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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 July 2009 (23.07.2009)

PCT

(10) International Publication Number
WO 2009/090588 A1

(51) International Patent Classification:
A61B 5/00 (2006.01) *A61B 18/00* (2006.01)

(21) International Application Number:
PCT/IB2009/050102

(22) International Filing Date: 12 January 2009 (12.01.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
08150264.3 15 January 2008 (15.01.2008) EP

(71) Applicant *(for all designated States except US)*: **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **THILWIND, Rachel, E.** [GB/NL]; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **SUIJVER, Jan, F.** [NL/NL]; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **DELADI, Szabolcs** [RO/NL]; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL).

(74) Agents: **VAN VELZEN, Maaike, M.** et al.; High Tech Campus Building 44, NL-5656 AE Eindhoven (NL).

(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, BR, BW, BY, BZ, CA, CH, 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, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:
— *with international search report*

(54) Title: APPARATUS, METHOD AND COMPUTER PROGRAM FOR APPLYING ENERGY TO AN OBJECT

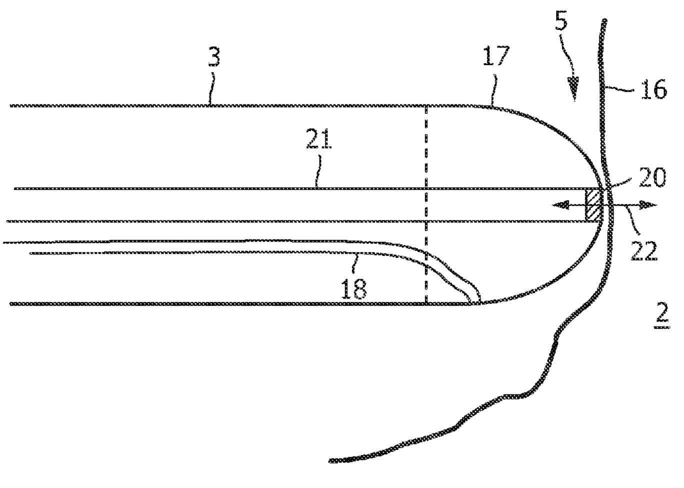

FIG. 2

(57) Abstract: The present invention relates to an apparatus for applying energy to an object. The invention relates further to a corresponding method and to a corresponding computer program. The apparatus comprises a catheter (3), which includes an energy applying unit (17, 18) for applying energy to the object (2) and a photoacoustic measurement unit (20, 21) for photo acoustically sensing the object (2). The photoacoustic measurement unit comprises preferentially a reflecting element (20), which is movable by an acoustic wave, wherein the apparatus comprises at least one optical fiber (21) located within the catheter (3) for guiding light to and/or from the movable reflecting element (20). The acoustic wave is preferentially measured by determining a phase shift of light reflected from the reflecting element (20), which moves, if the reflecting element is exposed to the acoustic wave.

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APPARATUS, METHOD AND COMPUTER PROGRAM FOR APPLYING ENERGY TO AN OBJECT

FIELD OF THE INVENTION

The present invention relates to an apparatus, a method and a computer program for applying energy to an object.

BACKGROUND OF THE INVENTION

US 5,782,899 discloses an apparatus for applying energy to an object being an endocardial mapping and ablation system for introduction into a chamber of a heart formed by a wall and having a passage leading thereto. The system is comprised of a catheter probe having a distal extremity. A plurality of electrodes are carried by the distal extremity for mapping the wall of the chamber. An ablation catheter is provided having a distal extremity. The ablation catheter has control capabilities whereby the distal extremity can be bent separately of movement of the catheter probe to come into close proximity to the wall of the heart. The distal extremity of the ablation catheter is provided with capabilities for ablating a portion of the wall of the heart to eliminate an arrythmia in the heart. The ablation catheter can apply electrical or optical energy for the ablation procedure. This apparatus has the disadvantage that the mapping does substantially not provide depth-related information. It is, for example, not possible to sense the properties of the tissue across the thickness of a heart wall with continued ablation.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an apparatus, a method and a computer program for applying energy to an object, wherein depth-related information about a property of the object can be determined, in particular, during applying energy.

In an aspect of the present invention an apparatus for applying energy to an object is presented, wherein the apparatus comprises a catheter, wherein the catheter includes an energy applying unit for applying energy to the object and a photoacoustic measurement unit for photoacoustically sensing the object.

The invention is based on the idea that a photoacoustic measurement allows to retrieve depth-related information about a property of the object. For example, light can be coupled into the object and can be absorbed within the object, thereby generating an acoustic wave within the object, which can be measured by a measuring unit for measuring an acoustic wave. Since the properties of the acoustic wave and the absorption of the light depend on properties of the object within the object, by sensing the acoustic wave depth-related information about a property of the object can be determined.

