March 25, 1969 R. F. SHAW ET AL **3,434,476**

PLASMA ARC SCALPEL

Filed April 7, 1966 Sheet 1 of 2

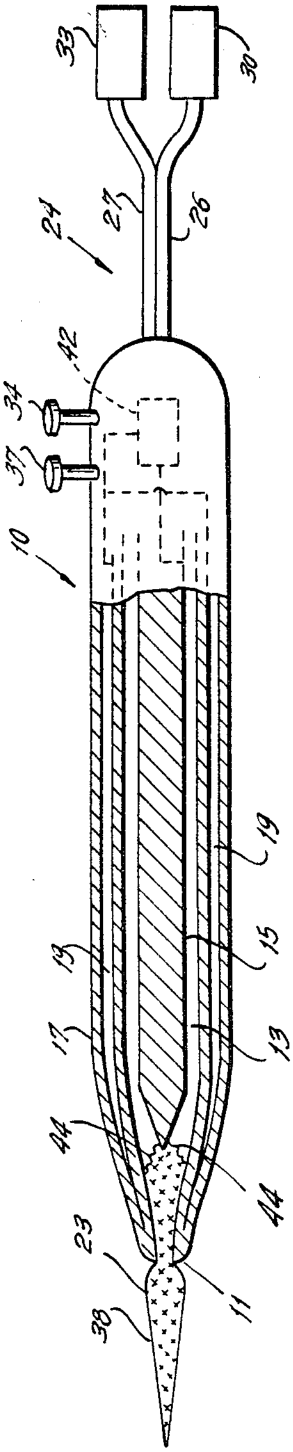
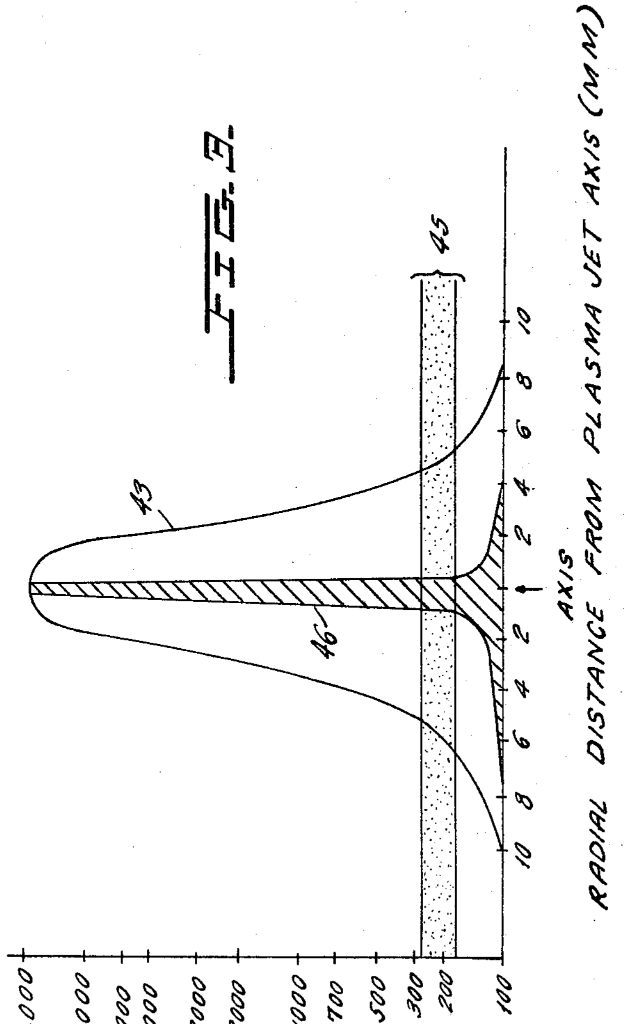


FIG. 1



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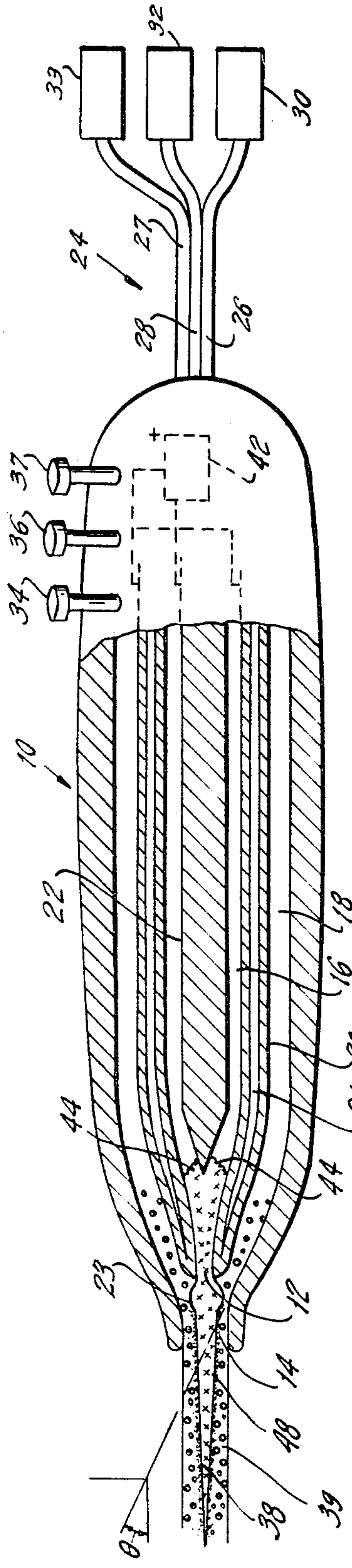
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FIG. 2.

