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(71) Applicant *(for all designated States except US)*: **CARDIOFOCUS, INC.** [US/US]; 126B Mid-Tech Drive, West Yarmouth, MA 02673 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **SINOFSKY, Edward, L.** [US/US]; 152 Whittier Drive, Dennis, MA 02638 (US). **BAXTER, Licoln, S.** [US/US]; 18 Pine Tree Drive, Centerville, MA 02532 (US). **FARR, Norman, E.** [US/US]; 35 Beach Street, Monument Beach, MA 02553 (US). **MACLEAN, Brian** [US/US]; 391 Linwood Avenue, Newton, MA 02460 (US). **MCINTYRE, Jon, T.** [US/US]; 429 Waltham Street, Newton, MA 02465 (US). **WIELER, William, E.** [US/US]; 66 Wamsutta Avenue, Pocasset, MA 02559 (US).

(74) Agents: **ENGELLENNER, Thomas, J.** et al.; Nutter, McClennen & Fish, LLP, One International Place, Boston, MA 02110-2699 (US).

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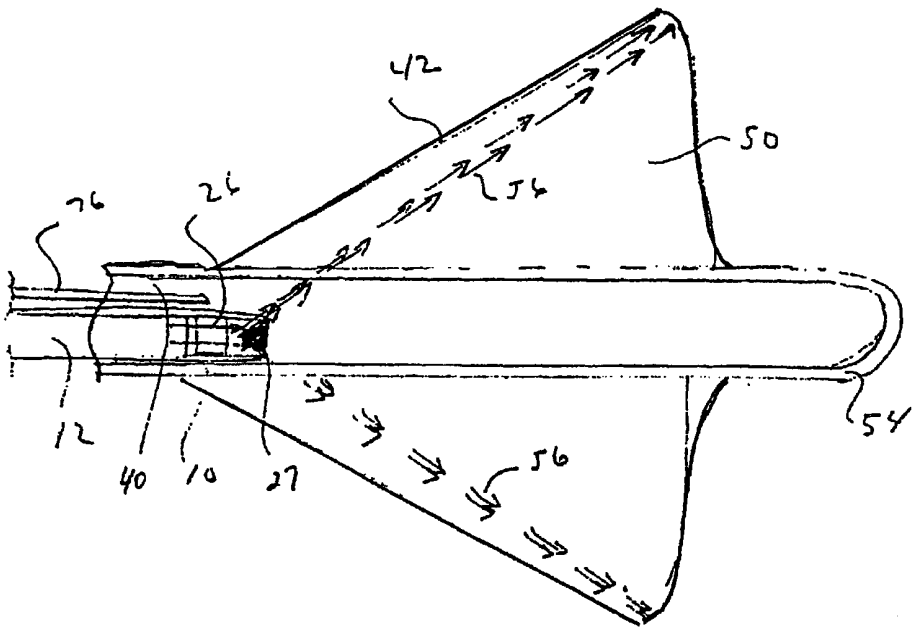

(57) Abstract: Methods and apparatus are disclosed for forming annular lesions in tissue. The methods include introduction of an optical apparatus proximate to a tissue site, via, for example, a catheter. The optical apparatus includes a pattern-forming optical waveguide in communication with a light transmitting optical fiber. Energy is transmitted through the optical fiber, such that radiation is propagated through the optical fiber and the waveguide projects an annular light pattern, e.g., a circle or a halo.

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PHOTOABLATION SYSTEM

Background of the Invention

The technical field of this invention is phototherapy and, in particular, methods and devices which employ optical fibers and flexible light waveguides to deliver radiation to a targeted site, such as the heart.

Cardiac rhythm irregularity, e.g., fibrillation, is a pathological condition of heart muscle that can be present in one or more of the atria or the ventricles of the plant. Until recently, efforts to alleviate these irregularities have focused on pharmacological treatments. While pharmacological treatments can be effective, drug therapy requires regular administration of so-called "beta-blocker" type drugs or prompt intervention with a therapeutic inhibitor of fibrillation. Moreover, drug therapy is frequently accompanied by side effects such as dizziness, nausea, vision problems or other difficulties.

Abnormal arrhythmias can occur in the atrium or ventricle, and are referred to, respectively, as atrial fibrillation and ventricular fibrillation. Atrial fibrillation is an atrial arrhythmia characterized by rapid randomized contractions of the atrial myocardium, causing an irregular, often rapid heart rate. Three of the most common types of atrial arrhythmia are ectopic atrial tachycardia, atrial fibrillation and atrial flutter. Atrial fibrillation can result in significant patient discomfort and even death due to an irregular heart rate. Ventricular fibrillation is an arrhythmia characterized by fibrillary contractions of the ventricular muscle due to rapid repetitive excitation of the myocardial fibers without coordinated contraction of the ventricles. Loss of synchronous atrioventricular contractions compromises cardiac hemodynamics and can lead to varying levels of congestive heart failure, or stasis of blood flow, which increases the likelihood of thromboembolism. It is difficult to isolate a specific pathological cause for atrial fibrillation although it is believed that the principle mechanism is one or more of the electrical reentry circuits within the left and/or right atrium. Such reentry circuits interfere with the normal rhythm of electrical signals that course the heart muscle to contact in a synchronized manner in order to perform its normal pumping function.

Recently, it has been suggested that arrhythmias can be treated by ablation procedures performed within the heart and/or the coronary blood vessels. Ablation of predetermined locations within the heart to form linear tracks or scars through the walls (transmural) of the

heart or blood vessels can provide a natural barrier to the formation of reentry circuits. These linear scars must be well defined within the heart to be effective. For example, the ablation catheters used to perform the ablation procedures produce scar tissue at the selected site from one of a number of different energy sources employing direct current, laser, microwave, or ultrasound energy. However, many of these energy sources are limited by the requirement that physical contact must be maintained with the target tissue region during the procedure.

Moreover, the present ablation systems do not provide a suitable way to know when contact has been achieved, or when sufficient energy has been applied to the tissue, without unnecessary scarring of exposed tissue, or to what extent the energy has penetrated the tissue.

In addition, serious complications can occur with presently known ablation techniques when such procedures are performed within a vein or artery. Veins and arterial blood vessels are delicate physiological structures. Traumatic stressing of a vein or artery, such as by surgery, or thermal destruction of tissue, can lead to stenosis, a reduction or collapse of the inner diameter of the blood vessel causing a reduction in blood flow. For example, many of the current techniques used to treat fibrillation are directed to ablation of tissue within the pulmonary vein, thus leading to stenosis of the site treated. Unfortunately, the resultant stenosed vessels reduces the blood flow back to the heart, thereby causing discomfort, pulmonary hypertension and other serious side effects. Often times, the patient must undergo additional procedures to treat the stenosis, which in turn causes a new site to be traumatically stressed and ultimately stenosed. This repetitive cycle can have serious consequences for the patient.

A need therefore exists for therapies and modalities of treatment that can overcome the above-described deficiencies of currently available photoablation techniques, especially for the treatment of cardiac arrythmias.

Summary of the Invention

Methods and apparatus for phototherapy are disclosed in which laser light or other radiation is projected in an annular pattern without requiring direct contact of the energy source, e.g. a laser (via fiber), with the targeted tissue. The invention is particularly useful in cardiac therapy in creating annular conduction blocks in atrial chamber issue, e.g. centered about but at a defined distance from a pulmonary vein orifice or coronary sinus orifice, to

eliminate aberrant wave conduction.

The invention is particularly useful for inducing phototherapeutic processes in tissue, including ablation and/or coagulation of the tissue. Typically the optical apparatus is contained within a catheter including a flexible elongate member having a proximal end, a distal end and at least one longitudinal lumen extending within the elongate member. The distal end of the flexible elongate member can be open or includes a transparent cap, a centering balloon, or a centering coil. The optical apparatus of the invention can be fixed or a distal location or preferably disposed within the first lumen in a manner that permits axial motion within the lumen. The optical apparatus serves to project light through, or from, the distal end of the flexible member. The optical apparatus can include an optical fiber and other light projecting elements.

The optical apparatus of the invention can include an optical fiber and a beam-shaping waveguide for projecting an annular pattern of light. Radiation, e.g., infrared, visible or ultraviolet light is propagated through the optical fiber that is optically coupled to a lens or other optical waveguide. The lens is configured to project an annular light pattern such that an annular lesion is formed in tissue. In one embodiment, the annular light pattern expands over distance like a hollow cone to project a beam in the form of a ring or a halo. The waveguide can include a graded intensity lens (GRIN) or other known refractive or reflective optics to project the annular light pattern.

The apparatus of the invention can also include a balloon member fixedly attached to the catheter. Injection of a solution or gas expands the balloon, thereby forcing blood and/or other body fluids from the tissue site.

In certain embodiments, the optical apparatus of the invention is slidably positioned within the lumen of a catheter proximate to a tissue site. Positioning the optical apparatus at the particular location within the balloon and/or by adjusting the size or shape of the balloon permits control over the size and distance of the forwardly projected annular ring. This control permits the annular beam of projected light to be dynamically changed to specifically target the atrial tissue surrounding the pulmonary veins or coronary sinus.

The present invention also pertains to methods for forming an annular lesion in a tissue by phototherapeutic processes in tissue, including ablation and/or coagulation of the tissue.

The methods include introduction of an optical apparatus proximate to a tissue site via, for example, a catheter. The optical apparatus includes a pattern-forming optical waveguide that is in communication with a light transmitting optical fiber. Energy is transmitted through the optical fiber, such that radiation propagated through the optical fiber and waveguide projects an annular light pattern, e.g., a circle or a halo. By these methods, an annular lesion can be formed in a targeted tissue. In certain embodiments, the tissue forms a lumen, e.g., vascular, atrial, ventricular, arterial, venous, brachial, or urethral lumen. Preferably the methods include projecting an annular light pattern via an optical apparatus that is located at a defined distance from the target tissue.

The invention further pertains to methods for forming annular lesions in cardiac tissue, e.g., trabecular tissue, by phototherapeutic processes that can include ablation and/or coagulation of the tissue. The methods include positioning an optical apparatus at a location proximate to the cardiac tissue via, for example, a catheter. The optical apparatus includes a pattern-forming optical waveguide optically coupled to a light transmitting optical fiber. Energy is transmitted through the optical fiber, such that radiation is propagated through the optical fiber, the waveguide and GRIN lens to forwardly project an annular light pattern, e.g., a circle or a halo. In a preferred embodiment, a balloon is inflated against the tissue, thereby forcing blood and/or body fluids away from the tissue targeted for treatment. Light energy is then passed through the optical apparatus onto the targeted tissue such that an annular beam is projected onto the site, thereby causing ablation, coagulation or photochemical processes to occur.

Methods for treating or preventing atrial arrhythmias by phototherapeutic processes in atrial tissue are disclosed. These processes can include ablation and/or coagulation of the tissue. The methods include introducing an optical apparatus proximate to atrial tissue via, for example, a catheter. The optical apparatus includes an optical waveguide in communication with a light transmitting optical fiber. Energy is transmitted through the optical fiber, such that radiation is propagated through the optical fiber and the waveguide projects an annular light pattern. The annular light pattern forms an annular lesion in the atrial tissue, thereby treating or preventing atrial arrhythmias.

In another aspect, the present invention is directed to methods of treating atrial arrhythmia. The methods include introducing a photoablation instrument into an atrium, positioning the photoablation instrument at a location within the atrium where light from an

optical assembly can be projected onto an inner surface of the atrium, and exposing a region of atrial tissue surrounding a pulmonary vein to radiation from an optical assembly without substantial ablation of the vein itself. The photoablation instrument includes an optical assembly for projecting a beam of radiation, e.g., an annular beam of radiation. The optical assembly can include an optical fiber and a GRIN lens and/or other refractive or reflective elements.

In certain embodiments, the resultant annular lesion has a mean diameter of between about 10 mm and 23 mm, preferably, greater than 10 mm, more preferably greater than 15 mm, and in some instances preferably greater than 20 mm or even greater than about 23 mm. Generally, the annular lesion has a width (of the annular ring) of less than 5 mm, preferably about 3 mm, and in some applications preferably less than or equal to 1.5 mm. Preferably, the treatment occurs without ablation of into the pulmonary vein tissue. For example, the center of a pulmonary vein at its mouth in an atrial chamber can be defined with an anchorage element as described below. A annular beam of radiation can be projected to form a ring like lesion concentric with the pulmonary vein center, but at a radial distance of at least 5 mm, preferably greater than 7 mm from the vein's centerline.

According to another aspect of invention, a region of atrial tissue surrounding the targeted pulmonary vein is exposed to infrared radiation from the optical assembly at a wavelength ranging from about 805 nm to about 1060 nm, more preferably from about 900 nm to about 1000 nm and most preferably from about 940 nm to about 980 nm. More generally, the energy and wavelength of the radiation are chosen to penetrate substantially the entire thickness of the atrial wall, e.g., between about 1 to about 4 mm, preferably, between about 2 to about 3 mm in depth.

In one embodiment of the present invention, the photoablation instrument includes an expandable balloon element adapted to surround the optical assembly upon inflation. The balloon element can be inflated with deuterium oxide or deuterated water, such that the inflated balloon provides a low loss transmission pathway for radiation between the optical assembly and an inner surface of the atrium. A region of atrial tissue surrounding a pulmonary vein can then be exposed to radiation from the optical assembly. Deuterium oxide provides the advantage that it absorbs less energy from the transmitted energy, thereby preventing the balloon from becoming heated.

In another aspect of the invention, anchoring balloon structures are disclosed for use with catheter instruments. Once a catheter is placed at an operative site, it is often desirable to fix the catheter at that position. Balloon structures are known in the art as mechanisms for anchoring a catheter in place. The balloon is inflated with fluid while the instrument is within the lumen. Once inflated, the balloon is engaged in direct contact with a wall of the lumen. The procedure is then performed. Once completed, the fluid is removed from the balloon, thereby deflating the balloon and allowing the catheter to be removed.

Although balloon anchored catheters can quite useful, they often suffer from one or more limitations. In particular, it is difficult to know when an anchoring balloon is properly inflated. Because lumen dimensions will vary from one patient to another, it is sometimes impossible to predict how much fluid should be used to inflate the balloon. Under inflation of the balloon will result in a less than optimal anchorage of the instrument. On the other hand, over inflation of the balloon can damage the lumen or lead to balloon rupture.

Thus, the present invention also encompasses improved anchoring balloon structures for use with catheters. An anchoring balloon structure is disclosed having an expandable balloon disposed about a port on a catheter. The port connects to a conduit in fluid communication with a source of inflation fluid. The balloon structure can further include a valve for regulating the pressure in the balloon while at the same time for providing irrigation to a body lumen. The balloon, when filled with fluid, expands to contact and engage with the tissue. Once the balloon is engaged, any additional inflation fluid can be released by the valve, thus regulating the pressure and also, optionally, providing irrigation at a treatment site (e.g. so that blood can be cleared from an ablation site). The balloon can be deflated by applying a vacuum which removes the fluid from the balloon. The valve can further prevent any back diffusion of external fluids thereby allowing the balloon to become fully deflated when suction is applied to the fluid conduit of the catheter body. Once fully deflated, the balloon can be easily removed from the body lumen.

