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United States Patent [19]

Goucher

[11] **3,838,242**

[45] **Sept. 24, 1974**

[54] **SURGICAL INSTRUMENT EMPLOYING ELECTRICALLY NEUTRAL, D.C. INDUCED COLD PLASMA**

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[73] Assignee: **Hogle-Kearns International**, Salt Lake City, Utah

[22] Filed: **May 25, 1972**

[21] Appl. No.: **256,714**

[52] **U.S. Cl.** .... **219/121 P**, 128/303.1, 219/75, 219/69 S, 313/231

[51] **Int. Cl.** **B23k 9/04**

[58] **Field of Search** .... 219/121 P, 75, 69 S; 128/303.1, 303.14; 315/111; 313/231

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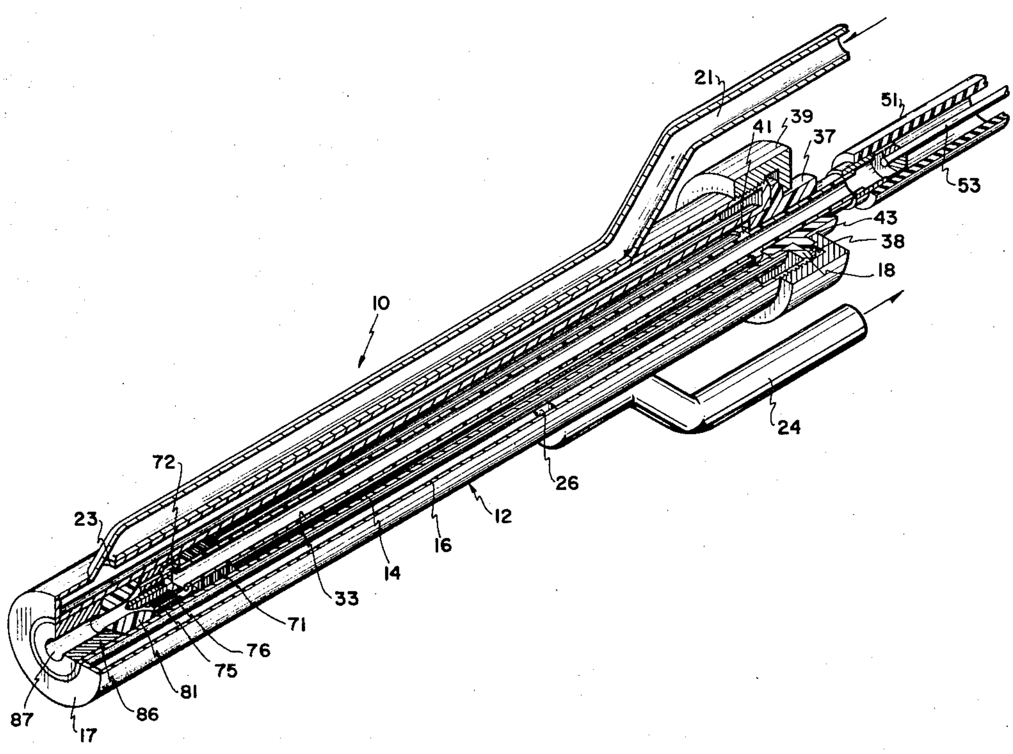
Primary Examiner—Bruce A. Reynolds
Attorney, Agent, or Firm—David V. Trask; Richard F. Bojanowski

[57] **ABSTRACT**

A surgical instrument (plasma scalpel) generates an electric field plasma in a carrier gas for cutting and/or cauterizing tissue. The instrument includes a tubular conductor for carrying both current and gas to an anode. The gas flows from the tubular conductor, around the surface of an anode, and thence through an annular cathode. The electric field between the anode and cathode excites the gas to a plasma state, and the excited gas then flows in a directed stream through the cathode and out the end of the instrument. The tubular conductor is surrounded by a cooling jacket which concomitantly serves as an electrical conductor to the cathode. A dielectric sheath may be provided over the cooling jacket. This sheath may be overlaid with a conductive skin connected to earth ground to prevent an excessive electric charge from accumulating thereon. The conductive skin is preferably grounded through a circuit breaking device to cut off all power to the instrument if the potential of the skin differs greatly from the potential of the cathode.

