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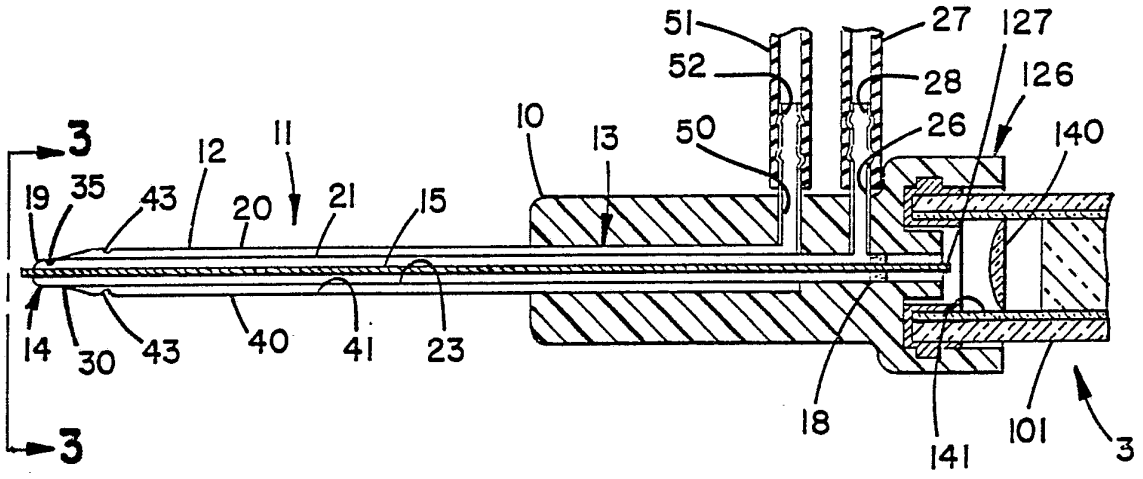
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(54) Title: METHOD AND APPARATUS FOR LASER EMULSIFICATION



(57) Abstract

A method and apparatus are provided for conducting laser emulsification of cataracts or the like. The apparatus comprises a tool (2) having a probe (11) extension thereon comprising a removeable and replaceable optical fiber (15), an inner tubular wall defining a first chamber (23), and an outer tubular wall defining a second chamber (41). The first chamber has the optical fiber mounted therein and extending therethrough, and surrounds same with an open chamber, i.e. the first chamber, to which suction can be applied. The first chamber is preferably an outer chamber useable to remove emulsified material from a patient's eye. The outer chamber, i.e. second chamber, surrounds the inner chamber and, for example, provides means by which fluids such as a saline solution can be injected into the region of emulsification. Preferred articulated arm arrangements are provided, to facilitate transmission of light from a laser source to the removeable and replaceable fiber optic. A variety of designs for the removeable and replaceable optical fiber are provided, to facilitate tissue and cataract handling.

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METHOD AND APPARATUS FOR LASER EMULSIFICATION

FIELD OF THE INVENTION

The present invention relates to laser surgery, and in particular to surgical operations on the eye. Specifically, the present invention concerns a method and apparatus for the emulsification and removal of cataracts, or similar surgical procedures.

BACKGROUND OF THE INVENTION

A cataract is a breakdown, or development of an opaque region in the crystal lens of the eye. Generally, the deterioration process is not reversible. Rather, the typical current treatment is to remove the cataract or lens material completely. After the surgery, artificial lenses are provided to facilitate vision. Such lenses may be of a variety of types, including extraocular eye frames and lenses, extraocular contacts, and intraocular contact lens devices.

Recently, various microsurgery techniques have been developed to enable easier removal of the cataracts. One relatively frequently used includes phaeco-emulsification. For application of this process, a small incision is made in the eye, and a probe is inserted therethrough. The probe includes a tip which vibrates in the ultrasonic region, on the order of 20,000 times per second. Such a probe is typically brought into direct contact with the lens, and the vibrations are used to break up, or emulsify, the lens material. This lens material is then withdrawn from the eye through means of suction devices or the like.

Many surgeons are reluctant to utilize the phaeco-emulsification technique, due at least in part to concerns about possible damage to various regions of the

eye. More specifically, the probe generates substantial risk of significant damage in various portions of the eye, if inadvertently brought into contact therewith. As a result, while phaeco-emulsification does offer many advantages over former surgical methods, it is still not fully accepted, nor is it completely advantageous.

What has been needed has been a method for cataract removal which does not involve phaeco-emulsification, i.e., use of a vibrating probe, and which is substantially free of the inconveniences and problems inherently associated therewith, but which otherwise utilizes the advantages of a microsurgery technique. Further, what has been needed has been an apparatus for application of the needed method.

OBJECTS OF THE INVENTION

Therefore, the objects of the present invention are: to provide an apparatus for advantageous removal of cataract, or lens material from the eye; to provide such an apparatus wherein laser surgery is applied to accomplish emulsification of the cataract; to provide a preferred such apparatus which utilizes light of a wavelength generally not posing substantial unacceptable risk of damage to the eye; to provide a preferred surgical tool for implementation of laser emulsification including a probe extension having an optical fiber removably mounted thereon, for transmission of a laser emission to the region of the eye in which the cataract is positioned; to provide such a device wherein the fiber is readily removable and replaceable; to provide such a device wherein the fiber is mounted in a probe extension including a suction means for removal of emulsified lens material; to provide such a tool including fluid transmission means, providing for

transmission of fluid to a site of emulsification, following emulsification, in order to fill the volume vacated and/or to rinse same; to provide such a device wherein the optical fiber includes a probe tip; to provide a plurality of optical fibers for utilization in association with such a device, wherein at least several of the optical fibers include different working or probe tips for advantageous utilization under different circumstances; to provide an optical fiber for utilization in association with such a device wherein a working tip on the optical fiber comprises a rounded end having an internal reflecting portion thereon; to provide means for transmission of light from a laser to a fiberoptic in such device, whereby light of a wavelength substantially absorbable by water and/or carbon dioxide can be efficiently transmitted to the optical fiber for use; to provide such a transmission means comprising a bendable arm arrangement having straight arm portions and at least one bendable or flexible elbow portion; to provide a preferred such arrangement wherein the straight portions comprise a hollow tube having a reflective internal surface for retaining light therein and transmitting light along a longitudinal axis thereof; to provide an alternate arrangement wherein the straight portions comprise tubes filled with infrared transmitting materials arranged to provide for reflection of light longitudinally along a longitudinal axis of the tube, by means of a multi-layed arrangement utilizing layers of differing refractive indices; to provide an arrangement wherein the elbow portion comprises a plurality of flexible optical fibers mounted in association with one another; to provide such an arrangement which is particularly well adapted for utilization in association with laser energy having a wavelength of about 2.94

micrometer; to provide an arrangement which is particularly well adapted for use in association with light generated by an erbium laser, an argon·fluoride laser, a holmium laser, a carbon dioxide laser, or a neodymium laser; to provide such an arrangement which utilizes a comparatively minimal distance of extension of fiberoptics therein; to provide an alternate elbow arrangement comprising a plurality of hollow, flexible tubes having reflective inner surfaces; to provide an apparatus according to the invention which is particularly well-adapted for application of the method proposed; and to provide such an apparatus which is relatively inexpensive and easy to produce, assemble and use, and which is particularly well-adapted for the proposed usages thereof.

It is a further object of the present invention to provide an arrangement and method well suited for adaptation as fiberoptic and laser technology changes, and which in particular is well suited for utilization in association with light transmission means involving substances which transmit light of preferred wavelengths readily, but which are not suitable to be drawn into fibers. Other objects and advantages of the present invention will become apparent from the following descriptions, taken in conjunction with the presented drawings, wherein are set forth by way of illustration and example certain embodiments of the present invention.

SUMMARY OF THE INVENTION

The present invention concerns the provision of an apparatus for utilization in association with laser surgery to emulsify lens or catact material in the eye. Laser probes, and laser surgery, are well-known.