In one embodiment, the valve is a pressure-relief valve connected to a second port in the catheter. The first and second ports are in communication with each other and with a single source of fluid. For example, a simple valve can be formed by surrounding the catheter body (and the second port) with an elastomeric sleeve. The sleeve covers the second port so as to force the fluid to enter the first port and fill the balloon. Once the balloon is full, the pressure of the balloon against the tissue is equal to or greater than the pressure of the sleeve

over the second port. Any additional fluid is then forced into the second port and pushed out of the sleeve to irrigate the lumen

In another embodiment, the pressure-relief valve can comprise an elongated slit in the catheter. When the balloon is expanded, the pressure exerted on the expanded balloon causes the elongated slit to open and release fluid into the lumen. The pressure-relief valve can further comprise a fluid diffusing sleeve over a second balloon disposed over an elongated slit or a second port.

In still another aspect, the present invention provides an annular light projection apparatus that includes a light transmitting optical fiber, a graded index lens and a conical reflector. Radiation propagated through the optical fiber when connected to the graded index lens is partially reflected by the conical reflector, to project an annular pattern of phototherapeutic radiation. In a preferred embodiment, a high refractive index material, such as silicone, is in communication with the optical fiber and graded index lens and the graded index lens and conical reflector. Typically, the optical fiber and graded index lens are located between about 0 mm and about 2 mm of each other and the graded index lens and the conical reflector are located between about 0 mm and about 0.5 mm of each other. A preferred graded index lens has a length of 1.66 mm and a diameter of 1 mm.

The methods of the invention can be performed therapeutically or prophylactically. In one embodiment, the treatment method is performed on the atrial wall around the atrial/pulmonary vein juncture or around the pulmonary vein or coronary sinus, e.g., not inside the atrial or pulmonary vein but about the pulmonary or atrial surface. A circular or ring-like section outside the pulmonary vein is created by the method of the invention. Formation of one or more circular lesions about the outside diameter of a vein, impedes the conduction of irregular electrical waves in the atrium.

Methods and apparatus for phototherapy are also disclosed in which laser light or other radiation is projected from within a catheter, through a balloon member, and toward the surface of tissue. In one embodiment, the light is projected in an annular pattern without requiring direct contact of the energy source, e.g. a laser (via fiber), with the targeted tissue. The light reflected from body fluids or the tissue surface is captured by a collecting device located within the catheter, e.g., within the balloon member, and the intensity of the reflected light (or a ratio of reflected light at certain wavelengths) is ascertained.

Quantification of the reflected light provides the operator with information to determine when the catheter if positioned at the treatment site.

The balloon member of the catheter serves to force any remaining body fluids, such as blood, away from the treatment site. The absence of body fluids, such as blood, causes an increase in the amount of reflected light from the tissue surface, thereby indicating to the operator when the instrument is advantageously positioned against the treatment site. The invention is particularly useful in cardiac therapy in creating annular conduction blocks in atrial chamber issue, e.g. centered about but at a defined distance from a pulmonary vein orifice or coronary sinus orifice, to eliminate aberrant wave conduction.

The invention is particularly useful for inducing phototherapeutic processes in tissue, including ablation and/or coagulation of the tissue. Typically the optical apparatus is contained within a catheter including a flexible elongate member having a proximal end, a distal end and at least one longitudinal lumen extending therebetween. The distal end of the flexible elongate member can be open or includes a transparent cap, a centering balloon, or a centering coil. The optical apparatus of the invention can be fixed at a distal location or preferably disposed within the first lumen in a manner that permits axial motion within the lumen. The optical apparatus serves to project light through, or from, the distal end of the flexible member of the catheter. The optical apparatus can include an optical fiber and other light projecting elements.

In certain embodiments, the optical apparatus of the invention is slidably positioned within the lumen of a catheter proximate to a tissue site. Positioning the optical apparatus at the particular location within the balloon and/or by adjusting the size or shape of the balloon permits control over the size and distance of the forwardly projected light. This control permits the annular beam of projected light to be dynamically changed to specifically target the atrial tissue surrounding the pulmonary veins or coronary sinus.

In one embodiment of the present invention, the photoablation instrument includes an expandable balloon member adapted to surround the optical assembly upon inflation. Injection of a solution or gas expands the balloon, thereby forcing blood and/or other body fluids from the tissue site. Preferably, the balloon member can be inflated with deuterium oxide or deuterated water, such that the inflated balloon provides a low loss transmission pathway for radiation between the optical assembly and the tissue surface. Deuterium oxide

provides the advantage that it absorbs less energy from the transmitted energy, thereby preventing the balloon from becoming heated.

The optical apparatus, projects light through the catheter and balloon toward a tissue surface. Reflected light from the surrounding area is then captured by a collector. This "feedback" array is in communication with spectrophotometers and a computer, which can be used to determine when the instrument is positioned correctly at the treatment site. A region of tissue can then be exposed to radiation from the optical assembly both for determining whether the instrument is positioned properly as well as therapeutic treatment.

Brief Description of the Drawings

Other objects, advantages and features of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, in which like reference numerals designate like parts throughout the figures thereof and wherein:

FIG. 1 is a schematic perspective view of an optical apparatus of the invention which projects an annular beam of light from a modified waveguide;

FIG. 1A is an end view of an annular beam of light projected by the apparatus of FIG. 1;

FIG. 2 is a cross sectional view of a modified waveguide of the invention;

FIG. 3 is another cross sectional view of a modified waveguide of the invention;

FIG. 4 is a schematic view of an optical apparatus of the invention that projects an annular beam of light from a conical reflector;

FIG. 5 is a cross-sectional view of the distal end portion of an embodiment of the invention having an optical apparatus and a balloon contained within a tubular body lumen in an uninflated state;

FIG. 6 is a cross-sectional view of a preferred device of the invention including an inflated balloon attached to a flexible elongate member having an optical apparatus contained

therein;

FIG. 7 is an expanded cross-sectional view of the optical apparatus of FIG. 6;

FIG. 8 is a depiction of annular lesions located at the atrium/pulmonary vein interface;

FIG. 9 is a schematic block diagram of a laser tissue treatment system according to the present invention;

FIG. 10 is a detailed schematic diagram of a reflectance monitor for use in the present invention.

FIG. 11 is a schematic, cross-sectional view of another cardiac ablation apparatus according to the invention having an anchoring balloon structure.

FIG. 12 is a more detailed schematic, cross-sectional view of the anchoring balloon structure of FIG. 11.

FIG. 13 shows another anchoring balloon structure according to the invention having an elongated slit.

FIG. 14 shows another anchoring balloon structure according to the invention having an elongated slit and a permeable sleeve.

FIG. 15 shows another anchoring balloon structure according to the invention having a porous balloon sleeve.

FIG. 16 is a schematic perspective view of an optical assembly according to the invention for sensing the position of an ablative apparatus;

FIG. 17 is a cut away view of a preferred optical fiber that can serve as both light emitter and reflected light collector in the Optical sensor assembly of FIG. 16;

FIG. 18 is a schematic block diagram of a laser tissue treatment system according to the present invention incorporating a position sensor;

FIG. 19A is a graph illustrating a typical reflectance spectrum of blood; FIG. 19B is a similar graph showing the reflectance spectrum of tissue; FIG. 19C is a reflectance spectrum from a balloon catheter instrument simulating a condition in which the balloon has been brought into contact with a target region of tissue; and

FIG. 20 is a flow diagram demonstrating the operation of the contact sensor of the invention.

Detailed Description of the Invention

The features and other details of the invention will now be more particularly described and pointed out in the claims. It will be understood that the particular embodiments of the invention are shown by way of illustration and not as limitations of the invention. The principle features of this invention can be employed in various embodiments without departing from the scope of the invention.

The present invention is based, at least in part, on a discovery that the present invention can be used for inducing hyperthermia, coagulation or phototherapeutic processes in tissue, e.g., ablation, degradation, or destruction of tissue, at a specified site in tissue without harming the surrounding tissue. The results are surprising and unexpected since the efficiency and efficacy of coherent light is generally diminished by light scatter, formation of "hot spots" due to inefficient light scatter, by the limitation that the light emitted from an optical fiber continues in a straight path, and/or from interaction(s) with blood and/or body fluids which surround a tissue site to be treated.

Prior to this invention, the energy emitter, e.g., a laser source, ultraviolet light, microwave radiation, radio-frequency, etc., has generally been required to be in contact with the tissue to effect a therapeutic or prophylactic treatment. In contrast to known apparatuses and methods, the present invention does not require direct contact between the energy source, e.g., a laser source, and the tissue site to be treated. Moreover, in certain embodiments the methods and apparatus of the invention circumvent the drawbacks of having blood or body fluid coagulate, degrade or be destroyed in the treatment area proximate to the targeted tissue due to interactions with the applied energy.

In one embodiment, the present invention is drawn to an apparatus for inducing phototherapeutic processes in tissue. These processes can include ablation and/or coagulation. Typically the optical apparatus is contained within a catheter including a flexible elongate member having a proximal end, a distal end and a longitudinal first lumen extending therebetween. The distal end or a portion of the distal end of the flexible elongate member is open, transparent, or includes a transparent cap. The optical apparatus of the invention can be slidably extended within the first lumen for projecting light through or from a distal end portion of the flexible member.

In one aspect, the present invention provides an optical apparatus of the invention that includes a pattern-forming optical waveguide for projecting an annular beam of light and a light transmitting optical fiber. Radiation is propagated through the optical fiber which is in communication with the waveguide. The waveguide is configured to forwardly project an annular light pattern such that an annular lesion is formed in tissue. Typically, the annular light pattern is projected at an angle between about 20 and 45 degrees from the center plane of the optical fiber. In one embodiment, the annular light pattern expands over distance and is in the form of a ring or a halo. Preferably, the optical apparatus further includes a graded intensity lens (GRIN) adjacent to the optical waveguide for imaging the light pattern.

The present invention provides the advantage that the annular light pattern is forwardly projected. The invention further provides that the angle of projection can be adjusted by a combination of either a GRIN lens, a waveguide, a conical reflector, and/or by the dimensions of a balloon, described *infra*, located proximate to the optical apparatus. The present invention, therefore, provides a beam of energy, e.g., coherent light, which is projected forwardly onto a tissue surface. This in turn provides the advantage that the optical assembly/apparatus remains separated from the treatment site. Typically, the optical assembly is positioned from about 14 mm to about 24 mm, preferably from about 16 mm to about 22 mm, most preferably from about 20 mm to about 24 mm from the tissue site with the beam of light projected forwardly over a distance of from about 14 mm to about 24 mm, preferably from about 16 to about 22 mm, most preferably from about 20 mm to about 24 mm.

In contrast to the present invention, conventional laser ablation devices rely upon on contact with target tissue sites or the projection of a focused spot of radiation. Such prior art devices can not create an annular ring about a preselected site or vary the size and/or shape of

the annulus to accommodate specific exposure constraints. In addition, the present invention can project ablative energy onto a specific site, unlike cryogenic or sonic techniques that treat a site along with tissue that surrounds the site due to energy dissipation about the treatment site.

The terms "optical assembly" or "optical apparatus" is intended to include various combinations of optical fibers, lenses, waveguides, reflectors and other optical elements.

The term "phototherapeutic" is intended to include photoablative, photochemical and photothermal processes that are therapeutic and/or prophylactic in a subject.

The terms "ablate" or "ablation" or "photothermal" are well recognized in the art and are intended to include thermal coagulation and/or removal of biological tissue. Ablation also includes the desiccation of tissue by the application of heat. For example, an ablating energy, such as those described above, would be one that would cause the tissue to reach a temperature of between about 50-90° C. Ablation increases the physiological temperature of a tissue by energetic stimulation to a temperature that degrades or eradicates tissue, thereby removing diseased tissue from a localized area. Ablation can be used as a therapeutic treatment, where diseased or otherwise unwanted tissue or cells exist, or as a preventative treatment to inhibit exigent physiological aberrations, e.g., arrhythmias e.g., fibrillations or flutters, growth of undesirable tissue or cells in a specific region of an organ or viscera. In order to obtain destruction of tissue exclusively by thermal effects, it is necessary for the energy to be able to reach a threshold of destruction referred to as the "thermal dose." This threshold is a function of temperature reached and of the duration of the application. Therefore, ablation, to some degree, is based on the rise of the local temperature of tissue.

The term "coagulation" is well recognized in the art and is intended to mean the action whereby cells and/or body fluids within a treated tissue site are caused to become necrotic, thickened and/or lacking in the ability to conduct electrical activity, thereby resulting in a coherent mass by the methods of the invention. The method and apparatus of the invention permit selective, coagulation of a targeted tissue area and not blood or other body fluids which are found external, e.g., surrounding, to the target site.

The term "body fluids" is intended to encompass those naturally occurring physiological components produced by a subject to maintain stasis. These fluids typically

include physiological components such as plasma, growth factors, platelets, lymphocytes, granulocytes, etc.

The term "photochemical" is well recognized in the art and includes various energetic processes, including chemical reactions initiated by photons generated by an energy source. Typically photochemical processes are associated with laser, ultra-violet light, visible light or infrared light. Photochemical processes include the generation of radicals by photons colliding with tissue. The radical species are generated within cell tissue, often times causing oxidation of the cell contents; degradation or eradication occurs after the radical species are generated. In the method of the invention, photochemical reactions are selective for the targeted tissue area and not blood or other body fluids that are found external to the targeted treatment site.

Photochemical processes cause injury to cells and tissue either by mechanical lysis or by the generation of by-products such as free radicals, e.g., such as HO_2•, OH^-•, HO• and H_2O•, which damage cell and/or tissue membrane. These reactive by-products can interact with the localized surrounding tissue area such that the tissue is cleansed of unwanted material. Photochemical processes can involve oxidation or radical polymerization of, for example, cell walls, extracellular matrix components, cell nuclei, etc. Such photochemical processes can be induced by infrared, visible and ultraviolet light energy.

The terms "into" and "onto" are used interchangeably and are intended to include treatment of tissue by focusing energy, e.g., ablative, coagulative, or photothermal, toward the afflicted area. In some instances the energy penetrates the tissue and in other instances the energy only superficially treats the surface of the tissue. An ordinary skilled artisan would understand what depths of penetration are required and those parameters that are dependent upon the application, tissue type, area to be treated and severity of condition. Accordingly, the amount of energy used to treat the afflicted area would be attenuated based upon the disease or condition being treated.

"Interstitial cavity," as the term is used herein, encompasses interstices in a tissue or structure of a natural body structure, spaces and gaps existing between layers of tissue or existing within organs, and can include interstices within the interior of the ureter, bladder, intestines, stomach, esophagus, trachea, lung, blood vessel or other organ or body cavity, and will be further understood to include any surgically created interstice that defines an interior

cavity surrounded by tissue.

The term "waveguide" is well recognized in the art and is intended to include those devices that constrain or guide the propagation of electromagnetic radiation along a path defined by the physical construction of the guide. Although optical waveguides in the form of optical fibers are preferred, other types of waveguides can be used to transmit electromagnetic radiation. Several waveguides are of importance, including hollow-pipe waveguides and dielectric waveguides. Hollow-pipe guides are used primarily in the microwave region of the spectrum, dielectric guides primarily in the optical region. Various guide shapes are possible, including circular, triangular, rectangular, or square and combinations thereof.