11 Claims, 6 Drawing Figures



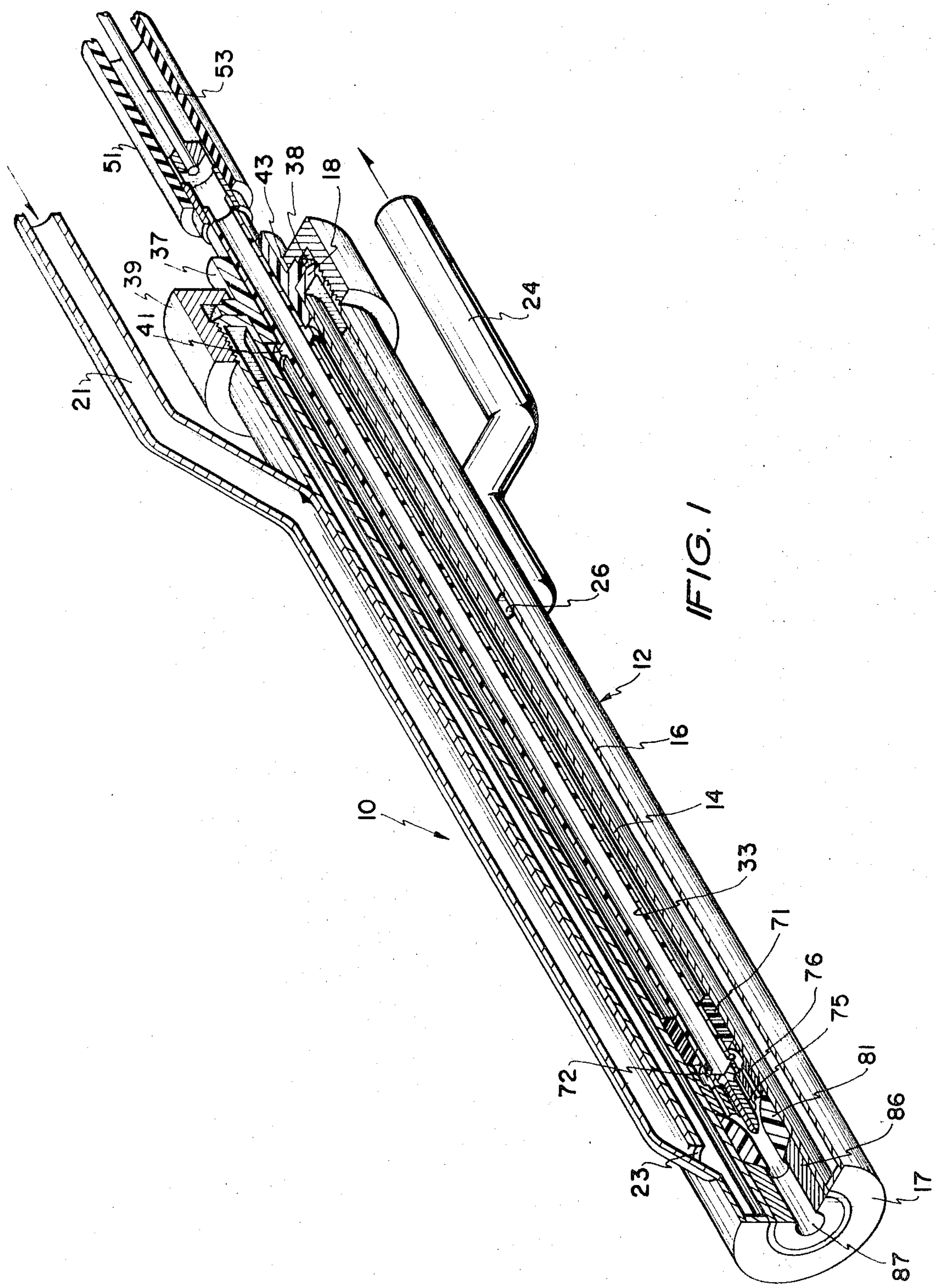

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FIG. 1

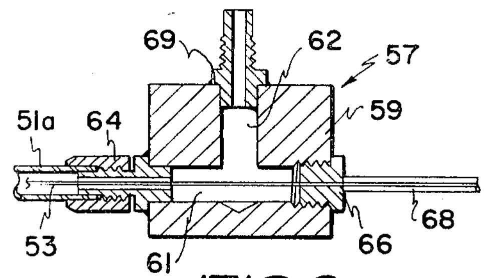

FIG. 6

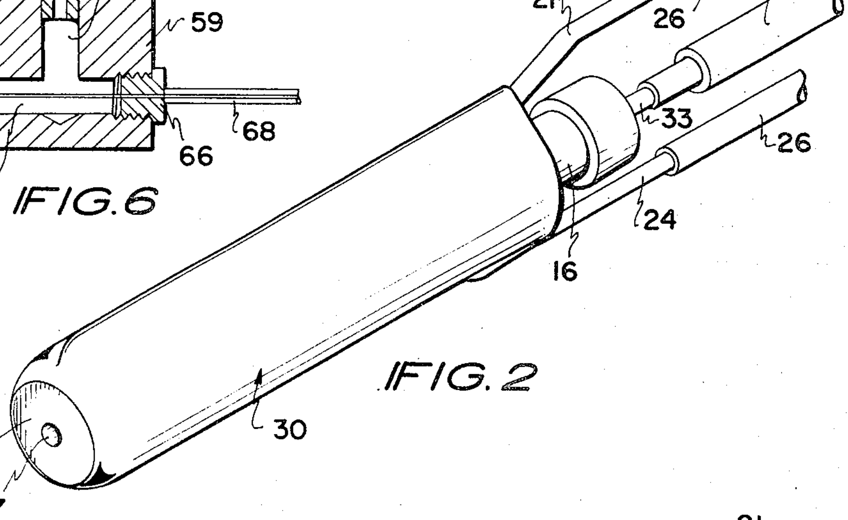

FIG. 2

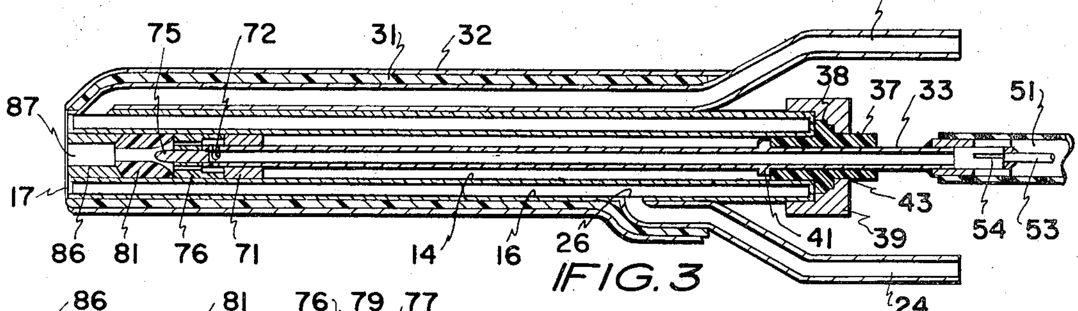

FIG. 3

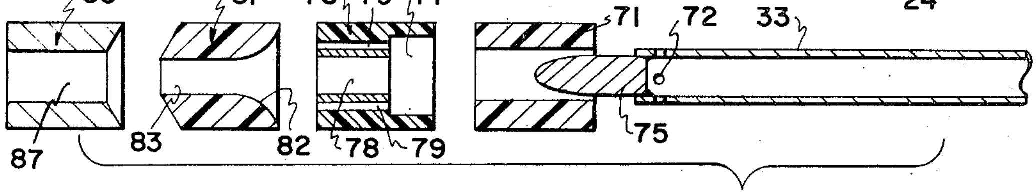

FIG. 4

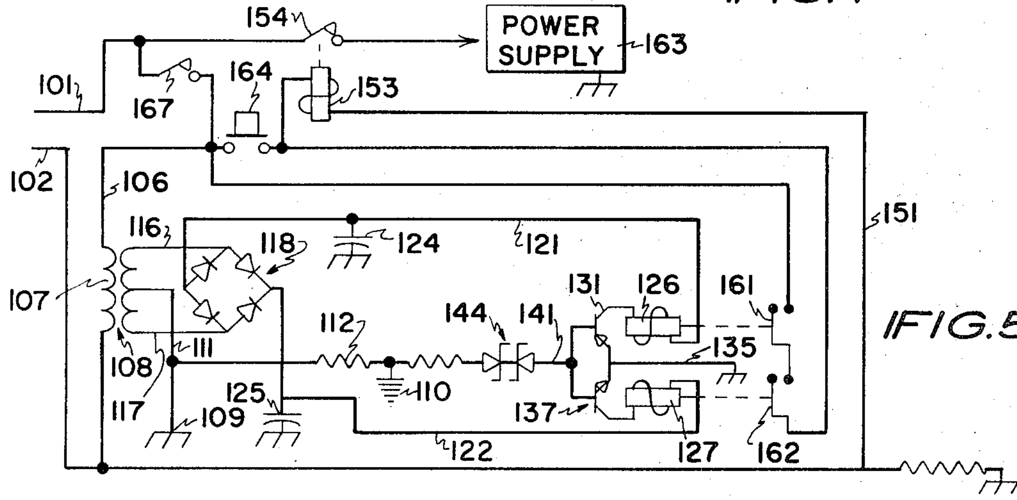

FIG. 5

SURGICAL INSTRUMENT EMPLOYING ELECTRICALLY NEUTRAL, D.C. INDUCED COLD PLASMA

RELATED APPLICATIONS

Commonly assigned, copending application Ser. No. 79,840, filed Oct. 12, 1970, now abandoned, discloses and claims methods and apparatus for plasma surgery. According to that application, a cold plasma is established and attenuated to a small cross section. This plasma is applied to tissue to produce an incision. Commonly assigned, copending application Ser. No. 253,494, filed May 15, 1972, claims the additional discovery that an electrically neutral, D.C.-induced cold plasma is especially useful for surgical applications, and discloses surgical apparatus suitable for producing such a plasma. The present application discloses such apparatus more fully and claims the same.

BACKGROUND OF THE INVENTION

1. Field

This invention relates generally to plasma scalpel devices which emit a flow of plasma for cutting or cauterizing tissue. It is specifically directed to such a device particularly useful for producing electrically neutral, D.C.-induced plasmas.

2. State of the Art