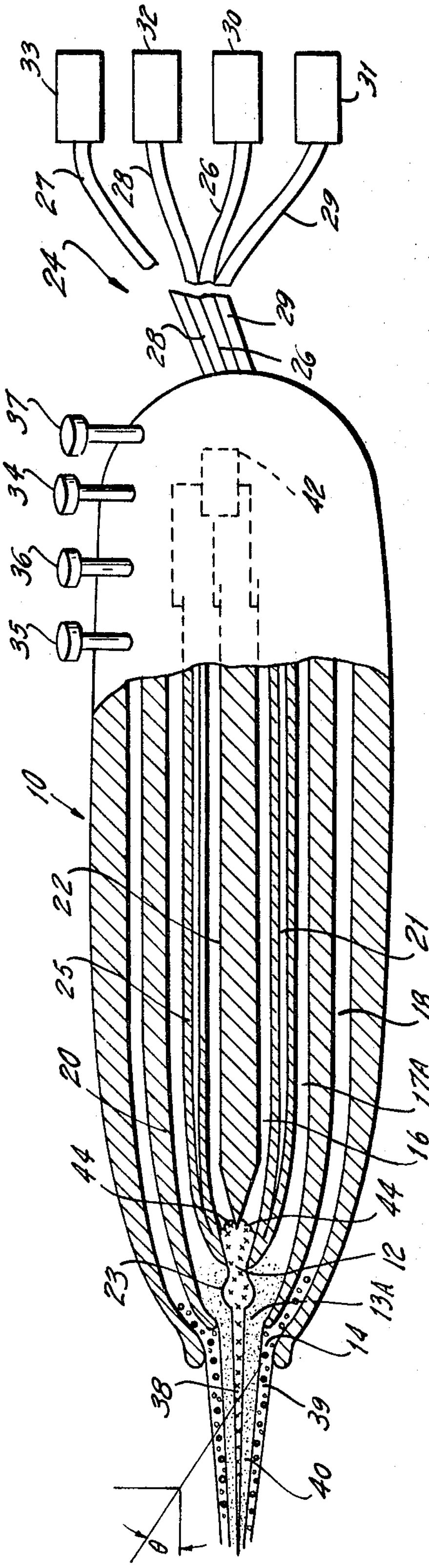
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FIG. 4.

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PLASMA ARC SCALPEL

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U.S. Cl. 128—303.1 21 Claims

ABSTRACT OF THE DISCLOSURE

A plasma arc scalpel for bloodless surgery utilizing a stream of ionized gas discharged from an orifice of preselected diameter so as to effectuate tissue parting without thermal damage. In an alternative embodiment the needle-like jet of plasma is enveloped by a second stream or mantle of cool gas having a preselected speed and converging angle so as to more precisely control cutting. As another alternative an intermediate layer of cryogenic gas may be introduced to coagulate severed tissue.

This invention relates to surgical cutting scalpels and more particularly to a scalpel which derives its "cutting" power from an application of the principles of plasma physics in such a manner as to permit relatively bloodless surgery.

Medical science, and especially the practice and science of surgery, has experienced dramatic advances during the past several decades. To a very large extent, this progress has been attributable to technological developments that have furnished new methods and instrumentation by which the frontiers of knowledge have been extended and diagnostic and therapeutic capabilities increased.

For example, the development of such instruments as the flame photometer, the spectrophotometer and polarographic techniques make possible ready chemical analysis of the most important constituents of patients' body tissue and fluid. These analyses reveal important facts concerning the body's metabolic response to injury, illness and surgery.

The dramatic and rapid development of heart surgery over a relatively few years is another striking case in point. It was the invention of a machine that could temporarily take over the work of the heart and lungs that is responsible for advancing the frontier of surgery into the previously unassailable interior of the human heart—an advance that has revolutionized the care and treatment of heart patients.

On the other hand, it is significant that while modern technology has furnished the analytic diagnostic and supportive devices that have enabled surgeons to press forth into previously unapproachable areas, the central event towards which all of this analysis, diagnostic and supportive work is directed—the surgical operation itself—is conducted with basically the same kinds of tools introduced over a thousand years ago, with the armamentarium of surgical instruments not strikingly changed during the past 100 years. Thus while modern operating rooms are crowded with complex consoles of technologically advanced instruments that aid and abet the surgeon in an ancillary fashion, increasingly complicated operations which require more and more precision and delicacy are conducted with essentially the same old assortment of knives, scissors, saws, hammers, chisels, clamps, pieces of string, etc.

As will be appreciated by those practicing surgery, hemorrhage is the arch enemy of the surgeon. The control of bleeding occupies perhaps 85% of operative time. The incessant bleeding that occurs whenever tissues are cut obscures the surgeon's vision, reduces his precision, dictates elaborate and indirect approaches to a surgical procedure, and declares many areas "out of bounds" and many lesions "inoperable."

The rhythm of surgical operations may come as a surprise to those unfamiliar with surgical procedures. Typically, each time the surgeon cuts into tissue, blood tissues from all cut surfaces into the freshly incised wound. The scalpel is set aside, small gauze sponges are used to blot the operative area, and the surgeon and his assistants grasp the tissue surrounding each tiny site of bleeding with the tips of pincher-like clamps (hemostat). By the time all "bleeders" are clamped, 30 to 40 clamps may fill the operative wound. The surgeon and his assistants then proceed to tie knots of string about the tip of each clamp, squeezing within the knots the tissue within which the opened ends of the small bleeding vessels reside. After two or three knots have been tied at the end of each clamp, and the clamps have been removed, the long ends of the string are cut short with scissors. Thus hemorrhage is controlled and the scapel once again taken in hand. The incision is extended slightly in depth, the wound fills with fresh hemorrhage, the scalpel is once again laid aside and the same tedious and time consuming procedure is repeated. Thus the rhythm of surgery consists of a brief interval of progress during which a shallow incision is made, followed by a sustained period of "blot the blood," "hunt and clamp," and "tie and cut."