The term "annular" is used to describe various circumferential or ring-like patterns including circular, elliptical, polygonal and irregular shapes. The annulus is preferably a closed figure but in certain applications an open (e.g. "C"-shaped) or discontinuous annular pattern can be useful or preferred.

In preferred embodiments, the electromagnetic radiation, e.g., coherent light, is emitted from the waveguide such that the projected energy expands over a distance. For example, annular projection of laser light from a circular waveguide forms an expanding cone. The angle of the cone of light is dependent upon the angle of reflection within the waveguide, the concavity of inner walls within the waveguide and the distance to an object to which it is projected. For example, as shown in FIG. 1, optical apparatus 10 includes an optical fiber 12 in communication with an optical waveguide 14 having a concave interior. The waveguide 14 passes an annular beam of light to a GRIN lens 26. The beam that exits from distal portion 18 of waveguide 14 will expand over a distance, d_1. Typically, the angle of projection from the central axis of the optical fiber 12 or waveguide 14 is between about 20 and 45 degrees.

As shown in FIG. 1, the projection of a beam of light 16 from waveguide 14 expands over distance d_1, thereby forming an annulus, an outline of a shape formed from light passing through a modified waveguide 14 and GRIN lens 26, having a diameter which is generally larger than the diameter of distal portion 18 of waveguide 14. The diameter of the annular beam of light 16, (X), is dependent upon the distance d_1 from the point of projection to point of capture by a surface, e.g., a tissue site, e.g., an interstitial cavity or lumen. Typically, the diameter of X is between about 10 mm and about 23 mm, preferably greater than 10 mm, greater than 15 mm, greater than 20 mm, and most preferably, greater than or equal to 23 mm.

The width, w_2, of the annulus is dependent upon the width w_1 of distal end 18, distance d_1, distance d_2, and angles α_1 and α_2. Width w_2 is typically between about 0.5 mm to about 5 mm, preferably between about 1 mm to about 4 mm, most preferably less than or equal to 1.5 mm. Varying angles α_1 and α_2 and distance d_2 maximizes or minimizes angle α_3 about the central axis as depicted in FIG. 1. Typically, angle α_3 of projected annular light is between about 20 and about 45 degrees, preferably between about 16 and about 30 degrees, most preferably between about 17 and about 25 degrees.

As shown in FIGS. 1, 2 and 3, the width, w_1, of distal portion 18 can be minimized or maximized depending upon where the modified portion, e.g., the concave portion, within waveguide 14 terminates. Typically the width, w_1, as shown in FIGS. 2 and 3, will be between about 0.05 mm and about 1.0 mm, inclusive, more preferably between about 0.1 mm and about 0.5mm, most preferably between about 0.1 mm and about 0.2 mm, inclusive. The distal portion 18, therefore, can be a rim which has substantially no appreciable width, w_1, e.g., a point where the exterior wall 20 of waveguide 14 and interior wall 22 intersect. Interior walls 22 of the tapered concave surface meet at position 24 within waveguide 14. In general, the diameter of waveguide 14 is between about 0.2 mm to about 1.0 mm, inclusive, more preferably between about 0.3 mm to about 0.8 mm, inclusive, and most preferably between about 0.4 mm to about 0.7 mm, inclusive.

Waveguides, as described in above and in FIGS. 1-3 can be made from materials known in the art such as quartz, fused silica or polymers such as acrylics. Suitable examples of acrylics include acrylates, polyacrylic acid (PAA) and methacrylates, polymethacrylic acid (PMA). Representative examples of polyacrylic esters include polymethylacrylate (PMA), polyethylacrylate and polypropylacrylate. Representative examples of polymethacrylic esters include polymethylmethacrylate (PMMA), polyethylmethacrylate and polypropylmethacrylate.

Internal shaping of the waveguide can be accomplished by removing a portion of material from a unitary body, e.g., a cylinder or rod. Methods known in the art can be utilized to modify waveguides to have tapered inner walls, e.g., by grinding, milling, ablating, etc. Preferably, a hollow polymeric cylinder, e.g., a tube, is heated so that the proximal end collapses and fuses together, forming an integral proximal portion which tapers to the distal end of the waveguide. In a preferred embodiment, the waveguide is flexible.

Waveguide 14 is in communication, e.g., connected, with optical fiber 12 by methods known in the art. These methods include for example, glueing, or fusing with a torch or carbon dioxide laser . In one embodiment shown in FIG. 1, waveguide 14, optical fiber 12 and, optionally, a gradient index lens (GRIN) 26 are in communication and are held in position by heat shrinking with a polymeric material 28, such as polyethylene terephthalate (PET) about the optical apparatus 10 and, optionally, GRIN lens 26.

In an alternative embodiment, as shown in FIG. 4, GRIN lens 26 is in communication, e.g., adjacent to, with optical fiber 12 by methods known in the art. These methods include for example, glueing, thermal bonding or fusion. In one embodiment shown in FIG. 4, optical fiber 12, GRIN lens 26 and conical reflector 31 are in communication and are held in position by welding with a polymeric material 28, such as TEFLON®, e.g., by melting the polymeric material about the optical apparatus 10 as described *supra*.

The distance between optical fiber 12 and the GRIN lens 26 can be from between about 0 mm and about 2 mm, from between about 0 mm and about 1.5 mm, and preferably, from between about 0 mm and about 1 mm. The gap between the optical fiber 12 and GRIN lens 26 can be filled with either air or, preferably, a high refractive material such as transparent silicone or transparent epoxy.

The GRIN lens 26, useful in this configuration generally has a length of between about 1 mm and about 2 mm, preferably from between about 1.5 mm and about 1.75 mm, and more preferably 1.66 mm. Typically, the diameter of the GRIN lens is about 1 mm.

The distance between the GRIN lens 26 and the conical reflector 31 can be from between about 0 mm and about 0.5 mm, between about 0 mm and about 0.25 mm, preferably, between about 0 mm and about 0.1 mm. Typically the gap formed between the GRIN lens and the conical reflector 31 is filled with air or, preferably, a high refractive index material, such as silicone or a transparent epoxy.

Typically the conical reflector 31 has an outer surface of a highly reflective material. For example, the surface can be coated with silver or gold. An additional layer, or layers of dielectric coating can be coated onto the reflective layer. Suitable dielectric layers include coatings of silica/titania mixtures. The apex portion of the conical reflector is positioned from about 0 mm to about 0.5 mm, generally from about 0 mm to about 0.25 mm, preferably from

about 0 mm to about 0.1 mm from the distal end of the GRIN lens 26. Conical reflector 31 has a shape sufficient to deflect light transmitted from the GRIN lens 26 to a selected tissue site at an angle of from about 20 to about 45 degrees.

In preferred embodiments, the electromagnetic radiation, e.g., coherent light, is emitted through the optical fiber through the optional GRIN lens and onto the conical reflector such that the projected energy expands uniformly over a distance. For example, annular projection of laser light from a conical reflector forms an expanding cone. The angle of the cone of light is dependent upon the angle of conical reflector and the distance to an object to which it is projected. Typically, the angle of projection from the central axis of the optical fiber 12 is between about 20 and 45 degrees.

The terms "gradient index lens" or "graded index lens" (GRIN) are well recognized in the art and are intended to mean those lenses which have a refractive index distribution, which takes place in a parabolic manner so that the refractive index is greatest at the central axis of the rod and so that the refractive index is progressively reduced from the central axis toward the periphery of the rod. As a result, the penetrating light is caused to move inside the rod in a zigzag manner. The shape of the GRIN lens can be cylindrical, oval, round, or convex.

The term "flexible elongate member" is well recognized in the art and is intended to refer to a hollow tube having at least one lumen. In general, a flexible elongate member is often termed a "catheter", a term which is well known in the art. The flexible elongate member has proximal and distal ends with at least one longitudinal lumen extending therebetween. The distal end can be open or closed as is known in the art. In one embodiment, the distal end of the flexible elongate member is open, thereby allowing an optical apparatus of the invention to protrude beyond the elongate member, e.g., into a catheter end, e.g., into a balloon member. In another embodiment, the distal portion of the elongate member is closed, thereby preventing an optical apparatus from passing beyond the distal end of the elongate member.

Flexible elongate members, e.g., tubular catheters, can be formed from biocompatible materials known in the art such as cellulosic ethers, cellulosic esters, fluorinated polyethylene, phenolics, poly-4-methylpentene, polyacrylonitrile, polyamides, polyamideimides, polyacrylates, polymethacrylates, polybenzoxazole, polycarbonates, polycyanoarylethers, polyesters, polyestercarbonates, polyethers polyether block amides, polyetherketones,

polyetherimide, polyetheretherketones, polyethersulfones, polyethylene, polypropylene, polyfluoroolefins, polyimides, polyolefins, polyoxadizoles, polyphenylene oxides, polyphenylene sulfides, polysulfones, polytetrafluoroethylene, polythioethers, polytraizoles, polyurethanes, polyvinyls, polyvinylidene fluoride, silicones, urea-formaldehyde polymers, or copolymers or physical blends thereof.

Preferably, the materials used to construct the flexible elongate member or the catheter end portion can be "transparent" materials, such as fluoropolymers. Suitable transparent materials include polyether block amides (PEBAX), polyethylene, nylon, polyurethanes and silicone containing polymers, e.g., silastic. Suitable fluoropolymers include, for example, fluorinated ethylene propylene (FEP), perfluoroalkoxy resin (PFA), polytetrafluoroethylene (PTFE), and ethylene-tetrafluoroethylene (ETFE). Typically the diameter of the flexible elongate member is between about 0.050 inches and about 0.104 inches, preferably between about 0.060 inches and about 0.078 inches. The diameter of at least one inner lumen of the flexible elongate member is between about 0.030 inches and about 0.060 inches, preferably between about 0.040 inches and about 0.050 inches. The length of the flexible elongate member varies with the intended application and in generally between about 60 cm and about 145 cm in length. For cardiac applications the flexible elongate member is between about 80 cm, and about 125 cm long, for bronchial applications the flexible elongate member is 125 cm long.

The term "catheter" as used herein is intended to encompass any hollow instrument capable of penetrating body tissue or interstitial cavities and providing a conduit for selectively injecting a solution or gas, including without limitation, venous and arterial conduits of various sizes and shapes, bronchioscopes, endoscopes, cystoscopes, culpascopes, colonscopes, trocars, laparoscopes and the like. Catheters of the present invention can be constructed with biocompatible materials known to those skilled in the art such as those listed *supra*, e.g., silastic, polyethylene, Teflon, polyurethanes, etc.

Typically, the optical apparatus of the invention is positioned proximate to the tissue targeted for treatment within a catheter. The catheter has been positioned proximate to the targeted tissue site and provides that the optical apparatus can be slidably positioned proximate to the tissue, thereby avoiding direct contact with the tissue and/or body fluids. In a preferred embodiment, a balloon is inflated against the tissue, thereby forcing blood and/or body fluids away from the tissue targeted for treatment. Light energy is then passed through

the optical apparatus and balloon onto the targeted tissue such that an annular image is projected onto the site, which causes ablation, coagulation and/or phototherapeutic processes to occur within the tissue.

The terms "about" or "surrounding" when used in conjunction with the term "a coronary vessel opening" is intended to describe the atrial surface surrounding the blood vessel mouth or orifice inside the heart. Similarly, the term "about the pulmonary vein" is intended to encompass the atrial surface surrounding the pulmonary vein and/or its orifice. "Cardiac vessels" include without limitation, the pulmonary veins, the coronary sinus, the inferior vena cava and the superior vena cava. The exposed (ablated) areas preferably do not include any interior portion of the coronary vessels in order to minimize the risk of inadvertent stenosis.

The term "biocompatible" is well recognized in the art and as used herein, means exhibition of essentially no cytotoxicity while in contact with body fluids or tissues. "Biocompatibility" also includes essentially no interactions with recognition proteins, e.g., naturally occurring antibodies, cell proteins, cells and other components of biological systems.

The term "transparent" is well recognized in the art and is intended to include those materials which allow diffusion of energy through, for example, the flexible elongate member, the tip, cap and/or a catheter end. Preferred energy transparent materials do not significantly impede (e.g., result in losses over 20 percent of energy transmitted) the energy being transferred from a optical apparatus to the targeted tissue or cell site. Suitable transparent materials include fluoropolymers, for example, fluorinated ethylene propylene (FEP), perfluoroalkoxy resin (PFA), polytetrafluoroethylene (PTFE), and ethylene-tetrafluoroethylene (ETFE).

The term "fixedly attached" is intended to include those methods known in the art to attach a catheter end portion, cap, or balloon to the distal portion of a flexible elongate member. Various means are known to those skilled in the art for fixedly attaching individual members of the present apparatus to each other. Such methods include thermal welding or glueing the two materials together to form a uniform seam which will withstand stresses placed upon the integral seam. For example, the catheter end portion or a tip is welded, e.g., thermal, photochemical, sonically, e.g., ultrasound, or glued, at the proximal most portion of the catheter end or tip to the distal end of the flexible elongate member. In another

embodiment, the proximal end of the catheter end is affixed to the distal end of the elongate member which is itself a sealed, e.g., having a tip or a cap.

The terms "tip" or "cap" are well recognized in the art and are intended to include those devices which are used to seal the end of a luminal body. In one embodiment, the cap is non-metallic. In certain embodiments, the cap is non-porous. In a preferred embodiment, the cap is non-metallic and non-porous, e.g., a polymeric material.

The term "catheter end portion" is intended to include a separate attachable, and in certain embodiments, detachable, catheter-like portion which is located proximate to the distal end of a catheter. The catheter end portion can be fixedly attached or integrally locked into place on the distal end of a catheter by methods known in the art, e.g., glueing, melting, ultrasonic welding, "snap on" fittings, male-female fittings, etc. Preferably the catheter end portion is energy transparent. An example of a catheter end portion is a silicone balloon anchor.

The term "control handle" is well recognized in the art and is intended to include various means to manipulate the apparatus of the invention, including at least the flexible elongate member, guidewires if present, and the optical apparatus. Various control handles useful with the present invention are commercially available, such as those manufactured by Cordis Webster, Inc., 4750 Littlejohn St., Baldwin Park, CA, 91706. When used, the control handle applies tension, e.g., stress, to the proximate end of a guidewire, thereby causing the distal end of the guidewire to bend, distort or deform. As a consequence of this action, the flexible elongate member to which the guidewire is attached, also bends, distorts or deforms in the same plane as the guidewire.

The phrase "light transmitting optical fiber" is intended to include those fibers, glass, quartz, or polymeric, which conduct light energy in the form of ultraviolet light, infrared radiation, or coherent light, e.g., laser light.

An exemplary manufacturing process suitable for joining the waveguide or GRIN lens, for example, to a glass-clad or polymer-clad optical fiber having an outer diameter of about 50 to 1,000 micrometers can begin by stripping off a buffer from the end of the fiber, e.g., exposing about 2 or 3 millimeters of the inner fiber core and its cladding. (It is not necessary to strip the cladding away from the core.) Prior to stripping, the fiber end face preferably

should be prepared and polished as is known in the art to minimize boundary or interface losses.