The use of D.C. arc plasma for surgery is suggested by U.S. Pat. No. 3,434,476, which discloses and claims apparatus intended for use as a surgical scalpel. The apparatus thus disclosed is apparently incapable of producing plasmas which are not substantially at thermal equilibrium. This instrument is reported to be unsafe for actual clinical use because it tends to char tissue. It is recognized in the disclosure of the aforementioned application Ser. No. 79,840 that plasmas of metastable noble gas are preferred for surgical applications. The apparatus there disclosed produces rf-induced plasmas which, although cold, are not electrically neutral.

As used hereinafter, the term "cold plasma" includes all plasmas which evidence a low wall-heating effect, whether or not such plasmas exhibit the appearance and/or other physical characteristics normally associated with the specific cold plasmas and glow discharge phenomena heretofore recognized in the art. The term refers generally to plasmas in substantial thermal nonequilibrium; i.e., those which exhibit a much lower tactile or gas temperature than the temperature equivalent of the energy level of the free electrons in the plasma.

SUMMARY OF THE INVENTION

The present invention provides a surgical instrument capable of producing electrically neutral, D.C.-induced cold plasmas in a form suitable for surgical applications. The instrument includes, inter alia, an elongate body in which is disposed a conduit made of electrically conductive material. The conduit concurrently serves to carry an electric current and a stream of surgical gas to an anode near the forward end of the instrument. The carrier gas passes around the anode, through a constrictor nozzle and then through an annular cathode which is fixed coaxially with respect to the anode to the forward end of the instrument. The electric field established between the anode and cathode generates plasma in the carrier gas which leaves the annular cathode in a directed stream. A cooling jacket surrounds the conduit and serves concomitantly as an electrical conductor to the cathode. Means are provided to convey cooling liquid into and from the jacket. In one embodiment of the invention, a sheath which includes a dielectric lining overlaid by a metallic skin is provided over the cooling jacket. A safety circuit may be connected to the skin to prevent the development of excessive potential differences between the cathode and the outer skin.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention may be better understood by referring to the following description and appended drawings which are offered by way of illustration and not in limitation of the invention, the scope of which is defined by the appended claims and equivalents. Specific reference herein to details of the illustrated embodiment is thus not intended to restrict the scope of the claims, which themselves recite those features regarded as essential to the invention.