Generally, problems have related to transmission of the necessary light to a region remote from the light source or laser, in this instance the eye, for surgical operation. Light such as that generated by erbium-, carbon dioxide-, holmium-, neodymium-, or argon fluoride lasers would be preferred. The wavelengths of such lasers are as follows: argon fluoride, 0.193 micrometers; neodymium, 1.06 micrometers; holmium, 2.08 micrometers; erbium, 2.94 micrometers; and, carbon dioxide, 10.6 micrometers. Such light, having a wavelength of between 0.193 micrometers and 10.6 micrometers, is generally sufficient to cause emulsification, although the mechanism causing emulsification may be different for light of different wavelengths.

Fiberoptic systems are being used to transmit laser beams over considerable distance, and around bends. However, materials suitable to be drawn into fibers and to transmit light of the desired wavelength for emulsification procedures, without substantial loss of energy, are not readily available. Thus, transmission from the source of the laser energy to the probe has been a problem. Many materials which do not appreciably absorb light of the wavelengths mentioned as desirable for laser emulsification surgery also do not readily form optical fibers. Such materials include: potassium chloride, greater than 90% transmission of light between 0.5 and 15.0 microns; potassium bromide, greater than 90% transmission of light between 0.6 and 20 microns; lithium fluoride, about 90% transmission of light between 0.3 and 5.0 microns; sodium chloride, about 90% transmission of light between 0.4 and 10 microns; barium fluoride, greater than 90% transmission of light between about 0.3 and 8.0 micrometers; calcium fluoride, about 90% transmission of light between 0.4

and 7.0 micrometers; and, magnesium fluoride, about 90% transmission of light between about 0.4 and 7.0 micrometers. Other materials having similar properties may also be usable in systems according to the present invention.

In applications wherein transmission through substantial distances involving turns is of concern, conventional methods have been through employment of articulated arms containing mirror arrangements providing for reflection around turns. Such mirror arrangements can be relatively complex and have generally been inadequate.

According to the present invention a method and apparatus are provided whereby the above-described problems are addressed. Specifically, a laser emulsification apparatus is provided for use in optical surgery. The probe comprises a tool including a handle member or portion utilizable by the surgeon to manipulate a fiberoptic probe into the immediate vicinity of the lens or cataract. The fiberoptic probe is removable and replaceable, as needed for example to facilitate a sterilized process. For a preferred embodiment, a plurality of shapes of fiberoptics are provided, each of which is shaped for a preferred use during surgery. Such probes can be removed from, and can be replaced in, the overall device, as necessary.

In a preferred embodiment, the removable and replaceable optical fiber is mounted within a probe extension. The preferred probe extension includes a mounting and release mechanism to facilitate removal and replacement of the optic fiber.

Preferably, the probe extension has two fluid communication systems therein. A first of these is a chamber which provides a means or system for application

of a suction, or fluid draw, from the immediate vicinity of emulsification. Through use of this vacuum or suction system, emulsified material can be readily withdrawn from the vicinity of the fiberoptic probe tip, without removal of the probe from the eye chamber and in some instances concurrently with emulsification.

A second fluid flow system in the probe extension provides a system for transmission of fluid or the like into the region wherefrom the emulsified lens is removed. This transmission system can provide for a cleansing wash of the area. Further, by means of this a fluid such as a saline solution can be provided to fill any void created by destruction of the lens. Generally, the second fluid flow system comprises a fluid jacket or chamber around the probe extension.

As previously suggested, the preferred device according to the present invention is particularly well suited for utilization in association with erbium, argon fluoride, carbon dioxide, holmium and neodymium lasers. Erbium lasers, for example, generate light having a wavelength on the order of about 2.94 micrometers. Light of such a wavelength is generally desirable for use in association with laser emulsification surgery since it is of relatively low energy and is readily absorbed by materials in the body such as water and carbon dioxide. Thus, it will generally be absorbed by body tissue before it is transmitted a sufficient distance to cause significant damage to tissues other than those in the immediate vicinity of the probe tip, for example, damage to portions of the eye other than those which are intended to be emulsified.

Fiberoptic techniques provide a preferred method of transmitting light energy from a laser source to a remote surgical tool or probe. A problem, however,

is that many conventional fiberoptic materials absorb light of wavelengths on the order of those generated by the low energy lasers described above. Thus, if relatively long extensions of conventional fiberoptic materials are utilized, it may be difficult to provide sufficient laser energy for transmission of adequate light to the remote working tip of the probe, to ensure effective and efficient emulsification. Synthetic quartz, for example, is a commonly used substance for elongate, solid, optical or optic fibers. This material is relatively inexpensive and readily available. However, it does have a tendency to absorb light of some desired wavelengths for laser emulsification. It would be possible to utilize such a material in association with higher energy light, for example, u.v. light, but not for some of the lower energy lasers mentioned previously.

As a result of the above, the preferred embodiment according to the present invention utilizes only a relatively short extension of synthetic quartz fiberoptic material. That is, light is transmitted through fiberoptic material only over a relatively short distance, so minimizing undesired absorption and energy loss. For the most part, light being transmitted from a laser source to a probe according to the present invention is transmitted through materials not suitable for manufacture into fibers, but which generally minimize absorption and energy reduction.

Hollow tubes having reflective inner surfaces could be used for the transmission of light. Such tubes may have a mirrored inner surface, provided, for example, by means of a gold, silver or aluminum reflecting surface. While such tubes may be utilized in devices according to the present invention, they often

are not preferred since they do not necessarily generate 100%, or near 100%, internal reflection. That is, some, and on occasion substantial, energy may be lost during transmission.

Preferred devices according to the present invention utilize light transmission means involving filled tubes having multi-layered inner cores comprising materials of different refractive indices, whereby the central layer has a refractive index greater than the outer layer. Light passing longitudinally through the central layer or core will generally be reflected at the interface between the core and outer layer and be directed back into the core. If an appropriate difference in refractive indices is selected, 100% transmission, or close to 100% transmission, in the straight portions of the filled tube can be achieved. Either solids or appropriately contained liquids may be used for the filler materials. For one preferred embodiment utilizable with an erbium laser, the straight tube sections of the light transmission means comprise glass or metal walled cylindrical tubing having two layers of material therein: a central core having a refractive index of about 1.5244 (NaCl); and, the next outer layer having a refractive index of about 1.4179 (CaF_2). As will be understood from the below descriptions this results in a critical angle of 68.5°, and thus a high efficiency of light transmission. It is noted that refractive index is wavelength dependent and the figures given are for an erbium laser, 2.94 micrometers.

Preferably the light transmission arrangement according to the present invention includes means for guiding the laser light through large angles. That is, it includes elongate straight tubular portions, such as

those previously described, and it also includes at least one bendable elbow portion. Conventional arrangements, utilizing mirrors to transmit light around corners or bends, are thus avoided. In their place, according to a preferred embodiment of the present invention, a bundle of optical fibers, each of which is bendable, is provided at the elbow. The light is transmitted around the elbow, by means of the bundle of optical fibers. Preferably the optical fibers are mounted in a rotatable bearing arrangement, to facilitate degrees of freedom. Such an arrangement is very flexible and represents a significant departure from former mirror arrangements requiring frequent adjustments.

In an alternate elbow arrangement, a plurality of small hollow flexible tubes are used, each having a reflective inner surface. As a unit, the packed tubes can bend, providing transmission of light around a bend.

In another alternate embodiment of the present invention, a single, flexible, main optical fiber is utilized to transmit light along the entire distance between the light source and the removable and replaceable optical fiber mounted within the probe. This main optical fiber would not be composed of synthetic quartz material, which unfortunately absorbs light of the desired wavelengths to a substantial degree. Rather, the fiberoptic would be manufactured using zirconium fluoride fiberoptic material, which is flexible and which does not appreicably absorb light of the desired wavelengths, for example light emitted by erbium lasers.