The energy applying unit comprises preferentially an energy emitting element, which emits energy to the object. This energy is, for example, optical or electrical energy. Furthermore, the energy emitting element can have a low temperature for killing tissue by coldness, in particular, by cryoablation, if the object is tissue of a patient, for example, heart tissue of a patient. Thus, the apparatus for applying energy to an object, in particular, the energy applying unit is preferentially used for an ablation procedure performed at a heart of a patient.

It is further preferred that the photoacoustic measurement unit comprises a reflecting element, which is movable by an acoustic wave, wherein the apparatus comprises at least one optical fiber located within the catheter for guiding light to and/or from the movable reflecting element. In particular, the reflecting element is movable with respect to the catheter. The reflecting element is, for example, movable by an acoustic wave, because it is in contact with a surface with the object and the surface of the object moves in accordance with the acoustic wave, or because the acoustic wave is transmitted to the reflecting element by another medium like a liquid, in particular, blood.

An acoustic wave, in particular an ultrasonic wave, can be generated within the object, in particular, within tissue of a human heart of a patient, by absorbing light in the object. This wave travels than outwards from the absorption side and is reflected back to the surface to the object. If the acoustic wave passes through the reflecting element, the reflecting element preferentially moves, in particular, in accordance with the acoustic wave. The movable reflecting element can move as a whole or only a part of movable reflecting element can move. The movement can also be an internal movement of the movable reflecting element, which modifies the position of reflection. Since the at least one optical fiber guides light to the movable reflecting element, wherein the light is preferentially coherent laser light, a signal can be generated by detecting the light reflected from the moving movable reflecting element, wherein the signal depends on the movement of the movable reflecting element and, thus, on the wave generated in the object by absorbing light. The movable reflecting element is preferentially an element, which changes a position of reflection, if an acoustic wave passes through the reflecting element, such that the length of the light path of the reflected light is altered, wherein the alteration of the length can be measured by using, for example, known interferometrical methods and devices, like a Michelson interferometer. The movable reflecting element is preferentially a thin-film reflector located at the end of an optical fiber. This at least one optical fiber and the movable reflecting element can easily be integrated in a catheter which comprises an energy applying unit.

It is further preferred that the movable reflecting element is optically transparent for allowing light passing the movable reflecting element. In particular, the reflecting element is optically transparent at least at a wavelength, which can be regarded as pumping wavelength, for excitation of an acoustical wave in the object, in particular, in tissue. Since light can pass the movable reflecting element, an acoustic wave can be generated within the object by absorbing light, which is directed to the movable reflecting element. Thus, at least partly the same optical elements can be used for guiding light for sensing the movement of the movable reflecting element and for coupling light into the object for generating an acoustic wave. This further increases the degree of integration of the photoacoustic measurement unit, wherein the size of the photoacoustic measurement unit can be decreased.

Preferentially, the movable reflecting element is in flush with an outer surface of a tip of the catheter. If the reflecting element is in flush with an outer surface of a tip of the catheter, the reflecting element can be in contact with a surface of the object, in particular, with a surface of a heart wall, wherein the propagation from the object into the reflecting element is improved.

It is further preferred that the movable reflecting element and/or the at least one optical fiber are adapted such that a part of the light guided by the at least one optical fiber can pass the movable reflecting element beside the movable reflecting element. This allows using a movable reflecting element, which is not or not sufficiently transparent for light, which is used for generating an acoustic wave within the object. Thus, the movable reflecting element can be designed more freely.

It is further preferred that the at least one optical fiber is adapted for guiding sensing light having a sensing wavelength to the movable reflecting element and for guiding pumping light having a pumping wavelength to the distal end of the catheter for coupling the pumping light into the object for generating an acoustic wave. The sensing wavelength and the pumping wavelength can be different or can be the same. The sensing wavelength can be optimized for sensing a movement of the movable reflecting element and the pumping wavelength can optimized for generating an acoustic wave within the object. Thus, the sensing wavelength and the pumping wavelength can be adapted independently from each other.

It is further preferred that the photoacoustic measurement unit comprises an ultrasound device for sensing an acoustic wave generated by absorption of light in the object.

In an aspect of the present invention a method for applying energy to an object is presented, wherein energy is applied to the object using an energy applying element included in a catheter and wherein the object is photoacoustically sensed by a photoacoustic measurement unit included in the catheter.

In a further aspect of the present invention, a computer program for applying energy to an object is presented, wherein the computer program comprises program code means for causing a computer to carry out the steps of the method as defined in claim 8, when the computer program is run on a computer controlling an apparatus as defined in claim 1.

It shall be understood that the apparatus of claim 1, the method of claim 8 and the computer program of claim 9 have similar and/or identical preferred embodiments, in particular as defined in the dependent claims.