Each of the ligated masses of tissue "dies" and is decomposed. Since it is a surgical maxim that the best surgery leaves behind the least dead tissue, all surgery is considerably compromised in this respect. The presence of any devitalized tissue or foreign debris in the wound tends to interfere with wound healing and promotes infection. In contrast, the greatest stimulus to healing is the body's response to a germ free wound, devoid of the debris of foreign materials or devitalized tissue.

In an effort to diminish somewhat the great preponderance of time devoted to control bleeding, the prior art has suggested an electrosurgical technique of rather limited applicability. By means of this electrosurgical technique, electrical energy in the form of a high frequency spark, which is converted to heat in the tissues, can be delivered through pincher clamps to the masses of tissue grasped by the jaws of the clamp. The heat that results coagulates the tissues and the incised blood vessels are sealed off so that the bits of tissue held by the clamp need not be tied.

The prior art has also suggested that the electrosurgical apparatus be used to cut tissues directly. While this latter technique has been somewhat effective in minimizing bleeding, many problems and difficulties have been encountered, which have limited its use to a small number of applications.

Specifically, when the applied high frequency current is properly adjusted, this instrument can be made to cut tissue with fair precision. However, in this "cutting mode" it does not control bleeding and is therefore no better than the conventional scalpel blade. When the high frequency current is increased and otherwise altered to achieve the so-called "cauterizing mode," the electrosurgical instrument cuts very poorly. Also in both modes of operation this instrument has the objectionable feature of electrically stimulating muscle tissue causing involuntary contractions which interfere with the surgeon's precision. Since, in the cauterizing mode, the heat transfer characteristics of the instrument cannot be very well controlled, considerable debris in the form of charred and dead tissue is left behind in the wound. This characteristic of the electrosurgical instrument is responsible for the strong prejudice held against it by many surgeons and the relatively small number of instances in which it can be successfully utilized.

In contradistinction to the prior art, the instant invention provides a generically new cutting instrument derived from the newest technology of modern science—"plasma physics." The plasma scalpel of the instant invention permits performance of operations with a precision, delicacy, speed and safety unlike that previously known. The high cutting energy developed by the plasma scalpel of the instant invention facilitates rapid precision cutting through all tissues, even bone, and, as will be further explained, provides an instrument for creating fresh, clean, operative wounds with a minimum of dead tissue while at the same time facilitates the performance of an essentially bloodless surgery.

In contrast to the prior art electrosurgical technique, the energy transfer characteristics of the plasma scalpel of the instant invention are precisely controlled. Operative areas are maintained clean and dry and neither the strangulated tissue of the "clamp and tie" method nor the charred debris of the electrosurgical technique will be left behind. Since bleeding will not obscure the operative field, surgery is precise and direct. With bleeding controlled and all tissues cut at a high rate of speed, the time required for surgical procedures is drastically reduced. As a consequence, many lesions now deemed inoperable, such as cancers metastatic to areas like the liver and/or lungs, become assailable. Surgery is safer, and many patients now considered unsafe as surgical risks become proper candidates for life saving procedures.

The instant invention is based on a practical application of one of the most modern branches of physics known as "plasma physics." Plasmas can best be described as very hot ionized gases; that is to say, gases containing particles having positive and negative electrical charges. It is the three striking physical characteristics of plasmas, (1) their high temperatures; (2) their electric charge; and (3) their gaseous state, that make plasmas so uniquely useful from a technological point of view. Because of the extraordinarily high temperatures, 5000–20,000° F. and higher, plasma instantly vaporizes solid and liquid substances with which they come in contact—the materials simply disappear "into thin air." Because the plasmas are electrically charged, they can be formed into jets and their energy content precisely controlled and regulated with the same highly developed techniques used to control ordinary electric current. Finally, because they are gaseous, precisely controlled plasma jets can be moved at a very high velocity, and consequently, materials which are instantly vaporized upon contact are entrained into the plasma stream and swept away before heat can be transferred from them to adjacent tissues and materials not directly touched by the plasma jets.

Recently the principles of plasma physics have been applied to metallurgical processes in that commercial plasma jet generators are presently available for cutting metals and similar materials. However, for reasons set forth below, before the instant invention, it was though impossible to employ the principles of plasma physics to surgical application.

Biological materials such as the tissues of the human body, consist chiefly of water, to the extent of 80–85%, plus a variety of organic materials which are volatile and which can be decomposed and disintegrated at temperatures under 600° C. Thus, the logical material, if one were to contemplate flame cutting of biological material, would be a chemical flame whose temperature was of that order. However, it turns out that owing to the peculiar properties of biological material, it is impossible to cut this material (in the sense that a metal is cut with a plasma jet or with an acetylene torch) with any chemical flame. For example, experience has shown that biological material cannot be cut with an oxyhydrogen flame even though it had the same dimensions as the plasma scalpel jet of the instant invention. The only reaction that is obtained is that the tissue is scorched and charred, but precise tissue parting does not occur.

Hence, when practical experience demonstrated that a chemical flame of only 600° C. or 800° C. failed to "cut" biological material, it was logically unthinkable to utilize the tremendously higher temperatures (5000–20,000° F.) existing in the effluent jet of the standard plasma jet generator for cutting biological tissue, and hence there has been no suggestion in the prior art that the principles of plasma physics be applied to surgical application. Furthermore, it was known that existing commercial plasma jet generators could not possibly serve the ancillary functions such as cautery; protecting areas adjacent the line of incision; and sweeping away volatized material, which characteristics are necessary in surgical operations.