In one embodiment, a transparent tubular structure will form a housing and attaching means for the waveguide or GRIN lens and prepared fiber end. The fiber and waveguide or GRIN lens are positioned such that they located so that the distal end of the stripped fiber and the proximal end of the waveguide are in communication. The tubular structure can be slid over the two components, thereby fixing the respective ends to each other. Preferably, a GRIN lens is placed in communication with the distal end of the waveguide or a conical reflector is placed in communication with the distal end of the GRIN lens and contained within the tubular structure. In one preferred embodiment, the housing is a Teflon® FEP or PET tubing available, for example, from Zeus Industries (Raritan, New Jersey).

Preferred energy sources include laser light, in the range between about 200 nanometers and 10.5 micrometers. In particular, wavelengths that correspond to, or are near, water absorption peaks are often preferred. Such wavelengths include those between about 805 nm and about 1060 nm, preferably between about 900 nm and 1000 nm, most preferably, between about 940 nm and 980 nm. Suitable lasers include excimer lasers, gas lasers, solid state lasers and laser diodes. A particularly preferred AlGaAs diode array, manufactured by Optopower, Tucson, Arizona, produces a wavelength of 980 nm. A preferred energy is coherent light, e.g., laser light, in the range between about 200 nm to about 2.4 micrometers, preferably between about 400 to about 3,000 nm, more preferably between about 805 and 1060 nm. Typically the optical apparatus emits between about 10 to about 25 watts of power to yield an energy fluence of ablative radiation at the heart tissue surface of about 0.5 watts/cm^2 to about 3 watts/cm^2.

In one embodiment, the optical apparatus can extend beyond the distal end of the flexible elongate member. In certain embodiments, the optical apparatus slidably extends into the space created by a balloon filled with a suitable solution or gas. Alternatively, the optical apparatus can be slidably located or fixed within a transparent flexible elongate member about which surrounds an inflated balloon. In this embodiment, the light is projected annularly through the transparent flexible elongate member, through an inflation solution, e.g., deuterium oxide, and into the inflated balloon and onto the targeted treatment site.

The light transmitting optical fiber transmits the energy from an energy source which

is in communication with the optical fiber. Suitable energy sources are known in the art and produce the above-mentioned types of energy. Preferred laser sources include diode lasers. The optical fiber is positioned within lumen formed by a flexible elongate member (described *supra*). The optical fiber can be slidably controlled within the lumen such that positioning of the optical fiber within the flexible elongate member is readily achieved. Preferably, the optical fiber is positioned proximate to the expanded balloon member.

The balloon, e.g., a biocompatible balloon, is affixed to the catheter body member near the distal end and is in fluid communication with at least one of inflation port. Upon injection of solution, the expandable balloon inflates forming a lumen or "reservoir" between the catheter body and the outer wall of the balloon. It should be understood that the term "balloon" encompasses deformable hollow shapes which can be inflated into various configurations including balloon, circular, tear drop, etc., shapes dependent upon the requirements of the body cavity.

In preferred embodiments useful in cardiac therapy, the balloon is configured such that the catheter does not enter into the pulmonary vein (See, for example, FIG. 6). As such, the distal region of the balloon is larger than the diameter of the pulmonary vein, thus permitting intimate contact with the atrial surface about the proximal region of the pulmonary vein. In a preferred embodiment, the balloon has a tear drop shape or a shape in which the distal end of the balloon is larger than the proximal end. The diameter of the distal portion of the balloon corresponds to the maximum diameter of the annularly projected light, thereby enabling the artisan to ablate tissue about the atrial surface in a lesion equivalent to the diameter of the distal portion of the balloon. This configuration prevents ablation of tissue within the pulmonary vein and provides the advantage of avoiding stenosis of the pulmonary vein.

The terms "treat," "treatment" or "treating" are intended to include both prophylactic and/or therapeutic applications. The methods of the invention can be used to protect a subject from damage or injury caused by a disease, physical aberration, electrical aberration, or can be used therapeutically or prophylactically treat the subject after the onset of the disease or condition.

The term "subject" is intended to include mammals susceptible to diseases, including one or more disease related symptoms. Examples of such subjects include humans, dogs, cats, pigs, cows, horses, rats and mice.

The term "tissue" is well recognized in the art and is intended to include extracorporeal materials, such as organs, e.g., mesentery, liver, kidney, heart, lung, brain, tendon, muscle etc.

The term "disease" is associated with an increase of a pathogen within a subject such that the subject often experiences physiological symptoms which include, but are not limited to, release of toxins, gastritis, inflammation, coma, water retention, weight gain or loss, ischemia and immunodeficiency. The effects often associated with such symptoms include, but are not limited to fever, nausea, diarrhea, weakness, headache and even death. Examples of diseases which can be treated by the present invention include undesirable cell proliferation, bacterial infection, cancer, e.g., bladder, urethral, mammarian, ovarian and lung cancer, or, ischemia, and benign prostatic hypertrophy or hyperplasia (BPH).

The language "undesirable cell proliferation" is intended to include abnormal growth of cells which can be detrimental to a subject's physiological well being. Effects of undesirable cell proliferation can include the release of toxins into the subject, fever, gastritis, inflammation, nausea, weakness, coma, headache, water retention, weight gain or loss, immunodeficiency, death, etc. The undesired cells which proliferate can include cells which are either benign or malignant. Examples of undesirable cell proliferation include bacterial cell proliferation and aberrant cell division and/or proliferation of foreign cells, such as in cancer cells.

The terms "aberrant cell" or "aberrant tissues" as used herein, are well recognized in the art and are intended to include aberrant cell division and/or proliferation where cells are generated in excess of what is considered typical in physiologically similar environment, such as in cancers.

The language "control of undesirable cell proliferation" or "controlling undesirable cell proliferation" is intended to include changes in growth or replication of undesired cells or eradication of undesired cells, such as bacteria, cancer, or those cells associated with abnormal physiological activity. The language includes preventing survival or inhibiting continued growth and replication of an undesired cell. In one preferred embodiment, the control of the undesired cell is such that an undesired cell is eradicated. In another preferred embodiment, the control is selective such that a particular targeted undesired cell is controlled while other cells, which are not detrimental to the mammal, are allowed to remain substantially

uncontrolled or substantially unaffected, e.g., lymphocytes, red blood cells, white blood cells, platelets, growth factors, etc.

The term "cancer" is well recognized in the art and is intended to include undesirable cell proliferation and/or aberrant cell growth, e.g., proliferation.

The term "modulate" includes effect(s) targeted tissue(s) that prevent or inhibit growth of diseased tissue, which may ultimately affect the physiological well being of the subject, e.g., in the context of the therapeutic or prophylactic methods of the invention.

The term " solution" is intended to include those solutions, e.g., aqueous solutions, which can be administered to a subject through a device of the present invention without subsequent adverse effects. In particular, the solution should not diminish the strength, quality, or wavelength of energy emitted, e.g., laser energy, from the optical apparatus. In general, the solution is considered a pharmaceutically acceptable carrier or vehicle.

The term "modify" is intended to encompass those changes to the targeted tissue site, e.g., the surface, that cause the tissue to no longer have undesired properties. For example, treatment of the anterior wall of the right atrium by the present invention changes the path of electrical conduction after photonic treatment. The result is a conduction block that redirects conduction through the tissue and prevents the conduction from traveling across the atrial wall as it did prior to treatment.

The present invention also pertains to methods for forming an annular lesion in a tissue by ablation, coagulation and/or phototherapeutic processes. The methods introduce an optical apparatus proximate to a tissue site via, for example, a catheter. The optical apparatus includes a modified optical waveguide that is in communication with a light transmitting optical fiber. Energy is transmitted through the optical fiber, such that radiation propagating through the optical fiber and waveguide projects an annular light pattern, e.g., a circle, ring, halo or an outline or a shape formed by and projected from the modified waveguide. Preferably, the light is projected through a graded intensity lens that is adjacent to the optical waveguide. This additional step attenuates aberrations in the light pattern and facilitates the forward annular projection of the therapeutic light. By these methods, an annular lesion can be formed in tissue. In certain embodiments, the tissue forms a lumen, e.g., vascular, atrial, brachial, urethral, ureteral, etc.

In another aspect, the invention includes methods for cardiac arrhythmia(s) by introducing a photoablation instrument into the heart, positioning the photoablation instrument in a location within the heart and exposing a region of heart tissue to radiation from the optical assembly. The photoablation instrument includes an optical assembly for projecting a beam of radiation as described *supra* and *infra*. One advantage of this method lies in the ability to project light from the optical assembly onto cardiac tissue within the heart in, for example, an annular pattern. Another advantage of the method is that the instrument can be positioned a distance proximate to the treatment site, thereby reducing the risk of overheating the tissue area. Consequently, this method of the invention can be used to treat, for example, the pulmonary vein, coronary sinus, inferior vena cava and superior vena cava. This method of the invention can also be useful in treating cardiac tissue associated with cardiac irregularities, e.g. arrhythmias, such as the pulmonary vein, coronary sinus, inferior vena cava and superior vena cava. Arrhythmias, for example, can occur in the atrium or ventricle, and are referred to, respectively, as atrial fibrillation and ventricular fibrillation. Atrial fibrillation is an atrial arrhythmia characterized by rapid randomized contractions of the atrial myocardium, causing an irregular, often rapid heart rate. Three of the most common types of atrial arrhythmia are ectopic atrial tachycardia, atrial fibrillation and atrial flutter. Ventricular fibrillation is an arrhythmia characterized by fibrillary contractions of the ventricular muscle due to rapid repetitive excitation of the myocardial fibers without coordinated contraction of the ventricles. In one embodiment, the method of the invention can be utilized to treat ventricular tachycardia by projecting an annular beam onto the ventricular tissue. The annular beam focuses energy onto the tissue and forms a lesion. The lesion forms a conduction block and impedes electrical conduction through the formerly problematic tissue, thereby preventing further abnormal electrical stimulation in the afflicted cardiac tissue.

The present invention further pertains to methods for forming annular lesions in cardiac tissue, e.g., trabecular tissue, by ablation, coagulation and/or phototherapeutic processes. The methods include introduction of an optical apparatus proximate to cardiac tissue via, for example, a catheter. The optical apparatus includes an optical waveguide in communication with a light transmitting optical fiber and preferably, a GRIN lens. Energy is transmitted through the optical fiber, such that radiation propagated through the optical fiber, waveguide and GRIN lens forwardly projects an annular light pattern, e.g., a circle or a halo. By these methods, an annular lesion can be formed in cardiac tissue.

The invention can employ an optical apparatus that includes, for example, a graded intensity lens that is in communication with a light transmitting optical fiber and is in communication with a conical reflector. Energy is transmitted through the optical fiber, such that radiation propagating through the optical fiber projects light onto the conical reflector such that an annular light pattern, e.g., a circle, ring, halo or an outline of a shape is formed by and projected from the optical apparatus. Preferably, the light is projected through a graded intensity lens that is located between the optical fiber and the conical reflector. Use of the graded intensity lens attenuates aberrations in the light pattern and facilitates the forward annular projection of the therapeutic light. By these methods, an annular lesion can be formed in tissue. In certain embodiments, the tissue forms a lumen, e.g., vascular, atrial, brachial, uretral, etc.

The present invention further pertains to methods for forming annular lesions in cardiac tissue, e.g., trabecular tissue, by ablation, coagulation and/or phototherapeutic processes. The methods include introduction of an optical apparatus proximate to cardiac tissue via, for example, a catheter. The optical apparatus includes, for example, a graded intensity lens in communication with a light transmitting optical fiber and a conical reflector. Energy is transmitted through the optical fiber, such that radiation propagated through the optical fiber and, optionally through the GRIN lens, is reflected by the conical reflector to project forward an annular light pattern, e.g., a circle or a halo. By these methods, an annular lesion can be formed in cardiac tissue, preferably encircling the atrial tissue about the pulmonary vein, coronary sinus or other vessels.

The term "trabecular" is well recognized in the art and is intended to include tissue, e.g., cardiac tissue, which is a elastic tissue often formed of bands and cords called *trabeculae* consisting of fibrous tissue, elastic fibers and muscle fibers.

The term "lumen," including derivatives thereof, is herein intended to mean any cavity or lumen within the body which is defined at least in part by a tissue wall. For example, cardiac chambers, the uterus, the regions of the gastrointestinal tract, the urinary tract, and the arterial or venous vessels are all considered illustrative examples of body spaces within the intended meaning.

The present invention also pertains to methods method for treating or preventing atrial arrhythmias by ablation, coagulation or photochemical processes. The methods include

introducing an optical apparatus proximate to atrial tissue via, for example, a catheter. The optical apparatus can include an optical waveguide or conical reflector in communication with a light transmitting optical fiber. Energy is transmitted through the optical fiber, such that radiation propagating through the optical fiber and waveguide or conical reflector projects an annular light pattern. The annular light pattern forms an annular lesion in the atrial tissue, thereby treating or preventing atrial fibrillation. The methods of the invention can be performed therapeutically or prophylactically.

Atrial fibrillation and atrial flutter are abnormalities in the rhythm or rate of the heart beat. For an adult at rest, the heart normally beats between 60 and 80 beats per minute, but when atrial fibrillation occurs, the atria may beat irregularly and very rapidly between 350 and 600 times per minute. This causes the ventricles to beat irregularly in response as they try to keep up with the atria. Atrial flutter is similar to atrial fibrillation. The atrial contractions are less rapid, however, usually between 200 to 400 beats per minute, and are regular. Atrial flutter is often associated with a heart attack or may occur after heart or lung surgery. Atrial fibrillation often results from a myriad of heart conditions such as angina, tachycardia, heart attack, heart valve problems, and even high blood pressure. All of these conditions can cause stretching and scarring of the atria that interfere with the heart conduction system. The heart muscle can be weakened if episodes lasting several months or longer (with rapid heart rates) occur. Briefer episodes only cause problems if the heart rate is very fast or if the patient has a serious heart problem in addition to the atrial fibrillation.

In FIG. 5, apparatus 30, constructed in accordance with the present invention, is depicted in its unexpanded form within a body cavity such as a lumen of a blood vessel 34. Flexible elongate member 32 includes at least one lumen 36 extending the length thereof from a proximal end to a distal end and can include, optionally, cap 48. Openings 38 in the side wall of the 32 define one or more pores that provide fluid communication between the lumen 36 and an outer balloon 42, which can be bonded at proximal end 44 and distal end 46 to flexible elongate member 32. Optical apparatus 10 can be slidably positioned within lumen 36 adjacent to balloon 42. Apparatus 30 can further include reflectance fiber 76 to monitor the progress of treatment as described *infra*. Optical apparatus 10 includes optical fiber 12, modified waveguide 14 and, optionally, GRIN lens 26. Alternatively, optical apparatus includes optical fiber 12, optionally, GRIN lens 26 and conical reflector 27. Injection of fluid or gas, through lumen 36 and pores 38, forces the fluid or gas to flow out of the pores 38 to fill the chamber 50 within the balloon 42, thereby inflating balloon 42. In a preferred

embodiment, the balloon is spherical or teardrop shaped. Preferably, flexible elongate member 32 and balloon 42 are energy transparent.

