(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 January 2017 (26.01.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/015257 A1

(51) International Patent Classification:
A61B 5/00 (2006.01)

(21) International Application Number:
PCT/US2016/042891

(22) International Filing Date:
19 July 2016 (19.07.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/194,276 19 July 2015 (19.07.2015) US
14/919,004 21 October 2015 (21.10.2015) US

(71) Applicant: **LUXCATH, LLC** [US/US]; 33 Arch Street, Boston, Massachusetts 02110 (US).

(72) Inventors: **RANSBURY, Terrance J.**; 112 Simerville Road, Chapel Hill, North Carolina 27517 (US). **ARMSTRONG, Kenneth C.**; 104 Modena Drive, Cary, North Carolina 27513 (US). **AMIRANA, Omar**; 21 Lilac Court, Cambridge, Massachusetts 02141 (US). **LARSON, Cinnamon**; 1549 Pathway Drive, Carrboro, North Carolina 27510 (US).

(74) Agents: **FAYERBERG, Roman** et al.; Greenberg Traurig LLP, One International Place, Boston, Massachusetts 02110 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,

[Continued on next page]

(54) Title: SYSTEMS AND METHODS FOR LESION FORMATION AND ASSESSMENT

(57) Abstract: Catheter for visualizing ablated tissue comprises a catheter body; a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light energy between the illumination cavity and tissue; a light directing member disposed within the illumination cavity, the light directing member being configured to split light energy received from a light source into multiple beams and to such beams to the tissue through the corresponding more openings in the distal tip.

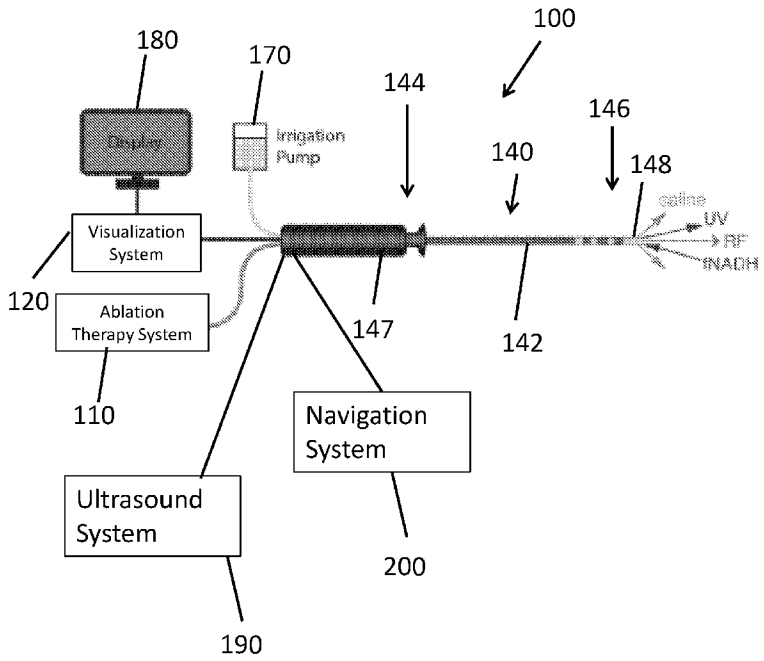

FIG. 1A

WO 2017/015257 A1

DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

TITLE

SYSTEMS AND METHODS FOR LESION FORMATION AND ASSESSMENT

RELATED APPLICATIONS

[0001[This application claims the benefit of and priority to U.S. Application Serial No. 14/919,004, filed on October 21, 2015 and U.S. Provisional Application Serial No. 62/194,276, filed on July 19, 2015, both applications are incorporated herein by reference in their entireties.

FIELD

[0002[The present disclosure generally relates to catheters, and more particularly ablation and visualization catheters.

BACKGROUND

[0003[Atrial fibrillation (AF) is the most common sustained arrhythmia in the world, which currently affects millions of people. In the United States, AF is projected to affect 10 million people by the year 2050. AF is associated with increased mortality, morbidity, and an impaired quality of life, and is an independent risk factor for stroke. The substantial lifetime risk of developing AF underscores the public heath burden of the disease, which in the U.S. alone amounts to an annual treatment cost exceeding $7 billion.

[0004[Most episodes in patients with AF are known to be triggered by focal electrical activity originating from within muscle sleeves that extend into the Pulmonary Veins (PV). Atrial fibrillation may also be triggered by focal activity within the superior vena cava or other atrial structures, i.e. other cardiac tissue within the heart's conduction system. These focal triggers can also cause atrial tachycardia that is driven by reentrant electrical activity (or rotors), which may then fragment into a multitude of electrical wavelets that are characteristic of atrial fibrillation. Furthermore, prolonged AF can cause functional alterations in cardiac cell membranes and these changes further perpetuate atrial fibrillation.

[0005[Radiofrequency ablation (RFA), laser ablation and cryo ablation are the most common technologies of catheter-based mapping and ablation systems used by physicians to treat atrial fibrillation. Physicians use a catheter to direct energy to either destroy focal triggers or to form electrical isolation lines isolating the triggers from the heart's remaining conduction system. The latter technique is commonly used in what is called pulmonary vein

isolation (PVI). However, the success rate of the AF ablation procedure has remained relatively stagnant with estimates of recurrence to be as high as 30% to 50% one-year post procedure. The most common reason for recurrence after catheter ablation is one or more gaps in the PVI lines. The gaps are usually the result of ineffective or incomplete lesions that may temporarily block electrical signals during the procedure but heal over time and facilitate the recurrence of atrial fibrillation.

[0006[Therefore, there is a need for system and method for forming and verifying proper lesions to improve outcomes and reduce costs.

SUMMARY

[0007[According to some aspects of the present disclosure, there is provided a catheter for visualizing ablated tissue comprising: a catheter body; a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light energy between the illumination cavity and tissue; a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip.

[0008[In some embodiments, the distal tip of the catheter may be configured to deliver ablation energy to the tissue, the ablation energy being selected from a group consisting of radiofrequency (RF) energy, microwave energy, electrical energy, electromagnetic energy, cryoenergy, laser energy, ultrasound energy, acoustic energy, chemical energy, thermal energy and combinations thereof.

[0009[In some embodiments, the light directing member and the one or more openings are configured to enable illumination of tissue in a radial direction and an axial direction with respect to a longitudinal axis of the catheter. In some embodiments, the one or more openings are disposed along side walls of the distal tip and the light directing member is shaped to split light energy and specifically direct the light energy at an angle relative to the longitudinal axis of the catheter through the one or more openings. In some embodiments, the light directing member comprises one or more through-holes and the distal tip comprises one or more openings disposed on a front wall of the distal tip to enable passage of light in longitudinal direction through the light directing member and the one or more openings of the front wall. In some embodiments, the catheter may further comprise an ultrasound transducer.

[0010[According to some aspects of the present disclosure, there is provided a system for visualizing ablated tissue comprising a catheter comprising a catheter body; a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light energy between the illumination cavity and tissue; a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip; a light source; a light measuring instrument; and one or more optical fibers in communication with the light source and the light measuring instrument and extending through the catheter body into the illumination cavity of the distal tip, wherein the one or more optical fibers are configured to pass light energy from the light source to the light directing member for illuminating tissue outside the distal tip and the one or more optical fibers are configured to relay light energy reflected from the tissue to the light measuring instrument.

[0011[According to some aspects of the present disclosure, there is provided a method for visualizing ablated tissue comprising: advancing a catheter to a cardiac tissue in need of ablation, the catheter comprising a catheter body; a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light between the illumination cavity and tissue; a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light to and from the tissue through the one or more openings in the distal tip; causing the light directing member to direct light through the one or more openings in the distal tip of the catheter to excite nicotinamide adenine dinucleotide hydrogen (NADH) in an area of the cardiac tissue including ablated cardiac tissue and non-ablated cardiac tissue; collecting light reflected from the cardiac tissue through the one or more openings and directing the collected light to a light measuring instrument; imaging the area of the cardiac tissue to detect NADH fluorescence of the area of the cardiac tissue; and producing a display of the imaged, illuminated cardiac tissue, the display illustrating the ablated cardiac tissue as having less fluorescence than non-ablated cardiac tissue.

[0012[In some embodiments, the method may further include ablating tissue with the distal tip prior to imaging the tissue, and ablating additional non-ablated cardiac tissue identified by distinguishing between the ablated cardiac tissue and the non-ablated cardiac tissue based on the amount of fluorescence.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013[The presently disclosed embodiments will be further explained with reference to the attached drawings, wherein like structures are referred to by like numerals throughout the several views. The drawings shown are not necessarily to scale, with emphasis instead generally being placed upon illustrating the principles of the presently disclosed embodiments.

[0014[FIG. 1 is an embodiment of an ablation visualization system of the present disclosure.

[0015[FIG. 2 is a diagram of a visualization system for use in connection with an ablation visualization system of the present disclosure.

[0016[FIG. 3 illustrates an embodiment of a distal tip of a catheter of the present disclosure.

[0017[FIG. 4A and FIG. 4B illustrate an embodiment of a light directing member of a catheter of the present disclosure.

[0018[FIG. 5A and FIG. 5B illustrate an embodiment of a distal tip of a catheter of the present disclosure.

[0019[FIG. 6A, FIG. 6B, FIG. 6C and FIG. 6D illustrate an optical fiber aligner of a catheter of the present disclosure.

[0020[FIG. 7A and FIG. 7B illustrate an embodiment of a light directing member of the present disclosure.

[0021[FIGs. 8A-8D illustrate various embodiments of a catheter of the present disclosure.

[0022[FIG. 9 illustrates an embodiment of a catheter of the present disclosure illuminating a fluorescent solution.

[0023[FIG. 10 is a flow chart of a method of using a system of the present disclosure.

[0024[While the above-identified drawings set forth presently disclosed embodiments, other embodiments are also contemplated, as noted in the discussion. This disclosure presents illustrative embodiments by way of representation and not limitation. Numerous other modifications and embodiments can be devised by those skilled in the art which fall within the scope and spirit of the principles of the presently disclosed embodiments.

DETAILED DESCRIPTION

[0025[The present disclosure generally relates to systems and methods for applying radiofrequency, laser or cryo ablation energy to the body to form therapeutic lesions. In some

embodiments, the systems and methods of the present disclosure may be employed for imaging tissue using nicotinamide adenine dinucleotide hydrogen (NADH) fluorescence (fNADH). By way of a non-limiting example, the present systems and methods may be used during the treatment of Atrial Fibrillation (AF).

[0026[In general, the system may include a catheter with an optical system for exchanging light between tissue and the catheter. In some embodiments, the instant systems allow for direct visualization of the tissue's NADH fluorescence, or lack thereof, induced by ultraviolet (UV) excitation. The fluorescence signature returned from the tissue can be used to determine the presence or absence of ablation lesions in illuminated tissue as well as information about a lesion as it is forming during ablation. This optical tissue interrogation can be performed on various tissue types, including, without limitation, various cardiac tissues, endocardial tissue, epicardial tissue, myocardium tissue, valves, vascular structures, and fibrous and anatomical structures. The systems and methods of the present disclosure may be used to analyze tissue composition including, but not limited to the presence of collagen and elastin. However, the presently disclosed methods and systems may also be applicable for analyzing lesions in other tissue types. The lesions to be analyzed may be created by application of ablation energy during the ablation procedure. In some embodiments, existing lesions, created by ablation or by other means, may also be analyzed using methods and systems disclosed herein.

[0027[In reference to FIG. 1, the system for providing ablation therapy 100 may include an ablation therapy system 110, a visualization system 120, and a catheter 140. In some embodiments, the system 100 may also include an irrigation system 170. The system may also include a display 180, which can be a separate display or a part of the visualization system 120, as described below.

[0028[In some embodiments, the ablation therapy system 110 is designed to supply ablation energy to the catheter 140. The ablation therapy system 110 may include one or more energy sources that can generate radiofrequency (RF) energy, microwave energy, electrical energy, electromagnetic energy, cryoenergy, laser energy, ultrasound energy, acoustic energy, chemical energy, thermal energy or any other type of energy that can be used to ablate tissue. In some embodiments, the system includes an RF generator, an irrigation pump 170, an irrigated-tip ablation catheter 140, and the visualization system 120.

