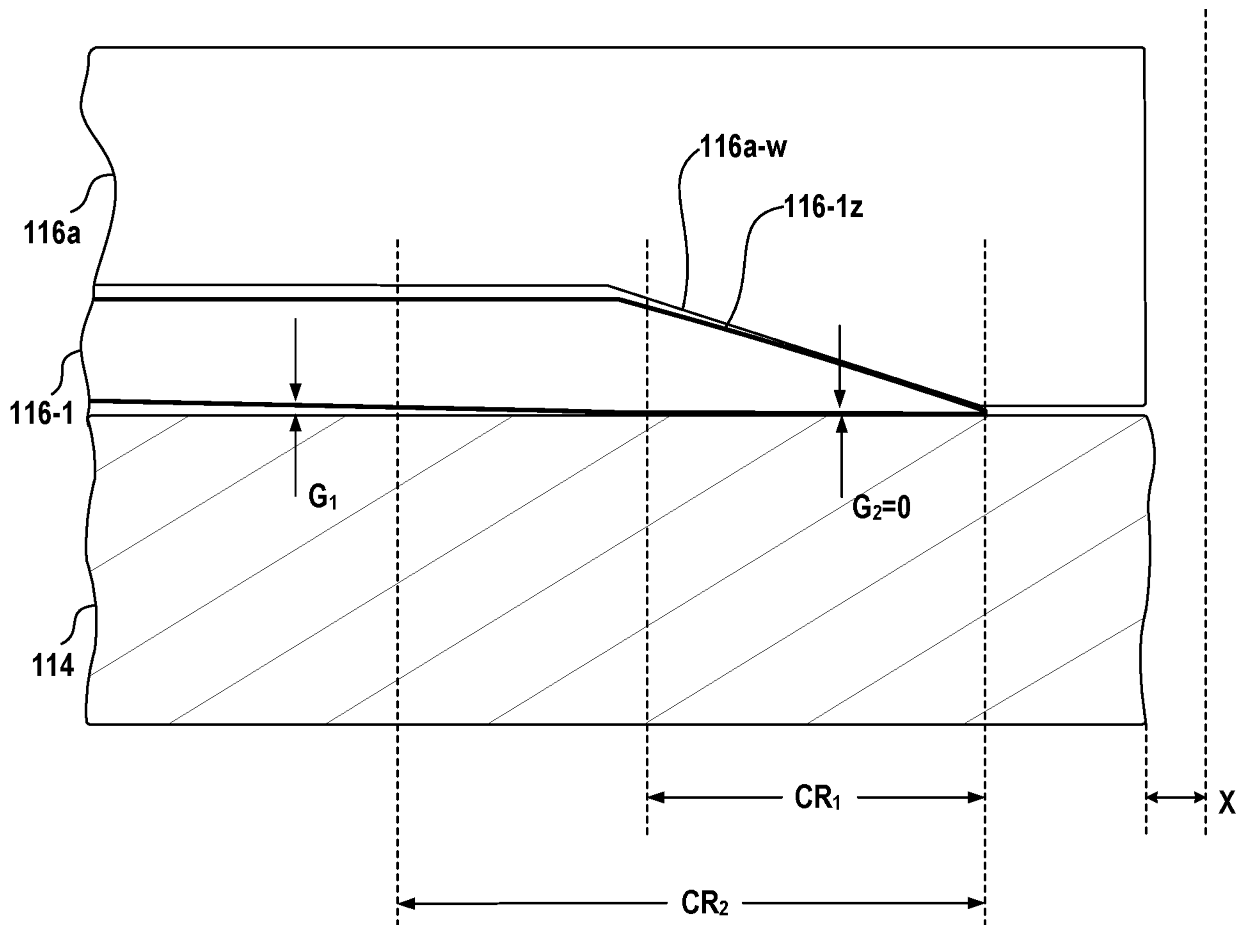

FIG. 3B

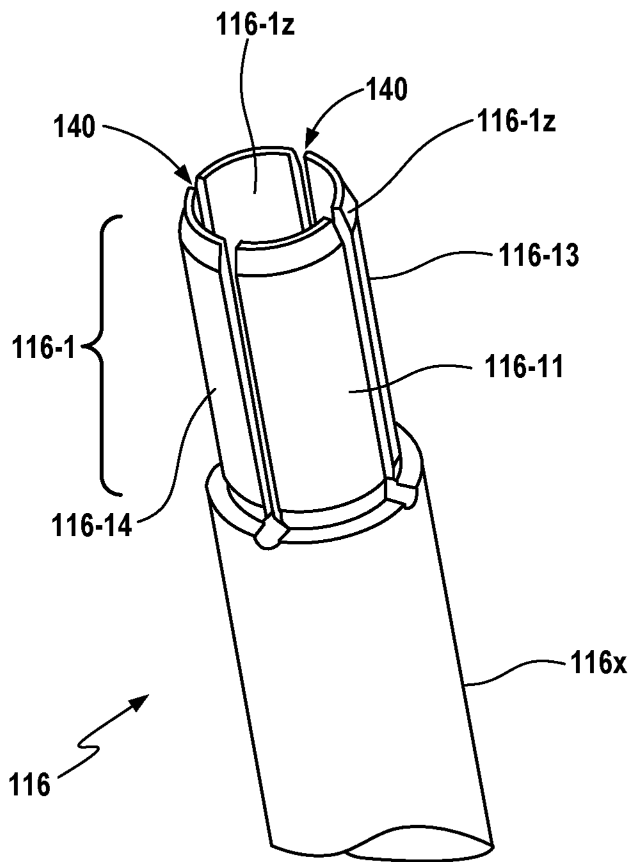

FIG. 4A

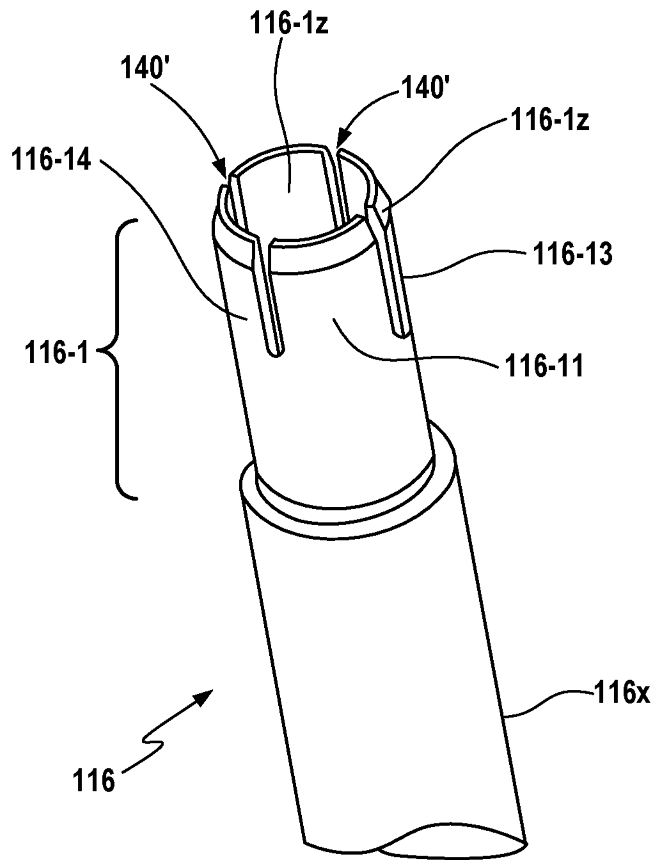

FIG. 4B

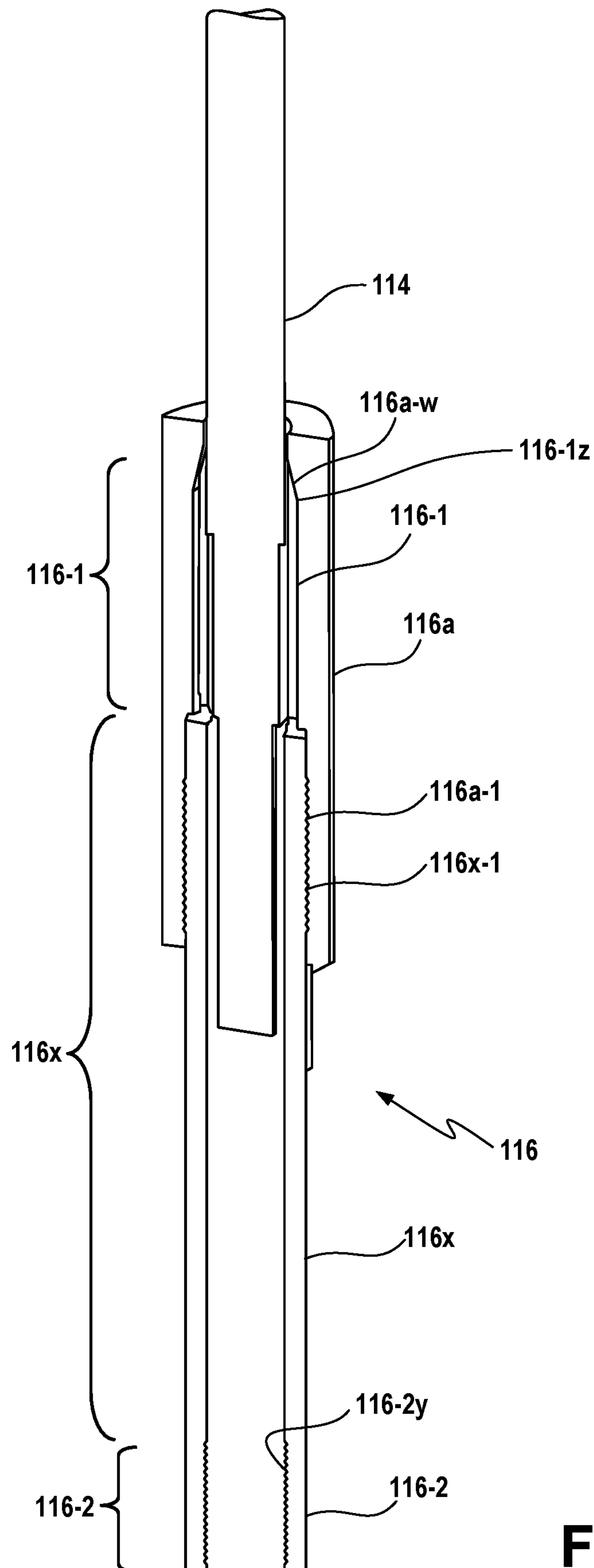

FIG. 5

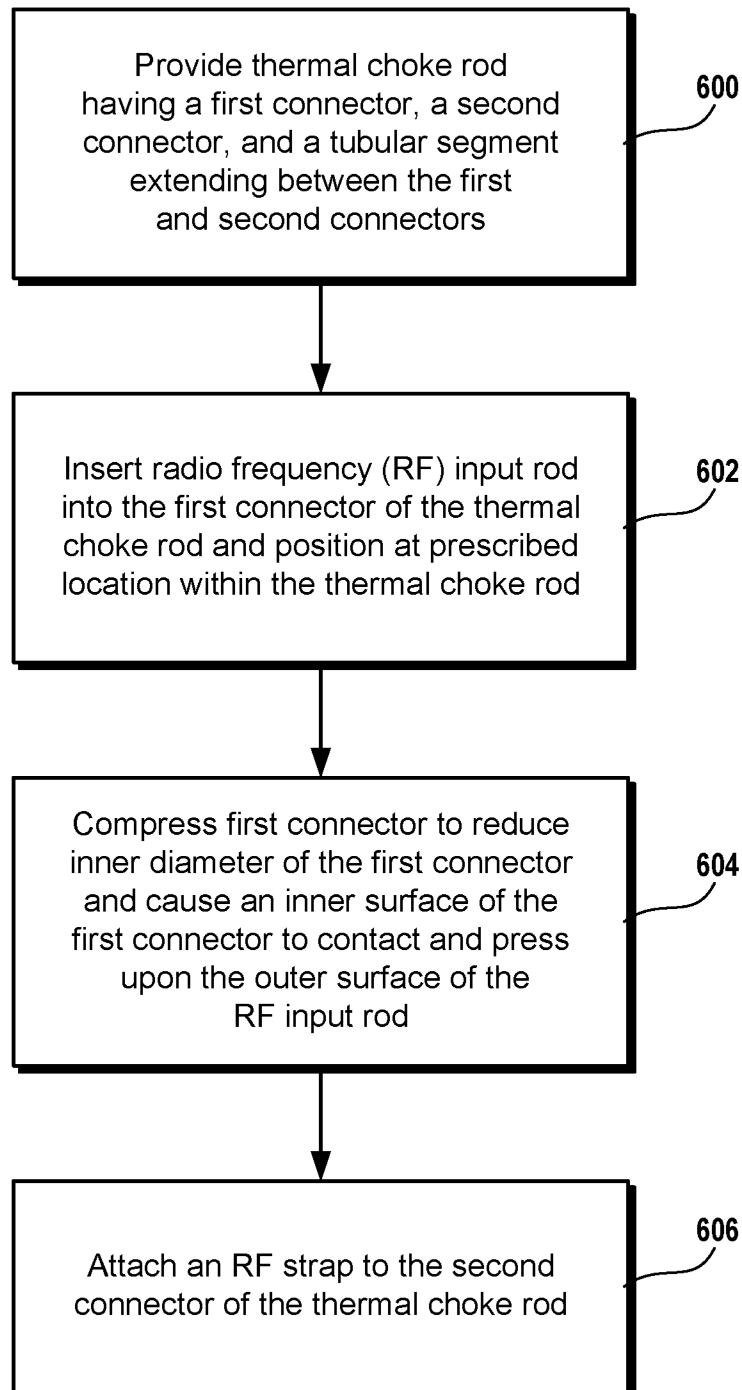

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/049267

A. CLASSIFICATION OF SUBJECT MATTER

H01J 37/32(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J 37/32; C23C 16/00; F16L 