Thus when experimenting with plasma jets for cutting biological materials, it was found that the experience of the prior art in cutting metals and similar inorganic materials was not applicable. For example, with jets above a given size (the minimum commercial size of ⅛" diameter at the exit orifice) there resulted excessive thermal damage accompanied by broad areas of dehydration and charring.

However, and in accordance with the instant invention, it has been discovered that by using plasma jets below a given size, dependent on the type of tissue being cut, the unexpected result of successful tissue parting without thermal damage has been achieved. Accordingly, in its simplest form the instant invention comprises a plasma scalpel in which the cutting blade is not cold steel or an electrical spark, but instead a fine needle-shaped jet of precisely controlled hot plasma defined by a nozzle orifice, the diameter of which is selectively chosen within a predetermined range (dependent on the type of tissue being cut) to effectuate tissue parting without extensive thermal damage.

As an advantageous feature of the thus defined basic plasma scalpel, it has been found that by properly adjusting the temperature and speed of plasma flow, the temperature of the outer layers of the jet can be controlled such that coagulation of the exposed surfaces of the cut tissue will occur virtually simultaneously with cutting thereby eliminating bleeding.

In an alternative embodiment of the instant invention the fine needle of hot plasma is completely enveloped by a mantle of cool gas such that although those tissues brought into direct contact with the plasma jet "blade" will be instantly vaporized, those tissues immediately adjacent will be protected by the cool mantel and unaffected. Further, and in accordance with the second embodiment of the instant invention, the exposed surfaces of the tissues being "cut" by the plasma jet will be simultaneously cauterized by an intermediate layer of gas (either warm or extremely cold) interposed between the plasma jet and cool mantle. Since the coagulation of the exposed surfaces will occur simultaneously with the cutting of the tissues there will be little if any raw surface to bleed.

As noted above, one embodiment of the instant invention contemplates that either warm gas or cryogenic (cold) gas may be utilized to form the intermediate coagulating layer. Where warm gas is being used as the coagulant, by the proper adjustment of flow rate, size, and inlet temperature of the mantle of cool gas, the desired cauterizing layer may be formed from the natural mixing of the cool mantle and plasma jet stream.

On the other hand, if cryogenic temperatures are being utilized for the coagulating layer, the instant invention contemplates that there be provided a third concentric orifice intermediate to the orifices used for the discharge of the hot plasma and cool mantle gas.

A paramount problem associated with the engineering application of plasma physics concerns the control of the plasma jet. The same problems have arisen in development of the instant invention. When the jet emerges from its associated nozzle, it has a tendenecy to expand such that the lateral temperature distribution does not fall off at the edges as sharply as might be desired for accurately cutting tissue. To solve such problem the instant invention proposes that the mantle of cool gas surrounding the plasma jet flow at a greater speed than the hot plasma and at a predetermined converging angle relative to the axis of the plasma jet. It has been found that when the mantle gas is caused to flow in laminar fashion and with sufficient speed relative to the plasma jet and at the proper angle, it markedly influences both the width and contour of the plasma jet. Thus by controlling the shape, speed, and angle of the mantle of cool gas, the cool gas can be made to converge and squeeze the plasma jet into a smaller diameter and longer length thereby more accurately defining the surgeon's blade. Furthermore, it has been found that if the linear velocity of the cool mantle of gas is sufficiently high relative to the hot plasma gas, so that lateral diffusion of the hot gas into the surrounding mantle is negligible over the effective cutting region, a considerable sharpening of the temperature gradient at the edges of the cutting plane is achieved. Thus, and as will be shown in greater detail, the instant invention contemplates that in the lateral direction, the gas temperature will drop to non-destructive values within less than one millimeter of the axis of the plasma jet.

The instant invention further contemplates that by precooling the mantle gas sufficiently, the downstream temperature on the axis of the plasma jet at a distance of about one additional jet length will be brought down to non-destructive temperatures. Hence the instrument may be held just above the tissues without fear of unintentional damage. Finally, the high speed of the mantle gas is useful in entraining and rapidly removing the volatized tissue material from the operating field.

As a further feature, the invention contemplates that a simple adjusting valve, push-button or otherwise, be utilized to selectively vary the discharge of the plasma jet to match its output with different tissues being cut.

In addition to permitting rapid, precise, and bloodless surgery of all tissues, the plasma scalpel of the instant invention has two further advantageous characteristics: first, sufficient light will be produced to illuminate the exact area at which the surgeon is working; second, sufficient ultraviolet energy will be produced to help sterilize the wound of germs and hence speed healing.

Accordingly, it is an object of the instant invention to provide a plasma scalpel which cuts through all tissues at a rapid rate of speed.

Another object of the instant invention is to provide such a plasma scalpel which entrains the cut tissue and sweeps it out of the wound, leaving behind an absolute minimum of dead tissue.

Still another object of the instant invention is to accomplish bloodless surgery by forming a thin shell of cauterized tissue on the exposed surfaces of tissue being "cut" by hot plasma gases.

Yet another object of the instant invention is to provide such a plasma scalpel which will help sterilize the wound of germs.

Still another object of the instant invention is to provide such a plasma scalpel which illuminates the exact area being worked on.

Still another object of the instant invention is to provide a relatively simple, small, lightweight, inexpensive plasma scalpel which may be easily and safely manipulated by the surgeon.

Yet another object of the instant invention is to provide a plasma scalpel which utilizes a precisely controlled, needle-like cutting "blade" consisting of plasma jet operating at temperatures between 5000–20,000° F. which will instantly vaporize and entrain tissues with which it is brought into contact.