By injecting a suitable solution or gas into chamber 50, balloon 42 can be inflated to engage body tissue (e.g., the tissue surrounding a natural or excised interstitial space within the body). In one embodiment, balloon 42 is non-porous and can engage the body tissue over a substantial portion of its length, thereby eliminating blood and/or other body fluids. A preferred inflation fluid is deuterium oxide.

A preferred embodiment is depicted in FIGS. 6 and 7 having a silicone balloon anchor 54 (not inflated). Optical apparatus 10 can be slidably positioned within lumen 36 adjacent to balloon 42. Optical apparatus 10 includes optical fiber 12, GRIN lens 26 and conical reflector 27. Gas, e.g., air, or a liquid can be injected into lumen 36 (shown partially in phantom) to inflate silicone balloon anchor 54 if required. A solution, e.g., water, saline, or, preferably, deuterium oxide, is injected through lumen 40 to inflate balloon 42. Apparatus 30 can further include reflectance fiber 76 to monitor the progress of treatment as described *infra*. In one embodiment, balloon 42 is preshaped to form a parabolic like shape. This is accomplished by shaping and melting a TEFLON® film in a preshaped mold to effect the desired form. The difference in refractive index between the gas or liquid within lumen 36 and the liquid in chamber 50 facilitates the projection of annular light beam 56 to be emitted at a radical angle from light reflected from the surface of the conical reflector 27, as shown again in FIG. 7.

The devices described in FIGS. 1-7 can be used for treating, e.g., ablating, coagulating and/or phototherapeutically treating, endocardial surfaces which promote arrhythmias or other disease states or conditions. For example, atrial therapies can be performed by inserting an apparatus of the invention 30 into the femoral vein. Flexible elongate member 32 having balloon 42 fixedly attached is guided through the inferior vena cava, and into the right atrium, and if required, it is guided into the left atrium via atrial septal puncture. Left ventricular treatment can be performed by inserting flexible elongate member 32 into the femoral artery. Flexible elongate member 32 is guided through the iliac artery, the aorta, through the aortic valve and adjacent to the wall of the left ventricle. Once balloon 42 is proximate to the tissue ablation site, a solution can be injected through lumen 36 or 40 to force blood and/or body fluids away from the treatment site. Optical apparatus 10 is guided through flexible member 32 via lumen 36 to a position proximate to the tissue ablation site and energy, e.g., laser energy, is emitted through balloon 42. Preferably, the composition of flexible elongate

member 32 and balloon 42 are transparent to the energy emitted through optical apparatus 10.

FIG. 8 depicts annular lesions 55 formed on the atrial surface encircling the pulmonary veins by the above described methods. It is considered advantageous to form the annular lesions 55 on and surrounding the atrial surface/vein interface, thereby preventing propagation of aberrant electrical waves through the cardiac region. Preferably, the lesion completely encircles the mouth of each of the target veins.

In the present invention, reflective feedback is used to monitor the state of coagulation, ablation and/or phototherapeutic processes of the treatment site so as to allow an optimal dose by either manipulation of the energy level or exposure time, or by controlling the sweep of energy across an exposure path.

Reflectance changes can also be employed by a control means in the present invention to adjust or terminate laser operation.

In another aspect of the invention, a real-time display means can be incorporated into a surgical microscope or goggles worn by a clinician during the procedure to provide a visual display of the state of tissue coagulation simultaneously with the viewing of the surgical site. The display can reveal reflectance values at one or more specific wavelengths (preferably, chosen for their sensitivity to the onset and optimal state of tissue modification), as well as display a warning of the onset of tissue carbonization.

In one method, according to the invention, application of laser to a biological structure(s) while the reflectance of light from the irradiated site is monitored. Changes in scattering due to coagulation, ablation, phototherapeutic effects or crosslinking of the tissue will cause a reflectance change. In addition, dehydration due to laser exposure also affects the site's reflection. The reflectance can be monitored in real-time to determine the optimal exposure duration or aid as visual feedback in the timing used in sweeping the energy across the treatment site during the procedure.

In FIG. 9, a schematic block diagram of a laser tissue treatment system 57 is shown, including a laser 58, power supply 60, controller 62 and reflectance monitor 64. The system further includes optical apparatus 30, and, optionally, illumination source 66, display 68 and/or tuner 70. In use, the output of laser 58 is delivered, preferably via optical apparatus 30,

to treatment site 72 to phototherapeutically treat selected tissue. As the laser beam irradiates treatment site 72 the biological tissue of the site is coagulated, ablated and/or phototherapeutically treated. The degree of treatment is determined by the reflectance monitor 64, which provides electrical signals to controller 62 in order to control the procedure. The reflectance monitor 64 receives light reflected by the site from a broadband or white light illumination source 66 via fiber 67 and/or from laser 58 via optical apparatus 30. In addition to controlling the laser operation automatically, the reflectance monitor 64 and/or controller 62 can also provide signals to a display 68 to provide visual and/or audio feedback to the clinical user. Optional tuner 70 can also be employed by the user (or automatically controlled by controller 62) to adjust the wavelength of the annealing radiation beam.

FIG. 10 is a more detailed schematic diagram of a reflectance monitor 64, including a coupling port 74 for coupling with one or more fibers 76 to receive reflectance signals. A preferred reflectance fiber is a 100 micrometer diameter silica pyrocoat fiber from Spectran (Spectran, Connecticut, part number CF04406-11). The reflectance monitor 64 can further include a focusing lens 78 and first and second beam splitting elements 80 and 82, which serve to divide the reflected light into 3 (or more) different beams for processing. As shown in FIG. 10, a first beam is transmitted to a first optical filter 84 to detector 86 (providing, for example, measurement of reflected light at wavelengths shorter than 0.7 micrometers). A second portion of the reflected light signal is transmitted by beam splitter 82 through a second optical filter 88 to detector 90 (e.g., providing measurement of light at wavelengths shorter than 1.1 micrometers). Finally, a third portion of the reflected light is transmitted to photodetector 92 (e.g., for measurement of reflected light at wavelengths greater than 1.6 micrometers). Each of the detector elements 86, 90 and 92 generate electrical signals in response to the intensity of light at particular wavelengths.

The detector elements 86, 90 and 92 can include synchronous demodulation circuitry and are used in conjunction with a modulated illumination source to suppress any artifacts caused by stray light or the ambient environment. (It should be apparent that other optical arrangements can be employed to obtain multiple wavelength analysis, including the use, for example, of dichroic elements, either as beam splitters or in conjunction with such beam splitters to effectively pass particular wavelengths to specific detector elements or spectrometers. It should also be apparent that more than three discreet wavelengths can be measured, depending upon the particular application.) The signals from the detector elements can then be transmitted to a controller and/or a display element (as shown in FIG. 9).

In the controller, signals from the reflectance monitor are analyzed to determine the degree of coagulation, ablation and/or phototherapeutic effect(s) which occurs in the biological tissue exposed to the laser radiation. Typically, such treatment is performed for 100 seconds or less. Such analysis can generate control signals that will progressively reduce the laser output energy over time as a particular site experiences cumulative exposure. The control signals can further provide for an automatic shut-off of the laser when the optimal state of treatment has been exceeded and/or the onset of carbonization is occurring.

In use, the apparatus of the present invention can be employed to analyze the degree of treatment by comparing the reflectance ratios of a site at two or more wavelengths. Preferably, intensity readings for three or more wavelength ranges are employed in order to assess accurately the degree of treatment and to ensure that the optimal state is not exceeded. The particular wavelengths to be monitored will, of course, vary with the particular tissue undergoing treatment. Although the tissue type (e.g., blood-containing tissue or that which is relatively blood-free) will vary, the general principles of the invention, as disclosed herein, can be readily applied by those skilled in the art to diverse procedures in which the phototherapeutic treatment of biological materials is desired.

XXXXXXXXXXXXXXX

In FIG. 11, a cardiac balloon catheter 150 is shown including an anchoring balloon structure 120. A primary balloon member 156 is disposed about the catheter 114 for inflation (via port 123) within the body (e.g., with the heart) to provide a transmission waveguide for projecting radiation to the tissue. The anchoring balloon structure 120 is shown engaged in direct contact with of a body lumen 153 (e.g. a pulmonary vein).

In FIG. 12 an anchoring balloon structure 120 is shown including a catheter 114 having a first port 118, an expandable balloon 112 disposed about the first port 118, and bonded collar elements 116A, 116B, disposed about each end of the expandable balloon element. A pressure-relief valve region 126 is shown. The anchoring balloon structure 120 is shown having first and second ports, 118, 122, which are in communication with a single source of fluid. An expandable balloon 112 is disposed about the first port 118 on the catheter 114. The expandable balloon is sealed to the catheter with bonded collars 116A and 116B. A sleeve 124 is shown disposed about the second port 122 on the catheter 114. The sleeve should impart a constriction about the catheter to insure that the sleeve will be retained in

place. The durometer and tightness of the sleeve, as well as the size of the ports can be altered to impart the desired constriction about the catheter and regulate the effectiveness of the valve.

Another embodiment of an anchoring balloon structure 130 is shown in FIG. 13 having an elongated slit 132 in the catheter. In the presence of pressure on the expandable balloon, the fluid pushes through the slit, opening up a channel for delivery of the fluid to the body lumen. FIG. 14 shows an alternative embodiment of the anchoring balloon structure 130. A fluid diffuser sleeve 134 can be disposed about the elongated slit 132 in the catheter 114. FIG. 15 shows another alternative embodiment of the anchoring balloon structure 130 wherein a second, expandable, liquid diffusing balloon 146 can be disposed about the second port 122. The expandable balloon 146 can contain pores 144, which release fluid and provide irrigation.

In use, a conduit defined in the catheter 114 directs fluid into the expandable balloon 112. The pressure-relief valve 126 forces the fluid to enter the balloon thereby causing the balloon to expand. The balloon, when fully expanded, engages and is in direct contact with the tissue of the body lumen. The pressure exerted on the balloon is then equal to or greater than the pressure exerted by the pressure-relief valve. The pressure-relief valve is then forced to release any additional fluid thereby providing irrigation to the body lumen.

In the preferred embodiment, the sleeve prevents the fluid from entering the second port thereby causing it to exit the first port. Insertion of fluid into the balloon causes the balloon to expand until the pressure exceeds the pressure exerted by the pressure-relief valve. Initially, the pressure of the sleeve over the second port, the slit, or the expandable liquid diffusing balloon continues to prevent the fluid from exiting the second port. Once the balloon is engaged and in direct contact with the tissue of a body lumen, pressure is exerted on the balloon. Once the pressure on the balloon is equal to or great than the pressure of the sleeve over the second port, any additional pressure will force fluid to exit the second port and the sleeve. The excess pressure thus causes fluid to be pushed out of the proximal end of the sleeve. Since the proximal end of the sleeve is not in direct contact with the tissue, the risk of damage from jetting is prevented. Thus, irrigation is provided to the body lumen while regulating over or under expansion of the balloon.

The anchoring balloon structure can be deflated by applying a vacuum that removes the fluid from the balloon. A syringe or other known methods can be used to remove the fluid. The sleeve effectively seals the second port and prevents any back diffusion of external

fluids, thereby allowing the balloon to become fully deflated. Once the anchoring balloon and primary balloon are fully deflated, the catheter can be easily removed from the body lumen.

The anchoring balloon structure can be a separate attachable, and in certain embodiments, detachable, portion which is located proximate to the distal end of a catheter. The balloon anchoring structure is fixedly attached or integrally locked into place on the distal end of a catheter by methods known in the art, e.g., gluing, melting, tying down, wrapping, ultrasonic welding, "snap on" fittings, male-female fittings, etc. Preferably the catheter end portion is energy transparent. An example of a catheter end portion is a silicone balloon anchor.

The materials used to construct the balloon anchor can be amorphous, semicrystalline, thermoplastics, or thermosets. Suitable materials include thermoplastic elastomers (TPE), latex, polyethylene terephthalate (PET), TPE blends, polyethylene, nylon, polyurethanes, silicone containing polymers, e.g., silastic, polyamides, poly(ether)amides, fluorinated ethylene propylene (FEP), perfluoroalkoxy resin (PFA), polytetrafluoroethylene (PTFE), and ethylene-tetrafluoroethylene (ETFE).

The cardiac balloon catheter (e.g., as shown in FIG. 11) can be used for a variety of procedures, including laparoscopic, endoluminal, perivisceral, endoscopic, thoracoscopic, intra-articular and hybrid approaches. For example, left ventricular fibrillation treatment can be performed by inserting the catheter 114 into the femoral artery. The catheter 114 is guided through the iliac artery, the aorta, through the aortic valve and adjacent to the wall of the left ventricle. Once the balloon 112 is proximate to the tissue ablation site, a solution can be injected through the lumen to expand and anchor the balloon. Exceed fluid is released from the pressure-relief valve to force blood and/or body fluids away from the treatment site. An optical apparatus is then guided through the catheter 114 via a lumen to a position proximate to the tissue ablation site. Energy is emitted through the balloon 112 to ablate the tissue.

In FIG. 16, another apparatus 210, constructed in accordance with the present invention, is depicted in its expanded form within a body cavity such as an atrial surface 212. Flexible elongate member 214 includes at least one lumen 216 extending the length thereof from a proximal end to a distal end and can include, optionally, cap 218 and/or an anchoring balloon 220. Openings 222 in the side wall of the flexible elongate member 214 define one or more pores that provide fluid communication between the lumen 216 and a

balloon 224, which can be bonded at proximal end 226 and distal end 228 to flexible elongate member 214. Optical apparatus 230 can be slideably positioned within lumen 216 adjacent to balloon 224. Apparatus 210 can further include reflectance fiber 232 to monitor the progress of treatment as described throughout the specification. Optical apparatus 230 can include optical fiber 234, a modified waveguide 236 and, optionally, a GRIN lens (not shown) which projects light 239 in a forward, and preferably, annular fashion. Alternatively, optical apparatus 230 includes optical fiber 234, optionally, a GRIN lens (not shown) and a conical reflector (not shown) that projects light in a forward or annular fashion .

In a preferred embodiment, an energy reflecting sheath 240 surrounds a portion of the balloon 224. The energy reflecting sheath 240 is generally made of a polymeric material, such as polyethylene terephthalate, with scattering particles contained therein. Suitable scattering particles include silicon oxide, titantium oxide, aluminum oxide and bismuth oxide. Typically, the energy reflecting sheath 240 is attached about the flexible elongate member 214 and covers approximately one third to one half of balloon 224 in a hemispherical arrangement. Preferably, the energy reflecting sheath 240 covers balloon 224 up to the portion of the balloon which contacts the tissue surface, for example, at a point of contact designated as 242. The energy reflecting sheath 240 serves to capture and return reflected light 244 from the tissue surface onto reflectance fiber 232, thereby decreasing the sensitivity of the collecting fiber 232 of the apparatus 210. The outer sheath 240 can also serve to provide further irrigation at the target site by passing an irrigation fluid through the space between balloon 224 and sheath 240. The fluid can then exit from the open distal end of the sheath and, thereby, flush or clear blood from the target site.

Injection of fluid or gas, through lumen 216 and pores 222, forces the fluid or gas to flow out of the pores 222 to fill the chamber 238 within balloon 224, thereby inflating balloon 224. Generally, a solution is preferred, e.g., water, saline, or, preferably, deuterium oxide to inflate balloon 224.

