

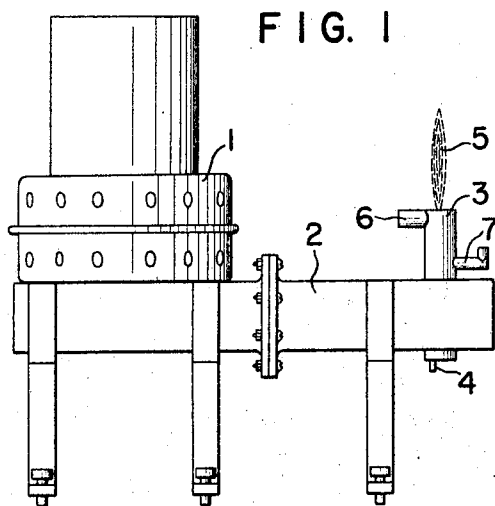
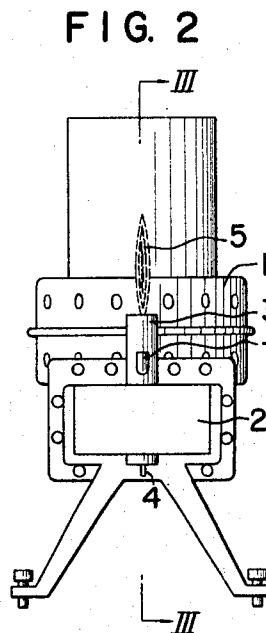
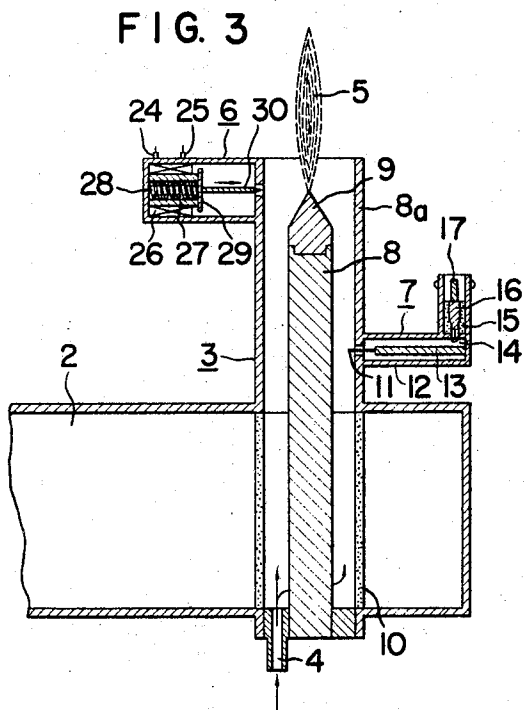
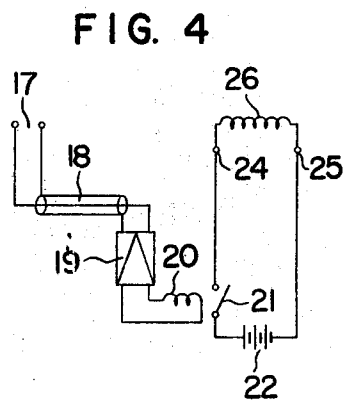
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WITH AN AUXILIARY ELECTRODE

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FIG. 5

The diagram illustrates a vacuum tube radio receiver circuit. Key components include:

- Antenna 23:** Connected to the tuning circuit.
- Tuning Circuit:** Consists of coils 32 and 33, and capacitors 34 and 35.
- Variable Capacitor 31:** Connected to the tuning circuit and an H.F. POWER SOURCE.
- Detector and Amplifier Stage:** Utilizes two vacuum tubes, 40 and 41, with various control and tuning components (36, 37, 38, 39, 42).
- Output Stage:** Connected to a speaker or earphone 50.

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3,353,060

HIGH-FREQUENCY DISCHARGE PLASMA GENERATOR WITH AN AUXILIARY ELECTRODE

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6 Claims. (Cl. 315-111)

ABSTRACT OF THE DISCLOSURE

A high frequency discharge plasma generator provided with a means to detect the state of plasma discharge, in which a probe is inserted in the vicinity of a position where a node or a voltage minimum point is produced in the standing waves generated at the time of no plasma discharge, thereby to detect the existence or non-existence of the discharge plasma in accordance with the amount of current flow in this probe. When the current flows through the probe, it indicates that there exists discharge plasma, and when the current does not flow therein in substantial amount, the discharge plasma is non-existent. This detection means is utilized not only to perform automatic actuation of the discharge plasma but also to protect the plasma from the reflected power of the high frequency power source.