Still another object of the instant invention is to provide such a plasma scalpel which further includes a cauterizing layer of gas interposed between a plasma jet and cool mantle of gas to cause coagulum sealing of the exposed surfaces of tissues being simultaneously cut by the plasma jet.

Yet another object of the instant invention is to provide a plasma scalpel which includes a continuous stream of hot ionized gas capable of volatizing tissue and a mantle of cool gas surrounding the stream of hot ionized gas for protecting areas adjacent itssues being cut by such ionized gas.

Other objects and a fuller understanding of the instant invention may be had by referring to the following description and drawings, in which:

FIGURE 1 is a cut-away perspective view, partly in section, of one embodiment of the instant invention;

FIGURE 2 is a cut-away perspective view, partly in section of an alternative embodiment of the instant invention;

FIGURE 3 is a graph illustrating some of the features of the apparatus shown in FIGURE 1; and

FIGURE 4 is a perspective cut-away view, partly in section, of an alternative embodiment of the instant invention.

Referring to FIGURE 1, there is shown the basic embodiment of the plasma scalpel of the instant invention which includes a generally cylindrical housing **10** having an exit orifice **11** disposed at one end thereof. Communicating with the exit orifice **11** is an internally disposed flow path **13** defined by a generally pointed central conductive member **15** and a concentrically disposed outer conductive layer **17**, the outer surface of which forms the exterior of the cylindrical housing **10**. Outer layer **17** includes an internally disposed concentric passageway **19** through which water may flow to cool the layer **17** in a manner to be further described.

Cooperating with the cylindrical housing **10** is a flexible supply conduit **24** which for simplicity of illustration has been shown to encompass two supply paths **26** and **27**. Supply path **26** communicates with flow path **13** and a source, schematically illustrated at **30** of the working gas, preferably one of the inert gases such as helium or argon. Supply path **27** communicates in a suitable manner with internal passageway **19** and a water supply, generally indicated at **33**. Adjusting valves **34** and **37** are schematically shown on the housing **10** and may function in a push-button mode or any other well known manner to regulate the flow of gas and water from the sources **30** and **33**, respectively, to the flow path **13** and passageway **19**, respectively. It is to be understood, however, that the showing of the control valves on the housing **10** is for the sake of illustration only and if desirable such control may be regulated from a console disposed adjacent sources **30** and **33** or from any other convenient point.

By proper regulation of the valve **34** and with the aid of suitable pumping apparatus (not shown) the working gas may be caused to flow through the supply path **26**, through the internally disposed flow path **13** and discharged out the exit orifice **11**. Such operation has been schematically illustrated at the left-hand portion of FIGURE 1 by the showing of a needle-shaped jet or stream of gas **38** identified by "x's."

To change the flow of inert gas to an ionized jet of hot plasma there is provided an electrical circuit comprising a DC source **42**, an anode (external layer **17** constructed preferably of copper or an equivalent conducting material) and a cathode (centrally disposed conductive member **15**, preferably constructed of tungsten or like metal). As there is no direct current path provided between the anode and cathode, the external power supply **42** must contain an igniter mechanism for initiating the arc discharge. This unit, as commonly employed for arc ignition, generates a momentary burst of high frequency voltage, causing a spark to jump from the pointed tip of cathode **15**, to the inside surface of anode **17**, while the voltage of DC source **42** is turned on. The open circuit voltage of source **42**, is adjusted to the range 40 to 120 volts, depending on the working gas, prior to the application of the high frequency spark. Once the gas between the tip of cathode **15** and anode **17** is electrically broken down by the high frequency spark, a steady electric arc discharge **44** is then established across the flow path **13**, the arc voltage automatically dropping to a steady value in the range of 20 to 60 volts by virtue of the well known dropping current-voltage characteristic of a typical arc voltage source. Water cooled passageway **19** prevents the anode structure from melting due to the heat of the arc, and causes the outside surface of anode **17** to remain cool enough to be handled comfortably by the surgeon.

As the inert gas flows through path **13**, past the electrical arc **44**, the gas is ionized and simultaneously heated to a very high temperature (in the range of 5000–20,000° F. or higher) by means of the arc. Consequently the needle-shaped jet or stream of gas **38** now possesses the characteristics of a plasma, that is, high temperature, ionized state, and gaseous flow, which makes a jet of plasma suitable for cutting through various materials. It is to be understood that although an electrical arc discharge technique has been illustrated for generating plasma, other techniques for generating plasma might be utilized.

The structure thus far defined in FIGURE 1 is similar to the commercial plasma jet generators available in the prior art. However, and as has been noted previously, when the inventors attempted to apply the commercial plasma jet generators to surgical applications, extensive thermal damage occurred. In accordance with the instant invention it has been discovered that if the diameter of the exit orifice **11** is chosen less than .060″ and preferably within the range from .005″ to .060″, dependent upon tissue being cut, successful tissue parting can be achieved with virtually no thermal damage. The optimum diameter for the exit orifice **11** has been found to be about .020″ and is to be contrasted with the diameter of the exit orifice of the smallest commercial jet plasma generator available of ⅛″.

In FIGURE 3 is shown a curve **43** which represents the temperature distribution of the plasma jet **38** shown in FIGURE 1, plotted as a function of the distance in millimeters from the central axis thereof. It can be seen that within a given segment of the graph identified at **45** and represented by little dots, the temperature of the outer layers of the plasma jet falls within the range of 150–250° F. which, depending upon the type of tissue being cut, is the proper temperature for thermal coagulation of the raw, exposed surfaces of the cut tissue. Thus by properly adjusting the jet **38** in accordance with the tissue being cut the jet performs a dual function in that it (1) cuts the tissue, and (2) simultaneously cauterizes the raw surface thereof. Thus by selectively choosing the diameter of the exit orifice **11** and regulating the discharge flow of the jet **38**, the instant invention has been able to further the development of conventional plasma jet generators in an area heretofore thought impossible by developing a miniaturized, self-cauterizing plasma jet surgical cutting instrument.