In a preferred embodiment, the outer balloon 224 is spherical, parabolic, or teardrop shaped. Preferably, flexible elongate member 214 and balloon 224 are energy transparent. Optical apparatus 210 can be slidably positioned within lumen 216 adjacent to balloon 224. Gas, e.g., air, or a liquid can be injected through a separate lumen to inflate silicone balloon anchor 220 if required.

The devices described above can be used for treating, e.g., ablating, coagulating and/or phototherapeutically treating, endocardial surfaces which promote arrhythmias or other disease states or conditions. For example, atrial therapies can be performed by inserting an apparatus of the invention 210 into the femoral vein. Flexible elongate member 214 having balloon 224 fixedly attached is guided through the inferior vena cava, and into the right atrium, and if required, it is guided into the left atrium via atrial septal puncture. Left ventricular treatment can be performed by inserting flexible elongate member 214 into the femoral artery. Flexible elongate member 214 is guided through the iliac artery, the aorta, through the aortic valve and adjacent to the wall of the left ventricle. Once balloon 24 is proximate to the tissue ablation site, a solution can be injected through lumen 216 to force blood and/or body fluids away from the treatment site. Optical apparatus 230 is guided through flexible member 214 via lumen 216 to a position proximate to the tissue ablation site. Positioning light 239 is emitted through optical fiber 234 and captured by a collecting device, such as a reflectance fiber 232. Optionally, reflectance fiber 232 and optical fiber 232 can serve as both light emitter and collector. Laser energy 239 is then emitted through balloon 224 via optical fiber 234, as described above, or through a separate optical fiber. Preferably, the composition of flexible elongate member 214 and balloon 224 are transparent to the energy emitted through optical apparatus 210.

FIG. 17 depicts an optical fiber 234 that can serve as both an energy emitter for positioning light and therapeutic light as well as a reflectance fiber 232. The optical fiber 234 is a wide aperture collecting fiber such as that described in U.S. Patent No. 6,071,302, the contents of which are incorporated herein by reference. For example, reflected light 244 can be captured in the tip 246 of 234.

In another aspect of the invention, a real-time display means can be incorporated into a surgical microscope or goggles worn by a clinician, during the procedure or displayed on a monitor to provide a visual display of contact between the balloon 224 and the tissue treatment site simultaneously with the viewing of the surgical site. The display can reveal reflectance values at one or more specific wavelengths (preferably, chosen for their sensitivity to the onset and optimal state of tissue modification), as well as display a warning of loss of optimum contact between the balloon 224 and tissue and/or provide for automatic shut-off.

In one method, according to the invention, application of laser to a biological structure(s) occurs while the reflectance of light from the irradiated site is monitored. Changes in positioning of the balloon 224 against the tissue site will cause a reflectance change especially when blood absorbs reflected light 244. The reflectance can be monitored in real-time to determine the optimal positioning of the apparatus 210 or aid as visual feedback in the timing used in sweeping the energy across the treatment site during the procedure.

In FIG. 18, a schematic block diagram of a laser tissue treatment system 248 is shown, including a laser 250, power supply 252, controller 254 and reflectance reflectance fiber 232. The system further includes optical apparatus 230, an illumination source 256, and display 258. In use, the output of illuminator 256 is delivered to the treatment site 260 to illuminate the surface via light 239, preferably white or green light or red and green light, with the surface reflecting light 244 toward a reflectance fiber 232. As discussed above, the intensity or ratio of light waves can be used to determine the accuracy and proximity to the treatment site surface 260. The output of laser 250 is also delivered, preferably via optical apparatus 230, to treatment site 260 to phototherapeutically treat selected tissue.

As the laser beam irradiates treatment site 260 the biological tissue of the site is coagulated, ablated and/or phototherapeutically treated. The placement accuracy to the treatment site 260 is determined by the reflectance monitor 264 (e.g., a spectrometer), which provides electrical signals to controller 254 in order to control the procedure. The reflectance monitor 264 receives light reflected by the site from a broadband or white light illumination source 256 via fiber 234 and/or from laser 250 via optical apparatus 230. In addition to controlling the laser operation automatically, the reflectance monitor 264 and/or controller 254 can also provide signals to a display 258 to provide visual and/or audio feedback to the clinical user. Optional filter 262 can be employed to block reflected light from the laser at the therapeutic wavelength.

In one embodiment, the spectrometer 264 can be synchronized with the illumination source 256 to variably detect different wavelengths of energy at differing cycles (Hz). For example, the detector can differentiate between a wavelength in the green light region at a cycle of 50 Hz from that of a wavelength in the red light region at 33 Hz. Additionally, therapeutic energy can also be detected at a third interval of time.

FIG. 19A, 19B and 19C are graphical representations of the reflectance and absorbance properties of blood, beef tissue and a beef tissue sample treated with blood where the blood has been removed under conditions simulated where a balloon of the above-described apparatus would force blood away from the tissue. In FIG. 19A, blood absorbs light with a wavelength range of 450 to about 580 nm, the blue and green spectra. FIG. 19B shows that tissue, such as beef tissue, reflects blue and green light in the ranges over 450 nm to about 525 nm and about 550 nm to about 580 nm. The reflectance intensity of green light is generally about one-third of that of red light, which is in the range of from about 600 to about 700 nm. FIG. 19C is a dramatic representation of how the present invention improves an operator's ability to accurately assess when a laser device is advantageously contacted with tissue, and blood is eliminated from the tissue area. For example, blood was contacted with beef tissue and a laser apparatus with a balloon was placed against the tissue to force blood away from the tissue. Illumination of the tissue surface produced the reflectance spectra of 19C. Comparison of FIG. 19C with FIG. 19B shows that the absorbencies are virtually identical, demonstrating that removal of blood from the tissue sight is critical and that the use of reflected light is useful for determining whether the instrument is properly positioned at a treatment site.

FIG. 20 is a schematic flow diagram demonstrating how an operator would optimize the use of the apparatus and method of the invention based on maximizing the intensity or ratio of reflected light. For example, the tissue surface is illuminated via white light (which contains red and green light) or pulsed red and green light. Reflected light is collected and the spectrum determined. A ratio between the reflected green light (alpha 1) and red light (alpha 2) is determined. If, for example, blood impedes the transmission of the illuminating light, the ratio approaches or is zero. In this instance, the balloon portion of the apparatus should be repositioned to remove blood from the treatment site. As blood is removed from the light field, the ratio of green to red light is maximized, and the position of the balloon should be maintained. Once the ratio of alpha 1/alpha 2 is greater than a threshold value, ablation of the tissue can begin.

Those having ordinary skill in the art will know, or be able to ascertain, using no more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. These and all other equivalents are intended to be encompassed by the following claims. All publications and references cited herein including those in the background section are expressly incorporated herein by reference in their entirety.

Claims

1. A phototherapeutic apparatus comprising a light transmitting optical fiber, an optical assembly coupled to the fiber for projecting an annular beam of light and a balloon surrounding the optical assembly to provide upon inflation a transmission pathway for the annular light beam from the optical assembly to a target tissue site.

2. The apparatus of claim 1 further compressing a source of inflation fluid in communication with the balloon.

3. The apparatus of claim 2 wherein the inflation fluid comprises deuterium oxide.

4. The apparatus of claim 1 wherein the optical assembly further comprises a graded index lens and a conical reflector, such that radiation propagating through the optical fiber when connected to the graded index lens is reflected by the conical reflector, thereby projecting an annular pattern of phototherapeutic radiation.

5. The apparatus of claim 1, further comprising a high refractive index material in communication with the graded index lens and the conical reflector.

6. The apparatus of claim 5, wherein the high refractive index material is silicone.

7. The apparatus of claim 5, wherein the high refractive index material is an epoxy resin.

8. The apparatus of claim 4, wherein the optical fiber and graded index lens are positioned from about 0 mm and about 2 mm of each other.

9. The apparatus of claim 4, wherein the graded index lens and the conical reflector are positioned from about 0 mm and about 0.5 of each other.

10. The apparatus of claim 4, wherein the graded index lens has a length of 1.66 mm.

11. The apparatus of claim 1, further comprising:

a flexible elongate member having an interior lumen extending therethrough for the delivery of an inflation fluid;

an expandable balloon disposed about a portion of the flexible elongate member and in fluid communication with the lumen via at least one port; and

a pressure-relief valve for regulating the pressure of fluid within the expandable balloon.

12. A device according to claim 11, wherein the flexible elongate member is a catheter.

13. A device according to claim 11, wherein the pressure-relief valve provides irrigation.

14. A device according to claim 11, wherein the pressure-relief valve regulates pressure.

15. The device of claim 11, further comprising means for inflating the expandable balloon.

16. The device of claim 15, wherein the means for inflating the expandable balloon comprises a conduit defined in the interior lumen of the flexible elongate member for directing fluid into the expandable balloon.

17. A device according to claim 11, wherein the expandable balloon comprises a polymeric material.

18. A device according to claim 11, wherein the expandable balloon is adapted, when expanded, to engage and contact with the tissue of a body lumen.

19. A device according to claim 11, wherein the pressure relief valve comprises a sleeve disposed about a second port in the flexible elongate member.

20. A device according to claim 19, wherein the sleeve provides irrigation.

21. A device according to claim 11, wherein the pressure relief valve comprises an expandable fluid diffusing balloon disposed about a second port in the flexible elongate

member.

22. A device according to claim 21, wherein the fluid diffusing balloon provides irrigation.

23. The apparatus of claim 1, further comprising:

a flexible elongate member having a side wall and an interior lumen extending therethrough, the side wall having first and second ports in communication with a source of fluid;

an expandable balloon disposed about the first port of the flexible elongate member having a proximal end and a distal end, the expandable balloon being bonded at the proximal end and distal end to the flexible elongate member; and

a sleeve disposed about the second port of the flexible elongate member.

24. The apparatus of claim 1, further comprising:

a flexible elongate member having a side wall and an interior lumen extending therethrough, the side wall having a port in communication with a source of fluid;

an expandable balloon disposed about the port of the flexible elongate member having a proximal end and a distal end, the expandable balloon being bonded at the proximal end and distal end to the flexible elongate member; and

an elongated slit passing through the flexible elongate member in communication with a source of fluid;

wherein pressure exerted on the expandable balloon can cause the elongated slit to open and release fluid.

25. The apparatus of claim 1, further comprising:

an illuminator which projects light through the balloon toward a tissue surface;

a collecting device positioned within the apparatus which receives reflected energy; and

a detector for at least one wavelength of the reflected energy as an indicator or the catheter's position.

26. The apparatus of claim 25, wherein the illuminator projects laser radiation.

27. The apparatus of claim 25, wherein the illuminator projects green light.

28. The apparatus of claim 25, wherein the illuminator projects both green and red light.

29. The apparatus of claim 25, wherein the illuminator projects white light.

30. The apparatus of claim 25, wherein the illuminator comprises an optical fiber.

31. The apparatus of claim 30, wherein the optical fiber is also a conduit for therapeutic radiation.

32. The apparatus of claim 30, wherein the optical fiber is in communication with a laser source, an arc lamp, an LED, or a tungsten filament bulb.

33. The apparatus of claim 25, wherein the illuminator and collecting device share an optical conduit.

34. The apparatus of claim 25, wherein the illuminator and the collecting device operate in synchrony.

35. The apparatus of claim 25, wherein the detector is a spectrometer.

36. The apparatus of claim 35, wherein the spectrometer is in communication with a computer that indicates changes in intensity of the reflected energy as the sensor is contacted with the tissue surface.

37. The apparatus of claim 36, wherein the computer analyzes the intensity of reflected green light.

38. The apparatus of claim 36, wherein the computer analyzes a ratio of reflected light at at least two different wavelengths.

39. The apparatus of claim 25, further comprising a sheath surrounding at least a portion of the balloon member to enhance the collection of reflected radiation.

40. The therapeutic medical device of claim 39, wherein the sheath comprises a polyethylene terephthalate polymer, which contains light scattering particles.

