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INITIATION PROCESS

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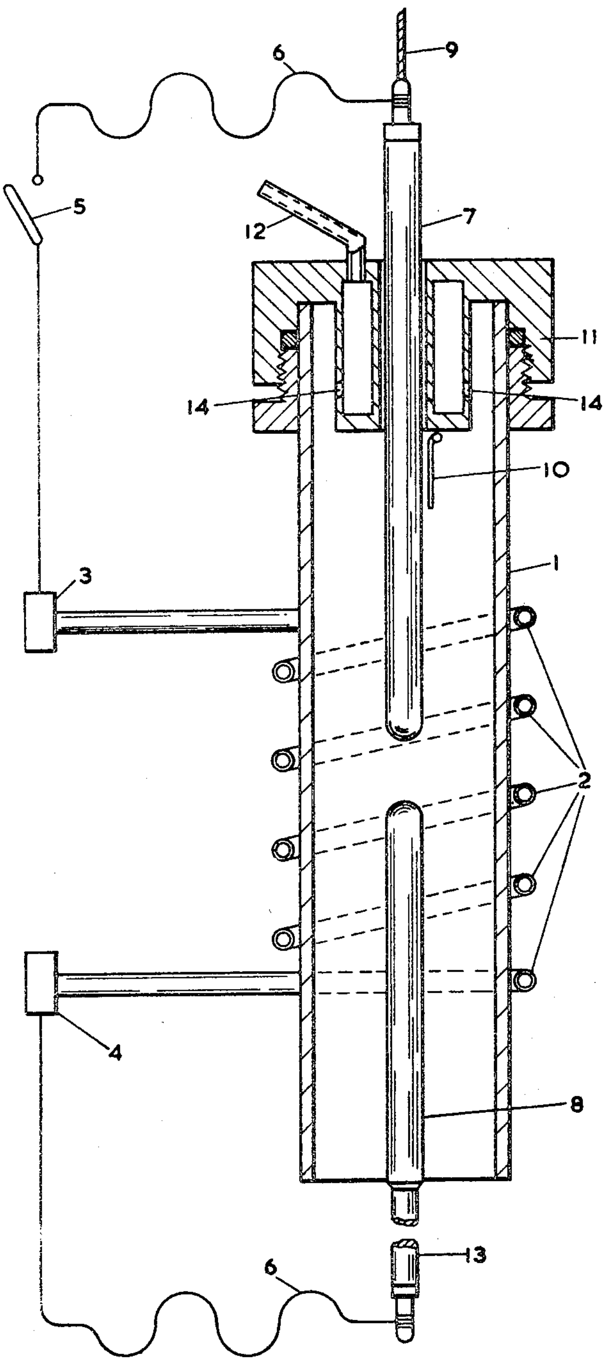

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INITIATION PROCESS

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ABSTRACT OF THE DISCLOSURE

A method of initiating and maintaining a hot gaseous plasma by striking an arc between two electrodes in the gas stream to establish a plasma in the gas and subsequently removing the electrodes while maintaining a plasma by the passage of an oscillatory current around the walls of the tube through which the gas is flowing. The invention also includes apparatus for initiating and maintaining a plasma comprising a pair of electrodes positioned in a tube and moveable therefrom and inlet means for a gas and an electrically-conductive element surrounding a portion of the tube in the region of the plasma.

The present invention relates to an improved method for the initiation of electrically induced gaseous plasmas which is particularly suitable for, but is not limited to, inductively heating a gas by means of an electrical current oscillating at a frequency below about 1 megacycle/second.

Hitherto, the initiation of gaseous plasmas inductively heated by means of an oscillating current of a frequency below about 1 megacycle/second has proved extremely difficult.

One method by which such a plasma may be initiated is described in Nature 211 pp. 841–842 (1966). This method requires the provision of two generators, one of which must be capable of producing an oscillating current having a frequency in excess of about 1 megacycle/second of appropriate power, for example at least about 1 kilowatt, and the other of which produces an oscillating current at the lower frequencies at which it is desired to maintain the plasma.

The output of the generator of the higher frequency current is then connected to the ends of a number of turns of an electrical conductor wound around a gas-confining tube and the output of the generator of the lower frequency current is coupled to the ends of a number of turns of an electric conductor wound around the gas-confining tube downstream (in the direction of plasma-forming gas flow).

The plasma-forming gas is passed through the gas-confining tube; the generators are switched on and a plasma is initiated beneath the turns of conductor coupled to the higher frequency generator by conventional means, for example by the insertion of a rod of conducting material to give the required ion density or by the use of a Tesla coil. The flow of gas is then increased thereby causing the plasma to move down the gas-confining tube until it is established under the turns of the conductor coupled to the lower frequency current. The latter is adjusted to the desired value, if necessary, to maintain the plasma and the higher frequency generator switched off.

It will be appreciated that such a method of initiation is expensive, since, inter alia, it requires the presence of two generators, is time-consuming and requires considerable care in operation to achieve the desired results.