Referring to FIGURE 2, there is shown an alternative embodiment of the plasma scalpel of the instant invention which includes a generally cylindrical housing **10** having first and second concentric orifices **12** and **14**, respectively, disposed at one end thereof. Communicating with the first and second openings **12** and **14**, respectively, are first and second internally disposed flow paths **16** and **18** separated and defined by a circular internal partition **20** constructed, preferably, of copper or some other electrically conducting material. Partition **20** includes a hollow passageway **21** to permit the continuous flow of a cooling fluid such as water therethrough. As will be further explained, partition

20 functions as the anode of an electric circuit which functions to ionize a gas flowing through the internal flow path **16** toward discharge through the central orifice **12**, in the same manner as described for the scalpel of FIGURE 1.

Disposed centrally within flow path **16** is a generally pointed conductive element **22**, which may be tungsten or similar metal, which cooperates with the anode **20** to ionize the gas flowing through central flow path **16**.

Cooperating with the cylindrical housing **10** is a flexible supply conduit **24** which for ease of illustration has been shown to encompass three supply paths **26**, **27** and **28**. Supply path **26** communicates with internal flow path **16** and a source, schematically illustrated at **30**, of the working gas preferably one of the inert gases such as helium or argon. Supply path **28** communicates in a suitable manner with internal flow path **18** and a supply generally indicated at **32** of cool gas which may be air, one of the inert gases, or a gas of other convenient choice. Supply path **27** communicates with water source **33** and passageway **21** to provide a continuous flow of cooling fluid therethrough. Adjusting valves **34**, **36** and **37** are schematically shown on the housing **10** and may function in a well known manner to regulate the flow of gases and water from the sources **30**, **32** and **33** to the flow paths **16** and **18**, and passageway **21**, respectively. It is to be understood, however, that the showing of the control valves on the housing **10** is for the sake of illustration only, and that if desirable such control may be regulated from a console disposed adjacent sources **30**, **32** and **33** or any point inbetween.

By proper regulation of the valves **34** and **36**, and by means of apparatus for causing the gases in supply sources **30** and **32** to flow under pressure, the gases in supply sources **30** and **32** may be caused to flow through the respective supply paths **26**, **28**, through the internally disposed flow paths **16** and **18**, and discharged out their respective concentric orifices **12** and **14**. Such operation has been schematically illustrated at the left-hand portion of FIGURE 2 by the showing of a needle-shaped jet or stream of plasma gas **38**, identified by little "x's" to correspond to the inert gas being supplied from source **30**, with a mantle of the cool gas **39** from source **32**, identified by the little "o's" enveloping or surrounding the jet of inert gas **38**.

As described with respect to FIGURE 1, in order to take advantage of the principle of plasma physics, it is necessary to ionize the jet of gas which will function as the "cutting" blade of the surgical scalpel. To this end there is provided the electrical circuit comprising the DC potential source **42**, the anode (internally disposed circular partition **20**), and the centrally disposed cathode member **22**. When appropriately ignited and maintained, a supply voltage (in the order of 20 to 60 volts) is impressed therebetween by means of potential source **42**, the electrical arc **44** is formed between the tip of the cathode **22** and the anode structure **20**.

As the inert gas flows through central flow path **16** through the electrical arc **44** maintained between the anode and cathode structure **20** and **22**, respectively, the gas is ionized and simultaneously heated to a very high temperature (in the range of 5000–20,000° F.) by means of the arc **44**. By increasing the potential drop, the arc may be made stronger and the temperature range increased. Consequently the needle-shaped jet or stream of gas **38** now possesses the inherent characteristics of a plasma, that is, high temperature, ionized state, and gaseous flow, which makes the jet of plasma suitable for cutting through materials such as tissue, bone, etc. It is to be understood that for the sake of simplicity of explanation the potential source has been shown as being disposed within the housing **10**. Actually potential source **42** would be preferably located far from the actual housing **10** and electrically connected to terminals provided on the anode and cathode **20** and **22**, respectively, by means of cables carried by the main supply conduit **24**.

By operating with an arc discharge at a voltage somewhat higher than would be required in the absence of gas flow, it is possible to maintain a steady flow of gas at a relatively high velocity without blowing the arc out. This feature is partially responsible for the effluence of the inert gas as a narrow unidirectional jet, instead of diffusing in all directions as would otherwise occur at very low gas flow rates.

As in the embodiment of FIGURE 1, when the invention is applied to cutting biological tissue the diameter of orifice **12** must be far less than the smallest diameter (⅛″) presently available in commercial plasma jet generators. Thus orifice **12** has a diameter less than .060″ and is preferably chosen within the range of .005–.060″ (optimum of .020″) in accordance with the tissue being cut, and makes possible the unexpected result of successfully applying the principles of plasma physics to surgical applications.