[0029[In reference to FIG. 2, the visualization system 120 may include a light source 122, a light measuring instrument 124, and a computer system 126.

[0030[In some embodiments, the light source 122 may have an output wavelength within the target fluorophore (NADH, in some embodiments) absorption range in order to induce fluorescence in healthy myocardial cells. In some embodiments, the light source 122 is a solid-state laser that can generate UV light to excite NADH fluorescence. In some embodiments, the wavelength may be about 355nm or 355 nm +/- 30 nm. In some embodiments, the light source 122 can be a UV laser. Laser-generated UV light may provide much more power for illumination and may be more efficiently coupled into a fiber-based illumination system, as is used in some embodiments of the catheter. In some embodiments, the instant system can use a laser with adjustable power up to 150 mW.

[0031[The wavelength range on the light source 122 may be bounded by the anatomy of interest, a user specifically choosing a wavelength that causes maximum NADH fluorescence without exciting excessive fluorescence of collagen, which exhibits an absorption peak at only slightly shorter wavelengths. In some embodiments, the light source 122 has a wavelength from 300nm to 400nm. In some embodiments, the light source 122 has a wavelength from 330nm to 370nm. In some embodiments, the light source 122 has a wavelength from 330nm to 355nm. In some embodiments, a narrow-band 355 nm source may be used. The output power of the light source 122 may be high enough to produce a recoverable tissue fluorescence signature, yet not so high as to induce cellular damage. The light source 122 may be coupled to an optical fiber to deliver light to the catheter 140, as will be described below.

[0032[In some embodiments, the systems of the present disclosure may utilize a spectrometer as the light measuring instrument 124. In some embodiments, the light measuring instrument 124 may comprise a camera connected to the computer system 126 for analysis and viewing of tissue fluorescence. In some embodiments, the camera may have high quantum efficiency for wavelengths corresponding to NADH fluorescence. One such camera is an Andor iXon DV860. The spectrometer 124 may be coupled to an imaging bundle that can be extended into the catheter 140 for visualization of tissue. In some embodiments, the imaging bundle for spectroscopy and the optical fiber for illumination may be combined. An optical bandpass filter of between 435nm and 485nm, in some embodiments, of 460nm, may be inserted between the imaging bundle and the camera to block light outside of the NADH fluorescence emission band. In some embodiments, other

optical bandpass filters may be inserted between the imaging bundle and the camera to block light outside of the NADH fluorescence emission band selected according to the peak fluorescence of the tissue being imaged.

[0033[In some embodiments, the light measuring instrument 124 may be a CCD (charge-coupled device) camera. In some embodiments, the spectrometer 124 may be selected so it is capable of collecting as many photons as possible and that contributes minimal noise to the image. Usually for fluorescence imaging of live cells, CCD cameras should have a quantum efficiency at about 460 nm of at least between 50-70%, indicating that 30-50% of photons will be disregarded. In some embodiments, the camera has quantum efficiency at 460 nm of about 90%. The camera may have a sample rate of 80 KHz. In some embodiments, the spectrometer 124 may have a readout noise of 8 e- (electrons) or less. In some embodiments, the spectrometer 124 has a minimum readout noise of 3e-. Other light measuring instruments may be used in the systems and methods of the present disclosure.

[0034[The optical fiber 150 can deliver the gathered light to a long pass filter that blocks the reflected excitation wavelength of 355nm, but passes the fluoresced light that is emitted from the tissue at wavelengths above the cutoff of the filter. The filtered light from the tissue can then be captured and analyzed by a high-sensitivity spectrometer 124. The computer system 126 acquires the information from the spectrometer 124 and displays it to the physician. The computer 126 can also provide several additional functions including control over the light source 122, control over the spectrometer 124, and execution of application specific software.

[0035[In some embodiments, the digital image that is produced by analyzing the light data may be used to do the 2D and 3D reconstruction of the lesion, showing size, shape and any other characteristics necessary for analysis. In some embodiments, the image bundle may be connected to the spectrometer 124, which may generate a digital image of the lesion being examined from NADH fluorescence (fNADH), which can be displayed on the display 180. In some embodiment, these images can be displayed to the user in real time. The images can be analyzed by using software to obtain real-time details (e.g. intensity or radiated energy in a specific site of the image) to help the user to determine whether further intervention is necessary or desirable. In some embodiments, the NADH fluorescence may be conveyed directly to the computer system 126.

[0036[In some embodiments, the optical data acquired by the light measuring instrument can be analyzed to provide information about lesions during and after ablation including, but not

limited to lesion depth and lesion size. In some embodiments, data from the light measuring instrument can be analyzed to determine if the catheter 140 is in contact with the myocardial surface and how much pressure is applied to the myocardial surface by the tip of the catheter. In some embodiments, data from the spectrometer 124 is analyzed to determine the presence of collagen or elastin in the tissue. In some embodiments, data from the light measuring instrument is analyzed and presented visually to the user via a graphical user interface in a way that provides the user with real-time feedback regarding lesion progression, lesion quality, myocardial contact, tissue collagen content, and tissue elastin content.

[0037[In some embodiments, the system 100 of the present disclosure may further include an ultrasound system 190. The catheter 140 may be equipped with ultrasound transducers in communication with the ultrasound system. In some embodiments, the ultrasound may show tissue depths, which in combination with the metabolic activity or the depth of lesion may be used to determine if definitively say if a lesion is in fact transmural or not. In some embodiments, the catheter 140 may be equipped with location or navigation sensors in communication with a location or navigation system 200, as is described below.

[0038[Referring back to FIG. 1, the catheter 140 includes a catheter body 142 having a proximal end 144 and a distal end 146. The catheter body 142 may be made of a biocompatible material, and may be sufficiently flexible to enable steering and advancement of the catheter 140 to a site of ablation. In some embodiments, the catheter body 142 may have zones of variable stiffness. For example, the stiffness of the catheter 140 may increase from the proximal end 144 toward the distal end 146. In some embodiments, the stiffness of the catheter body 142 is selected to enable delivery of the catheter 140 to a desired cardiac location. In some embodiments, the catheter 140 can be a steerable, irrigated radiofrequency (RF) ablation catheter that can be delivered through a sheath to the endocardial space, and in the case of the heart's left side, via a standard transseptal procedure using common access tools. The catheter 140 may include a handle 147 at the proximal end 144. The handle 147 may be in communication with one or more lumens of the catheter to allow passage of instruments or materials through the catheter 140. In some embodiments, the handle 147 may include connections for the standard RF generator and irrigation system for therapy. In some embodiments, the catheter 140 may also include one more adaptors configured to accommodate the optical fiber 150 for illumination and spectroscopy.

[0039[In reference to FIG. 3, at the distal end 146, the catheter 140 may include a distal tip 148, having a side wall 156 and a front wall 158. The front wall 158 may be, for example,

flat, conical or dome shaped. In some embodiments, the distal tip 148 may be configured to act as an electrode for diagnostic purposes, such as electrogram sensing, for therapeutic purposes, such as for emitting ablation energy, or both. In some embodiments where ablation energy is required, the distal tip 148 of the catheter 140 could serve as an ablation electrode or ablation element.

[0040[In the embodiments where RF energy is implemented, the wiring to couple the distal tip 148 to the RF energy source (external to the catheter) can be passed through a lumen of the catheter. The distal tip 148 may include a port in communication with the one or more lumens of the catheter. The distal tip 148 can be made of any biocompatible material. In some embodiments, if the distal tip 148 is configured to act as an electrode, the distal tip 148 can be made of metal, including, but not limited to, platinum, platinum-iridium, stainless steel, titanium or similar materials.

[0041[In reference to FIG. 3, an optical fiber or an imaging bundle 150 may be passed from the visualization system 120, through the catheter body 142, and into an illumination cavity or compartment 152, defined by the distal tip 148. The distal tip 148 may be provided with one or more openings 154 for exchange of light energy between the illumination cavity 152 and tissue. In some embodiments, even with multiple openings 154, the function of the distal tip 148 as an ablation electrode is not compromised. This light is delivered by the fiber 150 to the distal tip 148, where it illuminates the tissue in the proximity of the distal tip 148. This illumination light is either reflected or causes the tissue to fluoresce. The light reflected by and fluoresced from the tissue may be gathered by the optical fiber 150 within the distal tip 148 and carried back to the visualization system 120. In some embodiments, the same optical fiber or bundle of fibers 150 may be used to direct light to the light directing member 160 to illuminate tissue outside the catheter 140 in one or more directions and to collect light from the tissue.

[0042[In some embodiments, the one or more openings 154 may be provided in the side wall 156 of the distal tip 148, the front wall 158, or both. In some embodiments, the one or more openings 154 may be disposed circumferentially along the distal tip 148 around the entire circumference of the distal tip 148. In some embodiments, the one or more openings 154 may be disposed equidistantly from one another. The number of the openings may be determined by the desired angle of viewing coverage. For example, with 3 openings equally spaced, illumination and returned light occur at 120-degree increments (360 degrees divided by 3). In some embodiments, the one or more openings 154 may be provided in multiple

rows along the side walls 156 of the distal tip 148. In some embodiments, the distal tip 148 may include 3 or 4 openings in the side wall 156. In some embodiments, a single opening may be provided in the center of the front wall 158. In some embodiments, multiple openings 154 may be provided in the front wall 158. In some embodiments, the distal tip 148 is provided with 3 side openings and 1 front opening. The one or more openings 154 may also serve as an irrigation port in connection with the irrigation system. In some embodiments light is only directed through some of the side openings 154. For example, in some embodiments there may exist 6 openings in the side wall 156, but light may be directed through only 3 of the openings, while the other openings may be used for irrigation.

[0043[To enable the light energy exchange between the illumination cavity 152 and tissue over multiple paths (axially and radially with respect to the longitudinal central axis of the catheter), a light directing member 160 may be provided in the illumination cavity 152. The light directing member 160 may direct the illumination light to the tissue and direct the light returned through the one or more openings 154 within the distal tip 148 to the optical fiber 150. The light directing member 160 may also be made from any biocompatible material with a surface that reflects light or can be modified to reflect light, such as for example, stainless steel, platinum, platinum alloys, quartz, sapphire, fused silica, metallized plastic, or other similar materials. In some embodiments, the light directing member 160 may comprise a highly polished mirror. The light directing member 160 may be conical (i.e. smooth) or faceted with any number of sides. The light directing member 160 may be shaped to bend the light at any desired angle. In some embodiments, the light directing member 160 may be shaped to reflect the light only through the one or more openings. In some embodiments, the material for the light directing member 160 is chosen from materials that do not fluoresce when exposed to illumination between 310 nm to 370 nm.

[0044[In some embodiments, as shown in FIG. 3, the light directing member 160 may include one or more holes 162 through the centerline of the mirror, which allow illumination and reflected light to pass in both directions axially, directly in line with the catheter 140. Such an axial path may be useful when the distal-most surface of the distal tip 148 is in contact with the anatomy. The alternate radial paths may be useful when the anatomy will not allow the distal-most surface of the distal tip 148 to be in contact with the target site as is sometimes the case in the left atrium of the patient during pulmonary vein isolation procedures, common in treating atrial fibrillation. In some embodiments, in all pathways, lensing may not be required and the optical system is compatible with the irrigation system

170 as the light passes through the cooling fluid, which is often saline. The irrigation system 170 may also serve to flush the blood from the holes 162, thus keeping the optical components clean.

[0045[In reference to FIG. 4A, the light directing member 160 may have a front face 164 with multiple, angled facets 166. In some embodiments, the light directing member 160 may include 3 or 4 equidistant facets, although more or less facets may be used. In some embodiments, the number of facets 166 may correspond to the number of the openings 154 in the side wall 156. In some embodiments, there may be fewer facets 166 than the openings 154 in the side wall 156. In some embodiments, as shown in FIG. 4B, the facets 166 may be positioned at 45 degrees relative to central axis of the light directing member 160 (135 degrees relative to the axis of the catheter). In some embodiments, the facets 166 may be positioned at greater or lesser angles than 45 degrees in order to direct light more distally or more proximally.