This invention relates to improvements in or relating to so-called high-frequency discharge plasma generators of the type wherein high-frequency power is supplied into an appropriate discharge gas stream to cause high-frequency discharge within this gas stream and thereby to cause ionization of the discharge gas, whereby a jet (plasma flame) of ionized gas at an extremely high temperature is generated.

Since the plasma flame generated by a plasma generator of this type is at an extremely high temperature, it is being widely used in various applications as, for example, a heat source for various manufacturing processes such as cutting, welding, melting, and evaporation depositing of metals, for producing crystals, for various chemical reactions at high temperatures, and for heating specimens in spectroanalysis to cause excitation emission of the specimens.

A high-frequency discharge plasma generator of the above stated type comprises, in principle, a tubular discharge vessel forming a flow passageway for a discharge gas and having at least one end open to the outside air, an electrode member disposed coaxially within the discharge vessel with its discharge tip directed toward the open end of the discharge vessel, whereby an annular flow passageway for the discharge gas is formed between the electrode member and the inner wall of the discharge vessel, means to introduce the discharge gas into said flow passageway and cause the discharge gas so introduced to surround and flow past the discharge tip of the electrode member and then to be ejected from the open end of the discharge vessel into the outside air, and means to supply high-frequency power into the discharge vessel so as to cause high-frequency, high voltage to be induced at the discharge tip of the electrode member.

In the operation of the above described generator, high-frequency, high voltage is induced at the tip of the electrode member, and, under this condition, the discharge gas is introduced continuously so as to surround and flow past the tip of the electrode member. Then, by an appropriate discharge starting method such as causing a

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conductor rod to approach the electrode tip, a high-frequency discharge is caused at the electrode tip, whereupon the discharge gas is ionized by this high-frequency discharge, and a so-called high-frequency discharge plasma is generated. The continuously introduced discharge gas is heated in the plasma to a high temperature and is continuously ionized to become a plasma flame consisting of a dense jet of ionized gas (ions and electrons), which plasma flame is ejected through the open end of the discharge vessel into the outside air.

Known plasma generators of the instant type have had certain deficiencies and disadvantageous features as will be more fully described hereinafter.

It is a general object of the present invention to eliminate these disadvantageous features.

More specifically, a first object of the invention is to provide a new and unique high-frequency discharge plasma generator wherein automatic means are provided to detect the state of discharge whereby the complications of procedure for operation of the generator are greatly reduced.

A second object of the invention is to provide a high-frequency discharge plasma generator wherein automatic means are provided to detect the condition of no discharge and, in response thereto, to shut off power for energizing the high-frequency power source thereby to protect the high-frequency power source.

Other objects and advantages of the present invention will become apparent as the description proceeds.

According to the present invention, briefly stated, there is provided, in a high-frequency discharge plasma generator of the above described type, a coaxial discharge vessel comprising a coaxial wave-guide with at least one end thereof open to the atmosphere and an inner conductor with a tip constituting a discharge electrode at the open end of said coaxial waveguide, and a waveguide for transmitting high-frequency power from the high-frequency power source into the coaxial discharge vessel, and in which type the high-frequency power from the high-frequency power source is supplied through a high-frequency power supply path formed by said waveguide and the coaxial discharge vessel to the tip of said discharge electrode thereby to form a high-frequency discharge plasma extending outwardly from the tip of the discharge electrode, a detection device comprising a probe means inserted into a part of said high-frequency power supply path at which a voltage minimum point or node is produced in the standing waves which are formed when the high frequency discharge plasma is not generated so that electric current flows through said probe means in response to and in accordance with the state of generation of the discharge plasma and means to detect said state in accordance with said electric current.

According to the present invention there is further provided, in the discharge plasma generator of the above stated character, an automatic discharge plasma starting mechanism comprising a conductor rod for starting discharge and means to actuate and cause said conductor rod to retract away from and to approach the discharge electrode in response to the presence and absence of current flowing through the probe means.

According to the present invention there is still further provided, in the discharge plasma generator of the above stated character, a protection system for protecting the high-frequency power source comprising means operating in response to the flow of current in said probe means to cut off input power supply for energizing the high frequency power source.