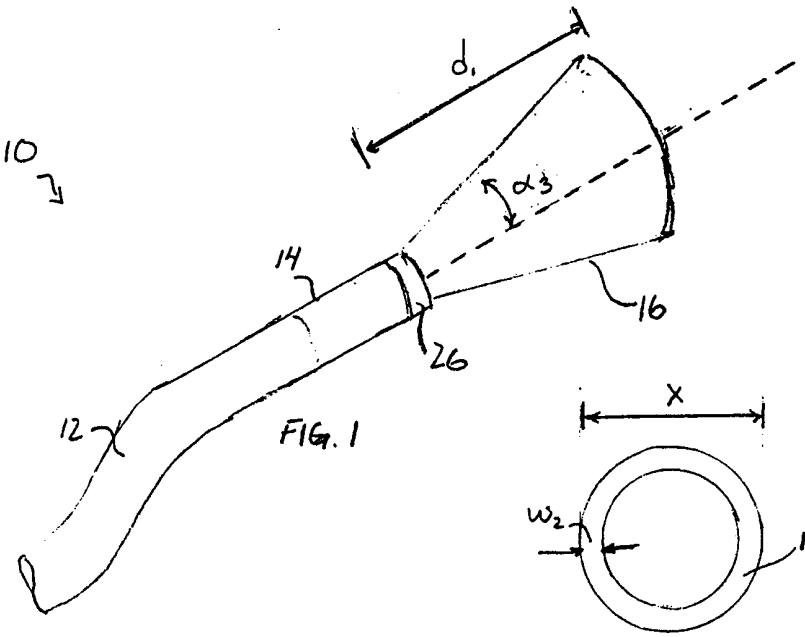

FIG. 1

FIG. 1A

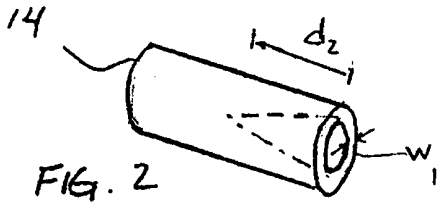

FIG. 2

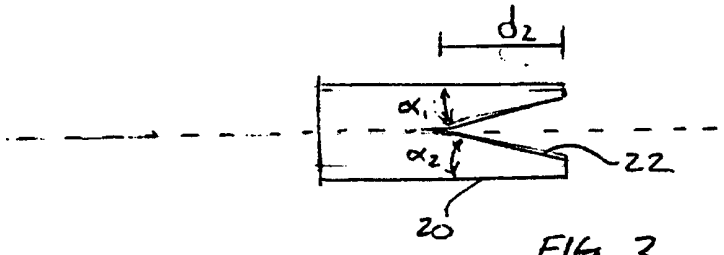

FIG. 3

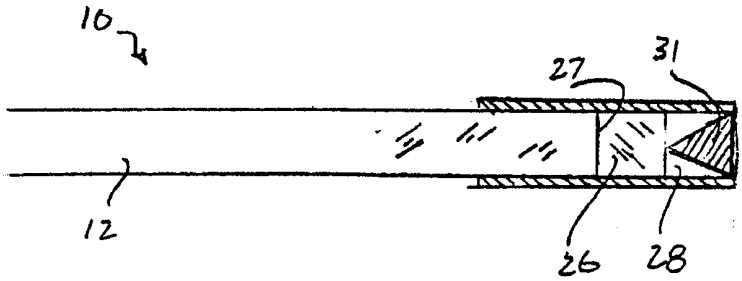

FIG. 4

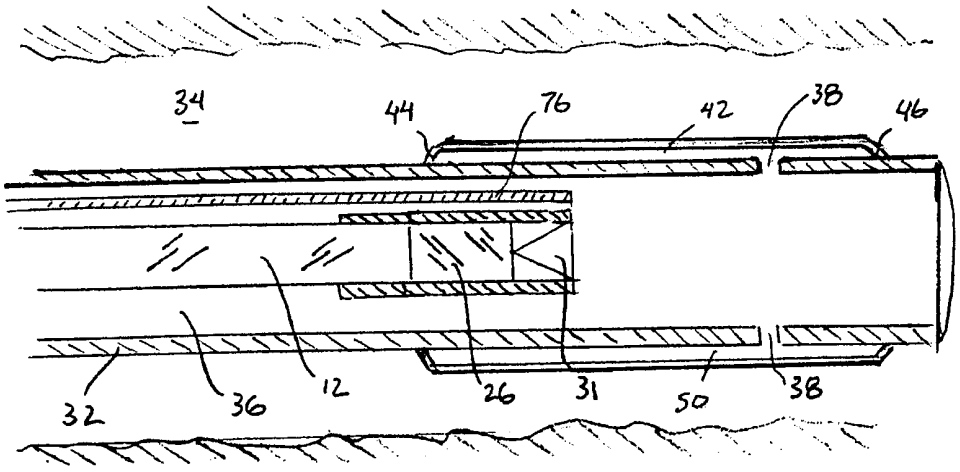

FIG. 5

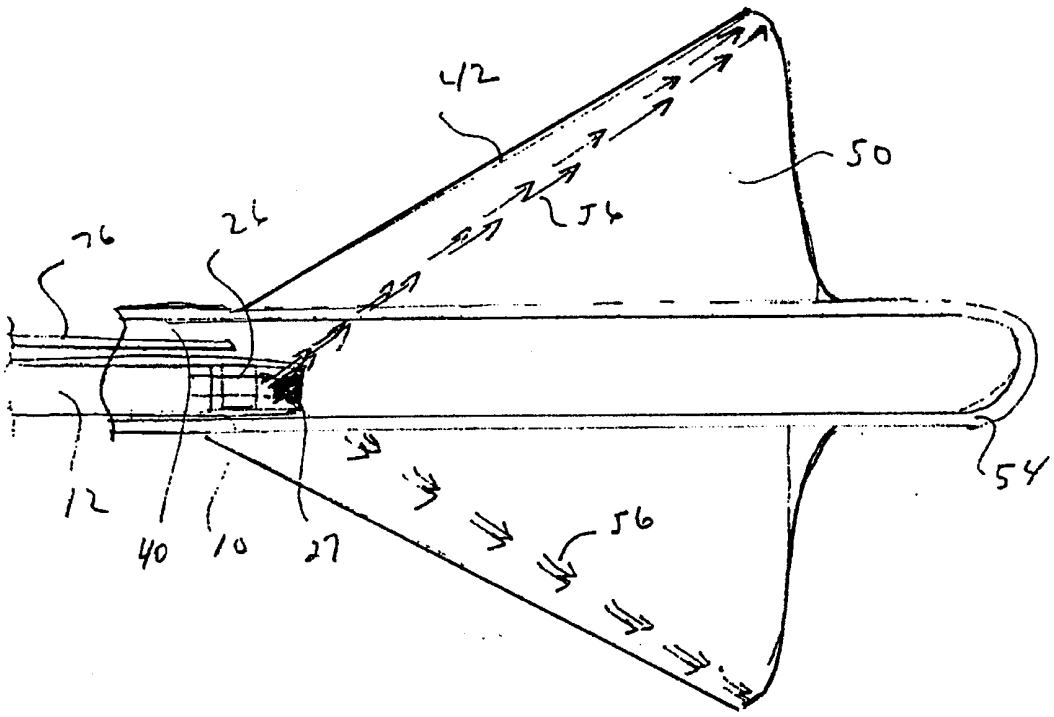

FIG. 6

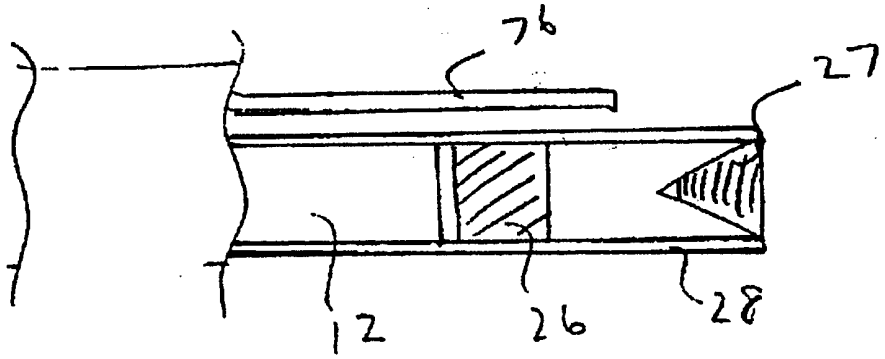

FIG. 7

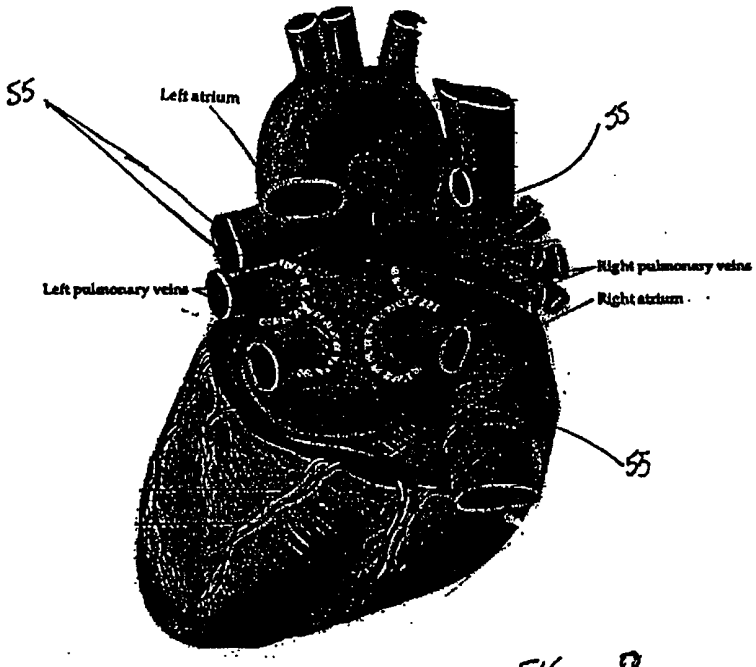
55
Left atrium
55
Right pulmonary veins
Left pulmonary veins
Right atrium
55

FIG. 8

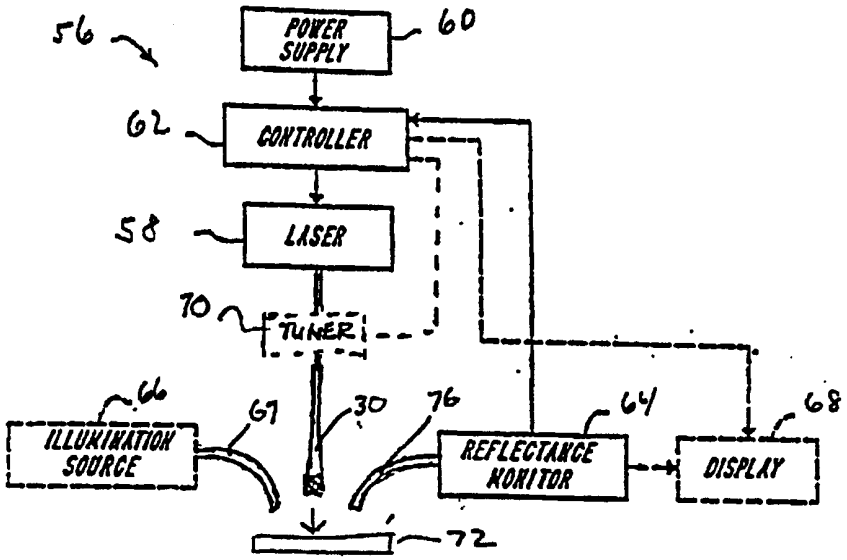
56
POWER SUPPLY
60
62
CONTROLLER
58
LASER
70
TUNER
66
ILLUMINATION SOURCE
67
30
76
64
REFLECTANCE MONITOR
68
DISPLAY
72