[0046[In reference to FIG. 5A, the light directed onto the light directing member 160 from the optical fiber 150 may be reflected by the light directing member 160. Some of the reflected light may exit the distal tip 148 through the one or more openings 154 in the side wall 156 of the distal tip 148. The light directing member may separate or split the light beam shined on the light directing member into multiple beams and specifically directing the split beams to exit through the corresponding openings 154. In this manner, the intensity of light from the light source may be substantially conserved and the intensity of illuminating the tissue may be increased. Otherwise, if the light is diffused through the illumination cavity, without the light directing member focusing the light into the openings 154, the intensity of the light illuminating the tissue may be insufficient for tissue imaging. In addition, in some embodiments, the light directing member is configured to collect light beams reflected from the tissue and to direct them the optical fiber, which can them relay them to the light measuring instrument. In some embodiments, the beams received from tissue may be combined before being sent to the optical fiber. In some embodiments, all light delivered into the illumination cavity may be directed by the light directing member to exit the illumination cavity 152 through the openings 154. In addition, light can also pass through the holes 162 in the light directing member 160 and through the openings 154 in the front wall 158 of the distal tip 148. By aligning the light directing member 160, the optical fiber 150 and the openings 154, the intensity of light to tissue may be adjusted and maximized. The angle of the facets 166, the size, number, and location of the openings 154, and the size,

number, and location of holes in the light directing member 160 can be adjusted and optimized to provide the desired balance of light returned from tissue illuminated at the distal tip 148 of the catheter via the openings in light directing member 160 and the light returned from tissue illuminated via the openings 154.

[0047[As shown in FIG. 5B, in some embodiments, the openings 154 may be directly in line with the facets 166 of the light directing member 160. In some embodiments, the correspondence between the openings 154 and the facets 166 may be different than 1:1. In some embodiments, the catheter 140 may include 3 openings or 4 openings corresponding to 3 facets or 4 facets 166, respectively, of the light directing member 160. It should be noted that, in some embodiments, some of the openings 154 may not be used for exchange of light due to the shape and orientation of the openings 154 and the light directing member 160, but are only used for irrigation purposes. As shown in FIG. 5B, the openings 154a may be aligned with the facets 166 for exchange of light, while openings 154b are not aligned with the facets 166, and thus are used primarily for irrigation, even if additional light is exchanged.

[0048[In reference to FIG. 6A and FIG. 6B, in some embodiments, a fiber aligner 168 may be provided in the distal tip 148 to align the optical fiber 150 with the light directing member 160. The fiber aligner 168 may include a fiber lumen 170 through which the optical fiber 150 may be advanced to align the optical fiber 150 with the light directing member 160. In some embodiments, the central axis of the optical fiber 150 may be aligned with the center axis of the light directing member 160 to uniformly illuminate the facets 166 of the light directing member 160 and to allow illumination in the central hole for illumination and return in the longitudinal direction. For example, the fiber lumen 170 may extend along the center axis of the fiber aligner 168 to center the optical fiber 150 relative to the light directing member 160. The position of the fiber in the fiber aligner 168 may be optimized to distribute light as desired between the central hole in the light directing member 160 and the openings 154 to maximize tissue fluorescence for the ablation application of interest.

[0049[As shown in FIG. 6C and FIG. 6D, the fiber aligner 168 may be inserted into the distal tip 148. When the optical fiber 150 is advanced through the fiber lumen 170 of the fiber aligner 168, the optical fiber 150 will assume a desired orientation and position relative to the light directing member 160.

[0050[Referring back to FIG. 6B, in some embodiments, the fiber aligner 168 may include one or more cut outs 172 and one or more ports 174. In this manner, when the fiber aligner

168 is inserted into the distal end 144 of the catheter 140, the cut outs 172 and the ports 174 allow passage of instruments and materials (such as, for example, irrigation fluid and electrode wiring for ablation into the distal tip 148).

[0051[In reference to FIG. 7A and FIG. 7B, the light directing member 160 may be provided with a key member 174 to help align the facets 166 of the light directing member 160 with the one or more openings 154. The angle of the facets on the light directing member 160 may align with the openings 154 on the distal tip 148. If they are misaligned, the light path may become inefficient. To ensure this alignment, in some embodiments, the light directing member 160 and the distal tip 148 have symmetrical key features so that the alignment of the facets 166 and the openings are deterministic. Once in place, a variety of technologies can be used to secure the light directing member 160 to the distal tip 148.

[0052[In reference to FIG. 8A and FIG. 8B, in some embodiments, the light directing member 160 may comprise a single faceted mirror that is capable of illuminating and receiving light in only one direction at a time. In some embodiments, such light directing member 160 may be rotatable relative to the catheter 140 to align the opening 154 in the side wall 156 with the target site. There are many ways of implementing a rotating mirror including, without limitation, a hydraulic turbine mechanism, having a torqueing mechanism in the handle 147 of the catheter 140 coupled to the light directing mirror. In reference to FIG. 8B, in some embodiments, a stationary mirror may be provided with a conical as opposed to a faceted geometry. FIG. 8C and FIG. 8D illustrate another embodiment of the light directing member 160 with 6 facets.

[0053[FIG. 9 illustrates a catheter 140 of the present disclosure oriented pointing at the viewer. When a vial of solution that fluoresces at the same wavelengths as NADH is held next to the catheter 140, light pathways that emanate radially from the distal tip 148 are interacting with the vial of solution. The pathways emanating from the opposite side of the distal tip 148 are not visible due to lack of fluorescence.

[0054[As noted above, the system 100 may also include an irrigation system 170. In some embodiments, the irrigation system 170 pumps saline into the catheter to cool the tip electrode during ablation therapy. This may help to prevent steam pops and char (i.e. clot that adheres to the tip that may eventually dislodge and cause a thrombolytic event) formation. For the proposed optical system, the fluid flow may clear the opening in the distal tip 148 of any blood that otherwise would otherwise absorb the illumination light.

[0055[The irrigation system 170 may be connected to the one or more openings in the distal tip 148 and can be used, for example, for flushing the openings with fluid to clear the tip of blood, cooling the tissue-electrode interface, prevention of thrombus formation, among many other possible uses. In some embodiments, the irrigation fluid is maintained at a positive pressure relative to pressure outside of the catheter for continuous flushing of the one or more openings 154.

[0056[In reference to FIG. 10, operation of the systems 100 of the present disclosure is illustrated. Initially, the catheter 140 is inserted into the area of heart tissue affected by the atrial fibrillation, such as the pulmonary vein / left atrial junction or another area of the heart (step 1010). Blood may be removed from the visual field, for example, by irrigation. The affected area may be illuminated by ultra-violet light reflected from the light directing member 160 (step 1015). Tissue in the illuminated area may be ablated (step 1020), either before, after, or during illumination. Either point-to-point RF ablation or cryoablation or laser or other known ablation procedures may be employed using the systems of the present disclosure.

[0057[Still referring to FIG. 10, the illuminated area may be imaged with the light directing member receiving the light from the tissue and directing such light to the optical fiber, which can then pass the light to the spectrometer (step 1025). In some embodiments, the methods of the present disclosure rely on imaging of the fluorescence emission of NADH, which is a reduced form of nicotinamide adenine dinucleotide (NAD+). NAD+ is a coenzyme that plays important roles in the aerobic metabolic redox reactions of all living cells. It acts as an oxidizing agent by accepting electrons from the citric acid cycle (tricarboxylic acid cycle), which occurs in the mitochondrion. By this process, NAD+ is thus reduced to NADH. NADH and NAD+ are most abundant in the respiratory unit of the cell, the mitochondria, but are also present in the cytoplasm. NADH is an electron and proton donor in mitochondria to regulate the metabolism of the cell and to participate in many biological processes including DNA repair and transcription.

[0058[By measuring the UV-induced fluorescence of tissue, it is possible to learn about the biochemical state of the tissue. NADH fluorescence has been studied for its use in monitoring cell metabolic activities and cell death. Several studies in vitro and in vivo investigated the potential of using NADH fluorescence intensity as an intrinsic biomarker of cell death (either apoptosis or necrosis) monitoring. Once NADH is released from the mitochondria of damaged cells or converted to its oxidized form (NAD+), its fluorescence

markedly declines, thus making it very useful in the differentiation of a healthy tissue from a damaged tissue. NADH can accumulate in the cell during ischemic states when oxygen is not available, increasing the fluorescent intensity. However, NADH presence disappears all together in the case of a dead cell. The following table summarizes the different states of relative intensity due to NADH fluorescence:

Cellular State	NADH Presence	Relative Changes of Auto-fluorescense intensity
Metabolically Active	Normal	Baseline
Metabolically Active but Impaired (Ischemia)	Increased due to Hypoxia	Increased
Metabolically Inactive (Necrotic)	None	Full Attenuation

[0059[Still referring to FIG. 10, while both NAD+ and NADH absorb UV light quite readily, NADH is autofluorescent in response to UV excitation whereas NAD+ is not. NADH has a UV excitation peak of about 340-360 nm and an emission peak of about 460 nm. In some embodiments, the methods of the present disclosure may employ excitation wavelengths between about 330 to about 370 nm. With the proper instrumentation, it is thus possible to image the emission wavelengths as a real-time measure of hypoxia as well as necrotic tissue within a region of interest. Furthermore, in some embodiments, a relative metric can be realized with a grayscale rendering proportionate to NADH fluorescence.

[0060[Under hypoxic conditions, the oxygen levels decline. The subsequent fNADH emission signal may increase in intensity indicating an excess of mitochondrial NADH. If hypoxia is left unchecked, full attenuation of the signal will ultimately occur as the affected cells along with their mitochondria die. High contrast in NADH levels may be used to identify the perimeter of terminally damaged ablated tissue.

[0061[To initiate fluorescence imaging, NADH may be excited by the UV light from the light source, such as a UV laser. NADH in the tissue specimen absorbs the excitation wavelengths of light and emits longer wavelengths of light. The emission light may be collected and passed back to the spectrometer, and a display of the imaged illuminated area may be produced on a display (step 1030), which is used to identify the ablated and unablated tissue in the imaged area based on the amount of NADH florescence (step 1035). For example, the sites of complete ablation may appear as completely dark area due to lack of

fluorescence. Accordingly, the areas of ablation may appear markedly darker when compared to the surrounding unablated myocardium, which has a lighter appearance. This feature may enhance the ability to detect the ablated areas by providing marked contrast to the healthy tissue and even more contrast at the border zone between ablated and healthy tissue. This border area is the edematous and ischemic tissue in which NADH fluorescence becomes bright white upon imaging. The border zone creates a halo appearance around the ablated central tissue.

[0062[The process may then be repeated by returning to the ablation step, if necessary, to ablate additional tissue. It should be recognized that although FIG. 10 illustrates the steps being performed sequentially, many of the steps may be performed simultaneously or nearly simultaneously, or in a different order than shown in FIG. 10. For example, the ablation, imaging and display can occur at the same time, and the identification of the ablated and unablated tissue can occur while ablating the tissue.

[0063[In some embodiments, the system of the present disclosure comprises a catheter, a light source, and a light measuring instrument. In some embodiments, the system further comprises an optical detection system having an optical detection fiber, the optical detection system being independent or immune from electrical or RF energy noise. In some embodiments, the optical detection fiber does not conduct electrically and an RF energy does not produce electromagnetic energy in a range of interest to the system.