The nature, principle, and details of the invention will be more clearly apparent from the following detailed description, taken in conjunction with the accompanying

drawings in which like parts are designated by like reference numerals and characters, and in which:

FIGS. 1 and 2 are, respectively, simplified side and front elevational views showing the essential construction of a preferred embodiment of the high-frequency discharge plasma generator according to the invention;

FIG. 3 is a fragmentary elevational view, in section taken along the plane and direction indicated by line III—III in FIG. 2, showing a coaxial discharge vessel and a part of a rectangular waveguide which constitute essential parts of the generator shown in FIGS. 1 and 2;

FIG. 4 is a circuit diagram showing one example of circuit arrangement and composition for accomplishing automatic discharge starting operation;

FIG. 5 is a circuit diagram showing one example of a protection device according to the invention for protecting the high-frequency power source; and

FIG. 6 is a circuit diagram, partly in block form, showing one example of circuit arrangement for automatic control according to the invention.

Referring to FIGS. 1, 2, and 3, the high-frequency discharge plasma generator illustrated therein comprises, essentially, a high-frequency power source 1 including a high-frequency oscillator tube such as, for example, a magnetron, a waveguide 2 constituting a high-frequency power supply path which, in the example illustrated, is a rectangular waveguide, and a coaxial waveguide 3 constituting a discharge vessel and, at the same time, functioning also as a high-frequency power transmission path.

The outer tubular structure of the coaxial waveguide 3 consists of a tubular outer conductor 8_a and a tubular extension 10 made of an electrically insulating material and extending through the rectangular waveguide 2. An inner conductor 8 is disposed coaxially within the outer conductor 8_a and its extension 10 and is provided at its upper end with a discharge electrode 9. The coaxial waveguide 3 is provided at its bottom with a discharge gas inlet 4.

The coaxial waveguide 3 is further provided with a discharge starting mechanism 6, which is positioned near the extreme tip of the discharge electrode 9, and a detecting device 7 for sensing the state of discharge.

The waveguide 2 constituting a high-frequency power supply path is not necessarily a rectangular waveguide, a waveguide of any other shape being suitable provided that it is a nature to operate co-operatively with the coaxial waveguide 3 to supply high-frequency power to the discharge plasma formed at the tip of the discharge electrode 9.

In the operation of this discharge plasma generator, the high-frequency power (from a number of hundreds of mc./sec. to a number of thousands of mc./sec. and from a number of hundreds of watts to a number of kilowatts) from the high-frequency power source 1 is passed through the rectangular waveguide 2 and transmitted into the discharge vessel formed by of the the coaxial waveguide 3 inserted perpendicularly into the rectangular waveguide, whereby a high-frequency current is induced in the inner conductor 8 of the coaxial waveguide 3. This high-frequency current causes a high-frequency electromagnetic field to be established within the coaxial waveguide 3, and a high-frequency, high voltage is induced in the electrode 9 mounted on the extremity of the inner conductor 8.

Then, as an appropriate discharge gas (for example, argon, nitrogen, hydrogen, oxygen, air, helium, city gas, or propane) is introduced through the inlet 4 into the discharge vessel, a conductor rod is caused to approach the tip of the electrode 9 by a discharge starting mechanism 6, which will be described in detail hereinafter, whereupon a high-frequency discharge is started between the conductor rod and the tip of the electrode 9. Once a discharge is started in this manner, it is maintained even when the conductor rod is retracted and moved away from the electrode tip to the original position. The high-

frequency torch discharge so established causes continuous ionization of the discharge gas, and the ionized gas is ejected into the outside air to form a plasma flame 5.

Since the plasma flame 5 thus generated is at an extremely high temperature (from 5,000 to 20,000 degrees C.), it is useful for many applications as hereinbefore enumerated.

In the case when this plasma flame is to be utilized as a heat source for excitation emission of specimens in spectroanalysis, each specimen is first secured to the tip of the electrode 9, or the specimen is prepared as a solution, which is then atomized and introduced, together with the discharge gas, through the inlet 4 into the plasma 5. The specimen thereupon dissociates in the high-temperature plasma 5, and light having line spectra characteristic of the constituent elements of the specimen is emitted. Therefore, by measuring these line spectra, the composition of the specimen can be analyzed.

A conventional generator of the instant type, however, is not provided with the discharge starting mechanism 6 and detecting device 7 for sensing the state of discharge as shown in FIG. 3. Consequently, in starting a discharge, it is necessary for the operator to resort to an extremely complicated procedure which involves manually moving the conductor rod so that it approaches or contacts the tip of the electrode 9 and, after a discharge is started, returning the conductor rod to its original position.

Furthermore, in the case when the discharge is suddenly extinguished by some cause, the load is abruptly removed, and, consequently, there is the risk of the high-frequency power source being damaged. However, there has heretofore been no proposal for means for providing protection against such an occurrence.

The present invention contemplates the elimination of the above described deficiencies and disadvantages.