FIG. 9

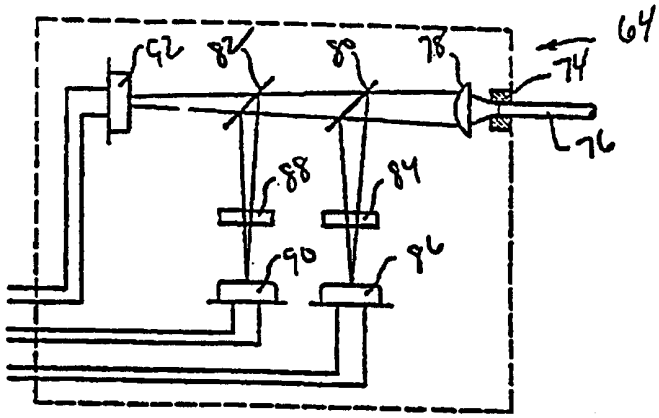
64
82
80
78
74
76
88
84
90
86

FIG. 10

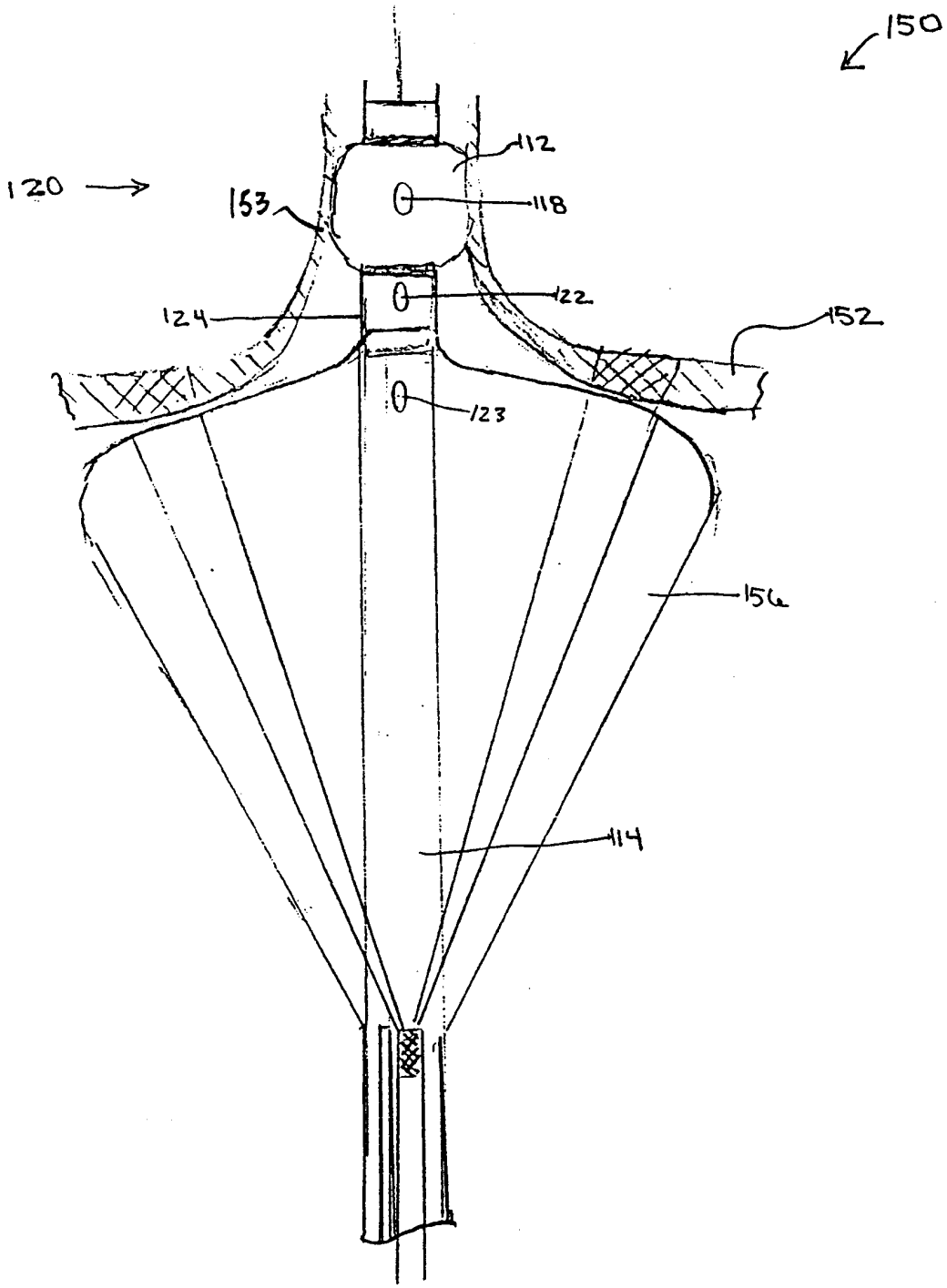

FIG 11

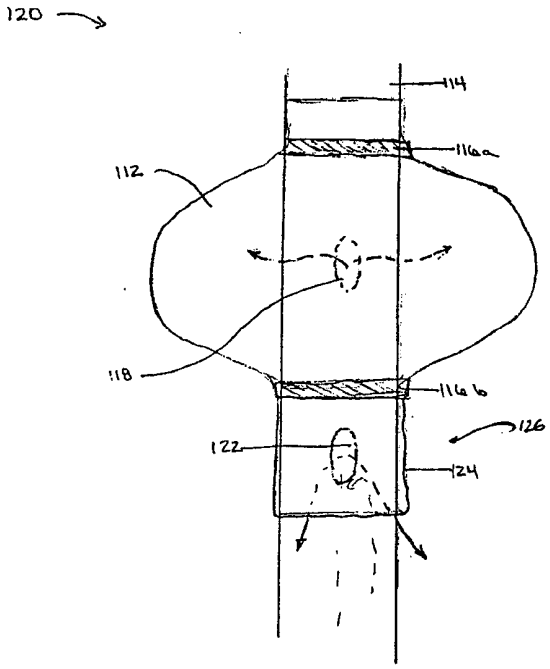
120
114
116a
112
118
116b
126
122
124

FIG 12

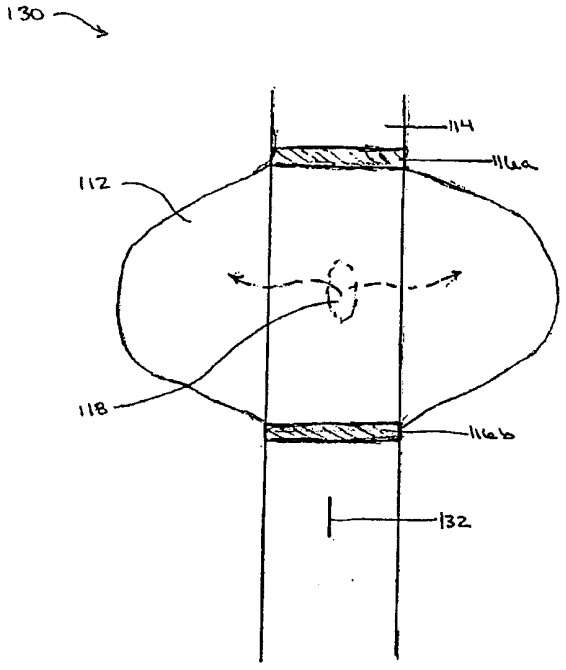
130
114
116a
112
118
116b
132

FIG 13

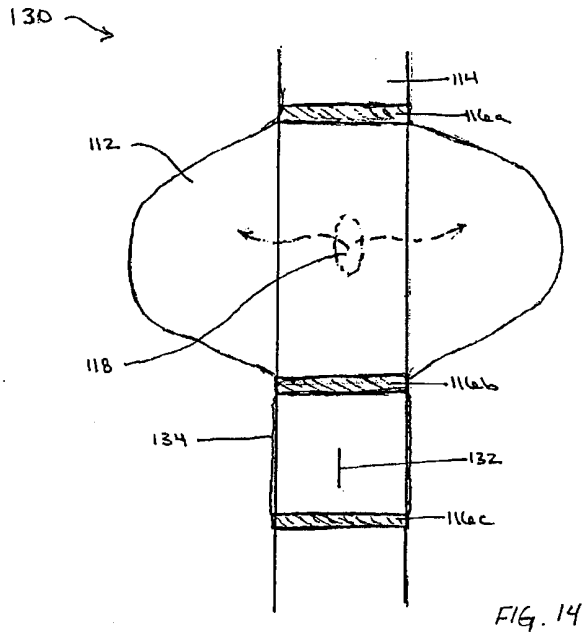
130
114
116a
112
118
116b
134
132
116c

FIG. 14

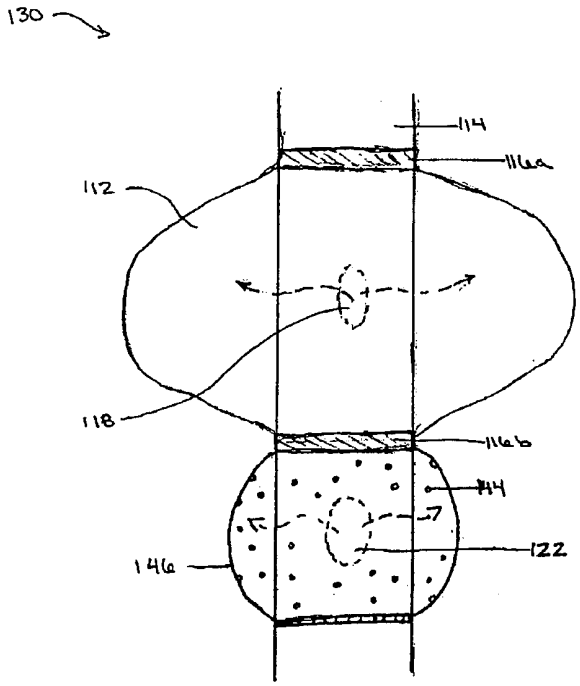
130
114
116a
112
118
116b
114
122
146

FIG. 15

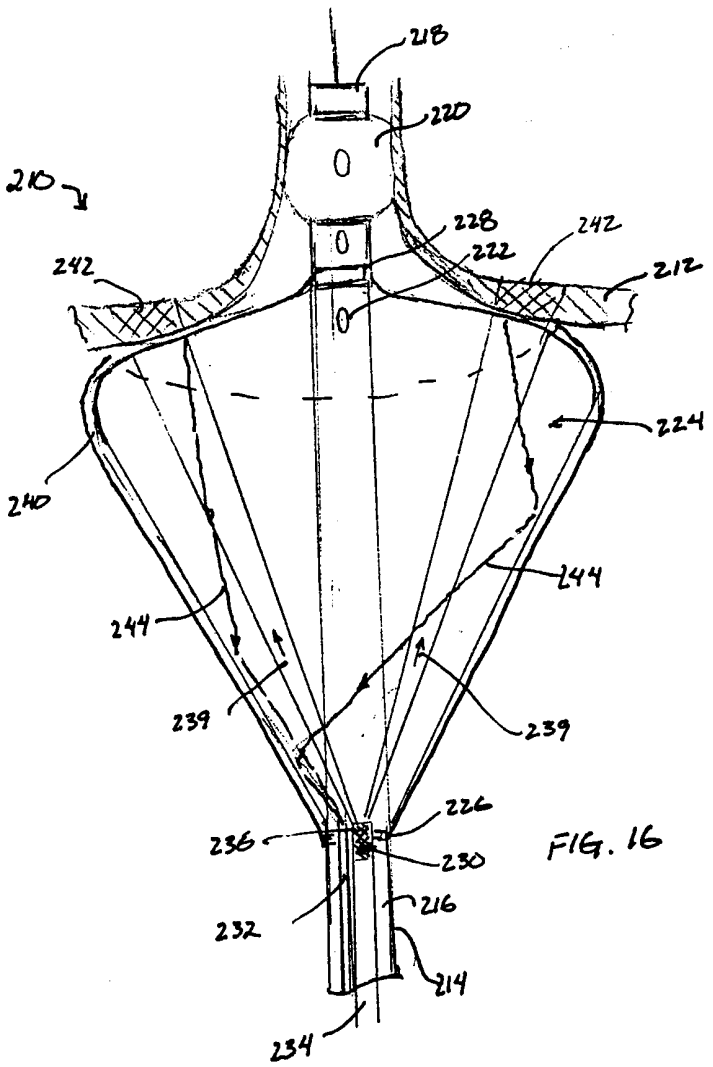
218
220
210
228
242
222
242
212
224
240
244
244
239
239
226
236
230
232
216
214
234

FIG. 16

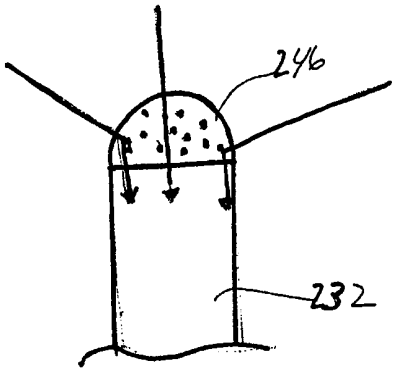
246
232

FIG 17

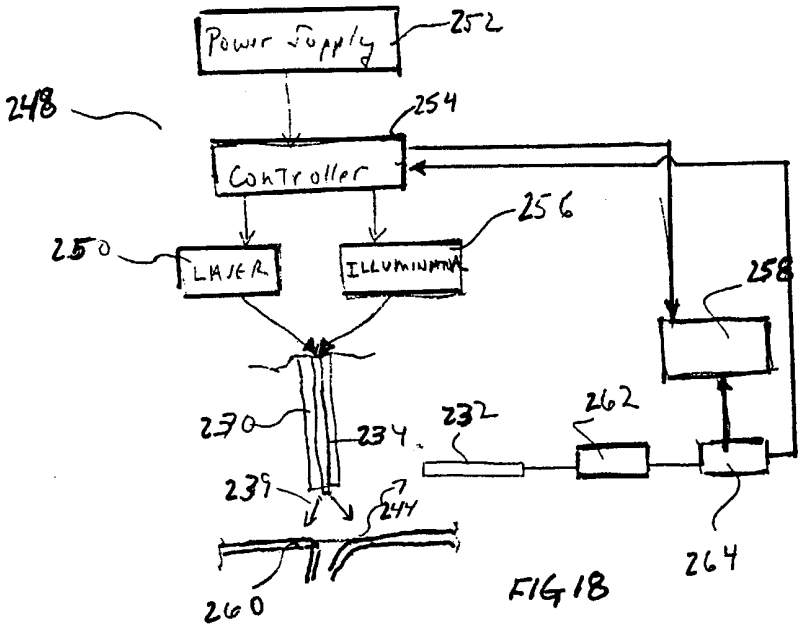
Power Supply
252
248
254
Controller
256
250
LASER
ILLUMINATOR
258
230
234
232
262
239
244
260
264

FIG 18

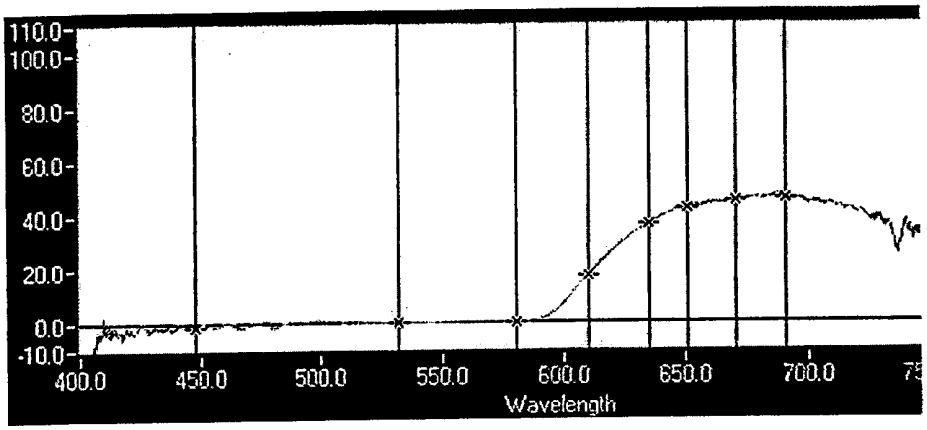

FIG. 19A

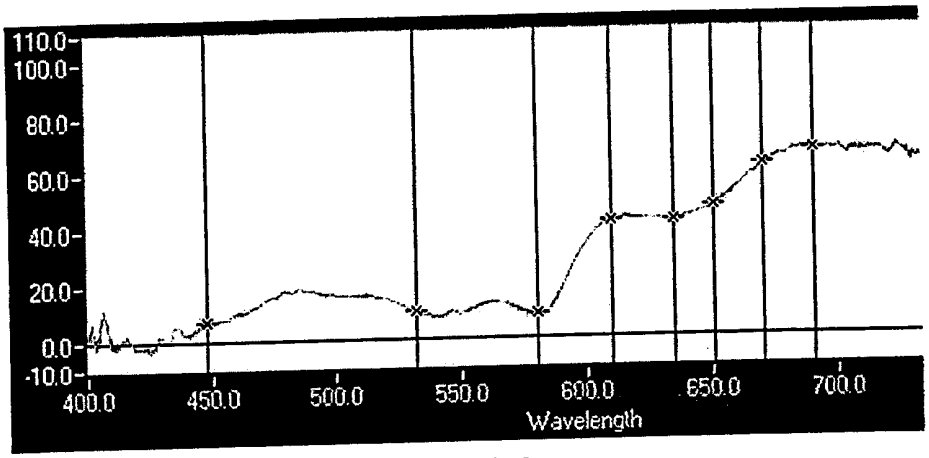

FIG. 19B

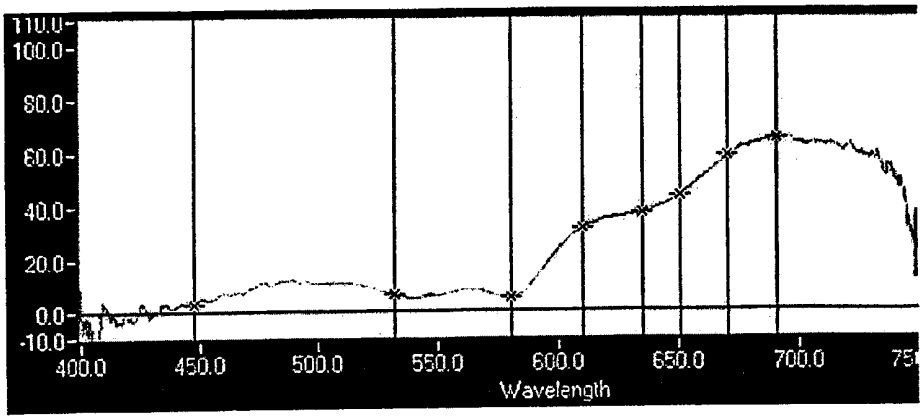

FIG. 19C

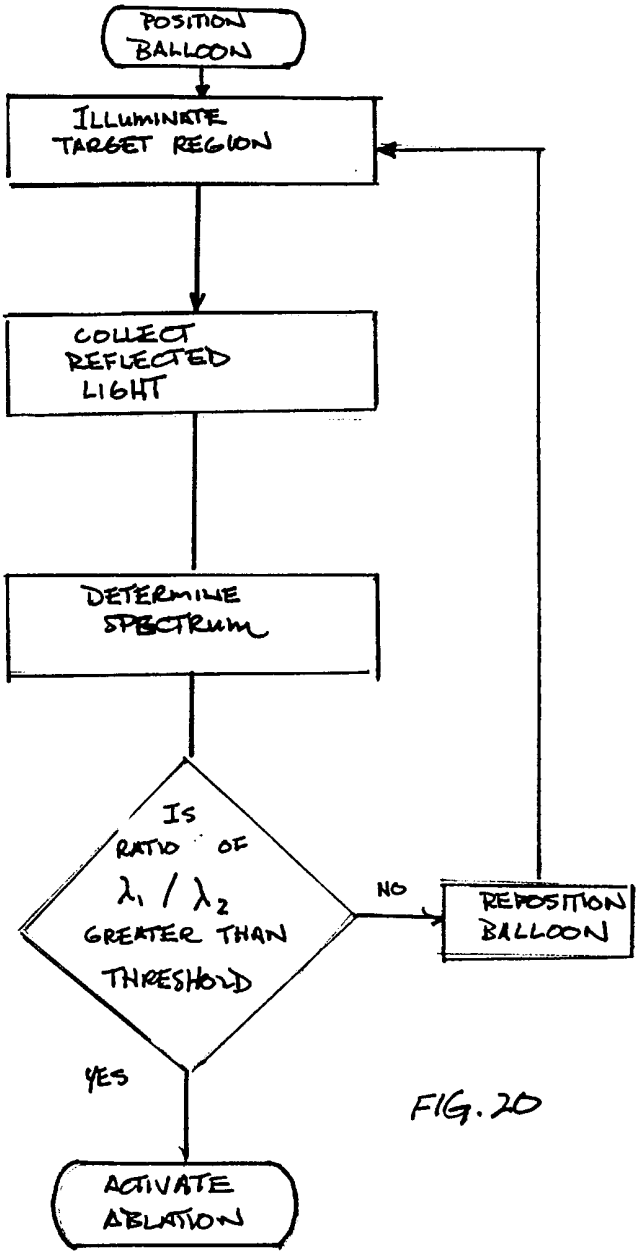
POSITION BALLOON
ILLUMINATE TARGET REGION
COLLECT REFLECTED LIGHT
DETERMINE SPECTRUM
IS RATIO OF λ_1 / λ_2 GREATER THAN THRESHOLD
NO
REPOSITION BALLOON
YES
ACTIVATE ABLATION

FIG. 20