[0064[In some embodiments, the system is adapted to optically interrogate a catheter environment in a biologic system. In some embodiments, the system is adapted to optically interrogate in real-time, via an NADH fluorescence, the catheter environment to determine or assess one or more of a complete or a partial immersion of an electrode in a blood pool. For example, the optical system can detect, by inference, that the catheter tip is completely or partially immersed in the blood pool. The reason for this is because unlike the tissue or vasculature that return a positive optical signature, the blood completely absorbs the illumination light at this wavelength and thus returns a null optical signature. This feature of complete absorption provides optical isolation and therefore noise insulation. The instrument can use this situation for optical calibration and the elimination of stray optical signatures coming from the catheter itself. In addition, the system may be used for a qualitative and or a quantitative contact assessment between a catheter tip and a tissue, a qualitative and or a quantitative assessment of a catheter contact stability, an ablation lesion formation in real time, an ablation lesion progression monitoring, a determination of when to terminate a

lesion, an identification of edematous zones which usually occur on a periphery of an ablation site and which can be associated with an incomplete ablation lesion, an ablation lesion depth, a cross-sectional area of the lesion, a temperature of the lesion, a recognition of steam formation or another physiologic parameter change to predict the onset of a steam pop, a formation of a char at a tip electrode during or after the ablation lesion formation, a detection of ischemia, a detection of a level of the ischemia, an ablation lesion assessment post lesion formation, an identification of edematous zones for re-ablation since edematous zones include myocardium that is electrically stunned, and a mapping of a location of previously ablated tissue by distinguishing metabolically active tissue from metabolically inactive tissue

[0065[In some embodiments, the system is adapted to optically interrogate a tissue parameter of an NADH fluorescence (fNADH).

[0066[In some embodiments, the system is adapted to optically interrogate a tissue, wherein the system analyzes parameters including a metabolic state of the tissue as well as a tissue composition of the tissue.

[0067[In some embodiments, the system is adapted to illuminate a tissue with a wavelength wherein illuminating leads to several optical responses. In some embodiments the optical responses comprises a myocardium containing NADH fluorescing if it is in a healthy metabolic state. In some embodiments, other tissues, such as collagen or elastin, fluoresce at different wavelengths, and the system uses a measurement of this information to determine a composition (i.e. collagen or elastin) of the tissue in contact with the catheter. In some embodiments the composition comprises myocardium, muscle, and myocardial structures such as valves, vascular structures, and fibrous or anatomical components. In some embodiments the composition comprises collagen, elastin, and other fibrous or support structures.

[0068[In some embodiments, a catheter of the present disclosure comprises a catheter body, a tip electrode, and one or more sensing electrodes. In some embodiments the catheter further comprises one or more zones of different flexibility, the zones of flexibility being in combination with a deflection mechanism adapted to allow a distal portion of the catheter to be bent for ease of navigation for a physician. In some embodiments, the zones of flexibility are located at the distal portion of the catheter, while a main body of the catheter is kept relatively stiff for pushability. In some embodiments, the main body of the catheter body is

flexible so that the physician can use a robotic system for catheter navigation. In some embodiments the catheter is flexible and capable of being manipulated within a catheter sheath manually or robotically.

[0069[In some embodiments, the catheter further comprises a deflection mechanism adapted to deflect the catheter tip for navigation. In some embodiments the deflection mechanism comprises one or more pull wires that are manipulated by a catheter handle and which deflect the distal portion of the catheter in one or more directions or curve lengths. In some embodiments, the catheter further comprises a temperature sensor, the temperature sensor being integral to the distal tip of the electrode. In some embodiments the catheter further comprises one or more ultrasound transducers, the ultrasound transducers being located in the distal section of the catheter, and preferably in the tip of the distal electrode. The ultrasonic transducers are adapted to assess a tissue thickness either below or adjacent to the catheter tip. In some embodiments, the catheter comprises multiple transducers adapted to provide depth information covering a situation where the catheter tip is relatively perpendicular to a myocardium or relatively parallel to a myocardium.

[0070[In some embodiments the catheter further comprises an irrigation means for the purposes of flushing catheter openings with an irrigation fluid to clear the tip of blood, cooling a tissue-electrode interface, preventing a thrombus formation, and dispersing an RF energy to a greater zone of tissue, thus forming larger lesions than non-irrigated catheters. In some embodiments, the irrigating fluid is maintained within the catheter tip at a positive pressure relative to outside of the tip, and is adapted for continuous flushing of the openings.

[0071[In some embodiments, the catheter further comprises an electric, magnetic or electromagnetic location or navigation sensor for locating and navigating the catheter. In some embodiments, the sensor is adapted to locate the tip of the catheter in a navigation system of any one of several catheter or system manufacturers. The sensor can send or receive energy from a source location and compute location through triangulation or other means. In some embodiments the catheter comprises more than one sensor or transducer adapted to render a position of the catheter body and a curvature of the catheter body on a navigation system display.

[0072[In some embodiments, a catheter adapted to ablate tissue comprises a catheter body, and a tip electrode adapted to ablate a tissue. In some embodiments the catheter further comprises at least one optical waveguide adapted to deliver light energy to the tissue, and one

or more optical waveguides adapted to receive light energy from the tissue. In some embodiments, the catheter further comprises a single optical waveguide adapted to deliver light energy to the tissue and receive light energy from the tissue.

[0073[In some embodiments, the catheter is adapted for an ablation energy, the ablation energy being one or more of RF energy, cryo energy, laser, chemical, electroporation, high intensity focused ultrasound or ultrasound, and microwave.

[0074[In some embodiments, the tip of the catheter comprises a first electrode adapted for sensing electrical activity of the tissue, a second electrode adapted for transmitting or conducting ablation energy or chemical, a light directing member to direct a light in one or more directions simultaneously, one or more openings for the transmission and receiving of light energy, one or more openings for an irrigation fluid to flow from the tip, and one or more openings adapted for transmitting and receiving light as well as concomitantly flowing irrigation fluid from the tip. In some embodiments the tip of the catheter comprises an electrically conductive material, adapted to allow the first electrode to sense the electrical activity of the tissue in contact with the catheter. In some embodiments, the tip further comprises an electrode adapted for transmitting or conducting ablation energy or a chemical energy. In some embodiments, the tip is adapted to conduct RF energy to the adjacent tissue. In some embodiments, the tip comprises an optically transparent material allowing conduction of laser ablation energy to the adjacent tissue. In some embodiments, the tip comprises a plurality of holes adapted to transmit a chemical used to alter cells of the tissue or of a tissue in close proximity to the tip. In some embodiments, the openings for transmitting and receiving light are in the distal tip. In some embodiments, the tip comprises additional holes adapted to cool the tip with a fluid during an application of ablation energy.

[0075[In some embodiments, the tip further comprises at least one opening adapted to allow a directed light energy to illuminate the tissue, and to allow the light energy to return from the tissue to the catheter. In some embodiments, the tip comprises at least one opening in the distal tip for illuminating a tissue along a longitudinal axis of the catheter. In some embodiments, the light energy is directed in a manner that is dependent upon a light directing member having a central lumen allowing a portion of the light to be directed in a longitudinal direction. In some embodiments, the tip further comprises at least one opening in the distal tip for illuminating the tissue in a radial axis with respect to the catheter. In some embodiments, the tip is adapted to direct the light by splitting the primary light source into specific multiple beams using the light directing member.

[0076[In some embodiments, the primary light source is a laser, the laser adapted to send a light beam down an optical fiber to the light directing member, wherein the light beam is sent in one or more directions, including straight ahead relative to the tip, to make sure a structure adjacent to the catheter is illuminated. In some embodiments, a structure that is illuminated will transmit optical energy back to the catheter tip and to the light directing member, which in turn reflects the returned light back up the fiber to a spectrometer.

[0077[In some embodiments, the tip is configured to direct the light energy independent of any polishing of the interior of the illumination cavity. In some embodiments, the directing of light energy does not depend on the use of an interior wall of the illumination cavity.

[0078[In some embodiments, a catheter adapted to support fNADH comprising one or more ultrasound transducers. In some embodiments, the catheter is adapted to measure a wall thickness of an area of interest. In some embodiments, the catheter is adapted to assess a metabolic state of the tissue throughout the wall thickness. In some embodiments, the catheter further comprises ultrasonic transducers adapted to measure cardiac wall thickness and adapted to assess a metabolic state of the myocardium during an application of an RF energy. In some embodiments, the catheter is adapted to identify any metabolically active tissue for the purposes of identifying electrical gaps in lesions.

[0079[In some embodiments, the catheter comprises a light-directing component adapted to send light in one or more radial directions and axially simultaneously. In some embodiments, the catheter further comprises a separate or a modular component of the tip electrode, wherein an light directing member is integrated into the tip of the electrode during. In some embodiments, the light directing member has a centrally located lumen for light to pass in the axial direction. In some embodiments, the light directing member is keyed to facilitate alignment of a facet of the light directing member to openings of the catheter tip permitting a transfer of light energy. In some embodiments, the light directing member is integrated into the catheter tip via a snap-fitting, welding, soldering, or gluing into a keyed position in the catheter tip.

[0080[In some embodiments, the light directing member is keyed to facilitate a correct alignment of one or more reflecting facets and one or more light ports in the tip of the catheter. In some embodiments, the light directing member is a separate component that is oriented into the catheter tip, adapted to provide a light path through the tip, inline with a longitudinal axis of the catheter. In some embodiments, the light directing member protrudes

through the tip and can be welded on the distal side of the tip so that the welding does not interfere or damage a reflective surface of the light directing member. In some embodiments, the light directing member comprises polished stainless steel. In some embodiments, the light directing member comprises platinum or platinum alloys, a material identical to the tip, any material with a reflective surface capable of reflecting or splitting light, or a material that does not fluoresce when illuminated from about 310nm to about 370nm. In some embodiments, the light directing member is larger than any aperture of the tip electrode to ensure the light directing member cannot escape through said aperture.

[0081[In some embodiments, the light directing member may be optimized to provide the optimum number of facets and the optimum optical path for efficiency. These attributes can be traded off against the desired radial coverage. For example, in connection with tissue contact with the distal tip parallel to the myocardial surface, the radial coverage can be designed so that at least one opening in the side wall of the distal tip is pointed at the myocardium when the tip is parallel to the heart tissue. Likewise, the opening in the front wall of the distal tip may ensure that light is both transmitted and received when the catheter tip is more or less orthogonal to the myocardial surface. In some embodiments, the light directing member is provided with 3 to 4 facets.

[0082[In some embodiments, a catheter of the present disclosure comprises of a catheter body with the following components: a catheter with a distal tip positioned at a distal end of the catheter body, the distal tip defining a light chamber, the distal tip having one or more openings for exchange of light energy between the light chamber and tissue, and a the same catheter with a light directing member disposed within the light chamber, the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip. In some embodiments, the catheter comprises of one or more optical waveguides extending into the light chamber to deliver light to and from the light chamber. In some embodiments, the catheter has a light directing member and the one or more openings are configured to enable illumination of tissue in the radial and the axial directions. In some embodiments, the catheter has a distal tip that has a dome shaped front wall and straight side walls. In some embodiments, the catheter has one or more openings that are disposed along sidewalls of the distal tip. In some embodiments, the catheter has one or more openings that are disposed circumferentially along the distal tip. In some embodiments, the catheter has one or more openings that are provided in multiple rows along side walls of the distal tip. In some embodiments, the catheter has a distal tip that is

comprised of a tissue ablation electrode. In some embodiments, the catheter has a light directing member that is configured to direct light radially through the one or more openings. In some embodiments, the catheter has a light directing member that is comprised of multiple facets. In some embodiments, the catheter has a light directing member that is comprised of multiple facets, wherein the facets are equally spaced. In some embodiments, the catheter has a light directing member that is comprised of multiple facets, wherein the number of the facets corresponds to the number of the openings along side walls of the distal tip. In some embodiments, the catheter has a light directing member that is shaped to reflect the light energy at an angle relative to the longitudinal axis of the catheter.

[0083[In some embodiments, the catheter has a light directing member that is comprised of a single-faceted mirror. In some embodiments, the catheter has a light directing member that is rotatable with respect to the light chamber. In some embodiments, the catheter has a light directing member that is comprised of one or more through-holes and the distal tip is comprised of one or more openings disposed on a front wall of the distal tip to enable passage of light in longitudinal direction through the light directing member and the one or more openings of the front wall.