It shall be understood that preferred embodiments of the invention can also be any combination of the dependent claims with a respective independent claim.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will apparent from and elucidated with reference to the embodiments described hereinafter. In the following drawings

Fig. 1 shows schematically and exemplarily an embodiment of an apparatus for applying energy to an object,

Fig. 2 shows schematically and exemplarily an embodiment of a distal end of a catheter,

Fig. 3 shows schematically and exemplarily another embodiment of a distal end of a catheter,

Fig. 4 schematically and exemplarily illustrates an embodiment of a method for applying energy to an object and

Fig. 5 schematically and exemplarily illustrates another embodiment of a method for applying energy to an object.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows schematically and exemplarily an apparatus 1 for applying energy to an object 2. The object 2 is, in this embodiment, a heart of a patient 4, which is located on a patient table 26. The apparatus 1 comprises a catheter 3 including an energy applying unit for applying energy to the object and a photoacoustic measurement unit for photoacoustically measuring a property of the object. In this embodiment, the energy applying unit and the photoacoustic measurement unit are located at a distal end 5 of the catheter 3. This distal end 5 of the catheter 3 including the energy applying unit and the photoacoustic measurement unit will be described in more detail further below.

The apparatus 1 for applying energy to an object further comprises a catheter control unit 6, which comprises an electrical energy source 19, in particular, a radio frequency source, for applying electrical energy, in particular, radio frequency energy to the object 2, via the energy applying unit. The catheter control unit 6 further comprises a light source 7, which provides light, which is guided to the photoacoustic measurement unit at the distal end 5 of the catheter 3 for generating an acoustic wave in the tissue of the heart 2 and for sensing the generated acoustic wave.

A light source 7 is preferentially a pulsed laser, wherein the pulsed laser light is absorbed by the object resulting in an acoustic wave within the object. The light source can comprises one or several laser devices. For example, the light source can comprise a pulsed laser device, which generates light, which is absorbed in the object for generating an acoustic wave, and a continuous wave laser device which generates light for sensing the acoustic wave.

The pulsed laser device has preferentially a pulse duration of about 10 ps to about 1 μs, in particular, in order to ensure ultrasound originating at well-defined positions. The pulsed repetition frequency is preferentially within a range of 100 Hz to 100 kHz. Preferentially, the delivered energy, i.e. the applied energy, is within a range of about 1 nJ/pulse to about mJ/pulse. It is further preferred that the delivered energy is about 1 μJ/pulse. The continuous wave laser device is preferentially a single-mode laser having a wave length within the range of about 500 to about 1500 nm. Instead of a continuous wave laser device also a pulsed laser device can be used for sensing the acoustic wave, wherein the pulse duration is preferentially larger than 10 ps, further preferred larger than 100 ps, if the pulse duration leads to a coherence length, which is sufficient for measuring a movement of the reflecting element caused by an acoustic wave passing through the reflecting element.

The pulsed repetition frequency is preferentially larger than about 100 kHz, and the delivered energy is preferentially smaller than about μJ/pulse, if a pulsed laser is used for sensing the acoustic wave, and preferentially smaller than about 10 mW, if a continues wave laser device is used for sensing the acoustic wave.

The apparatus 1 for applying energy to an object further comprises a interferometrical unit 8 for generating a signal, which depends on the acoustic wave generated in the object, from light reflected from a movable reflecting element, which is exposed to the acoustic wave. The interferometrical unit 8 preferentially comprises a presentation unit like a monitor for showing the determined signal. The interferometrical unit 8 is adapted such that it can measure the phase shift in the light reflected from the movable reflecting element induced by the movement of the movable reflecting element, wherein the movement of the movable reflecting element is caused by an acoustic wave. The interferometrical unit 8 comprises, in this embodiment, a Michelson interferometer. In other embodiments, the interferometrical unit can comprise another kind of interferometer, like a Mach-Zehnder interferometer.

In addition, the interferometrical unit can comprise a spectrometer for analyzing light reflected from the object, in particular, from the tissue, which has been guided via an optical fiber from the object to the spectrometer. In another embodiment, the spectrometer can be separated from the interferometrical unit, i.e. the spectrometer and the interferometrical unit can be separate units. The interferometrical unit comprising the spectrometer, or the separate interferometrical unit and spectrometer, are arranged such that light reflected from the movable reflecting element is guided to the interferometrical part and that light that has been reflected from the object, in particular, from the tissue of a heart, is guided to the spectrometer. The spectrometer is, for example, a cryo-cooled high resolution linear InGaAs photodiode array, with a sensitivity between about 0.8 um and about 1.7 um for working in the near-infrared range, or a silicon CCD device with operating range covering deep UV to VIS/NIR.

The apparatus 1 for applying energy to an object further comprises a steering unit 9 for steering the distal end 5 of the catheter 3 to a desired location within the object 2.

During the guidance of the distal end 5 of the catheter 3 to the desired location within the object 2 and preferentially also during the application of energy to the object 2 a fluoroscopy device images the location of the distal end 5 of the catheter 3 within the patient 3 and, in particular, within the heart 2, which is in this embodiment the object. The fluoroscopy device comprises an X-ray source 11, which generates an X-ray beam 15, which is schematically shown in Fig. 1, for traversing a region of the patient, in which the catheter 3, in particular, the distal end 5 of the catheter 3, is present. After the X-ray beam 15 has traversed the patient 4, the X-ray beam 15 is detected by an X-ray detector 12. The X-ray source 11 and the X-ray detector 12 are controlled by a fluoroscopy control unit 13, which preferentially also comprises a display for showing a fluoroscopy image.