It is an object of the present invention to provide an improved method for initiating and maintaining an inductively-coupled gaseous plasma which is particularly suited for use with oscillating currents having a frequency below about 1 megacycle/second.

According to the present invention a method for initiating the formation of a hot plasma in a plasma-forming gas comprises passing the gas through a gas-confining tube provided with two electrodes, supplying the electrodes with an electric current while passing an oscillating current capable of maintaining inductively a plasma in the gas around the gas-confining tube, forming an arc between the electrodes thereby establishing a plasma in the gas and thereafter disconnecting and withdrawing the electrodes while inductively maintaining the plasma by means of the oscillating current passing around the gas-confining tube.

According to the present invention also apparatus for the initiation and maintenance of a hot plasma in a plasma-forming gas comprises a gas-confining tube, inlet means for said gas, an electrically-conductive element surrounding at least a portion of said tube connectable to a source of oscillatory electric current to maintain a plasma in said gas within said tube, a pair of electrodes moveable to positions within said tube and connectable to a source of electric current to generate an arc between said electrodes in the volume of the tube enclosed by the coil and means to withdraw said electrodes from said volume.

The plasma-forming gas is preferably argon but may, if desired, by another monatomic gas having a low ionisation potential and low energy requirement per unit volume to reach ionisation temperature. Examples of such gases are neon and krypton.

The gas-confining tube is preferably of a non-conducting material, for example silica, but it may be possible to use a tube of an electrically-conducting material, particularly if such a tube has the characteristics described and claimed in our co-pending United States application 506,109 i.e. a tube having a thin wall which is divided longitudinally by electrically insulating material.

The electrodes which are placed within the gas-confining tube are preferably of carbon. It is preferred not to use metals if metallic contamination of the gas-confining tube is to be avoided.

The electrodes are normally introduced into each end of the gas-confining tube. It has been found convenient to introduce the upper electrode through a self-sealing aperture on the underside of the distribution head for the plasma-forming gas, for example through a spring loaded flap or the like. The lower electrode may be introduced through the open end of the gas-confining tube through which the gas heated by the plasma issues.

For ease of operation it has been found advisable to provide mechanical means for withdrawing the electrodes from the tube, once the plasma has been established, for example by means of an electric motor attached by cable or the like to the upper electrode and by means of a rod member or the like to the lower electrode.

The supply of an electric current to the electrodes is normally obtained by connecting the electrodes to the output of the generator which is to supply the oscillatory current to inductively maintain the plasma. Alternatively the electrodes can be supplied from a separate source such as a D.C. generator. Suitable switching gear is provided to disconnect the supply of current to the electrodes, when required.

The output of the oscillating current generator is coupled to an electrically conducting element wound around the gas-confining tube. This element is conveniently a length of copper tube, through which a coolant, for example water, can be passed and the ends of which are adapted to be connected to the source of oscillating current.

There are suitably at least three and preferably at least five turns of the conducting element around the gas-confining tube and the first and/or last turn may be reversed in order to conduct the current in the opposite direction to that of the adjacent coil. This assists in maintaining the plasma within that part of the gas-confining tube beneath the turns of the electrically conducting element. Where the first and last turns are reversed, there should be at least five turns in all.

The normal operation according to the process of the present invention is to introduce the electrodes (the switch in the circuit from the oscillating current generator being in the open position) into the gas-confining tube until the space between them is such that an arc will be formed between them when the power available is switched on. The switch is then closed and the flow of plasma-forming gas is commenced. The generator is then switched on.

An arc is formed between the electrodes and when this is established the electrodes are withdrawn slowly and the power from the generator increased to a value sufficient to ensure that a plasma can be inductively maintained in the gas-confining tube. As the electrodes are withdrawn the arc becomes attenuated and is finally extinguished by opening the switch. It is simultaneously replaced by an inductively heated gaseous plasma.

The electrodes are then finally withdrawn from the gas-confining tube.

When striking and initially maintaining the arc, it has been found convenient to supply the electrodes with current at a frequency in the range 100 kilocycles/sec. to 1 megacycle/sec. and particularly in the range 100 kilocycles/sec. to 300 kilocycles/sec. and a generator power in the range 30 to 50 kilowatts and to maintain the resulting hot plasma with currents of these frequencies and generator powers.

It is, however, equally applicable to the initiation and maintenance of inductively heated plasmas at currents of higher frequency. Such plasmas can, however, be initiated easily by more conventional means and the process of the present invention may be unnecessary in such cases.

One device for carrying out the process of the present invention will now be described by way of example only with reference to the diagrammatic illustration shown in the accompanying drawing.

As shown in the drawing the device consists of a gas-confining tube **1** partly encircled by a coil forming a conducting element **2** the ends of which are connected to output terminals **3** and **4** of an oscillating current generator (not shown) capable of producing an oscillating current of the desired frequency and power. Provision is also made (but not shown) for passing a coolant through the electrically conducting element **2**.