[0084[The foregoing disclosure has been set forth merely to illustrate various non-limiting embodiments of the present disclosure and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the disclosure may occur to persons skilled in the art, the presently disclosed embodiments should be construed to include everything within the scope of the appended claims and equivalents thereof.

CLAIMS

What is claimed is:

1) A catheter for visualizing ablated tissue comprising:

a catheter body;

a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light energy between the illumination cavity and tissue;

a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip.

2) The catheter of claim 1 further comprising one or more optical fibers extending into the illumination cavity to deliver light to and from the illumination cavity.
3) The catheter of claim 2, wherein the distal tip further comprises a fiber aligner configured to align the one or more optical fibers with a central axis of the light directing member.
4) The catheter of claim 1 wherein the light directing member and the one or more openings are configured to enable illumination of tissue in a radial direction and an axial direction with respect to a longitudinal axis of the catheter.
5) The catheter of claim 1 wherein the one or more openings are disposed along side walls of the distal tip and the light directing member is shaped to direct the light energy at an angle relative to the longitudinal axis of the catheter through the one or more openings.
6) The catheter of claim 5 wherein the light directing member comprises one or more through-holes and the distal tip comprises one or more openings disposed on a front wall of the distal tip to enable passage of light in longitudinal direction through the light directing member and the one or more openings of the front wall.
7) The catheter of claim 5 wherein the light directing member is aligned with the one more openings to reflect light only through the one or more openings.
8) The catheter of claim 1 wherein the one or more openings are disposed circumferentially along the distal tip and are spaced apart from one another by equal distance and the light directing member comprises multiple, equally spaced facets in alignment with the one or more openings.

9) The catheter of one of claims 1-8 wherein the distal tip is configured to deliver ablation energy to the tissue, the ablation energy being selected from a group consisting of radiofrequency (RF) energy, microwave energy, electrical energy, electromagnetic energy, cryoenergy, laser energy, ultrasound energy, acoustic energy, chemical energy, thermal energy and combinations thereof.

10) The catheter of one of claims 1-8 further comprising an ultrasound transducer.

11) The catheter of one of claims 1-8 further comprising a location or navigation sensor.

12) A system for visualizing ablated tissue comprising:

a catheter comprising a catheter body; a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light energy between the illumination cavity and tissue; a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip;

a light source;

a light measuring instrument; and

one or more optical fibers in communication with the light source and the light measuring instrument and extending through the catheter body into the illumination cavity of the distal tip, wherein the one or more optical fibers are configured to pass light energy from the light source to the light directing member for illuminating tissue outside the distal tip and the one or more optical fibers are configured to relay light energy reflected from the tissue to the light measuring instrument.

13) The system of claim 12 wherein the one or more optical fibers include a fiber bundle or a single fiber.

14) The system of claim 13 wherein the distal tip further comprises a fiber aligner configured to align the one or more optical fibers with a central axis of the light directing member.

15) The system of claim 12 wherein the light directing member and the one or more openings are configured to enable illumination of tissue in a radial direction and an axial direction with respect to a longitudinal axis of the catheter.

16) The system of claim 12 wherein the one or more openings are disposed along side walls of the distal tip and the light directing member is shaped to direct the light energy at an angle relative to the longitudinal axis of the catheter through the one or more openings.

17) The system of claim 16 wherein the light directing member comprises one or more through-holes and the distal tip comprises one or more openings disposed on a front wall of the distal tip to enable passage of light in longitudinal direction through the light directing member and the one or more openings of the front wall.

18) The system of claim 16 wherein the light directing member is aligned with the one more openings to reflect light only through the one or more openings.

19) The system of claim 12 wherein the one or more openings are disposed circumferentially along the distal tip and are spaced apart from one another by equal distance and the light directing member comprises multiple, equally spaced facets in alignment with the one or more openings.

20) The system of one of claims 12-19 wherein the distal tip is configured to deliver ablation energy to the tissue, the ablation energy being selected from a group consisting of radiofrequency (RF) energy, microwave energy, electrical energy, electromagnetic energy, cryoenergy, laser energy, ultrasound energy, acoustic energy, chemical energy, thermal energy and combinations thereof.

21) The system of one of claims 12-19 wherein the catheter further comprises an ultrasound transducer.

22) The system of one of claims 12-19 wherein the catheter further comprises a location or navigation sensor.

23) A method for visualizing ablated tissue comprising:

advancing a catheter to a cardiac tissue in need of ablation, the catheter comprising a catheter body; a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light between the illumination cavity and tissue; a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light to and from the tissue through the one or more openings in the distal tip;

causing the light directing member to direct light through the one or more openings in the distal tip of the catheter to excite nicotinamide adenine dinucleotide hydrogen (NADH) in an area of the cardiac tissue including ablated cardiac tissue and non-ablated cardiac tissue;

collecting light reflected from the cardiac tissue through the one or more openings and directing the collected light to a light measuring instrument;

imaging the area of the cardiac tissue to detect NADH fluorescence of the area of the cardiac tissue; and

producing a display of the imaged, illuminated cardiac tissue, the display illustrating the ablated cardiac tissue as having less fluorescence than non-ablated cardiac tissue.

24) The method of claim 23 further comprising ablating tissue with the distal tip prior to imaging the tissue.

25) The method of claim 24 further comprising ablating additional non-ablated cardiac tissue identified by distinguishing between the ablated cardiac tissue and the non-ablated cardiac tissue based on the amount of fluorescence.

26) The method of claim 23, wherein the light directing member and the one or more openings are configured to enable illumination of the cardiac tissue in a radial direction and an axial direction with respect to a longitudinal axis of the catheter.

27) The method of claim 23 further comprising one or more optical fibers extending into the illumination cavity to deliver light to and from the illumination cavity.

28) The method of claim 27 wherein the distal tip further comprises a fiber aligner configured to align the one or more optical fibers with a central axis of the light directing member.

29) The method of claim 23 wherein the light directing member and the one or more openings are configured to enable illumination of tissue in a radial direction and an axial direction with respect to a longitudinal axis of the catheter.

30) The method of claim 23 wherein the one or more openings are disposed along side walls of the distal tip and the light directing member is shaped to direct the light energy at an angle relative to the longitudinal axis of the catheter through the one or more openings.

31) The method of claim 30 wherein the light directing member comprises one or more through-holes and the distal tip comprises one or more openings disposed on a front wall of the distal tip to enable passage of light in longitudinal direction through the light directing member and the one or more openings of the front wall.

32) The method of claim 30 wherein the light directing member is aligned with the one more openings to reflect light only through the one or more openings.

33) The method of claim 23 wherein the one or more openings are disposed circumferentially along the distal tip and are spaced apart from one another by equal

distance and the light directing member comprises multiple, equally spaced facets in alignment with the one or more openings.

34) The method of one of claims 23-33 wherein the distal tip is configured to deliver ablation energy to the tissue, the ablation energy being selected from a group consisting of radiofrequency (RF) energy, microwave energy, electrical energy, electromagnetic energy, cryoenergy, laser energy, ultrasound energy, acoustic energy, chemical energy, thermal energy and combinations thereof.

35) The method of one of claims 23-33 further comprising an ultrasound transducer.

36) The method of one of claims 23-33 further comprising a location or navigation sensor.

37) A system for visualizing ablated tissue comprising:

a catheter comprising a catheter body, a distal tip positioned at a distal end of the catheter body, the distal tip being configured to deliver ablation energy to tissue, the distal tip defining an illumination cavity having one or more openings for exchange of light energy between the illumination cavity and the tissue, a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip,

the catheter further including one or more ultrasound transducers and one or more electromagnetic location sensors;

an ablation therapy system in communication with the distal tip to deliver the ablation energy to the tissue;

a visualization system comprising a light source, a light measuring instrument, and one or more optical fibers in communication with the light source and the light measuring instrument and extending through the catheter body into the illumination cavity of the distal tip, wherein the one or more optical fibers are configured to pass light energy in and out of the illumination chamber;

an irrigation system for irrigation the one or more openings;

an ultrasound system in communication with the one or more ultrasound transducers for ultrasound evaluation of the tissue; and

a navigation system in communication with the one or more electromagnetic location sensors for locating and navigating the catheter.

38) The system of claim 37, wherein the ablation energy is selected from the group consisting of radiofrequency (RF) energy, microwave energy, electrical energy, electromagnetic energy, cryoenergy, laser energy, ultrasound energy, acoustic energy, chemical energy, thermal energy and combinations thereof.

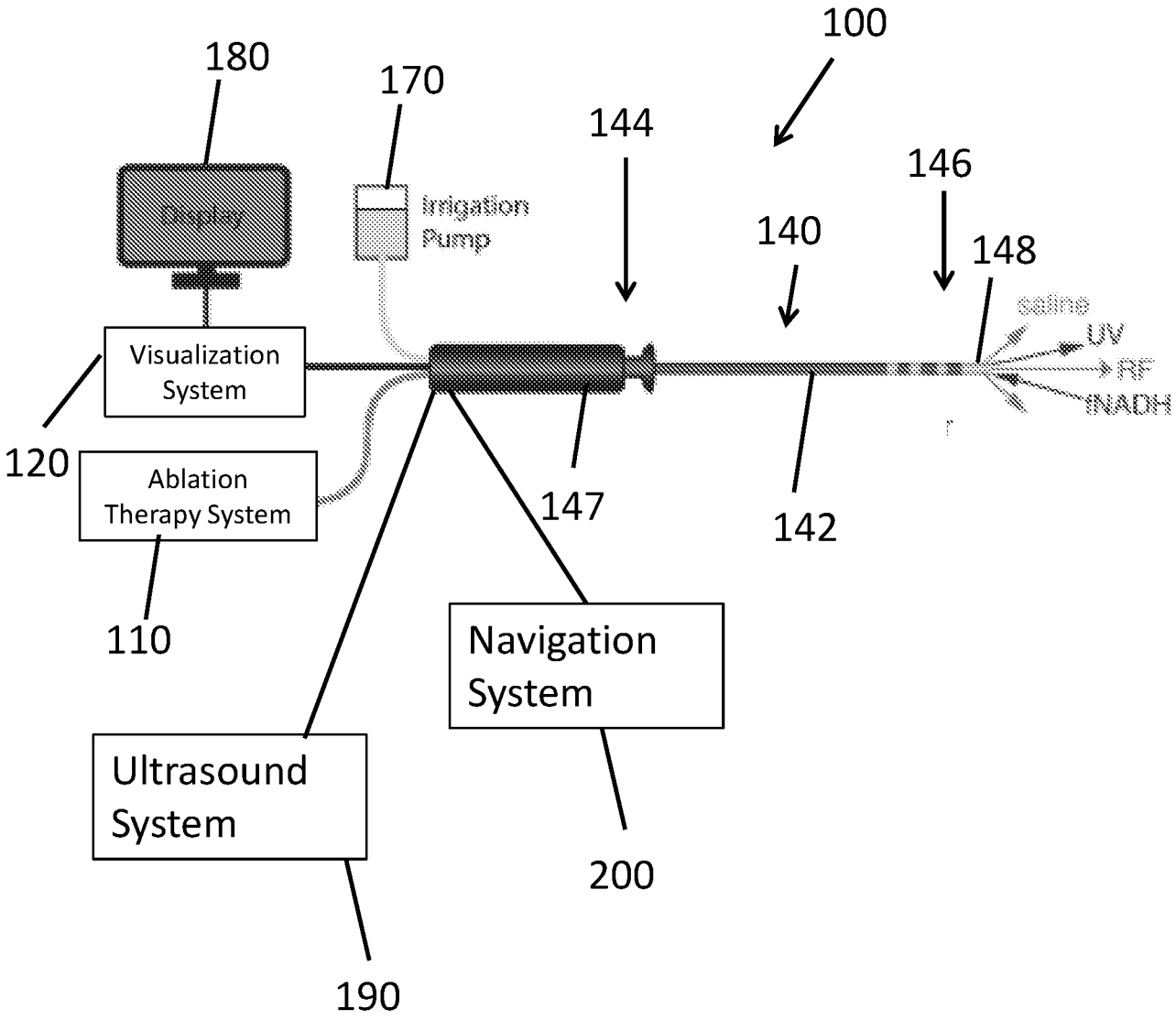
180
170
100
144
146
140
148
Display
Irrigation Pump
saline
UV
RF
INADH
Visualization System
120
Ablation Therapy System
110
147
142
Navigation System
Ultrasound System
200
190