The apparatus 1 for applying energy to an object further comprises an apparatus control unit 10 for controlling the apparatus 1 for applying energy to an object, in particular, for controlling the catheter control unit 6 and preferentially the fluoroscopy device. In particular, the apparatus control unit 10 preferentially controls the electrical energy source 19, the light source 6, the interferometrical unit 8 and a possible additional spectrometer.

An embodiment of a distal end 5 of a catheter 3 is exemplarily and schematically shown in more detail in Fig. 2.

The catheter 6 comprises an energy applying unit in the form of a catheter electrode 17, in particular, in this embodiment a radio frequency catheter electrode 17, which is connected to the electrical energy source 19 via a contact lead 18. Thus, electrical energy, in this embodiment, radio frequency energy, can be applied to an object 2 having a surface 16 by the electrical energy source 19 via the contact lead 18 and the catheter electrode 17.

The catheter 3 further comprises an optical fiber 21, which is located within the catheter 3 comprising the catheter electrode 17, preferentially centrally. At the distal end of the optical fiber 21 a movable reflecting element is provided. This movable reflecting element is, for example, a thin-film reflector coating on the distal end of the optical fiber 21. The movable reflecting element 20 is, in this embodiment, movable substantially along the moving direction 22. The movable reflecting element 20 is optically connected to the light source 6 and the interferometrical unit 8, which comprises, in this embodiment, a spectrometer for analyzing light reflected from the object, via the optical fiber 21. The movable reflecting element 20 reflects light and is partly transparent to light such that a part of the light, which is guided to the movable reflecting element 20 via the optical fiber 21 is reflected by the movable reflecting element and another part of the light transmits through the movable reflecting element 20 and is coupled into the tissue of the object 2. This light is at least partly absorbed within the object 2, wherein an acoustic wave is generated, in particular, light pulses are absorbed in the tissue of the heart resulting in a generation of a local thermoelastic wave in the tissue. This wave than travels outwards from the absorption side and is reflected back to the surface of the tissue. The movable reflecting element 20 is moved, in particular, in this embodiment, the thin-film reflector thickness is altered, by the wave incident upon its surface, wherein an interference signal in the light pulse train is created, which is transported via the optical fiber 21 to the interferometrical unit 8. In this way, the reflected acoustic wave can be detected as an optical signal corresponding to the light absorption in the object, in particular, in the tissue of the human heart.

The reflecting element is preferentially a thin reflecting element, most preferably directly placed in flush with the optical fiber behind it. As a typical embodiment, one can have a ~100 nm thick homogeneous film of a reflecting metal (e.g.: silver, gold, palladium, platinum, tantalum, aluminum, …) deposited directly on the end facet of the optical fiber.

The movable reflecting element 20 is in flush with the outer surface of the distal end 5 of the catheter 3.

Fig. 3 shows schematically and exemplarily a further embodiment of a distal end 5 of a catheter 3. Similar reference signs in Figs. 2 and 3 denote similar elements.

The embodiment shown in Fig. 3 comprises a sensing optical fiber 23 and a pumping optical fiber 24. A movable reflecting element 25 is located at the distal end of the sensing optical fiber 23. The light source is adapted such that sensing light having a sensing wavelength λ_s is guided to a movable reflecting element 25 via the sensing optical fiber 23. Furthermore, light reflected from the movable reflecting element 25 is guided back and decoupled from the sensing optical fiber 23 such that the reflected light is guided to the interferometrical unit 8 for generating a signal, which depends on the movement of the movable reflecting element 25 and, thus, on the acoustic wave generated in the object 2.

The catheter 3 further comprises in the embodiment shown in Fig. 3 a pumping optical fiber 24 connected to the light source 7 such that pulsed laser light is guided to the distal end 5 of the catheter 3 for coupling the pulsed laser light into the object 2, wherein in the object 2, in particular, within the tissue of the human heart, a thermoelastic wave is generated, which can be detected by a movement of the movable reflecting element 25, which is exposed to this wave.

In the following an embodiment of a method for applying energy to an object will be described with reference to Fig. 4.

It is assumed that the distal end 5 of the catheter has been steered to a desired location within a human heart by using the steering unit 9 and that the distal end 5 of the catheter 3 comprising the movable reflecting element 20 and the catheter electrode 17 is in contact with the surface 16 of the tissue.

In the following a preferred embodiment of a method for applying energy to an object will be described with respect to the embodiment of a distal end of a catheter schematically and exemplarily shown in Fig. 2.

In step 101, energy is applied to the tissue by the energy applying element, i.e., in this embodiment, by the catheter electrode 17, which is connected to the electrical energy source 19 via the contact lead 18.