As discussed above, a major problem associated with the application of plasma physics to a surgical plasma scalpel concerns the control of the cutting jet such as **38** in FIGURE 1. When the jet emerges from its associated orifice **12**, it has a tendency to expand slightly (see **23** in FIGURES 1, 2 and 4) and if unrestrained the jet spreads out such that lateral temperature distribution does not fall off at the edges as sharply as is desirable for cutting tissue. The instant invention remedies this problem by providing that the enveloping mantle of cool gas **39** flow at a greater speed and at a predetermined angle relative to the hot gas in the plasma jet **38**. Thus if the mantle gas **39** is caused to flow in a laminar fashion so as to reduce turbulence and with sufficient speed relative to the plasma gas, preferably within the range of 2–8 times faster, it markedly influences both the width and contour of the effluent jet. Furthermore, if the outer orifice is directed at an angle θ in FIGURES 2 and 4 preferably within the range of 15–45°, the plasma jet **38** will be diametrically squeezed and elongated to more accurately define the surgeon's "blade." (Compare the jet **38** of FIGURE 1 with the jet **38** of FIGURES 2 and 4.) Testing has suggested that optimum results may be achieved with the mantle of cool gas flowing at approximately 5 times the speed of the plasma jet and at an angle θ of 30° relative to the axis thereof.

A graphical illustration of the above feature is depicted in FIGURE 3 wherein curve **43** shows the temperature distribution of the plasma jet **38** of FIGURE 1. For such curve it may be seen that extremely high temperatures are present as far out as 3, 4 and 5 millimeters from the axis of the plasma jet. In contradistinction thereto, curve **46** shows the temperature distribution for the plasma jet **38** when it is surrounded by the cool mantle of gas **39** flowing at a predetermined speed faster than jet **38** and at a predetermined angle relative thereto. For curve **46** it may be seen that a well defined needle-shaped contour of the plasma jet is possible with the high temperature thereof falling off to acceptable limits within 1 millimeter of the central axis of the plasma jet. Thus the effective cutting region of the plasma scalpel of the instant invention is well defined and for purposes of analysis may be though of as a very fine needle capable of accurate manipulation by the surgeon.

Further, and in accordance with the instant invention, by precooling the mantle gas to room temperature or below, the downstream temperature on the axis of the plasma jet **38** at a distance of about one additional jet length will be brought down to safe temperatures and hence the instrument may be held just above a subject without fear of unintentional damage. Finally, the high speed of the mantle of cool gas **39** is also useful in entraining and rapidly removing the volatized tissue material from the operating field.

As has been previously discussed, the instant invention provides that the exposed surfaces of tissues being cut by the hot ionized plasma jet **38** be simultaneously cauterized by means of a coagulating layer of gas interposed between the plasma jet **38** and the cool mantle of gas **39**. In the event that a warm layer of gas, preferably in the range of 150–250° F. is chosen as the proper coagulating temperature, then an interlayer of coagulating gas such as that represented by the dots **48** in FIGURE 2 may be suitably disposed between the plasma jet **38** and the mantle of cool gas **39** by simply adjusting the flow rate, size and inlet temperature of the cool mantle of gas **39**, such that the desired cauterizing layer forms from the natural mixing of the cool gas and the plasma jet stream.

On the other hand, if cryogenic temperatures are desired for the cauterizing layer then an embodiment such as that shown in FIGURE 4 is desirable for the plasma scalpel of the instant invention.

Turning to FIGURE 4, there is shown a plasma scalpel similar to that shown in FIGURE 2, and consequently like numbers have been used to identify like parts. A cylindrical housing **10** is provided having concentric orifice openings **12**, **13A** and **14**. Orifices **12** and **14** correspond to orifices **12** and **14** in FIGURE 1 and permit the discharge of the plasma jet **38** and mantle of cool gas **39**, respectively. In the same manner as was explained with respect to FIGURE 1 internally disposed flow paths **16** and **18** are provided to facilitate the passage of the respective gases from the supply paths **26** and **28** which emanate at the supply sources **30** and **32**, respectively. Valves **34** and **36** are schematically shown, as in FIGURE 1, to regulate flow of gases from supply **30** and **32**.

The embodiment o FIGURE 4 differs from the embodiment of FIGURE 2 in that there is provided the third concentric intermediate orifice **13A** disposed between the central and outermost orifices **12** and **14**, respectively. Similarly, there is provided a central flow path **17A** disposed intermediate the centermost and outermost flow paths **16** and **18**, respectively, to facilitate the passage of a cryogenic gas from a third supply path **29** of the supply conduit **24** which in turn is connected to a third supply source **31**.

As can be seen most clearly in FIGURE 4, the discharge of orifice **13A** provides an intermediate cryogenic layer of gas **40** symbolized by the dotted showing. An adjusting valve **35** is schematically shown to illustrate that the flow and discharge of cryogenic gas **40** may be controlled in a manner similar to that disclosed for the control of the plasma jet **38** and cool mantle gas **39**.

One further distinction between the embodiments of FIGURE 4 and FIGURE 2 is related to the electrical means for ionizing the gas flowing through central passageway **16**. Specifically the anode structure for the embodiment of FIGURE 4 is now an intermediate partition **25** rather than the partition **20** as in FIGURE 1, with the DC circuit comprising the source **42** intermediate partition **25**, the arc **44** and the cathode structure **22**.

In the operation of the embodiments of either FIGURE 2 or FIGURE 4, the housing **10** is held above the surface to be cut such that the tip of the hot ionized needle-shaped jet of plasma volatizes tissue brought into contact therewith. Simultaneously the exposed surfaces of tissue being "cut" by the plasma jet are coagulated by the coagulating layer of gases (either **48** or **40** of FIGURES 2 and 4, respectively, depending on whether warm or cryogenic temperatures are chosen) to prevent bleeding therefrom during the entire cutting operation. The cool mantle of gas **39** insulatively protects all tissue adjacent the tissue being cut such that a well defined incision may be made.

Thus there has been described a novel plasma scalpel which applies the principles of plasma physics to provide a cutting instrument capable of performing surgery in a precise, speedy and essentially bloodless manner heretofore unknown in the prior art.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appending claims.