In the drawings:

FIG. **1** is a pictorial view, partially cut away and in section, of a preferred embodiment of the plasma scalpels of the invention;

FIG. **2** is a pictorial view of the scalpel of FIG. **1** slightly modified;

FIG. **3** is a side view in section of the scalpel shown in FIG. **2**;

FIG. **4** is an exploded detail, in section, of structure at the forward end of the scalpel of FIGS. **1, 2** and **3**;

FIG. **5** is a schematic diagram of a safety circuit for use with the scalpel of FIGS. **2** and **3**; and

FIG. **6** is a detail in cross section of a connector for use with the illustrated instruments.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The illustrated instrument **10** has an elongate body comprising a cooling jacket generally designated **12** in which water or other cooling liquid is circulated. The illustrated jacket **12** is a tube-within-a-tube arrangement having a cylindrical inner wall **14** spaced coaxially from a cylindrical outer wall **16** by respective, radially extending end walls **17** and **18.** Together, the walls define an enclosed annular space. Preferably, the walls of the jacket are made of an electrically conductive material.

An inlet conduit **21** connects into the jacket at an aperture **23** formed through the outer wall **16** near the forward end of the instrument, and an outlet conduit **24** connects into the jacket through an aperture **26** near the rear of the instrument. Cooling liquid flows through the inlet conduit **21** into the jacket, thence circulates the length of the jacket before exiting therefrom via outlet conduit **24.** The flow direction is indicated by the arrows in FIG. **1.** Preferably, the conduits **21, 22** are rigid. Flexible tubes **26** (shown in FIG. **2**) may be connected to the distal ends of the conduits so that the instrument can be freely moved about.

FIGS. **2** and **3** illustrate a configuration of the instrument with an insulating sheath **30** secured about the cooling jacket **12.** The sheath is connected to chassis or earth ground and is isolated from the cathode which is normally at D.C. ground potential. Such isolation is desirable because it is possible for the D.C. ground potential to shift significantly from chassis ground potential. The most likely discharge path in that event would be through the body of either the surgeon or the patient. Aside from the sheath, the instrument shown in FIGS. 2 and 3 is identical to that shown in FIG. 1. The sheath 30 may include a dielectric lining 31 overlaid with a metallic skin 32. The skin 32 provides a protective cover which is readily sterilized for antiseptic use. The dielectric lining 31 may be heat-shrinkable plastic fitted to the cooling jacket as shown. The metallic skin 32 may comprise one or more coatings of metal applied by well-known dipping, spraying or electroplating techniques. The outer surface of the skin is desirably of nickel or similar metal acceptable for hospital use.

Ordinarily, the grounded metallic skin of the sheath provides adequate protection against accidental discharges. Nevertheless, the safety circuit of FIG. 5 is desirably incorporated in the power supply for the scapel. This circuit automatically shuts off the power supply and connects the D.C. and chassis grounds in response to shifts in their relative potentials. The hazards of sparking and shocking are thereby eliminated.

The particular configuration of the sheath is of no consequence so long as the instrument can be firmly held. However, the overall shape and dimensions of the instrument are important. The utility and acceptance of any surgical instrument depends largely upon the facility with which it can be manipulated by a surgeon. An important aspect of the presently claimed instrument is that it can be constructed on a scale comparable to an ordinary scalpel, yet generate a reliable and controllable plasma suitable for surgical use.

Preferably, both cylindrical walls of the cooling jacket 12 serve as conductors for carrying an electric current to the cathode 86 of the instrument. However, the term "cathode conductor" as used hereinafter particularly refers to the inner cylindrical wall 14. This cathode conductor, in turn, coaxially surrounds a metallic tube 33 which carries an electric current to the anode 75 of the instrument. This metallic tube 33 is referred to hereinafter as the anode tube or anode conductor. The cathode conductor is insulated from the anode conductor, and together the two conductors comprise a coaxial electrical line. In the illustrated embodiment, the conductors are finitely spaced apart and air therebetween effects an electrical insulation.