FIG. 1A

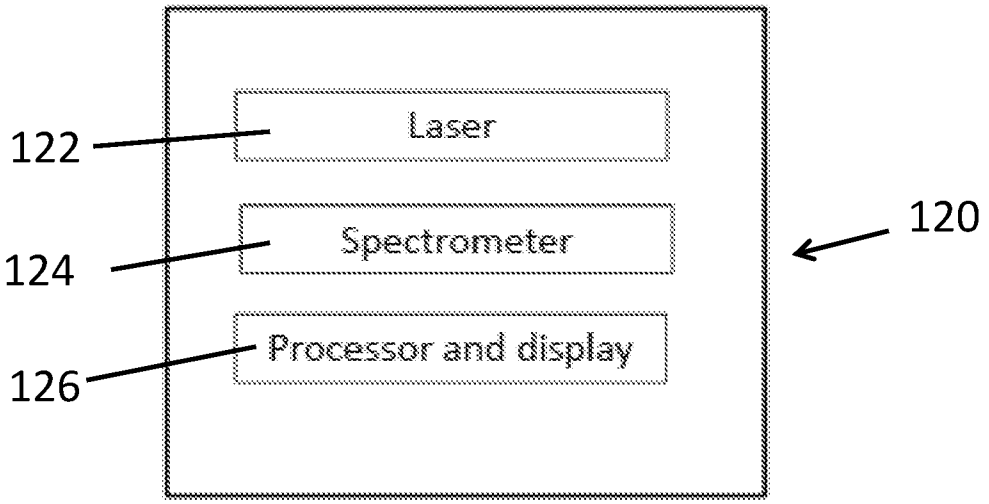
Laser
Spectrometer
Processor and display
122
124
126
120