The drawings constitute a part of the specification and include exemplary embodiments of the invention while illustrating various objects and features

thereof. It will be understood that in some instances relative material thicknesses, and relative component sizes, are shown exaggerated to facilitate an understanding of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a fragmentary perspective view of a laser emulsification device or arrangement according to the present invention.

Fig. 2 is an enlarged fragmentary cross-sectional view taken generally along line 2-2, Fig. 1.

Fig. 3 is an enlarged, end elevational view, taken generally from the perspective of line 3-3, Fig. 2.

Fig. 4 is a side elevational view of that portion of the apparatus depicted in Fig. 3; specifically Fig. 4 is a fragmentary side elevational view of a removable and replaceable optical fiber utilized in association with the device depicted in Figs. 1 and 2.

Fig. 5 is a fragmentary side elevational view of an alternative optical fiber to that shown in Fig. 4.

Fig. 6 is an end elevational view of the optical fiber depicted in Fig. 5.

Fig. 7 is a side elevational view of an alternate to the optical fiber depicted in Figs. 4 and 5.

Fig. 8 is an end elevational view of the optical fiber shown in Fig. 7.

Fig. 9 is a side elevational view of an alternate optical fiber to that depicted in Figs. 4, 5 and 7.

Fig. 10 is an end elevational view of the optical fiber depicted in Fig. 9.

Fig. 11 is a fragmentary end elevational view of an alternate optical fiber to that depicted in Figs.

4, 5, 7 and 9.

Fig. 12 is an end elevational view of the optical fiber depicted in Fig. 11.

Fig. 13 is an enlarged fragmentary side elevational view of a portion of the apparatus depicted in Fig. 1, with phantom lines indicating portions out of view.

Fig. 14 is an enlarged fragmentary cross-sectional view of a preferred embodiment taken generally from the prospective of line 14-14, Fig. 13.

Fig. 15 is a cross-sectional view taken generally along line 15-15, Fig. 13.

Fig. 16 is a fragmentary cross-sectional view of a portion device according to an alternate embodiment of the present invention, taken generally from the point of view of Fig. 14.

Fig. 17 is a fragmentary perspective view of a device according to yet another alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED AND ALTERNATE EMBODIMENTS

As required, detailed embodiments of the present invention are disclosed herein. However, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which may be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but rather as the basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed system.

The present invention comprises a method and

apparatus for use in emulsification procedures and the like. Referring to Fig. 1, the reference numeral 1 generally designates a device or apparatus 1 according to the present invention. The apparatus 1 comprises a laser emulsification tool 2 to which light is transmitted from a laser by means of a transmission mechanism 3. It will be understood that the variety of transmission mechanisms 3 maybe utilized in association with many of the principles of the present invention, to obtain advantages. However, several unique and advantageous systems are preferred, for reasons presented in detail below. Initially, for purposes of description attention will focus on the tool portion 2 of the device 1.

The tool 2 includes a handle member 10 and a probe extension 11. During use, portions of the probe extension 11 are inserted into the eye, and brought into alignment with the lens or cataract material to be emulsified and removed. Laser energy is transmitted longitudinally through the probe extension 11, and is directed at the cataract to be emulsified. The probe extension 11 includes means, as described below, to provide for withdrawal of emulsified cataract material. Further, the probe extension 11 includes means described below which provide for direction of fluid into the cavity from which the emulsified lens material has been removed. By such means, a washing of the lens chamber can be accomplished. Further, any space left void by the removal of the lens can be readily filled.

Referring to Fig. 2, handle or handle member 10 comprises a tool or the like on which probe extension 11 is mounted. It will be understood that handle 10 may be formed from a variety of materials, including plastics, and may be designed in a variety of shapes.

Generally it will be preferred that a convenient shape for gripping, such as a cylindrical shape, be provided.

Probe extension 11 includes a tubular member 12 having first and second end portions, 13 and 14 respectively. The probe extension 11 juts outwardly from handle 2, and carries a working optical fiber 15 therein. The preferred optical fiber is a solid, elongate, optical fiber having a generally circular cross-section on the order of about 300 microns in diameter. Such an optical fiber is small enough to be maneuvered close to individual cataracts, while probe extension 11 is inserted through a relatively small incision, and can be brought into, or manuevered into, very close contact with a lens or cataract to be emulsified. A variety of materials, including ones yet to be developed, may be utilized for the optical fiber 15. Generally for applications according to the present invention synthetic quartz materials may be utilized, even though they absorb, to some degree, light of preferred wavelengths for emulsification according to the present invention, i.e. light having wavelength on the order of 0.19-10.6 micrometers, generated from erbium lasers, or argon fluoride-, carbon dioxide-, neodymium-, or holmium- lasers. A reason for this is that only a relatively short extension of fiber optic material 15, on the order of about 3-6 inches, is required for most uses. Over such a relatively short distance, relatively little energy is lost due to absorption. It is foreseen that fiber optic materials, such as zirconium fluoride materials, may be fully developed for the transmission of light on the order of 0.19-10.6 micrometers without substantial absorption. If cost effective, it is foreseen that fiber optic 15 may be formed from such materials.

Preferably, fiber 15 is removeably mounted within extension 11 by means of a mounting and release mechanism. Referring to Fig. 2, for the preferred embodiment the mounting and releasing mechanism operates by means of a pair of bushings, preferably comprising internal bushing 18 and external end bushing 19. Internal bushing 18 is mounted within handle portion 10 in the first end portion 13 of member 12, and includes a central aperture through which fiber 15 extends during use. End bushing 19 forms an aperture in the end of extension 11, i.e. the second end portion 14 of tubular member 14, through which fiber 15 extends to project outwardly. It will be understood that fiber 15 is preferably mounted through frictional contact with appatures provided at bushings 18 and 19 respectively.

Generally, synthetic quartz is a preferred material for fiber 15, and it will often be preferred that fiber 15 be disposed of after use or wear. Synthetic quartz materials are relatively inexpensive and readily available.

Preferably probe extension 11 comprises a multi-walled extension 20 projecting outwardly from handle portion 10. Extension 20 comprises a first, in this instance inner, chamber system or cylindrical wall 21 forming a tubular chamber 23 having fiber 15 extending therethrough. Referring to Fig. 2, wall 21 extends into handle portion 10, and is in communication with relief chamber 26. By means of internal chamber 23 and relief chamber 26 a suction or fluid draw can be applied through suction means to the volume immediately surrounding working probe or fiber 15. This suction or vacuum can be applied, for example, through tube 27 attached by means of hose connector 28. The purpose of the attachment is understood from the following:

Cylindrical wall or tubular element 21 includes an extension 30 thereon, in the immediate vicinity of working tip or probe tip 31 of the fiber 15. Extension 30 is insertable into the eye, in the region of the cataract, during a laser emulsification operation. For this purpose, a preferred diameter for extension 30 is on the order of about 500 micrometers. Extension 30 includes at least one drainage aperture 35 therein providing for fluid flow communication with chamber 23. As a result of aperture 35, when extension 30 is inserted into the eye, and into the area of the cataract to be emulsified, emulsified material can be withdrawn through aperture 35 and chamber 23 by means of suction applied through 27 at connector 28 and passageway 26. Preferably, aperture 35 is positioned substantially near tip 31, so that emulsified cataract material can be readily withdrawn. Generally aperture 35 for preferred uses is on the order of about 30 microns in diameter.

Probe extension 11 also includes a second chamber system, preferably comprising an outer tube member or portion 40, forming a jacket member, fluid transmission system, or chamber 41 around an outer portion of tube 21. Near end portion 30, tube 40 terminates short of aperture 35, as shown at 42, Fig. 1.

Positioned substantially near end 42 are a pair of fluid flow apertures 43, for the preferred embodiment each having a diameter of about 100 microns. It will be understood that when probe extension 11 is inserted into the eye, fluids such as saline solution may be introduced therein by passage through chamber 41 and appatures 43. Exterior to the eye, fluid flow communication with chamber 41 is provided by means of passage 50, and hcse 51. The hose 51 is mounted by

means of hose connector 52, in a conventional matter.