A bushing-like insulator member 37 made of dielectric material is fitted around the anode tube 33 and spaces it from the cathode conductor 14 at the rear of the instrument. The bushing 37 has a circumferential shoulder 38 of greater diameter than the cathode conductor 14 abut the end of that conductor. The anode tube includes an integral collar 41 which abuts the forward end of the bushing 37. A cap 39 is threaded or otherwise releasably fixed over the rear of the jacket 12 and has a central aperture 43 formed therethrough which is of such size as to allow the end of the anode conductor and a portion of the bushing 37 to extend therethrough. The shoulder 38 of the bushing is, however, clamped between the rear of the jacket 12 and the cap 39. Consequently, the cap secures in position the bushing, which in turn abuts the collar 41 to prevent the anode conductor from slipping rearward.

The cap 39 is made of an electrically conductive material and serves as a lead to the cathode conductor. An electrical wire, not shown, connects the cap to D.C.

ground potential. The cap 39 is insulated from the anode conductor by the bushing 37.

While the wall of the anode tube 33 conducts an electric current to the anode of the instrument, the interior of the tube provides a closed channel for carrying a stream of gas to the tip of the instrument. The gas is supplied to the tube through a flexible hose 51 fitted to its rearwardly protruding end, entering through side ports 54. The hose houses a current-carrying wire 53 which may or may not be insulated. The wire 53 is connected, e.g., by soldering, to the wall of the anode tube 33.

The emote end 51a of the hose 51 is connected to a gas supply source (not shown) by connector assembly generally designated 57 in FIG. 6. THe connector includes a rigid block 59 having intersecting channels 61 and 62 formed therein. The end of the hose 51 is connected into channel 61 by a threaded adapter 64. The wire 53 extends through the channel 61 to another adapter 66 for connection to a power source (not shown) through an insulated wire 68. A fitting 69 leads from the connector block 59 to the gas source. The connector block may, of course, be electrically insulated from both the power source and the gas source.

Referring to the instrument proper 30, the forward end of the anode tube 33 is spaced from the inner wall of the jacket by an annular spacer 71 (see especially FIG. 3) made of insulating material. The spacer lies wholly somewhat behind the forward end of the anode tube and effects a seal between the anode tube and the inner wall of the jacket 12 to prevent gas which leaves the anode tube from flowing back into the instrument. The spacer may be epoxied or otherwise fixed to the anode tube. Ahead of the spacer 71, the wall of the anode tube is perforated and gas carried inside the tube can escape therefrom through the perforations 72.

An electrically conducting tip 75 is secured to the forward end of the anode tube and is, in fact, the anode of the instrument. Preferably, this tip prevents gas from exiting out the anode tube end and, consequently, the total gas flow is out the perforations 72 in the tube wall.

A cylindrical, gas entry member 76, which is formed of a dielectric material, is fitted around the anode 75. The gas entry member 76 insulates the carrier gas from the inner wall of the jacket, and holds the anode in proper position with respect to the flowing gas. Accordingly, the member 76 has an enlarged central recess 77 formed in its rearward end; an axial channel extends from the recess to the forward end of the member and closely surrounds the anode 75. With the instrument assembled, the rearward end of the member 76 abuts the forward end of the spacer and the recess 77 forms a small plenum for the gas flowing out of the anode tube 33. A plurality of gas ports 79 extend from the recess to the forward face of the member 76 and carry substantially all of the gas to the tip of the anode 75. These gas ports 79 are desirably formed to impart a helical movement to the gas exiting therefrom.

Ahead of the member 76, but still within the jacket, is a cylindrical constrictor or nozzle entry section 81. The constrictor is preferably made of dielectric material, such as boron nitride, and includes a converging axial channel 82. This channel surrounds the tip of the anode, and communicates, at its enlarged end, with the gas ports in the cylindrical member 76. The wall of the converging channel maintains the gas which flows from the ports insulated from the inner wall **14** of the cooling jacket. The anode extends into, but not all the way through, the channel **82.** Gas passing the anode **75** enters a nozzle throat portion **83** of the constrictor section **81.**

Abutting the forward end of the constrictor is the cathode **86** of the instrument. The cathode is annular and fits within (i.e., is surrounded by) the inner wall **14** of the cooling jacket **12.** The cathode may be brazed or otherwise fixed to the jacket to make a good electrical connection therewith. The orifice diameter **86** of the cathode is somewhat larger than the throat **83** of the constrictor member **81** and functions as a nozzle exit. As shown, the cathode **86** desirably terminates at the end wall **17** of the cooling jacket.