In step 102, which can be performed simultaneously with step 101, the tissue is photoacoustically sensed by the photoacoustic measurement unit, i.e., in this embodiment, by the movable reflecting element 20 and the optical fiber 21, wherein pulsed laser light partly transmits through the movable reflecting element 20, wherein the pulsed light is absorbed within the tissue and generates thereby an acoustic wave, which travels through the tissue, in particular, to the surface 16 of the tissue, and which moves the movable reflecting element 20 by passing through the reflecting element, which is, in this embodiment, in contact with the surface 16. Another part of the pulsed laser light is reflected by the movable reflecting element 20 and the reflected light is guided back to the interferometrical unit 8 for generating a signal, which depends on the movement of the movable reflecting element 20 and, thus, on the acoustic wave, wherein the acoustic wave depends on properties of the tissue. Therefore, the signal generated by the interferometrical unit 8 is related to properties of the tissue. The signal is preferentially generated by phase shifts in the reflected laser light, which are caused by the movement of the movable reflecting element 20. In addition, in this embodiment, the spectrometer of the interferometrical unit is used for analyzing the light reflected from the tissue for determining further properties of the tissue.

In the following a further embodiment of a method for applying energy to an object will be described with reference to Fig. 5.

Also in this embodiment it is assumed that the distal end 5 of the catheter has been steered to a desired location within a human heart by using the steering unit 9 and that the distal end 5 of the catheter 3 comprising the movable reflecting element 25 and the catheter electrode 17 is in contact with the surface 16 of the tissue.

In the following a preferred embodiment of a method for applying energy to an object will be described with respect to the embodiment of a distal end and of a catheter schematically and exemplarily shown in Fig. 3.

In step 201 energy is applied to the object as described above with reference to step 101.

In step 202, which is preferentially performed simultaneously with step 201, pulsed laser light having a pump wave length λ_p generated by the light source 7 is coupled into the object 2 via the pumping optical fiber 24. The pulsed laser light is absorbed within the object 2 and an acoustic wave is generated, which travels through the object 2 and, in particular, to the surface 16 of the object 2, which is, in this embodiment, in contact with the movable reflecting element 25. Thus, the movable reflecting element 25 moves depending on the acoustic wave and this movement is detected by using sensing laser light having a sensing wave length λ_s , which is also generated by the light source 7. Preferentially, the light source 7 comprises a pulsed laser device for generating the pump light and a sensing laser device, which is preferentially a continuous wave laser device, for generating the sensing light. The sensing light is guided onto the movable reflecting element 25, which is moved because of the generated acoustic wave, and light reflected from the movable reflecting element 25 is guided back through the optical fiber 23 to the interferometrical unit 8. The interferometrical unit 8 generates a signal, which depends on the movement of the movable reflecting element 25, in particular, which depends on phase shifts in the reflected light, which are generated by the movement of the movable reflecting element 25 and, thus, by the acoustic wave.

The photoacoustic sensing minimizes the risk of overheating and underheating during the application of energy, in particular, during an ablation catheter procedure.

Although in the above described embodiment mainly radio frequency is applied to the object, in other embodiments, also other kinds of energy can be applied to the object, for example, cryogenic, microwave, laser or focused ultra sound energy can be applied to the object.

Although in the above described embodiment, the object is preferentially a human heart, in other embodiments, energy can be applied to other objects, for example, to other parts of a patient, for example, to other organs of a patient. Furthermore, the apparatus for applying energy to an object can also be applied to technical objects, in particulars, to hollow technical objects, wherein energy has to applied within these technical objects.

Preferentially, a hole is made into the resin on the distal end of the catheter and the movable reflecting element is arranged within this hole preferentially such that the movable reflecting element is in flush with the outer surface of the distal end of the catheter, in particular, in flush with the outer surface of a catheter electrode located at the distal end of the catheter. This allows that the movable reflecting element is always in contact with a surface of the object during the application of energy, in particular, during an ablation procedure.

The optical fiber, and, preferentially, also at least a part of the movable reflecting element is preferentially arranged within a hollow space, which is present near the distal end of existing radio frequency catheters and existing cryo-ablation catheters. Thus, this hollow space can be used to incorporated the optical fiber, which is, in particular, a lesion monitoring fiber.

The absorption of light within the object, which generates the acoustic wave, and generally also the transmission through the object to the movable reflecting element depend on the properties of the object. Thus, the photoacoustic signal generated by the interferometrical unit can be used for determining properties of the object, in particular, for characterizing the object. This is described in more detail in "Characterization of post mortem arterial tissue using time-resolved photoacoustic spectroscopy at 436, 461 and 532 nm", Beard, P.C., Mills, T. N., Phys. Med. Biol. 42 (1997) 177-198, which is therewith incorporated by reference.