The invention, in one aspect thereof, provides a new high-frequency discharge plasma generator wherein means are provided for automatic detection of the state of discharge and for automatic starting, maintenance, and stopping of the discharge in accordance with the discharge state thus detected, whereby the complexity of procedure for operating the generator is greatly reduced.

The invention, in another aspect thereof, provides a high-frequency discharge plasma generator wherein means are provided for automatic and prompt detection of the state of no discharge and for automatic stoppage, in response to the state thus detected, of the supply of power for energizing the high-frequency power source, whereby said power source can be protected.

The objects of the present invention can be achieved, in general, by providing, first, a device for detecting the state of discharge in a part of the supply path of the high-frequency power, for example, in a part within the coaxial discharge vessel 3 for causing discharge as shown in FIG. 3, or in a part within the waveguide 2 at which a voltage minimum point of standing waves is formed when there exists no discharge plasma. More specifically, for example, a probe means is inserted at a voltage minimum point of the standing wave generated within the coaxial discharge vessel, when there exists no discharge plasma, and the variation in the electric field strength at that point is sensed thereby to detect the variation in the state of discharge.

The principle on which such means is based is that, within a waveguide for supplying high-frequency power to a high-frequency discharge plasma, that is, within the coaxial discharge vessel, there exist standing waves which are composed of the incident waves and the reflected waves from the open end of the coaxial discharge vessel, and the degree to which the incident waves are reflected varies in accordance with the presence or absence of the discharge plasma. If the probe is inserted at a point, at which a voltage minimum point of the standing waves is formed when there exists no discharge plasma, electric current will seldom flow through the probe until the dis-

charge plasma is generated. When the discharge plasma is generated, the high-frequency power is consumed for the plasma, and the reflection of power at the open end of the vessel is greatly reduced. As a result, an electric field is produced at the position where the probe is inserted, whereby the state of generation of the discharge plasma can be detected. By inserting a probe into the interior of the vessel, the variation in this electric field strength can be detected as a variation in the current flowing through the probe, whereby the state of generation of the discharge plasma can be detected. Of course, the state of generation of the discharge plasma can be similarly detected also when the probe is inserted into the waveguide 2.

According to the present invention, a device for detection of the discharge state based on this principle is used to detect the discharge state, and, in conjunction with automatic control means, automatic control of the state of generation of the discharge plasma and automatic control of power supply to the high-frequency power source are accomplished, as described hereinbelow with respect to a preferred embodiment of the invention.

Referring to FIG. 3, in the coaxial discharge vessel 3 for causing discharge, there exist standing waves (which are composed of the incident waves and the reflected waves), and the degree of reflection of this standing wave varies in accordance with the presence or absence of the discharge plasma 5.

Then, by inserting a probe 11 at a part of the space within the vessel, at which a voltage minimum point of the standing waves is formed when there exists no discharge plasma, and taking out the variation in the electric field strength in the form of variation in the current flowing through this probe 11, it is possible to detect the presence or absence and strength variation of the plasma from this current variation. Furthermore, by sending appropriate signals in response to this current variation, discharging starting operation and protective operation for protecting the high-frequency power source can be caused to take place.

In the example shown in FIG. 3, the detecting device 7 for detection of the discharge state has a coaxial resonator 12 from which a probe 11 is inserted into the space within the discharge vessel. A current flowing through the probe 11 is led to an inner conductor 13 of the coaxial resonator 12 and is then led out through a coupling loop 14 to a crystal diode 16 supported by an insulator 15. The crystal diode 16 rectifies the current into a direct current, which is led out through coaxial output terminals 17.

At the time when power is supplied from the high-frequency source 1, and a high-frequency voltage is impressed on the electrode 9, but a discharge plasma 5 has not yet been generated, the high-frequency voltage is reflected at the open end of the discharge vessel 3, and a standing wave is produced in the space within the vessel 3. As the probe 11 is inserted at a voltage minimum point (or node) of the standing waves formed at the time when there exists no discharge plasma, no current will flow through the probe 11, and, consequently, no output current will flow out of the output terminals 17, until a discharge plasma is generated. Here, the term "voltage minimum point of the standing waves" is meant a point where a node of the standing waves is produced within the discharge vessel 3 when there is no discharge plasma at the open end of the vessel 3. However, even when no discharge plasma exists at the open end of the vessel 3, perfect reflection of the incident wave can hardly occur at this point. Accordingly, in the strict sense, such node is not possibly formed, but the voltage merely becomes minimum at this position. Therefore, in this invention, the term "node" signifies "the voltage minimum point."