The anode tube **33** is prevented from slipping forward in the instrument by the above-described structure. That is, the spacer **71** is fixed to the anode tube and presses, via member **76** and constrictor **81,** against the cathode **86** which is fixed to the cooling jacket. As previously described, however, the anode tube is readily removable from the rear of the instrument by releasing the cap **39.**

In operation, a direct current (D.C.) voltage source (not shown) is connected to the instrument. The positive terminal of the source is connected to the anode lead wire **53** and the negative terminal (or ground) is connected to the cap **39.** Initially, a current flows to the anode **75** and away from the cathode **86,** but because the anode is spaced apart from the cathode, the current flow stops once the potential drop across these electrodes equals the potential of the D.C. source. Concurrently, gas is delivered to the instrument through the hose **51.** A typical gas flow is 1.0 CFH (STP). The gas flows through the anode tube **33** to its forward end thence escapes through the perforations into the plenum **77.** From the plenum the gas flows through the gas ports **79** into the entry section **82** of the nozzle (**81** and **86**).

The voltage of the source is increased until the ionization potential of the gas is exceeded. The gas then "ignites;" i.e., it is transformed into a plasma state under the influence of the potential difference between the anode and the cathode. The plasma exits the orifice **87** of the cathode **86** in a directed jet stream. The characteristics of the plasma produced by the claimed instrument depend upon the amount of current available to it from the source. Increasing the power applied to the gas results in very small increases in the voltage drop across the plasma but correspondingly large increases in the current carried by plasma until the critical arcing level is exceeded; i.e., the power level at which the plasma converts to a "hot" plasma (at substantial thermal equilibrium). A notable characteristic of the claimed instrument is the ease with which the character of the plasma may be controlled. The arrangement of the annular cathode with respect to the anode assures an electrically neutral plasma, which is beneficial for surgical use. Cathodes of copper, tungsten or alloys thereof are generally satisfactory. A satisfactory anode material is nichrome wire.

The electric field between the anode and cathode produces a certain amount of heat. The cooling liquid which circulates through the jacket **12** as previously described effectively removes such heat. Accordingly, the instrument is at all times comfortable to touch. Usually, the cooling liquid is ordinary tap water.

The safety circuit of FIG. **5** prevents a large net electric charge with respect to D.C. ground potential from building on the metal skin of the sheath of the instrument. Lines **101** and **102** are the usual 120 volt A.C. lines leading to a conventional transformer (not shown) which generates the voltage supplied to the instrument. A connection is made by line **106** from line **101** to line **102** through the periphery winding **107** of a conventional transformer **108.** The secondary winding of the transformer **108** is connected to chassis ground at **109** by center tap line **111,** and to D.C. ground return **110** through a high value resistor **112.** The output lines **116** and **117** of the secondary winding are connected to a conventional full wave bridge rectifier **118** which converts the alternating current in the secondary to a direct current across the bridge output lines **121** and **122.** Preferably, the potential across the lines **121** and **122** is about **16** volts. Grounded capacitors **124** and **125** may be connected to the output lines **121** and **122,** repsectively, to smooth the output voltage.

Each of the lines **121** and **122** lead to ordinary solenoids (**126** and **127**) respectively; when the voltage is held constant, the solenoids are inactive. Line **121** leads from solenoid **126** to the collector of an ordinary PNP transistor **131.** The emitter of that transistor is common to chassis ground (via line **135**) and to the emitter of an ordinary NPN transistor **137.** The collector of this second transistor **137** connects to the output line **122** coming from the solenoid **127.** The two transistors are connected in common-emitter, base-input arrangement so that the current which the transistors conduct is readily controlled by the potential applied between the transistors' common base and emitter leads **134, 135.**

The emitter lead **135** is at chassis potential. The base lead **141** is ordinarily at ground or zero potential; it connects through series opposed zener diodes **144** and **146** (having, for example, about 5 volt values) to a relatively small resistor, which is connected in series with the D.C. ground return **110.** Ordinarily, the series opposed zener diodes do not conduct current in either direction. However, if the potential difference between chassis ground and D.C. ground exceeds the zener breakdown point, as when a large net charge accumulates on the skin of the sheath, a current flows through the diodes. When such a current flows, it causes the transistor output to vary considerably. Accordingly, the current through the respective solenoids **126** or **127,** depending upon the polarity of the accumulated charge, changes and one or the other of the solenoids acts to break the power supply circuit, as hereinafter explained.