In operation, probe extension 11 is inserted into an eye, in a manner bringing the tip 31 of the optical fiber 15 into the immediate vicinity of the lens or cataract material could be emulsified. Through means described below, light is transmitted to and through the optical fiber 15, and the cataract material is emulsified. A vacuum draw applied by means of hose 27 is used to withdraw emulsified material, through appature 35 and chamber 23, outwardly from the eye. Saline solution introduced through chamber 41 and appature 43 can selectively provide for flushing of the site of surgery and also replacement of lost volume. At the end of surgery, probe extension 11 is readily withdrawn from the eye.

For the preferred embodiment described and shown, the inner chamber 23 is for suction, and the outer 41 is for insertion of fluid. In alternate embodiments opposite arrangements may be used. Further, arrangements involving chambers which are not concentric, and for example with neither chamber occupying an "inner" or "outer" position with respect to the other, can be utilized. Also, the fiber 15 may be positioned in a chamber independent of the chamber for suction and for flush.

It will be readily understood that a variety of sizes of probes may be provided, for various and different uses. Typically, an overall diameter of about 500-1000 microns will be preferred, control of such a probe being facilited through conventional microsurgery techniques. Preferably probe extension 11 is relatively short, for easy control and to reduce the extension of fiber 15, for synthetic quartz fibers or the like, through which the laser energy must pass. By this latter, undesired absorption and loss of energy are at

least reduced to at or below acceptable minima.

It is a particularly advantagous feature of the present invention that tool 2 is constructed in a manner permitting optic fiber 15 to be readily removed and replaced. As previously indicated, optic fiber 15 is mounted by means of bushings 18 and 19, and thus can be removed simply by pulling same outwardly from the bushing. Insertion of fiber 15 may be accomlished in a reverse manner. As a result, optic fiber 15 can be readily removed for purposes of sterilization and/or disposal. Further, it is foreseen that a variety of different optical fibers may be desired, for a variety of uses. This will be understood by reference to Figs. 3-12. From the description of these it will be understood that a kit can readily be provided, to facilitate laser emulsification surgery, the kit comprising the tool 2 as described, a light transmission mechanism 3 and at least one optical fiber. A plurality of optical fibers, of different shapes, may be provided in the kit.

Figs. 3 and 4 comprise end, and fragmentary side elevational views, respectively, of probe tip 31 of fiber optic 15 depicted as mounted tool 2, in Fig. 2. It will be understood from Figs. 3 and 4 that optic fiber 15 is circular in cross-section, and includes a blunt tip 31, i.e. tip 31 is truncated at substantially 90° to a longitudinal axis of optic 15. In a conventional manner light emitted from tip 31 will have a more or less Gaussion energy distribution across the circular cross-section, defined by the entire blunt tip 31. Thus, fiber 15 presents a broad, blunt, working fiber that can be used to transmit a substantial amount of energy to the cataract, to help break it up in conjunction with physical manipulations.

In Figs. 5 and 6 an alternate optical fiber 60 is depicted, in fragmentary side elevational and end elevational views respectively. By reference to Fig. 5, it will be understood that optical fiber 60 has an angularly truncated end 61 forming a tip or forward edge 62. Referring to Fig. 6, end 61 is shaped in a manner which still provides for a Gaussion light distribution, throughout the circular cross-section, and also in a high energy passage. However, edge 62 provides a cutting or knife edge that can be used to facilitate the surgical process. A variety of truncating angles may be used, the one of about 45° disclosed in Fig. 5 providing a preferred example. Preferred angles are between about 40-60°, as they are relatively easy to effect and provide sharp, yet strong, cutting edges.

Yet another alternate embodiment is depicted in Figs. 7 and 8, in fragmentary side elevational and fragmentary end elevational views respectively. Referring to Fig. 7, fiber 65 is shown truncated along two planes 66 and 67, to form a tip 68 having a central ridge 69 extending thereacross and projecting therefrom. Such a tip 68 provides a cutting tool, similar to the arrangement shown in Figs. 5 and 6. It also provides for a Gaussion light distribution in cross-section, and is easily handled. A variety of angles of tips may be used, the angles of about 52° between planes 66 and 67 providing an example.

Another alternate embodiment is depicted in Figs. 9 and 10, in fragmentary side elevational and end elevational views respectively. More specifically, optical fiber 71 of the embodiment shown in Figs. 9 and 10 has a rounded tip 72. While variety of curvatures for tip 72 might be selected, for the preferred embodiment shown in Figs. 9 and 10 tip 72 is semi-spherical.

Optical fiber 71 is particularly well suited for use close to the surface of the lens, whereat extreme care is necessary to avoid unintended damage to the eye. Tip 72 having only curved edges is (mechanically) non-cutting and thus unlikely to damage tissue. Also, a preferred form of tip 72 includes a reflective portion 73 thereon. For the embodiment shown in Figs. 9 and 10 portion 73 is formed from a spot or reflecting barrier of reflective material such as gold, silver, or the like, coated onto fiber 71. This material will tend to reflect light directed there against, from inside the fiber 71, back into the fiber. Thus, a substantial amount of laser energy is prevented from the being emitted outwardly from fiber 71 in the vicinity of spot 73. During use of optic fiber 71 according to the present invention, spot 73 can be directed toward portions of the eye which are particularly sensitive to damage from laser surgery. That is, spot 73 is used to block light from being directed into particularly sensitive areas. Thus, emulsification can be effected relatively safely, even in particularly sensitive areas of the eye.

Yet another embodiment is depicted in Figs. 11 and 12, again in side elevational and end elevational views respectively. Optical fiber 80, of Figs. 11 and 12 is shaped into a point 81, thus the tip 82 of fiber 80 is conically shaped. A very fine, sharp, point such as point 81 can be used, for example, to initially insert the probe into the eye without use of a separate incision. That is, tip 82 can simply be punched through a portion of the eye. It is noted that for the particular embodiment shown in Figs. 11 and 12 light emission distribution would be fairly constant across the entire cross-section of the fiber 80. Alternate

arrangements can be provided.

From the above descriptions of Figs. 3-12, it will be readily understood that a variety of optical fibers can be provided for use in association with a tool 2, such as that illustrated in Figs. 1 and 2. Different shapes of optical fibers may have different advantages, for various uses. Further, surgeons may find personal preferences for some of the various designs shown, or variations of them. It will also be understood that in a variety of manners reflecting portions such as portion 73 in Figs. 11 and 10 can be utilized in association with any of the fibers shown. Further, shapes not illustrated might be applied.

A particular problem to the utilization of laser emulsification methods for cataract surgery involves the transmission of light of appropriate energy or wavelength to the site of emulsification. In particular, as previously discussed it is desired to utilize relatively low energy light, on the order of 0.19-10.6 micrometers and preferably about 2.94 micrometers in wavelength. Light in the above range of wavelengths, particularly light of about 2.94 micrometers, is of low energy and is of a wavelength readily absorbed by materials found in the body, such as carbon dioxide and water. Thus, the laser energy is substantially dissipated, in part through absorption by bodily fluids, before it can be transmitted a sufficient distance to cause much damage to more remote optical tissue regions. As previous indicated, carbon dioxide-, argon fluoride-, holmium-, neodymium-, and erbium-, lasers all provide light of desired wavelengths for use in laser emulsification in laser surgery. Erbium lasers are particularly desirable, as they generate light of about 2.94 microns.

As previously discussed, a major problem in

applying this light in laser emulsification concerns the fact that synthetic quartz may absorb substantial part of the light emitted by such lasers. Thus, it can be relatively difficult to get sufficient light from the source all the way to the tip of the optical fiber 15, in the region of the cataract, without excessive loss of energy. There are two basic approaches to overcoming this problem. These theoretically include use of a substance for optical fiber construction which does not readily absorb this light. While no such materials are presently readily commercially available, there is a substantial likelihood that such materials, for example zirconium fluoride materials, will become widely available. Even when they do, they may be of such mechanical characteristics that it is undesired to use them for fibers to be inserted into the eye. However, they might be used to transmit energy from the laser source to the tool 2 itself, i.e. along transmission mechanism 3. This will be discussed in more detail below.