Output terminal **3** is connected via switch **5** and flexible lead **6** to an electrode **7** slidably located axially in the gas-confining tube **1** at its upper end. Output terminal **4** is connected via a flexible lead **6** to electrode **8** axially moveable within tube **1** at its lower end.

The electrode **7** is formed of carbon and to the top is attached a cord **9** by which the electrode can be withdrawn through an axially aligned aperture fitted with a spring loaded flap **10** in the plasma-forming gas distribution head **11**. The head **11** is fitted with a conduit **12** for the supply of gas to the gas-confining tube via holes **14**.

The upper part of electrode **8** is carbon and is mounted on a brass rod **13**. This electrode may be moved manually upwardly and downwardly as desired.

The following example shows one method of carrying out the process of the invention.

Example

An apparatus as described above was set up in which the gas-confining tube **1** was formed of silica and had an internal diameter of 2 inches and a length of 14 inches. The gas distribution head **11** was formed of brass and was provided with 4 holes **14** each having a diameter of $\frac{3}{16}$ inch equidistantly spaced around the circumference.

The carbon electrodes each had a diameter of 0.5 inch.

$5\frac{1}{2}$ turns of $\frac{3}{16}$ inch diameter copper tube formed the coil around the gas-confining tube and cooling water was passed through this at a rate of 4 litres/minute.

Argon was supplied to the distribution head through conduit **12** at a rate of 70 litres/minute.

With the switch **5** in the open position, the position of the electrodes was adjusted so that a gap of $\frac{1}{8}$ inch was left between them and the generator adjusted to provide a current at a frequency of 200 kilocycles/second.

The switch **5** was closed and the generator started, thus forming an arc between the electrodes **7** and **8**. The electrodes **7** and **8** were then slowly withdrawn from each other and the plate power of the generator was increased to 30 kilowatts at a frequency of 200 kilocycles/second.

Finally, the arc was broken by opening the switch **5** and the inductively coupled plasma was thereby initiated and maintained. The electrodes **7** and **8** were withdrawn from the gas-confining tube **1** (thereby allowing the spring loaded flap **10** through which the electrode **7** had passed to close).

The hot gaseous plasma was thereafter maintained without difficulty.

What is claimed is:

1. A method of initiating the formation of a hot plasma in a plasma-forming gas which comprises passing the gas through a gas-confining tube provided with two electrodes, supplying the electrodes with an oscillating electric current while passing an oscillating electric current capable of maintaining inductively a plasma in the gas around the gas-confining tube, said oscillating electric current having a frequency of 100 kilocycles per second to 1 megacycle per second and a generator power of from 30 to 50 kilowatts, forming an arc between the electrodes and withdrawing and disconnecting the electrodes to break the arc and to establish a plasma in the gas, the plasma being inductively maintained by means of the oscillating current passing around the gas-confining tube.

2. A method according to claim **1** in which the frequency is from 100 kilocycles per second to 300 kilocycles per second.

3. A method according to claim **1** in which after formation of an arc between the electrodes the power of the oscillating current is increased to a value sufficient to maintain the plasma while the electrodes are withdrawn from the tube and prior to extinguishing the arc.

4. A method according to claim **1** in which the gas is a monatomic gas.

5. A method according to claim **4** in which the monatomic gas is argon.

6. A method according to claim **1** in which the electrodes are introduced one at each end of the gas-confining tube.

7. Apparatus for the initiation and maintenance of a hot plasma in a plasma-forming gas comprising a gas-confining tube, inlet means for said gas, an electrically-conductive element surrounding at least a portion of said tube connectable to a source of oscillatory electric current to maintain a plasma in said gas within said tube, a pair of electrodes moveable to positions within said tube and connectable to a source of electric current to generate an arc between said electrodes in the volume of said tube enclosed by the element and means to withdraw said electrodes from said volume.

8. Apparatus according to claim **7** in which the electrodes are formed of carbon.

9. Apparatus according to claim **7** in which the electrodes are introduced one at each end of said tube which is mounted substantially vertically.

10. Apparatus according to claim **7** in which the gas-confining tube is fitted with a gas-distribution head at one end having an axially aligned aperture fitted with sealing means adjacent the interior of the tube.

11. Apparatus according to claim **10** in which one of said electrodes is moveable within said aperture to extend into said tube.

12. Apparatus according to claim **10** in which the sealing means is a spring loaded flap.

13. Apparatus according to claim **11** in which the means to withdraw the electrode comprises a cable.

14. Apparatus according to claim **11** in which the other electrode is introduced into the tube at the other end and is carried by a moveable rod member.

15. Apparatus according to claim **7** in which the electrically-conductive element is a coil wound round a portion of the gas-confining tube.

16. Apparatus according to claim **15** in which the coil is formed of copper tube.

17. Apparatus according to claim **16** in which the coil has at least three turns around the gas-confining tube.

18. Apparatus according to claim **17** in which the coil has at least five turns around the gas-confining tube.

19. Apparatus according to claim **7** in which the source of oscillatory electric current is connected through switch means to the electrodes and also to said electrically-conductive element.

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