Then, when a discharge plasma 5 is generated, the high-frequency power is consumed for this plasma 5, and the reflection of power at the open end of the vessel is greatly reduced. As a result, an electric field is produced at the

position where the probe 11 is inserted, whereby a high-frequency current flows through the probe 11.

This current flows through the inner conductor 13 of the coaxial resonator 12 and excites the resonator 12, whereby a high-frequency electromagnetic field is produced within the resonator 12. This high-frequency electromagnetic field causes a high-frequency current to flow through the coupling loop 14, which current is rectified by the crystal diode 16, whereby a D-C output is obtained at the coaxial output terminals 17.

That is, when the discharge plasma 5 is not being generated, there is no output at the output terminals 17, whereas when the plasma 5 is generated, a D-C output appears at the terminals 17. Therefore, by the presence or absence of this output current, it is possible to detect the presence or absence of the discharge plasma. Moreover, this current can be utilized to accomplish various automatic control operations and operational actuations.

As one example of application of this detecting device 7 for detecting the discharge state, the following description with respect to a specific example of its use for automatic starting of the discharge plasma is presented.

In the example shown in FIG. 3, the discharge starting mechanism 6 consists of an actuating mechanism which operates to move a conductor rod 30 having a needle point toward and away from the tip of the electrode 9. The conductor rod 30 is constantly urged by a spring 28 toward the electrode 9 and is so aligned that its needle point can approach or contact the tip of the electrode 9, and the actuating mechanism is so constructed that the conductor rod 30 is retracted away from the electrode 9 only when a magnetic disk 29 fixed to the conductor rod 30 is attracted by an electromagnet 27 energized by a coil 26 to overcome the force of the spring 28. The coil 26 is supplied with power through excitation terminals 24 and 25.

By this construction and arrangement of the discharging starting mechanism, when, with the conductor rod 30 for starting discharge in its position in contact with or near the electrode 9, a high-frequency voltage is supplied to the tip of the electrode 9 to start a discharge, the electromagnet 27 is immediately excited and retracts the conductor rod 30 away from the electrode 9.

In one example of electrical circuit arrangement as illustrated in FIG. 4 for automatically accomplishing the above described discharge starting operation, there is provided a D-C power source 22 for energizing the exciting coil 26 of the electromagnet 27 for retracting the conductor rod 30 and a relay 20 provided with an on-off switch contact 21 for opening and closing this circuit. The output current of the aforementioned coaxial output terminals 17 of the discharge state detecting device 7 is led through a coaxial cable 18 to the relay 20, which is driven by this current. In the case where the output current from the output terminals 17 is low, an amplifier 19 may be provided as shown.

By this circuit arrangement, the relay 20 is energized when there is an output current from the terminals 17 and closes the contact 21 thereby to cause the electromagnet exciting coil 26 to be energized. That is, when the discharge plasma is not being generated, the relay contact 21 is open. Consequently, the electromagnet 27 is not energized, and the conductor rod 30, being pushed by the spring 28, is caused to be in the vicinity of or is in contact with the electrode 9.

When, with the discharge starting device in the above described state, the high-frequency power source is energized, and a high-frequency, a high voltage is induced at the tip of the electrode 9, a spark jumps between the electrode 9 and the conductor rod 30, and a high-frequency discharge is started. When the discharge plasma 5 is thus generated, a current flows through the probe 11, and the relay operates to cause the electromagnet 27 to be energized, whereby the conductor rod 30 is retracted away from the electrode 9. Once the discharge plasma 5 is

generated in this manner, it is not extinguished even when the conductor rod is withdrawn and is maintained continuously, being aided by the high conductivity of the plasma itself.

When, in stopping the operation of this plasma generator, the generated discharge plasma is to be extinguished factitiously, the supply of high-frequency power from the power source 1 to the discharge vessel is cut off. Simultaneously with the extinguishing of the discharge, the relay contact 21 opens, and the conductor rod 30 is again thrust to its discharge starting position.

At a time other than that of discharge stopping, some sudden occurrence (for example, an abrupt change in the output of the high-frequency power source) may cause an undesired extinction of the discharge. In such a case also, the conductor rod 30 is thrust to its discharge starting position, and the discharge starting operation is automatically repeated. Then, if the generator has returned to its normal state, the discharge plasma will immediately be generated again.

In some cases, the cause of discharge extinction may be of such disruptive nature that the generator cannot easily return to its normal state, and even with repetition of the restarting operation the discharge plasma cannot be generated. For example, a failure may occur in the means for supplying the discharge gas and stop the flow of the discharge gas, or an extreme increase in the gas flow may prevent the discharge from being generated.