The second primary method of overcoming the light transmission problem involves utilization of a tube transmission mechanism. That is, the light is transmitted along the inside of a tube. Application of such a tube transmission, would comprise a hollow glass, quartz or metal tube is provided with an internal reflective surface by means of a conventional coating such as silver or the like. Light transmitted along the longitudinal axis of the tube may tend to diffuse toward the walls, however it is reflected back into the main path of light by means of the reflective surface. One problem with such reflective or mirrored surface tubes is that they are not 100% efficient in transmitting light, that is, each reflection introduces a small but

significant loss of energy.

While some of the advantages of the present invention can be obtained with use of hollow tube systems, in some preferred applications filled tube transmitters are preferred. For such an arrangement, straight tube portions are filled with solid or liquid material capable of transmitting light of appropriate wavelength. A central core and an outer cylinder of materials having different indices of refraction are used. If organized, as described below, in a preferred manner total reflection, meaning 100% reflection longitudinally along the tube, takes place.

A major problem with conventional tube transmission systems concerns the introduction of degrees of freedom into the transmission mechanism. That is, ends, joints, elbows, and the like may be necessary to facilitate ease of use of the tool, but may be difficult to provide in such systems, since light propagates in a straight line. To accommodate deflection about bends or turns, some conventional systems have used relatively complex mechanical arrangements formed from mirrors and the like. These have generally been undesirable since they lack substantially complete freedom of movement and use, are relatively expensive and complicated, and have, in the past, used somewhat inefficient reflective means.

According to the present invention either of two preferred general light transmissions may be provided for efficiently transmitting light from a laser source, not shown, to the probe or tool tube. A first of these (with elbow portions) is depicted in Figs. 1, 2, 13, 14 and 15, with an alternate shown in Fig. 16. The second (using an elongate flexible fiber) is depicted in Fig. 17.

Referring to Figs. 1, 2, 13, 14 and 15, light transmission mechanism 3 depicted comprises a tube/elbow system 100. Referring to Fig. 1, one end 101 of the system 100 is provided in communication with tool 2, while the other end 102 provides for communication with a source of laser energy, not shown. Generally, tube/elbow system 100 includes straight tube portions 105 and at least one flexible, or elbow, portion 106. Referring to Fig. 13, the embodiment depicted thereat includes three straight tube portions 110, 111 and 112 connected by two elbow portions 113 and 114.

The straight tube portions for the embodiment of Figs. 1, 2, 13, 14 and 15 are as follows:

Referring to Fig. 14, tube section 112 is depicted in cross-section. Generally tube portions 110 and 111 may be substantially identical in cross-section. Tube section 112 generally comprises an elongate, cylindrical outer wall or tube 120, which may or may not be transparent, for the transmission of light along a longitudinal axis 121 thereof. It will be understood that a variety of materials may be utilized for tube 120.

For the preferred embodiment depicted, rather than use of a reflective coating such as metal or the like, a preferred, highly efficient, system of providing reflection along axis 121 is provided by means of layers 122 and 123. Layers 122 and 123 are materials applied to an inside surface 125 of the tube 120. Specifically, layer 122 is provided against surface 125, and layer 123 fills the remainder of tube 120 as a core. The material of this core may be solid or liquid in nature. The materials comprising layers 122 and 123 are such as to permit the transmission of light of the selected wavelength(s) therethrough. However, importantly, the

refractive index of layer 123 is greater than 122. Some of the light passing through layer 123 is reflected as it encounters layer 122. In this case it is reflected back into layer 123 as indicated by arrow 131.

Specifically, and referring to Fig. 14, the critical angle A_c can be defined as follows:

$$\text{Sin } A_c = n_{122}/n_{123}$$

n_{123} being the index of refraction of material 123 and n_{122} being the index of refraction of material 122. Angle A_c is the critical angle measured from a normal line, for example line 132. Any light directed against the interface between sections 122 and 123 will be substantially 100% reflected, if it is directed at a greater angle to the norm 132 than A_c, according to Snell's Law. If materials having appropriate light transmission characteristics are chosen for the layers, nearly 100% transmission of light energy along axis 121 can be achieved. It is noted that the index of refraction of a material will depend on the wavelength of light being tranmitted therethrough. For an erbium laser a suitable combination includes: sodium chloride as the inner core fill (n_{123} = 1.5244) with calcium fluoride as the outer layer (n_{122} = 1.4179) giving a critical angle of 68.5°; for a CO_2 laser: potassium bromide as the inner core fill (n_{123} = 1.5264) with a sodium chloride (n_{122} = 1.4949) inner layer, giving a critical angle of 78°. Preferably, the critical angle is no less than about 60°, i.e. the ratio n_{122}/n_{123} is no less than about 0.866. Preferred critical angles will be about 80-89°. It will be understood that a variety of materials can be utilized to achieve this.

Referring to Fig. 2, tubing extension 101 is mounted on tool 2 by a conventional engagement using a bayonet type disconnect 126. Such connections are

conventional and are not detailed herein. They generally involve a mating of coupling members on each of two components. Locking is typically achieved by means of a pin/groove engagement. It is noted that disconnection permits access to end 127 of fiber 15, for removal and replacement. It will be understood that conventional adhesives, clamps, or other connection arrangements may be provided to make a secure engagement in place of a bayonet system.

Referring to Fig. 2, a lens mechanism 140 is shown depicted in the foremost tube extension 101, i.e. the extension in engagement with tool 2. Lens 140 is preferably positioned to collect light traveling longitudinally through transmission mechanism 3 and to focus same on the optical fiber 15, Fig. 2, mounted in the tool 2. For the embodiment shown, lens 140 is in a hollow portion 141 of the system 100. A partial vacuum, if desired, could be provided in portion 141 to facilitate transmission without absorption by air, for those wavelengths which are subject to absorption in air. Further, lens 140 could be provided with means for adjustment to focus light onto, and into, optical fiber 15.

As previously indicated, transmission mechanism 3 comprises tube/elbow arrangement 100. That is, a bending means is provided between extensions of tube transmission portions, such as portions 110, 111 and 112. Referring to Fig. 3, this is provided by elbows 113 and 114. For the preferred embodiment the two elbows 113 and 114 are substantially identical and are as described below. Attention is directed to Fig. 15, which shows a portion of elbow 113 in cross-section, and also Fig. 13.

Elbow 113 comprises a bundle of small

transmission units 150. For a preferred embodiment, the units 150 comprise fibers 151 closely packed into a pair of bearings 152 and 153, by which the bundle of fibers 151 are mounted in, and communicate between, an associated pair of tube sections, for example sections 111 and 112, Fig. 13. By "closely packed" it is meant that the units 150, for example fibers 151 preferred ones of which are about 300 microns in diameter, are packed as closely as the geometry of the individual fibers permits and therefore transmit as much light as theoretically possible around the bend. While a variety of sizes of tubing for sections 113 and 114 may be utilized, generally relatively small diameters will be preferred, to facilitate bending.

It is generally desirable to maintain fibers 151 as short as possible, to keep loss of energy due to absorption by the fiberoptic material, to a minimum. Generally fiber lengths of about 5-10 cm with fiber diameters of 4-6 mm will be effective and preferable in providing sufficient bending for needed articulation. By the mechanism described, generally complicated and difficult to assemble and operate mirror arrangements are avoided. However, advantage is taken of fiber flexibility characteristics, for short flexible sections.

The end bearings, for example bearings 152 and 153 for joint 113, provide means for rotation of tube 112 with respect to tube 111 and add some additional degrees of freedom to the tube/elbow system. That is, the elbow 113 can be rotated with respect to the two arms 111 and 112 in which it is mounted. This rotational engagement between the bearings 152 and 153 and the straight arm sections 111 and 112 may be provided by conventional means.