The signal generated by the interferometrical unit depends on the change in the optical properties of tissue upon ablation, in particular, if the object is a human heart during an ablation procedure. When cardiac tissue is ablated, the absorption and scattering coefficients change dramatically, yielding a significant spectral signature which distinguishes healthy tissue from ablated tissue. Unlike pure optical techniques, the acoustic wave generated by the absorption of light suffers less from attenuation in tissue and the photoacoustic sensing can therefore be applied to highly scattering, optically thick tissue samples. During the application of energy, in particular, during an ablation catheter procedure, photoacoustic signals relating to the real-time status of the tissue are obtained. When the tissue is coagulated and an arrhythmia-blocking lesion is created, the photoacoustic signal will indicate this change in the tissue, and the ablation catheter can be removed from the site or the application of energy, i.e. the delivery of energy, can be ceased. In this way, the photoacoustic signals can help to control the application of energy, in particular, the ablation procedure, and prevent accidental under- and overheating. The optical fiber and the movable reflecting element can be arranged within existing ablation catheters only by making a hole in the catheter tip, in particular, in the resin tip at the distal end of the catheter shaft, through which to fix the optical fiber and the movable reflecting element. Further changes of an existing ablation catheter are not required. The optical fiber and the movable reflecting element, which can be parts of a fiber-optic assembly, which can comprise further optical elements, can be of the order of 0.1 mm in diameter. Thus, a heating or freezing profile of the catheter tip with the hole is preferentially not or substantially not modified and not increased in size in comparison to existing ablation catheters.

The apparatus for applying energy to an object is preferentially adapted for an application in electrophysiology applications, in particular, the monitoring of coagulation and lesion development in the arterial wall during catheter-based cardiac ablation procedures. But, in other embodiments, the apparatus for applying energy to an object can also be adapted for other applications, as already mentioned above.

Although in the above described embodiment the reflecting element is preferably in contact with a surface of the object, in particular, with a surface of a heart, in other embodiments, a distance can be present between the reflecting element and the surface, wherein an acoustic wave can still move the reflecting element. For example, if an ablation procedure is performed within a human heart, the acoustic wave can propagate through the blood and pass through the reflecting element such that the acoustic wave can be sensed, even if the reflecting element is not in contact with a surface of the heart tissue. However, since blood attenuates the acoustic wave, preferentially the distance between the reflecting element and the surface of the heart tissue is minimized.

Although in the above described embodiment the photoacoustic sensing unit comprises a reflecting element and an interferometer for measuring phase shifts in the reflected light for determining a movement of the reflecting element caused by an acoustic wave and, thus, for sensing the acoustic wave, in another embodiment, alternatively or in addition, the acoustic wave can be detected by other means for measuring ultrasound, like an ultrasound array, which is preferentially also integrated in the distal end of the catheter.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

A single device or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage.

Several functions which are realized by different units in the above described embodiments can be realized by any other number of units, also by only one unit. For example, the light source 7 and the interferometrical unit 8 can also be integrated into a single unit.

A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. An apparatus (1) for applying energy to an object (2), the apparatus comprising a catheter (3), wherein the catheter includes an energy applying unit (17, 18) for applying energy to the object (2) and a photoacoustic measurement unit (20, 21) for photoacoustically sensing the object (2).

2. The apparatus as defined in claim 1, wherein the photoacoustic measurement unit comprises a reflecting element (20), which is movable by an acoustic wave, wherein the apparatus comprises at least one optical fiber (21) located within the catheter (3) for guiding light to and/or from the movable reflecting element (20).

3. The apparatus as defined in claim 2, wherein the movable reflecting element (20) is optically transparent for allowing light passing the movable reflecting element (20).

4. The apparatus as defined in claim 2, wherein the movable reflecting element (20) is in flush with an outer surface of a tip of the catheter (3).

5. The apparatus as defined in claim 2, wherein the movable reflecting element (25) and/or the at least one optical fiber (23, 24) are adapted such that a part of the light guided by the at least one optical fiber can pass the movable reflecting element beside the movable reflecting element.

6. The apparatus as defined in claim 2, wherein the at least one optical fiber (23, 24) is adapted for guiding sensing light having a sensing wavelength (λ_s) to the movable reflecting element (25) and for guiding pumping light having a pumping wavelength (λ_p) to the distal end (5) of the catheter (3) for coupling the pumping light into the object (2) for generating an acoustic wave.

7. The apparatus as defined in claim 1, wherein the photoacoustic measurement unit comprises an ultrasound device for sensing an acoustic wave generated by absorption of light in the object.

8. A method for applying energy to an object, wherein energy is applied to the object (2) using an energy applying element (17, 18) included in a catheter (3) and wherein the object (2) is photoacoustically sensed by a photoacoustic measurement unit (20, 21) included in the catheter (3).

9. A computer program for applying energy to an object, wherein the computer program comprises program code means for causing a computer to carry out the steps of the method as defined in claim 8, when the computer program is run on a computer controlling an apparatus as defined in claim 1.