In such a case, the high-frequency power source 1 is placed in a state of no load, and the high-frequency power is almost fully reflected and, returning to the power source 1, is transformed therein into heat according to Joule's law. If this state continues for some time, there is the risk of the high-frequency power source 1 suffering damage such as burning out of the heater or melting of the glass parts. According to the present invention, however, the high-frequency power source 1 can be protected against such damage in the following manner.

In one example of the means for protecting the power source 1 according to the invention as illustrated in FIG. 5, the circuit is provided with input terminals 23 to be connected to an A-C power source of commercial frequency, output terminals 31 for high D-C voltage for energizing the high-frequency power source 1 (here assumed to be a magnetron of anode-grounded type), and terminals 17 which are the coaxial output terminals of the aforementioned detecting device 7 for detecting the discharge stage. By this circuit, a high D-C voltage obtained between the terminals 31 is impressed across the anode and cathode of the magnetron (not shown) constituting the power source 1 to energize and cause the power source to operate. This circuit operates in the following manner.

First, A-C input power of commercial frequency is applied continuously to the input terminals 23. For starting, a push-button switch 32 is pressed, whereupon a relay 33 operates to close contacts 34 and 35. The closure of the contact 34 causes the relay 33 to be self-held, and, at the same time, the closure of the contact 35 causes the A-C input to be applied to the primary side of a high-voltage transformer 50, whereby a high D-C voltage output is produced at the terminals 31 to energize the high-frequency power source 1.

Next, when the discharge plasma 5 is generated, a direct-current output is obtained from the coaxial output terminals 17, by which current a relay 36 is energized to close a contact 37 and open a contact 38. The closure of the contact 37 causes a slow-operating relay 39 to operate to close a contact 40, but since the contact 38 is fully opened prior to the closure of the contact 40, no current flows through a relay 41 connected in series to the contact 40, and a contact 42 of the relay 41 remains in the closed state.

The discharge plasma is maintained with the protection circuit in the above described state. However, when the discharge plasma is extinguished by some cause as mentioned hereinbefore, the output from the coaxial output terminals 17 stops, and current no longer flows through the relay 36, whereby the contact 38 closes, and the contact 37 opens.

However, since the relay 39 is a slow-operating relay, the opening of the contact 40 is delayed to an instant subsequent to the closure of the contact 38. Consequently, the relay 41 operates in the period from the closure of the contact 38 to the opening of the contact 40 and opens the contact 42. As a result, the self-held relay 33 is de-energized, and the contacts 34 and 35 open. Therefore, the supply of power to the high-frequency power source 1 is cut off, and the power source is thereby protected from a no-load condition.

When the circuit shown in FIG. 5 is used, since the power source 1 is automatically protected when the discharge is extinguished, it is not necessary to use, additionally, the aforescribed automatic discharge-starting mechanism. When, in the case of the example shown in FIG. 5, it is desired to stop the discharge factitiously, the A-C power to the input terminals 23 is cut off.

While the examples of the invention described above illustrate cases wherein an automatic discharge starting mechanism and a device for protecting the high-frequency power source are used separately, it is possible, of course, to use them together. One example of an automatic control circuit arrangement in this case is illustrated by the circuit diagram shown in FIG. 6.

In this circuit arrangement, there is provided a high D-C voltage generating circuit 43 for receiving A-C input power of commercial frequency and generating a high D-C voltage. This circuit 43 has D-C input terminals 23 connectable to a commercial-frequency power source (not shown) and output terminals 31 for supplying high D-C voltage output which are connected to the anode and cathode of an anode-grounded type magnetron (not shown) constituting the high-frequency power source 1.

The control system of this circuit arrangement shown in FIG. 6 comprises a relay R_A connected to the output terminals 17 and activated by the output thereof, one of its contacts (r_{a1}) being connected to make or break the circuit for energizing the electromagnet coil 26, relays R_B , R_C , R_D , R_E , and R_F connected in parallel across the commercial frequency A-C power supply lines between the input terminals 23 and the circuit 43 and respectively having various contacts described hereinafter, the relays R_C , R_D , and R_E being slow-operating (or time-delay) relays, a motor 44 also connected across said power supply lines, and a rotary disk switch 45 which rotates in coupled relation to the motor 44. This control system operates in the following manner.

First, when the discharge plasma 5 is not being generated, no output is produced at the coaxial output terminals 17 of the discharge state detector 7, and the relay R_A is not energized. Accordingly, the contact r_{a1} of the relay R_A is open, and no current flows through the electromagnet coil 26 connected between the terminals 24 and 25. Therefore, the conductor rod 30 shown in FIG. 3, being pushed by the spring 28, is in a position in the vicinity of the electrode 9. Furthermore, since the relay R_B is also not energized, contact r_{b1} is open, and the high-frequency power source 1, consequently, is not operating. The plasma generator is thus in its inoperative state.