35/00; H01L 21/205; H01L 21/3065; H01L 21/687; H01P 3/12; H05H 1/46

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: plasma, RF generator, thermal, choke, feed, rod, conductive, isolate, tube

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005-0274324 A1 (SYUICHI TAKAHASHI et al.) 15 December 2005 See paragraphs [0021]-[0033], [0046]; and figures 1, 4, 6.	1-20
A	KR 10-2015-0099400 A (LAM RESEARCH CORPORATION) 31 August 2015 See paragrphs [0025]-[0033], [0036]-[0052]; and figures 1, 3.	1-20
A	US 2012-0247678 A1 (CHIKAKO TAKAHASHI et al.) 04 October 2012 See paragraphs [0057]-[0065]; claims 1-2; and figure 1.	1-20
A	US 05829791 A (VINCENT Y. KOTSUBO et al.) 03 November 1998 See column 3, lines 7-48; and figures 1-2.	1-20
A	US 2017-0040148 A1 (LAM RESEARCH CORPORATION) 09 February 2017 See paragraphs [0027]-[0030]; and figures 2-3B.	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 December 2018 (26.12.2018)	**26 December 2018 (26.12.2018)**

Name and mailing address of the ISA/KR

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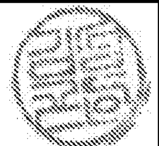
KIM, Sung Gon



Telephone No. +82-42-481-8746

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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US 2017-0040148 A1	09/02/2017	None	