FIG. 2

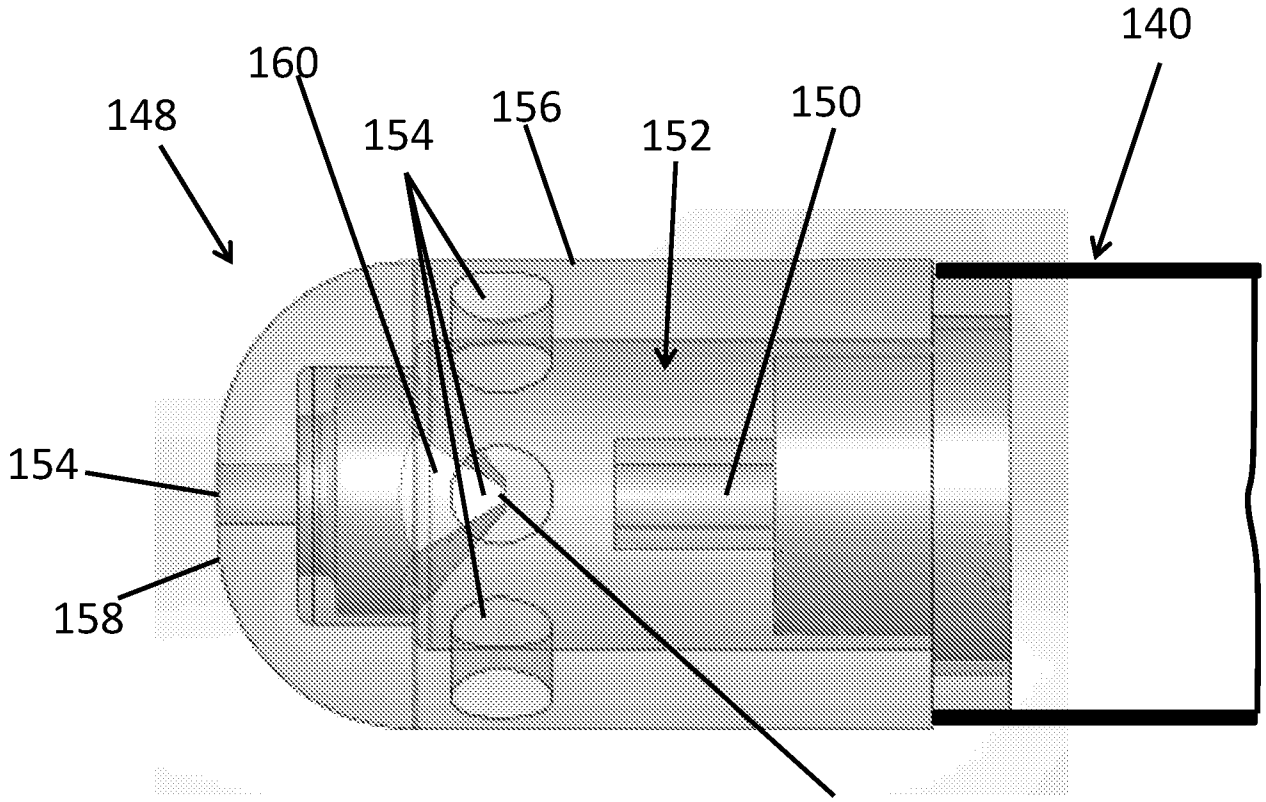
140
160
148
154
156
152
150
154
158
162

FIG. 3

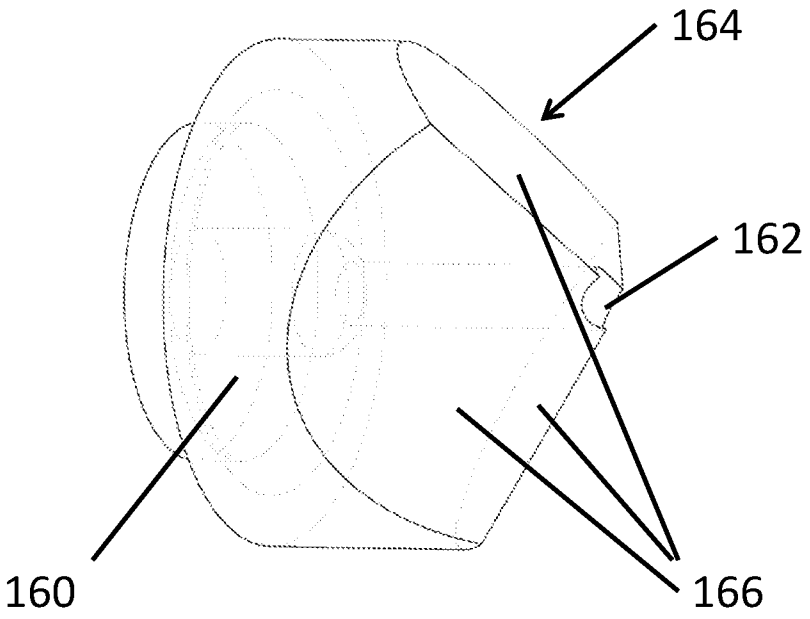
164
162
160
166

FIG. 4A

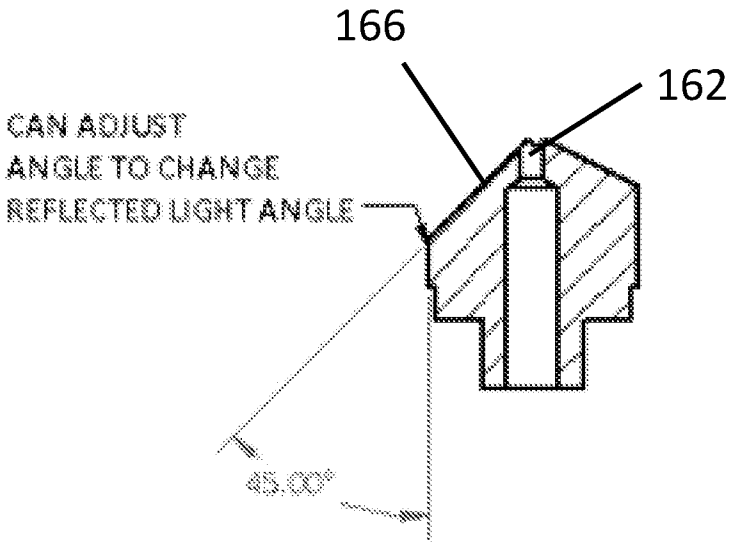
166
162
CAN ADJUST
ANGLE TO CHANGE
REFLECTED LIGHT ANGLE
45.00°

FIG. 4B

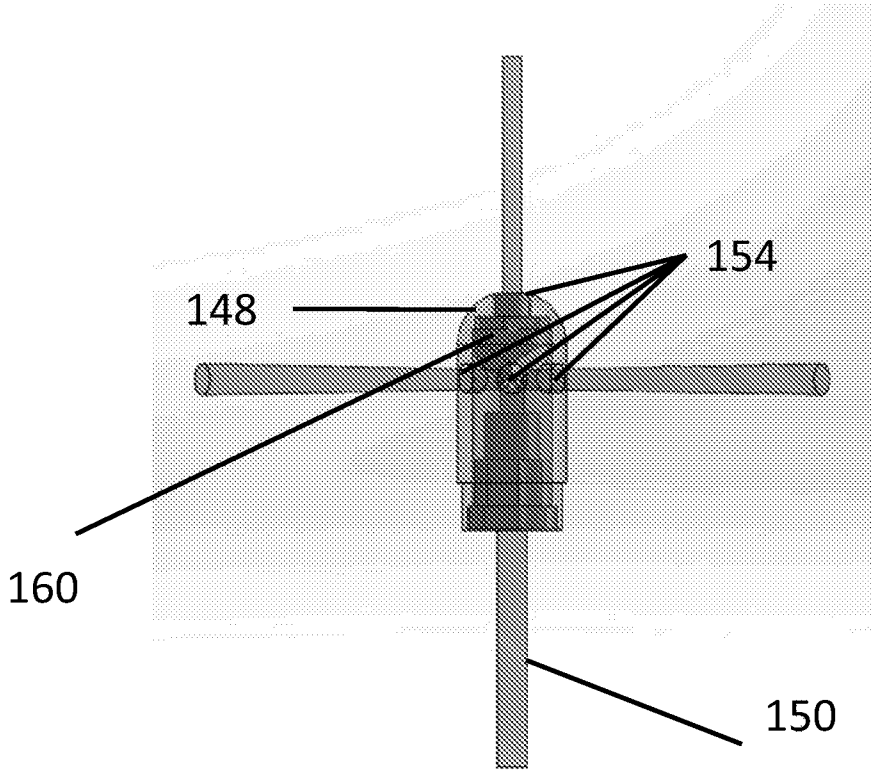

FIG. 5A

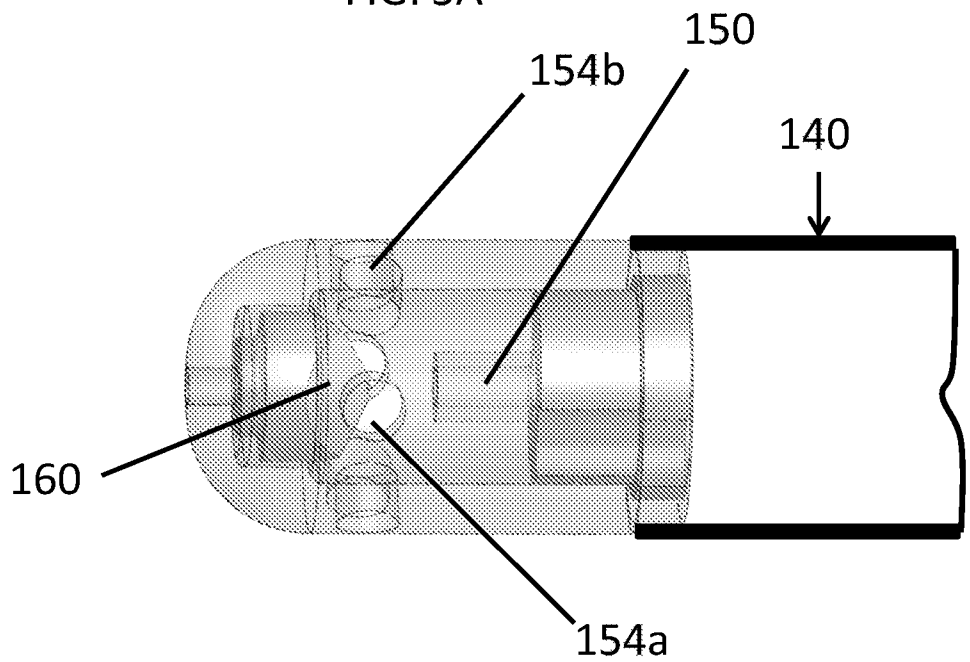

FIG. 5B

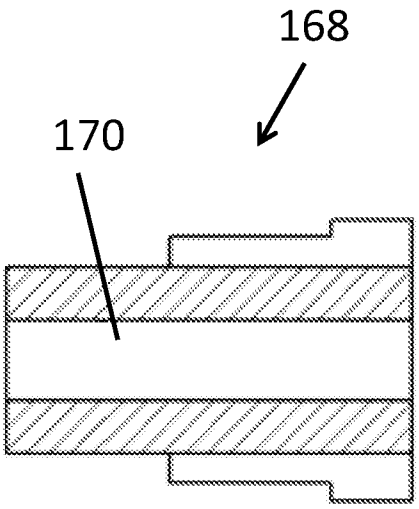

FIG. 6A

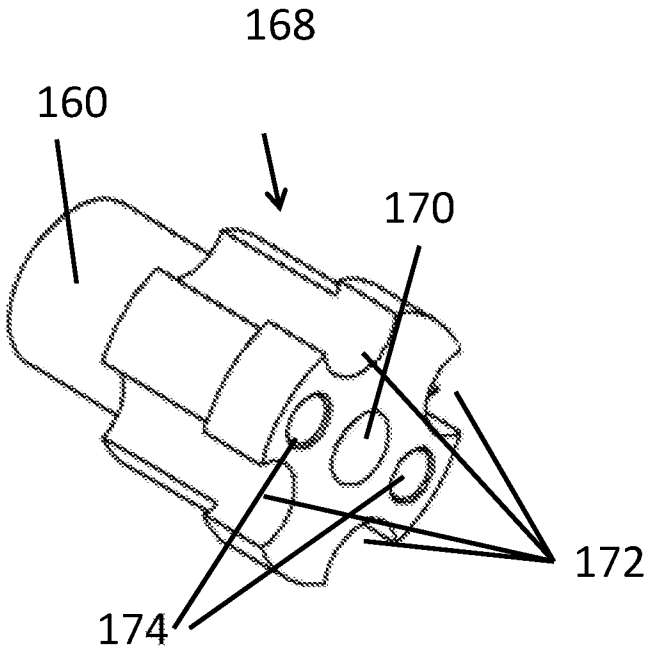

FIG. 6B

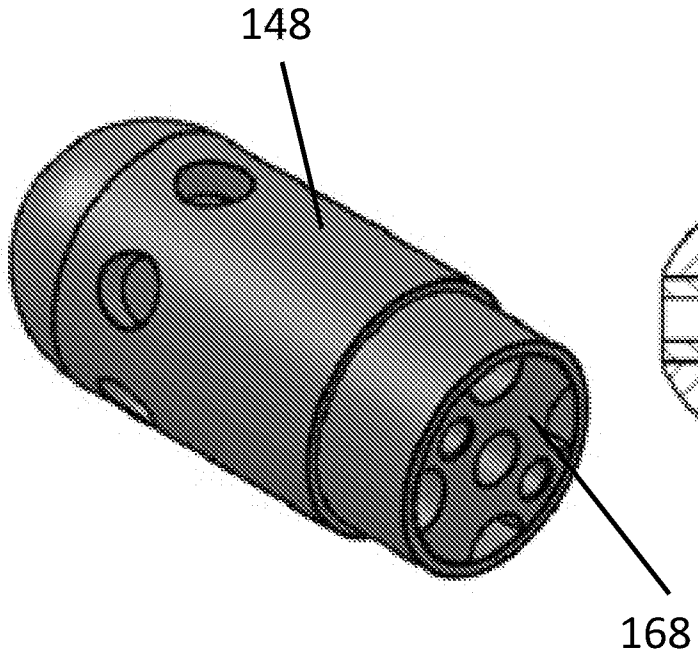

FIG. 6C

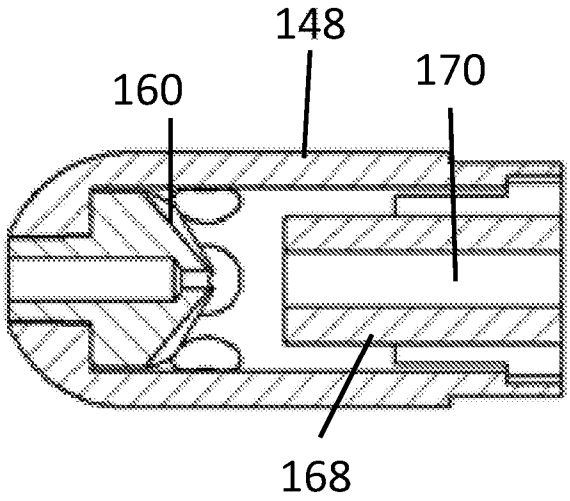

FIG. 6D

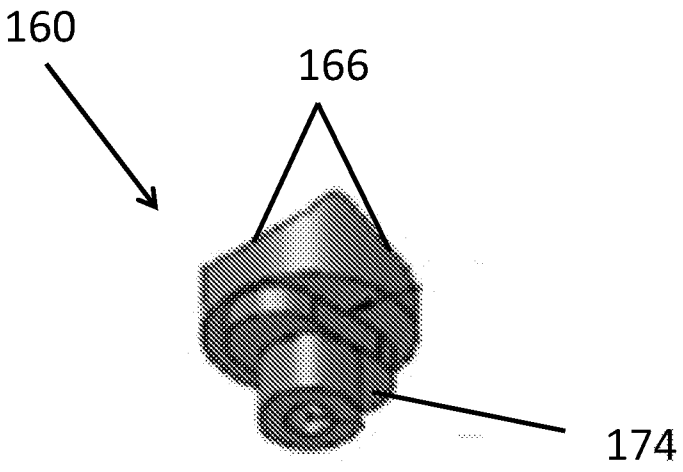

FIG. 7A

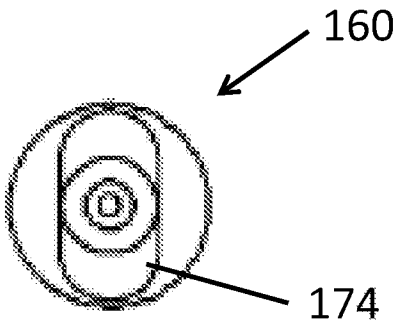

FIG. 7B

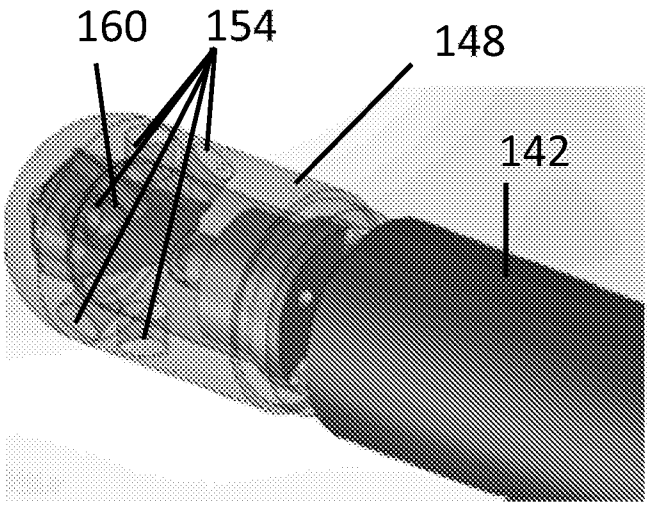

FIG. 8A

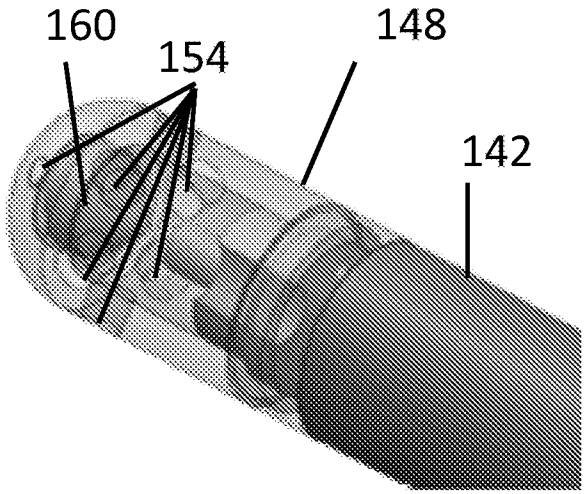

FIG. 8B

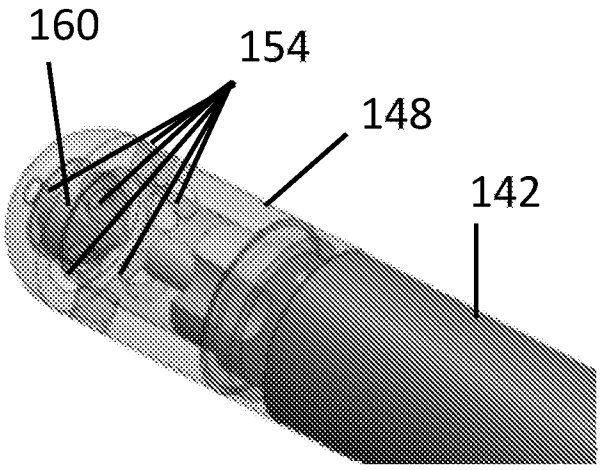

FIG. 8C

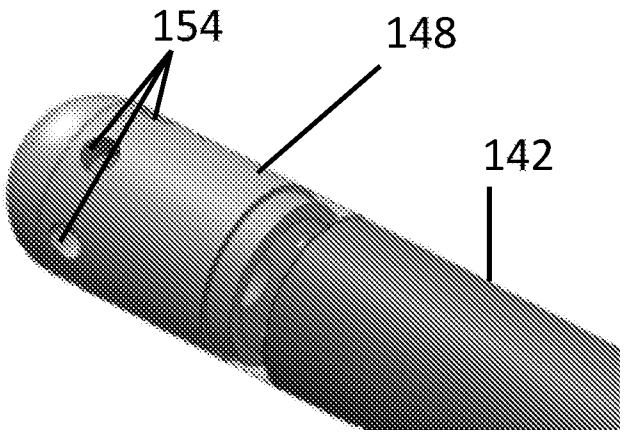

FIG. 8D

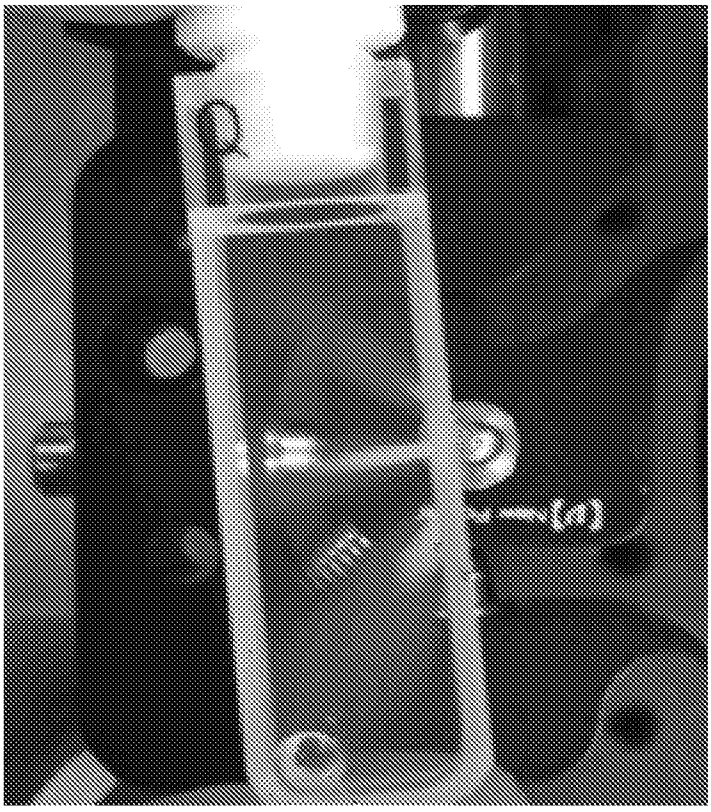

FIG. 9

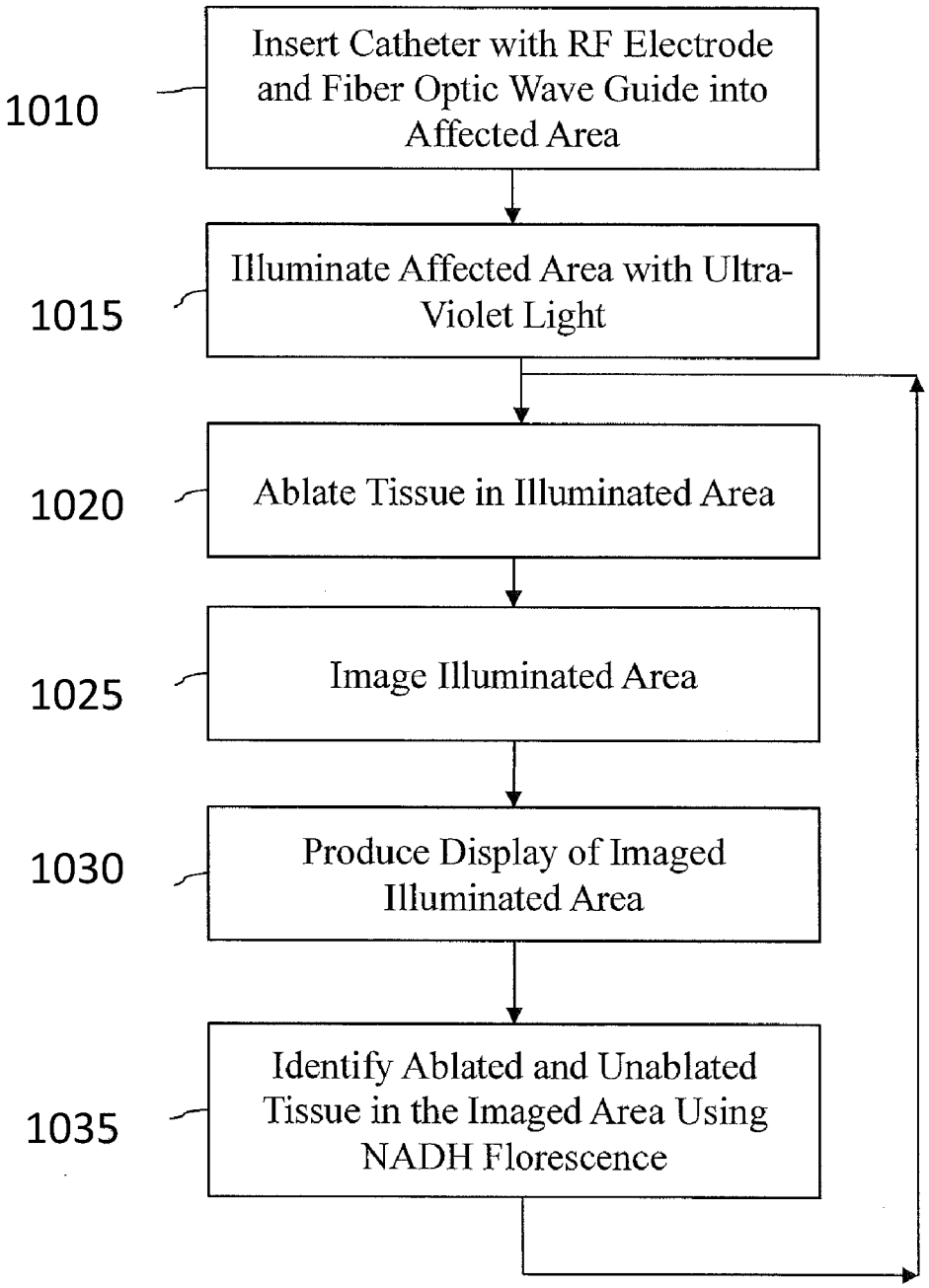
1010
Insert Catheter with RF Electrode and Fiber Optic Wave Guide into Affected Area
1015
Illuminate Affected Area with Ultra-Violet Light
1020
Ablate Tissue in Illuminated Area
1025
Image Illuminated Area
1030
Produce Display of Imaged Illuminated Area
1035
Identify Ablated and Unablated Tissue in the Imaged Area Using NADH Florescence

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/42891

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61B 5/00 (2016.01)
CPC - A61B 18/12, A61B 18/02, A61B 5/0044, A61B 5/0084, A61B 2576/023, A61B 5/02028
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8) A61B 5/00 (2016.01)
CPC: A61B 18/12, A61B 18/02, A61B 5/0044, A61B 5/0084, A61B 2576/023, A61B 5/02028, A61B 2018/00351

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC (8) A61B 5/02 A61B 18/00 (2016.01);
-*-see extra sheet-*-

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase; Google (Web, Scholar, Patents)
Search terms: illumination ablation catheter tissue lesion organ target heart atrial fibrillation light irradiation member element device system tip end irrigation ultrasound distal cavity directing opening lesions instrument system optic fiber exchange

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y -- A	US 2009/0131931 A1 (LEE et al.); 21 May 2009 (21.05.2009); entire document, especially Figs. 1, 4A, 7; paras. [0013], [0050]-[0055], [0059], [0065], [0078].	1-2, 4-8, (9,11)/(1-2,4-8), 12-13, 15-19, (20, 22)/(12-13,15-19) --- 10/(1-2,4-8), 21/(12-13,15-19), 23-27, 29-33, (34-36)/(23-27,29-33), 37-38 --- 3, 9-11/(3), 14, (20-22)/(14), 28, (34-36)/(28)
Y	US 2006/0089636 A1 (CHRISTOPHERSON et al.); 27 April 2006 (27.04.2006); entire document, especially Abstract; Fig. 1.	10/(1-2,4-8) 21/(12-13,15-19), 35/(23-27,29-33), 37-38 23-27, 29-33, (34-36)/(23-27,29-33)
Y --- A	US 2013/0102862 A1 (MERCADER et al.); 25 April 2013 (25.04.2013); entire document, especially Figs. 1A-C, 3; 11B; para. [0052]-[0058], [0061], [0071]-[0076], [0099].	--- 28, (34-36)/(28) 1-28
A	US 2014/0088418 A1 (RADULESCU et al.); 27 March 2014 (27.03.2014); entire document, especially Fig. 4B, para. [0053], [0055].	1-28
A	US 2006/0122587 A1 (SHARAREH); 8 June 2006 (08.06.2006); entire document.	

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 November 2016	08 DEC 2016
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/42891

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-22, and 37-38 directed to a system for visualizing ablated tissue.

Group II: Claims 23-26 directed to a method for visualizing ablated tissue.

-*-See extra sheet-*-

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/42891

-*-Box No. III- Lack of unity of invention-*-