Next, the control system is operated in the following manner when the discharge plasma is to be started. First, a push-button switch 46 is pushed, whereupon the relay R_B is energized to close the contact r_{b1} and, at the same time, to close contact r_{b2} , which is self-held. Consequently, the A-C input of commercial frequency is supplied to the circuit 43, the high D-C voltage output of which energizes the high-frequency power source 1, and

a high-frequency, high voltage is induced at the tip of the electrode 9 shown in FIG. 3.

At this time, since the conductor rod 30 is in the vicinity of the electrode 9, a spark jumps therebetween, and a high-frequency discharge plasma 5 is generated. At this time, of course, the discharge gas is being continuously introduced through the inlet 4 into the discharge vessel.

When the discharge plasma 5 is generated, a current flows through the probe 11, and a D-C output is produced at the coaxial output terminals 17. If necessary, this output current can be amplified by an amplifier 19 and then supplied to energize the relay R_A , which thereupon operates to close its contacts r_{a1} , r_{a2} , and r_{a4} and open contacts r_{a3} and r_{a5} . The closure of contact r_{a1} causes a power supply 22 to energize the electromagnet coil 26, whereby the conductor rod 30 is retracted away from the electrode 9. However, as mentioned hereinbefore, the discharge plasma 5 is maintained constantly.

The closure of the contact r_{a2} causes the slow-operating relay R_C to be energized and to close its contacts r_{c1} and r_{c2} , the relay R_C being self-held by the closure of the contact r_{c1} . In this case, since the relay R_C is a slow-operating relay, the contact r_{c2} closes after the contact r_{a3} has fully opened. Consequently, relay R_D is not energized, and the discharge plasma is constantly maintained with the control system in this state, which will herein be referred to as the "discharge state P_1 ."

When extinction of the discharge plasma due to some cause occurs, the output from the output terminals 17 disappears, and the relay R_A becomes de-energized, whereby all of its contacts r_{a1} , r_{a2} , r_{a3} , r_{a4} , and r_{a5} return to their original positions. That is, contacts r_{a1} , r_{a2} , and r_{a4} open, and contacts r_{a3} and r_{a5} close. The opening of the contact r_{a1} causes the electromagnet coil 26 to be de-energized, and the conductor rod 30 again approaches the electrode 9 to restart the discharge plasma. At this time, the closure of the contact r_{a3} causes the slow-operating relay R_D to be energized to close its contact r_{d1} and be self-held and, at the same time, to close its contacts r_{d2} and r_{d3} .

If, at the time of this restarting of the discharge plasma, the plasma generator has returned to its normal operating state, the discharge plasma 5 is again generated, and the relay R_A is again energized to close its contacts r_{a1} , r_{a2} , and r_{a4} and open its contacts r_{a3} and r_{a5} . The closure of the contact r_{a1} causes the conductor rod 30 to be retracted away from the electrode 9, and, together with the maintenance again of the discharge plasma, the closure of the contact r_{a4} causes the slow-operating relay R_E to be energized to open its contact r_{e1} and close its contacts r_{e2} , r_{e3} , and r_{e4} . The closure of the contact r_{e2} causes the relay R_E to be self-held, and the opening of the contact r_{e1} causes the slow-operating relay R_D to be de-energized, whereby its contacts r_{d1} , r_{d2} , and r_{d3} return to their original positions.

At this time, the relay R_F is not energized since the contact r_{e3} closes after the contact r_{a5} opens, but the closure of contact r_{e4} causes the motor 44 to be driven. Then, if the discharge is maintained in the normal manner, the rotary disk switch 45 rotates in coupled relation to the motor 44 and opens the self-holding circuit of the slow-operating relay R_E , which is thereby de-energized. As a result, contacts r_{e1} , r_{e2} , and r_{e3} return to their original states, and the system returns to the aforementioned discharge state P_1 . In this manner, the starting, maintaining, and restarting of the discharge plasma are automatically accomplished.

On the other hand, in the case when the operational condition of the plasma generator becomes completely abnormal, and when the restarting operation is repeated, the discharge plasma is not generated or is once generated but is immediately extinguished, the relay R_A is de-energized prior to the opening of the self-holding circuit of the slow-operating relay R_E by the disk switch 45, whereby the contact r_{a5} is closed. Consequently, the

relay R_F is energized, and the contact r_f in the power supply line to the circuit 43 is opened. The power supply to the high-frequency power source 1 is thereby cut off, and the power source 1 is thus protected against a no-load state. At the same time, all of the relays are de-energized, and the system circuit is returned to the aforementioned inoperative state.