For an alternate embodiment, units 150 can comprise flexible hollow tubes having mirrored inner surfaces, closely packed in bearings 152 and 153. Generally, diameters on the order of about 1-3 mm would be flexible enough to be usable and still large enough for relatively easy internal mirror coating.

In yet another alternate embodiment, the flexible bundle of tubes may comprise hollow, transparent, tubes with a refractive index of n_1, filled with a material, solid or liquid, having a refractive index n_2. If the materials are chosen such that n_2 is greater than n_1, then internal reflection according to Snell's law, analogously to that previously described, will occur.

From the above, it will be understood that a relatively lightweight, flexible and easily handleable light transportation system is provided.

An alternate to the filled tube system of Fig. 14 is shown in Fig. 16. Here, the tube 157 (analogous to tube 112) is hollow, and has a mirror coating 158 on an inner surface thereof. The mirror coating 158 may be gold, silver or the like. If desired, vacuum can be provided within the tube 157, to inhibit loss of energy by absorption of air. A straight tube section such as tube 157 may be used analogously to section 122 previously discussed.

An alternate overall light transmission mechanism is illustrated in Fig. 17. Referring to Fig. 17, tool 162, with probe 163 extending outwardly therefrom, is shown having light transmission mechanism 165 mounted in association therewith, for transmission of light thereto. Mechanism 165 includes a single elongate fiber 167. Rather than having been manufactured from synthetic quartz, however, preferably fiber 167 is composed of

a material, such as zirconium fluoride, which does not appreciably absorb light of the desired wavelengths for use in optical surgery involving laser emulsification. If fiber 167 is substantially larger in diameter than removeable and replaceable fiber 168, mounted in extension 163, then lens and/or focus means, not shown, may be provided to concentrate light passing through fiber 167 and focus same on fiber 168. Conventional means may be utilized to accommodate this, for example a conventional lens or the like. Mechanism 165 includes a flexible sheath 169, for protection of fiber 167.

From the above descriptions, it will be understood that also according to the present invention a method is provided for the removal of cataracts. Generally, steps of the method comprise application of laser emulsification through the utilization of a device such as that described capable of transmitting relatively low energy laser emissions to a selected point of surgery within a patient's eye. More specifically, the preferred method involves utilization of a tool having a removeable and replaceable optical fiber therein, the fiber optic member being, for one in preferred embodiment, constructed from synthetic quartz or the like. Also, preferably, the tool 2 utilized to effect the method includes means associated therewith for removal of emulsified material, and also fluid transport means for provision of a saline solution or the like into the location from which the emulsified material has been removed.

It is to be understood that while certain embodiments of the present invention have been illustrated and described, the invention is not to be limited to the specific forms or arrangement of part herein described and shown.

WHAT IS CLAIMED AND DESIRED TO BE SECURED BY LETTERS PATENT IS AS FOLLOWS:

1. An apparatus for use in conducting laser emulsification surgery; said apparatus comprising:
   (a) a handle member;
   (b) a probe extension mounted on said handle member; said probe extension including an optic fiber mounting and release mechanism;
   (c) an elongate optic fiber removably mounted in said probe extension and retained therein by said probe extension mounting and release mechanism; said optic fiber having a probe tip projecting outwardly from said probe extension; and,
   (d) a light transmission mechanism constructed and arranged to transmit light energy from a source of such energy to said optic fiber.

2. An apparatus according to claim 1 wherein:
   (a) said probe extension includes an elongate tubular element having a first end portion and a second end portion;
      (i) said probe extension tubular element first end portion being mounted on said handle member;
      (ii) said probe extension tubular element second end portion being oriented remote from said handle member;
   (b) said optic fiber mounting and release mechanism comprises first and second friction bushings; said first friction bushing being positioned in said tubular element first end portion and being sized for a friction fit of

said optic fiber therein; said second friction bushing comprising an aperture in said tubular element second end portion sized for a friction fit of said optic fiber therein; and,

(c) said elongate fiber extends between said first and second friction bushings.

3. An apparatus according to claim 2 wherein:

(a) said tubular element second end portion includes a drainage aperture therein; and,

(b) said apparatus includes suction means constructed and arranged to facilitate fluid draw into said drainage aperture and through said tubular element.

4. An apparatus according to claim 3 including:

(a) a fluid jacket member mounted on said tubular extension; said fluid jacket member having an end portion substantially adjacent said tubular element second end portion; said jacket member end portion having at least one fluid flow aperture therein; and,

(b) means constructed and arranged to selectively enable fluid flow outwardly through said jacket member fluid flow aperture from within said jacket member;

(c) whereby fluid may be introduced into a volume substantially adjacent said tubular extension second end portion.

5. A kit for use in conducting laser emulsification surgery; said kit comprising:

(a) a surgical tool comprising a handle member and a probe extension;

(i) said probe extension including an elongate tubular element having a first end portion and a second end portion; said tubular element first end portion being mounted on said handle member, and said tubular element second end portion being remote therefrom;

(ii) said probe extension including an optic fiber mounting and release mechanism comprising first and second friction bushings; said first friction bushing being positioned in said tubular element first end portion and said second friction bushing comprising an aperture in said second end portion;

(b) a light transmission mechanism constructed and arranged to transmit light from a source of such energy to said surgical tool; and,

(c) at least one elongate optic fiber sized to extend between said first end and second friction bushings and to project outwardly from said tubular element second end portion.

6. An optic fiber for use in a kit according to claim 5; said optic fiber comprising an elongate member having a circular cross-section and a probe tip; said probe tip being a blunt end truncated at substantially 90° with respect to a longitudinal axis of said fiber.

7. An optic fiber for use in a kit according to claim 5; said optic fiber comprising an elongate member having a circular cross-section and a probe tip; said probe tip having a sharp forward edge defined

by a plane-of-truncation of 40-60° with respect to a longitudinal axis of said optic fiber.

8. An optic fiber for use in a kit according to claim 5; said optic fiber comprising an elongate member having a circular cross-section and a probe tip; said probe tip having a sharply defined central ridge.

9. An optic fiber for us in a kit according to claim 5; said optic fiber comprising an elongate member having a circular cross-section and a probe tip; said probe tip being rounded.

10. An optic fiber according to claim 9 having a reflecting barrier thereon.

11. An optic fiber for use in a kit according to claim 5; said optic fiber comprising an elongate member having a circular cross-section and a probe tip; said probe tip being conical-shaped and having a central point.

12. An apparatus for use in conducting laser emulsification surgery, said apparatus comprising:
(a) a handle member;
(b) a probe extension mounted on said handle member; said probe extension including an optic fiber mounting and release mechanism;
(c) an elongate optic fiber removably mounted in said probe extension and retained therein by said probe extension mounting and release mechanism; said optic fiber having a probe tip projecting outwardly from said probe exten-

sion; and,

(d) a light transmission mechanism constructed and arranged to transmit light energy from a source of such energy to said optic fiber; said light transmission mechanism comprising an articulated arm arrangement having at least one elbow portion therein.

13. An apparatus according to claim 12 wherein:

(a) said elbow portion comprises a flexible bundle of relatively small optic fibers.

14. An apparatus according to claim 13 wherein:

(a) said elbow portion includes first and second rotatably mounted bearings; and,

(b) said flexible bundle of relatively small optic fibers comprises fibers mounted within and extending between said first and second bearings.

15. An apparatus according to claim 12 wherein:

(a) said elbow portion comprises a flexible bundle of relatively small hollow tubes each of which has a reflective inner surface.

16. An apparatus according to claim 15 wherein:

(a) said elbow portion includes first and second rotatably mounted bearings; and,

(b) said flexible bundle of relatively small tubes comprises tubes mounted within and extending between said first and second bearings.

17. An apparatus according to claim 12 wherein:

(a) said elbow portion comprises a flexible bundle

of transparent hollow tubes having a refractive index n_1; said tubes each being filled with transparent material having a refractive index n_2; n_2 being greater than n_1.