The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The invention of Group II includes the special technical feature of a method for visualizing ablated tissue comprising: causing the light directing member to direct light through the one or more openings in the distal tip of the catheter to excite nicotinamide adenine dinucleotide hydrogen (NADH) in an area of the cardiac tissue including ablated cardiac tissue and non-ablated cardiac tissue; imaging the area of the cardiac tissue to detect NADH fluorescence of the area of the cardiac tissue; and producing a display of the imaged, illuminated cardiac tissue, the display illustrating the ablated cardiac tissue as having less fluorescence than non-ablated cardiac tissue, not required in Group I.

The inventions of Groups I-II share the technical features of a catheter comprising a catheter body, a distal tip positioned at a distal end of the catheter body, the distal tip defining a illumination cavity, the distal tip having one or more openings for exchange of light between the illumination cavity and tissue, a light directing member disposed within the illumination cavity, the light directing member being configured to direct the light to and from the tissue through the one or more openings in the distal tip; and a light measuring instrument. Specifically, Groups I and II are related as an apparatus (Group I) and methods for using the apparatus (Group II). The apparatus is known in prior art as shown in US 2007/0287998 A1 to Sharareh et al. (hereinafter 'Sharareh'). Therefore, Groups I and II lack unity since the shared technical features do not represent a contribution over Sharareh:

Burkinshaw discloses a catheter comprising a catheter body (catheter 10, Figs. 1, 11); a distal tip positioned at a distal end of the catheter body (intermediate section 14, Fig. 1, 3A), the distal tip defining a illumination cavity (chamber 49 provides for multi-directional radiation and/or collection of light at the tip electrode of intermediate section 14, Fig. 3A; para. [0041]), the distal tip having one or more openings for exchange of light energy between the illumination cavity and tissue (openings 80a,b are provided for transmission of light, Fig. 3A; para. [0053]);
a light directing member disposed within the illumination cavity (passages 71, Fig. 4), the light directing member being configured to direct the light energy to and from the tissue through the one or more openings in the distal tip (fiber optic cables for emitting and receiving light run through passages 71 to openings 80a, b; Fig. 4; para. [0054]); and
a light measuring instrument (detection component 130, Fig. 11; para. [0064]).

As the common features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Therefore, Groups I-II lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.

-*-Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched-*-

CPC: A61B 5/0071, A61B 18/00, A61B 1/0684, A61B 1/05, A61B 1/00186, A61B 1/0676, A61B 2034/301, A61B 2090/365, A61B 90/30, A61B 90/361, A61B 18/1492, A61B 18/00, A61B 5/6853, A61B 5/1459, A61B 5/14546, A61B 5/14503, A61B 1/0638, A61B 1/043, A61B 1/00082, A61B 1/00045, A61B 1/00009, A61B 2018/0022, A61B 2018/0212, A61B 5/004

专利名称(译)	用于病变形成和评估的系统和方法		
公开(公告)号	EP3324832A4	公开(公告)日	2019-03-20
申请号	EP2016828397	申请日	2016-07-19
申请(专利权)人(译)	LUXCATH，LLC		
[标]发明人	RANSBURY TERRANCE J ARMSTRONG KENNETH C AMIRANA OMAR LARSON CINNAMON		
发明人	RANSBURY, TERRANCE J. ARMSTRONG, KENNETH C. AMIRANA, OMAR LARSON, CINNAMON		
IPC分类号	A61B5/00		
CPC分类号	A61B90/30 A61B17/00234 A61B18/02 A61B18/06 A61B18/1206 A61B18/1492 A61B18/1815 A61B18/24 A61B90/361 A61B90/37 A61B2017/00057 A61B2017/00061 A61B2018/00351 A61B2018/00357 A61B2018/00363 A61B2018/00577 A61B2018/0066 A61B2018/00982 A61B2018/00994 A61B2018/0212 A61B2018/1861 A61B2034/2051 A61B2090/306 A61B2090/3614 A61B2090/376 A61B2218/002 A61N7/00		
优先权	62/194276 2015-07-19 US 14/919004 2015-10-21 US		
其他公开文献	EP3324832A1		
外部链接	Espacenet		

摘要(译)

用于可视化消融组织的导管包括导管主体;远端尖端定位在导管主体的远端，远端尖端限定照明腔，远端尖端具有一个或多个开口，用于在照明腔和组织之间交换光能;设置在照明腔内的导光构件，导光构件构造成将从光源接收的光能分成多个光束，并通过远端尖端中相应的更多开口将光束分离到组织。