What is claimed is:

1. A plasma scalpel comprising a housing having an opening disposed at one end thereof, said opening having a diameter equal to or less than .060 inch; said housing including an internally disposed flow path communicating with said opening, and electric means for ionizing a gas which may be flowing through said flow path.

2. The plasma scalpel of claim **1**, wherein said opening has a diameter within the range of .005–.060 inch, inclusive.

3. The plasma scalpel of claim **2**, wherein said opening has a diameter of .020 inch.

4. The plasma scalpel of claim **1**, wherein said flow path is defined by an outer conductive layer of said housing and an inner conductive member concentrically disposed within said outer conductive layer; said outer conductive layer and said inner conductive member forming part of said electric means for ionizing a gas which may be flowing through said flow path.

5. The plasma scalpel of claim **4**, wherein said electric means includes a potential source for impressing a potential between said outer conductive layer and said inner conductive member to maintain an electric arc therebetween, and said outer conductive layer includes a water passageway therethrough to continually cool said outer conductive layer.

6. The plasma scalpel of claim **1**, and further including a supply source of inert gas, a supply path communicating with said supply source and said flow path, and adjusting means for regulating the flow of inert gas between said supply source and said flow path.

7. A plasma device comprising:

first means for providing a continuous stream of hot ionized gas capable of volatizing material;

second means surrounding said first means for enveloping said stream of hot ionized gas with a concentric stream of relatively cool gas;

whereby areas adjacent to material volatized by said hot ionized gas will be insulated therefrom; and

wherein said stream of relatively cool gas flows at a predetermined greater speed than said stream of hot ionized gas, whereby the width and contour of said stream of hot ionized gas can be accurately controlled, while at the same time lateral diffusion of the hot gas into the relatively cool gas can be minimized to increase the temperature gradient at the juncture of said hot and relatively cool gases.

8. The plasma device of claim **7**, wherein said stream of relatively cool gas flows at a speed of from 2–8 times as fast as said stream of hot ionized gas.

9. The plasma device of claim **7**, wherein said stream of relatively cool gas flows at a speed approximately five times greater than said stream of hot ionized gas.

10. The plasma device of claim **7**, wherein said second means includes shaped orifice means for causing said stream of relatively cool gas to be discharged at a predetermined angle relative to said stream of hot ionized gas whereby said stream of hot ionized gas is diametrically reduced and elongated.

11. The plasma device of claim **10**, wherein said predetermined angle is within the range of 15°–45°.

12. The plasma device of claim **11**, wherein said predetermined angle is 30°.

13. The plasma device of claim **7**, wherein said second means includes shaped orifice means for causing said stream of relatively cool gas to be discharged at a predetermined angle relative to said stream of hot ionized gas whereby said stream of hot ionized gas is diametrically reduced and elongated.

14. The plasma device of claim **7**, wherein said first means includes a discharge orifice having a diameter less than or equal to .060 inch.

15. The plasma device of claim **14**, wherein said discharge orifice has a diameter within the range of .005–.060 inch, inclusive.

16. The plasma device of claim **14**, wherein there is further provided a coagulating layer of gas interposed between said streams of hot and relatively cool gases, respectively, whereby when said plasma device is being utilized to volatize tissue, exposed surfaces of tissue being volatized by said stream of hot ionized gas will be simultaneously cauterized by said coagulating layer of gas to prevent bleeding thereof.

17. A plasma device comprising a housing having first and second concentric openings at one end thereof, said housing including internally disposed first and second flow paths communicating with said first and second concentric openings, respectively; said housing further including electric means for ionizing a gas which may be flowing through said first flow path; and further including means communicating with said first and second flow paths for supplying first and second gases, respectively, thereto; said first gas being passed through said first flow path, ionized by said electric means, and discharged by said first opening as a continuous stream of hot, ionized, plasma capable of volatizing material; said second gas being passed through said second flow path and discharged by said second opening as a mantle of relatively cool gas which surrounds said stream of hot, ionized plasma to insulate areas adjacent material being volatized thereby; and wherein said mantle of relatively cool gas flows at a predetermined greater speed than said stream of hot, ionized plasma, whereby the width and contour of said stream of hot, ionized plasma can be accurately controlled, while at the same time lateral diffusion of the hot plasma into the relatively cool gas can be minimized to increase the temperature gradient at the juncture of said hot plasma and relatively cool gas.

18. The plasma device of claim **17**, wherein said second opening is shaped such that said mantle of relatively cool gas is discharged at a predetermined angle relative to said stream of hot ionized plasma whereby said stream of plasma is diametrically reduced and elongated.

19. The plasma device of claim **17**, wherein said first opening has a diameter within the range of .005–.060 inch.

20. The plasma device of claim **19**, wherein there is further provided a coagulating layer of gas interposed between said stream of plasma and said mantle whereby when said plasma device is being utilized to volatize tissue, exposed surfaces of tissue being volatized by said stream of plasma will be simultaneously cauterized by said coagulating layer of gas to prevent bleeding thereof.

21. The plasma device of claim **20**, and further including a third concentric opening disposed between said first and second openings; a third flow path disposed between said first and second flow paths and communicating with said third opening; and means for supplying a third gas of predetermined coagulating temperature to said third flow path; said third gas being passed through said third flow path and discharged through said third opening to form a coagulating layer of gas disposed between said stream of plasma and relatively cool gas to coagulate exposed surfaces of tissues being simultaneously volatized by said hot plasma.

References Cited

UNITED STATES PATENTS

2,708,933	5/1955	August	128—303.14
2,874,265	2/1959	Reed et al.	219—121
3,158,729	11/1964	Gross	219—121 XR
3,204,076	8/1965	Browning	219—121 XR
3,300,561	1/1967	Foex	219—121 XR

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