When, after the cause of abnormal condition in the plasma generator has been removed, the discharge plasma is to be generated anew, the only procedure needed is that of merely pushing the push-button switch 46.

When, unrelatedly to any abnormal operation of the plasma generator, the discharge plasma is to be intentionally extinguished to return the plasma generator to its inoperative state, a power cut-off switching means as, for example, a manually operated switch 47, is opened.

As is apparent from the foregoing description with respect to specific embodiments of the invention, the starting, maintaining, and restarting of the discharge plasma in the plasma generator of the invention are accomplished automatically, and the stopping of the generator can be accomplished in a simple manner. Accordingly, the procedure of operating the generator is greatly simplified, and, moreover, the generated discharge plasma becomes stable.

Furthermore, in the case when an abnormal operational condition occurs in the plasma generator, whereby the discharge cannot be started even by the restarting operation, the power supply to the high-frequency power source 1 is automatically cut off, and the high-frequency power source 1 is thereby prevented from operating continuously under a no-load condition. Accordingly, unexpected damage to the high-frequency power source is prevented, and, at the same time, loss of power is minimized. Therefore, the high-frequency discharge plasma generator according to the present invention is highly advantageous for applications to the various uses enumerated hereinbefore.

It should be understood, of course, that the foregoing disclosure relates to only preferred embodiments of the invention and that it is intended to cover all changes and modifications of the examples of the invention herein chosen for the purposes of the disclosure, which do not constitute departures from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. In a high-frequency discharge plasma generator of the type which has a high-frequency power source, a coaxial discharge vessel comprising a coaxial waveguide with at least one end thereof open to the atmosphere and an inner conductor with a tip constituting a discharge electrode at the open end of said coaxial waveguide, and a waveguide for transmitting high-frequency power from the high-frequency power source into the coaxial discharge vessel, the high-frequency power from the high-frequency power source being supplied through a high-frequency power supply path formed by said waveguide and the coaxial discharge vessel to the tip of said discharge electrode thereby to form a high-frequency discharge plasma extending outwardly from the tip of the discharge electrode, a detection device comprising a probe means inserted into the high-frequency power supply path at a location of minimum voltage of the standing waves produced when no discharge plasma is formed such that electric current flows through said probe means in response to and in accordance with the state of generation of the discharge plasma and means to detect and state in accordance with said electric current.

2. In a high-frequency discharge plasma generator of the type which has a high-frequency power source, a rectangular waveguide for transmitting high-frequency power from said power source, a coaxial discharge vessel passed through the rectangular waveguide with a disposition such that its axis is perpendicular to the axis of the rectangular waveguide and having at least one end open to the outside air, said coaxial discharge vessel having an outer conductor constituting its outer wall and an inner conductor with

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a tip constituting a discharge electrode, and means to cause a discharge gas to flow between said outer conductor and discharge electrode in a manner such as to surround completely at least the tip of the discharge electrode, and in which type a high-frequency discharge plasma extending outwardly from the tip of the discharge electrode is caused to be formed by the high-frequency power supply from the high-frequency power source into the coaxial discharge vessel, a detection device comprising a probe means inserted into the coaxial discharge vessel at a location of minimum voltage of the standing waves produced when no discharge plasma is formed such that electric current flows through said probe means in response to and in accordance with the state of generation of the discharge plasma and means to detect said state in accordance with said electric current.

3. In the high-frequency discharge plasma generator as set forth in claim 1, an automatic discharge plasma starting mechanism comprising a conductor rod for starting discharge and means to actuate and cause said conductor rod to retract from and to approach the discharge electrode in response to the presence and absence of current flowing through the probe means.

4. In the high-frequency discharge plasma generator as set forth in claim 2, an automatic discharge plasma starting mechanism comprising a conductor rod for starting discharge and means to actuate and cause said conductor rod to retract from and to approach the discharge electrode in response to the presence and absence of current flowing through the probe means.

5. In the high-frequency discharge plasma generator as

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set forth in claim 1, a protection system for protecting the high-frequency power source comprising means operating in response to the flow of current in said probe means to cut off input power supply for energizing the high-frequency power source.

6. In the high-frequency discharge plasma generator as set forth in claim 2, a protection system for protecting the high-frequency power source comprising means operating in response to the flow of current in said probe means to cut off input power supply for energizing the high-frequency power source.

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