18. An apparatus according to claim 12 wherein:
(a) said articulated arm arrangement includes at least one, substantially straight, light transmission segment comprising a cylindrical member having an inner wall defining a longitudinal channel;
(b) said straight segment including: an inner core of light-transmitting material having a first index of refraction, positioned within said longitudinal channel; and, an outer layer of light-transmitting material, positioned between said inner core and said cylindrical member inner wall, said outer layer having a second index of refraction;
(c) said inner core first index of refraction being greater than said outer layer second index of refraction.

19. An apparatus according to claim 18 wherein the ratio of said second index of refraction to said first index of refraction is at least 0.866.

20. An apparatus according to claim 18 wherein:
(a) said elbow portion comprises a flexible bundle of relatively small optic fibers.

21. An apparatus according to claim 20 wherein:
(a) said elbow portion includes first and second rotatably mounted bearings; and,
(b) said flexible bundle of relatively small optic

fibers comprises fibers mounted within and extending between said first and second bearings.

FIG. 1

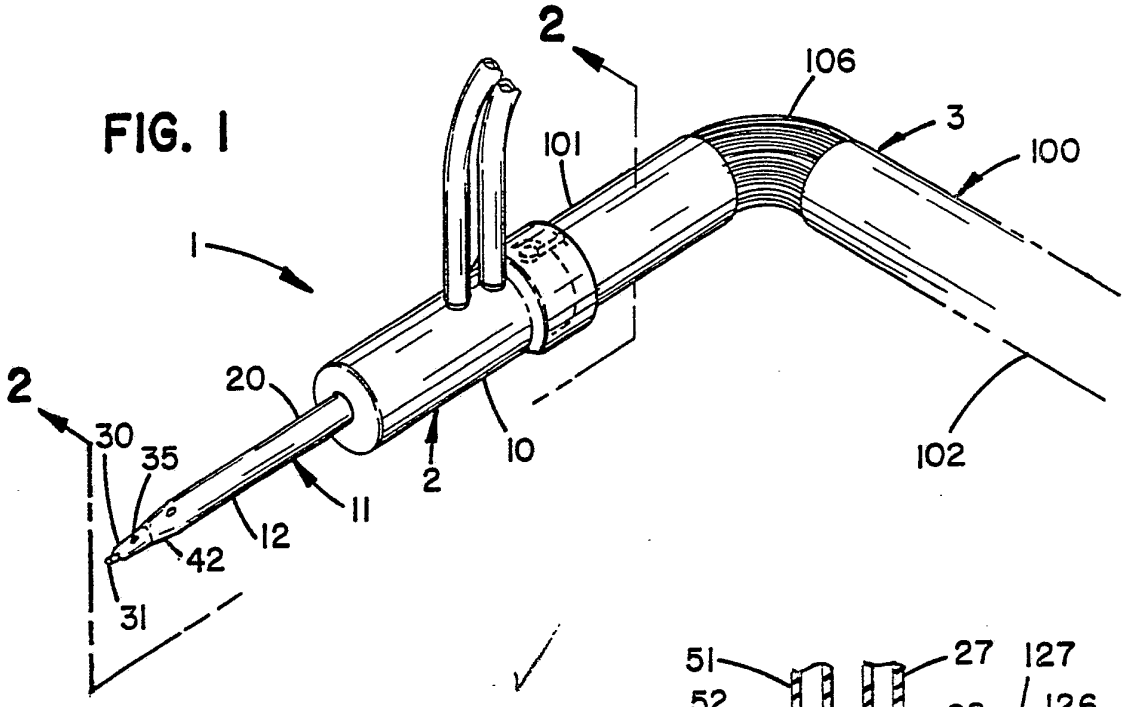


FIG. 2

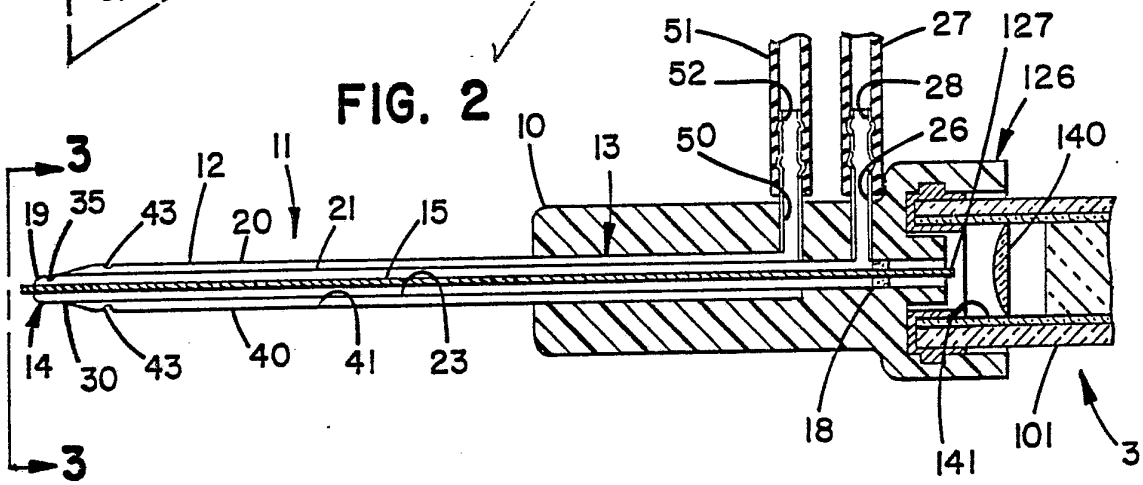


FIG. 3 FIG. 6 FIG. 8 FIG. 10 FIG. 12

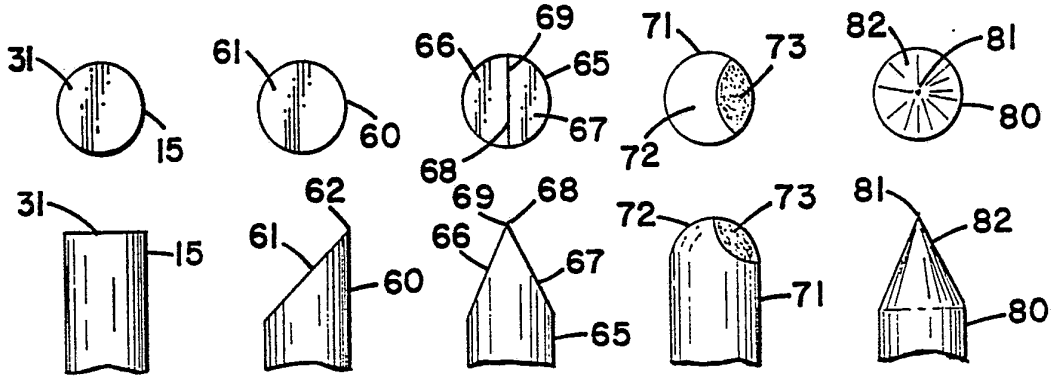


FIG. 4 FIG. 5 FIG. 7 FIG. 9 FIG. 11

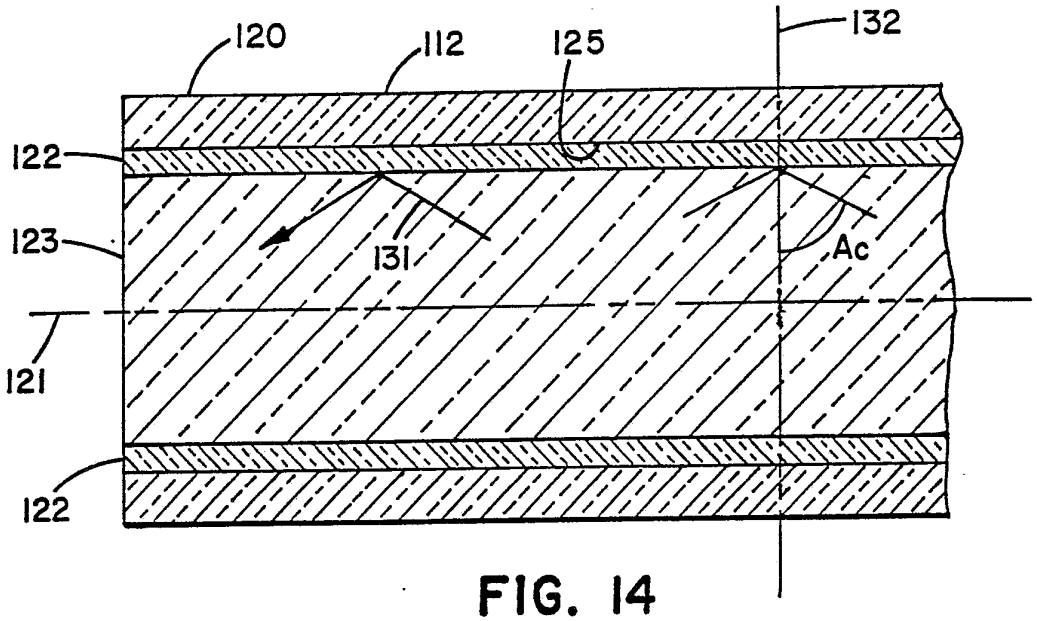


FIG. 14

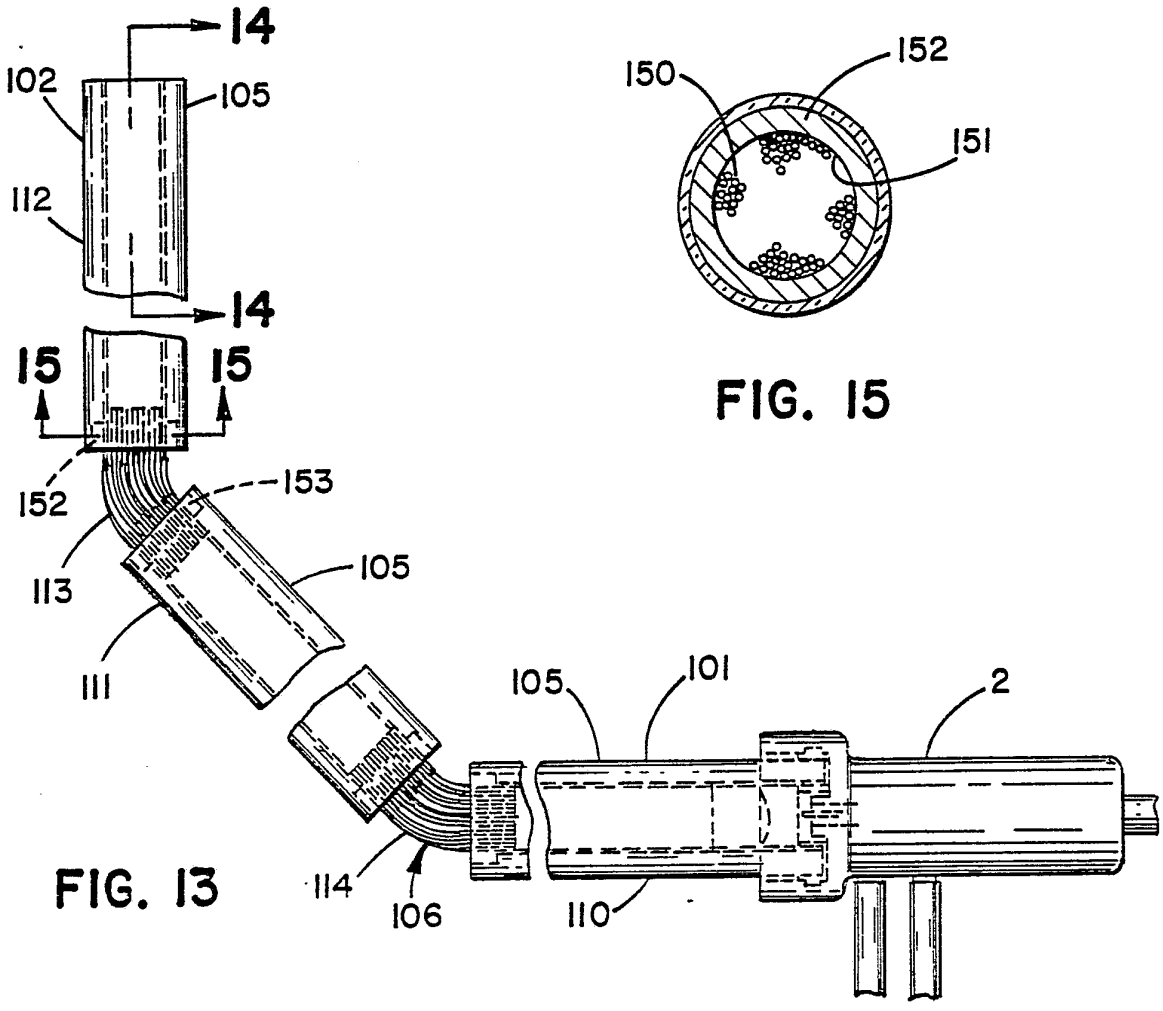


FIG. 13

FIG. 15

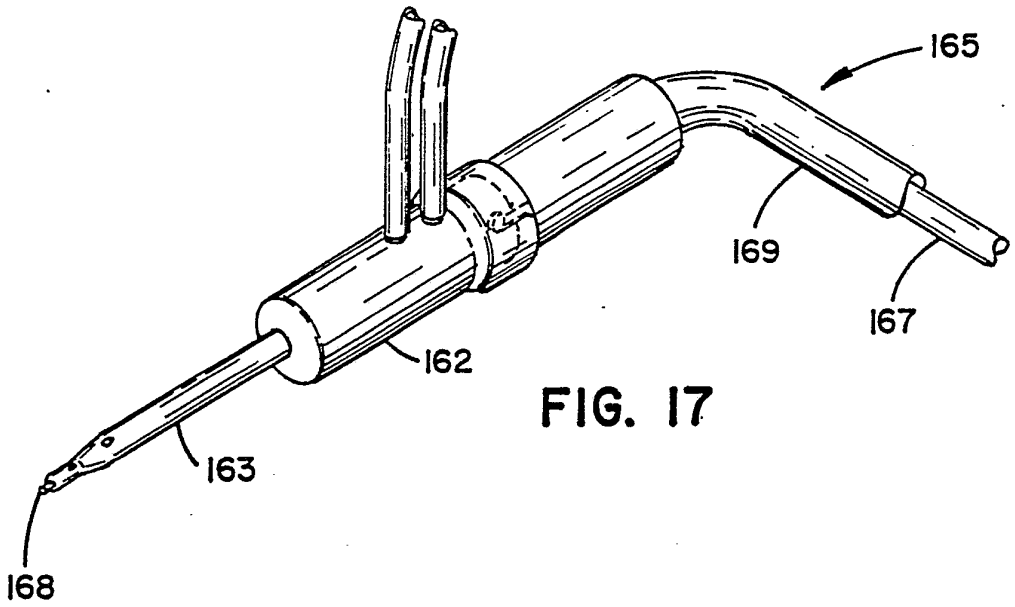


FIG. 17

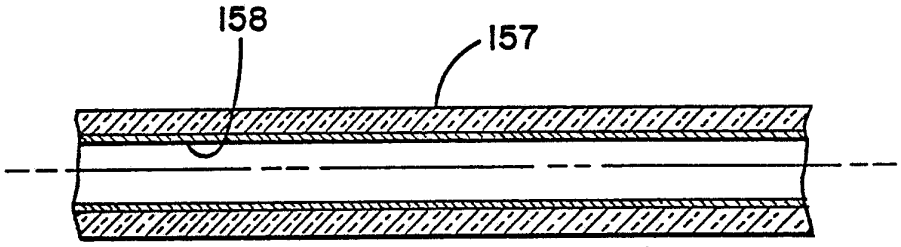


FIG. 16