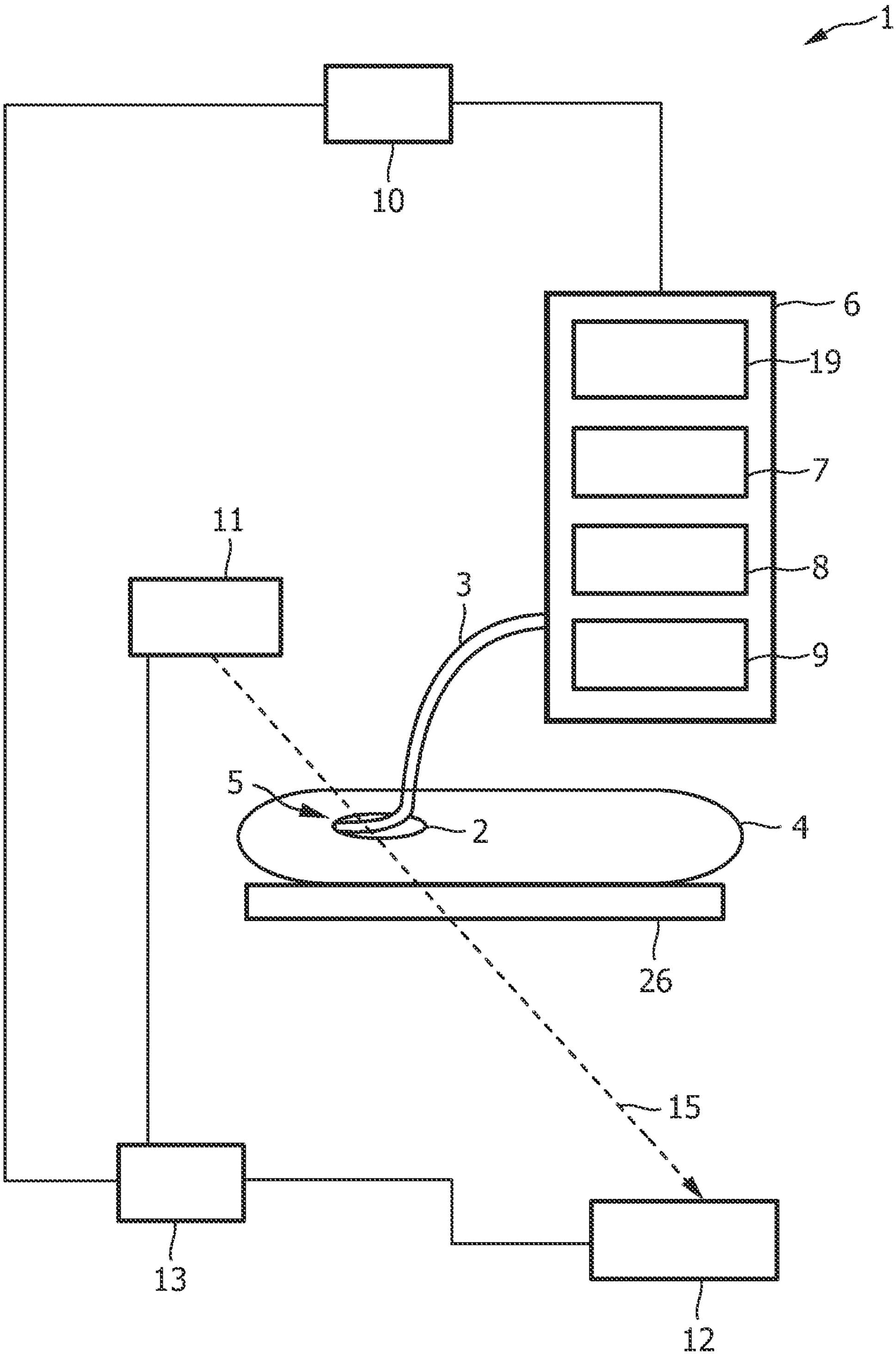

FIG. 1

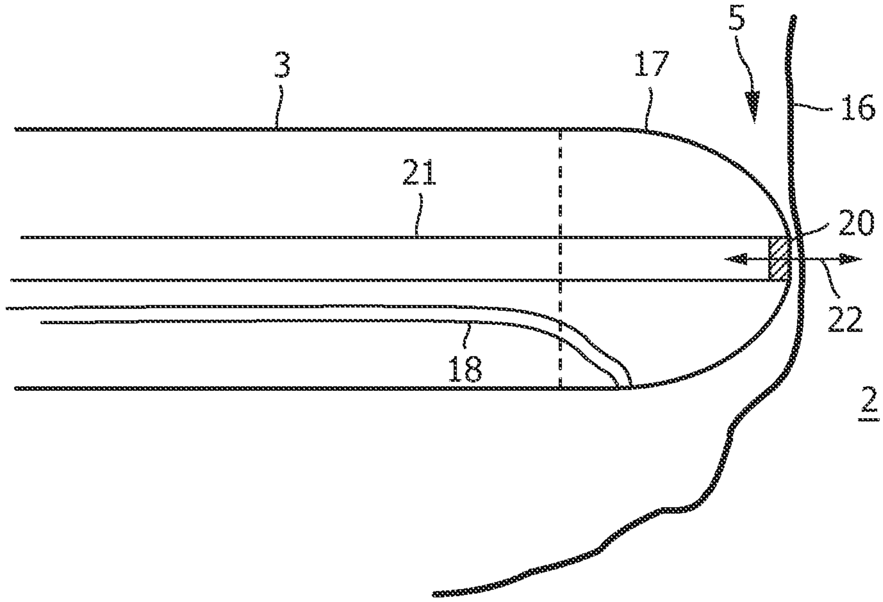

FIG. 2

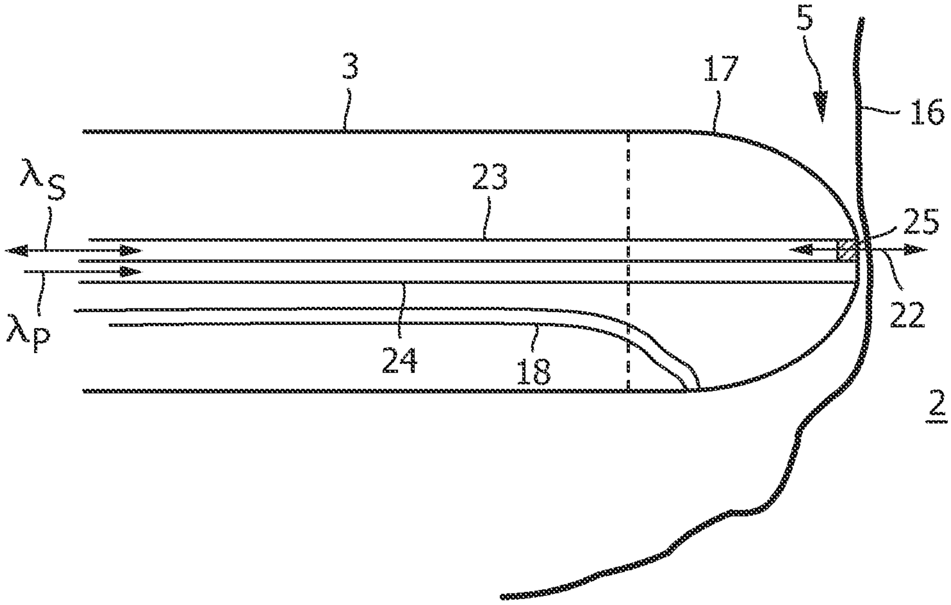

FIG. 3

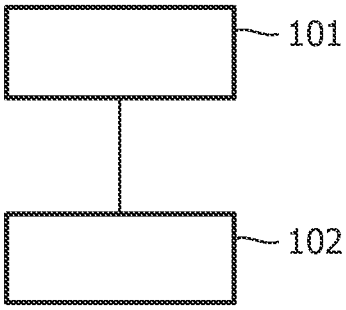

FIG. 4

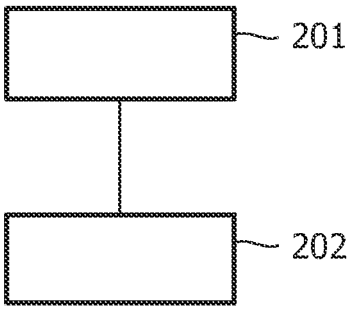

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/050102

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/00 A61B18/00

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)
A61B

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/241572 A1 (ZHOU GAN [US]) 26 October 2006 (2006-10-26) paragraphs [0039], [0046] - [0056]; figures 1,4-8	1-7,9
X	WO 2004/000148 A (GLUCON INC [US]; PESACH BENNY [IL]; BALBERG MICHAL [IL]) 31 December 2003 (2003-12-31) page 10, line 25 - page 11, line 27; figures 1A,1B page 3, lines 8-23	1,7,9
P,X	EP 1 935 332 A (BIOSENSE WEBSTER INC [US]) 25 June 2008 (2008-06-25) paragraphs [0035], [0036], [0055], [0057]; figures 1A,1B	1,7,9

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

☒ See patent family annex.

* 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 document 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
7 April 2009	20/04/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Rosenblatt, Thomas

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 8

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy and surgery

Claim 8 relates to a method for applying energy to an object. According to the description, the method encompasses the application of energy to the human body, e.g. to the human heart, for ablation of tissue. The ablation is of surgical nature and has a therapeutical effect.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2009/050102

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. [X] Claims Nos.: 8
because they relate to subject matter not required to be searched by this Authority, namely:

see FURTHER INFORMATION sheet PCT/ISA/210

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:

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

2. [ ] As all searchable claims could be searched without effort justifying an 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 reportcovers 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

Information on patent family members

International application No
PCT/IB2009/050102

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2006241572	A1	26-10-2006	NONE			
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EP 1935332	A	25-06-2008	BR	PI0705970	A	12-08-2008
			CA	2615340	A1	22-06-2008
			CN	101243968	A	20-08-2008
			JP	2008178676	A	07-08-2008
			US	2008154257	A1	26-06-2008