A line **151** is connected across the 120 volt A.C. lines **101** and **102** to control solenoid **153.** That solenoid, in turn, can move to actuate a switch **154** in the main line **101.** Ordinarily, the solenoid **153** retains the switch closed so that current flows through line **101.** Two switches **161** and **162** are connected along line **151** (as indicated by the dotted lines) to the solenoids **126** and **127.** Ordinarily, those solenoids allow the switches **161** and **162** to remain closed so that current flows through line **151.** However, when the output current of the transistors changes due to a base current in the transistors **131** and **137,** at least one of the solenoids is activated and opens the switch to which it is connected. In that event, line **151** becomes an open circuit and solenoid **153** is released and opens the switch **154** whereupon the source of power for the power supply **163** is cut.

To reset the safety circuit, a button or switch **164** is closed which short-circuits the two switches **126** and **127.** Solenoid **154** is thus energized to close switch **154.** A manual switch **167** may also be provided in line **151** to selectively manually cut the current in the line **101.**

I claim:

1. A surgical instrument for generating an electrically neutral, D.C.-induced, cold plasma, comprising:

an elongate body member with a hollow interior;

nozzle means contained within and at the forward end of said body member, said nozzle means including a nonconductive entry portion, a nonconductive throat portion and a conductive exit portion formed as an annular cathode element;

conductor means for connecting said cathode element to the negative side of a D.C. power supply;

gas supply means extending from communication with said entry portion of said nozzle, through said hollow interior and out the rearward end of said body member for connection to a source of gas;

anode means fixed to the forward end of said gas supply means and disposed within said entry portion of said nozzle in coaxial arrangement with said cathode such that gas delivered to the gas supply means flows around said anode, through the nozzle, and out through the cathode; and

conductor means for connecting said anode to the positive side of a D.C. power supply.

2. An instrument according to claim **1,** wherein said gas supply means includes a tube made of electrically conductive material, means are provided to electrically insulate said tube from said body, and the wall of said tube serves as the conductor means for connecting said anode to said power supply.

3. An instrument according to claim **1,** wherein said body comprises an annular cooling jacket and including means for delivering cool liquid thereinto and for removing warmed liquid therefrom.

4. An instrument according to claim **3,** wherein said cooling jacket is made of electrically conductive material and serves as conductor means for connecting said cathode to said power supply.

5. An instrument according to claim **4,** wherein said gas supply means includes a tube made of electrically conductive material, means are provided to electrically insulate said tube from said body, and the wall of said tube serves as the conductor means for connecting said anode to said power supply.

6. An instrument according to claim **5,** wherein said anode forms a closure at the end of said tube and perforations are formed through the wall of said tube behind said anode so that carrier gas is forced through said perforations and said perforations are disposed within a gas entry element abutting the entry portion of said nozzle and openly communicating therewith.

7. An instrument according to claim **6,** wherein the gas entry element includes a plenum chamber in open communication with said perforations and longitudinal parts openly connecting said plenum chamber with said entry portion of said nozzle.

8. An instrument according to claim **5,** wherein a protective sheath is provided about said electrically conductive cooling jacket and said sheath includes a lining of dielectric material.

9. An instrument according to claim **8,** wherein said protective sheath further comprises a metallic skin which is fixed over said dielectric lining and is insulated thereby from said jacket.

10. An instrument according to claim **9,** wherein said skin is connected to earth ground.

11. An instrument according to claim **10,** wherein said skin is connected to ground through a safety circuit, the elements of said circuit being actuated by differences in potential between earth ground and the cathode to cut the supply of electric power to said instrument.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,838,242 Dated September 24, 1974

Inventor(s) Robert G. Coucher

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 4, line 13, change "emote" to --remote--;

Col. 4, line 26, insert "again" after the word referring;

Col. 4, line 15, change "THe" to --The--;

Col. 5, line 12, change "86" to --87--;

Col. 6, line 10, change "periphery" to --primary--;

Col. 6, line 22, change "repsectively" to --respectively--.

Signed and sealed this 7th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents