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(54) Title: TISSUE ABLATION DEVICE WITH PHOTOACOUSTIC LESION FORMATION FEEDBACK

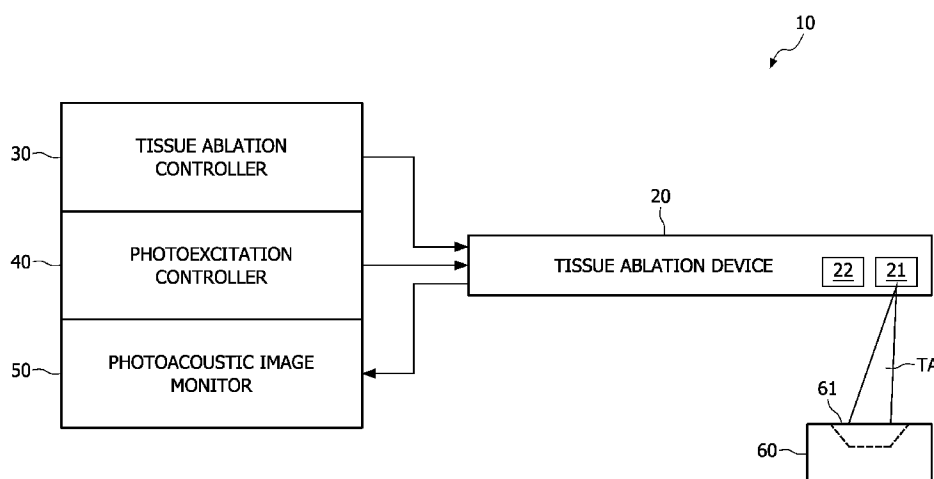


FIG. 1

(57) Abstract: A tissue ablation device employs one or more energy emitters (21) and one or more photoacoustic sensors (22) in a cooperative arrangement for applying a tissue ablation therapy to a tissue (60). In operation, the energy emitters (21) emit a tissue ablation beam (TA) into a target portion of the tissue (60) to form a lesion (61) therein, and alternatively or concurrently emit a photoexcitation beam (PE) into the target portion of the tissue (60) to excite a photoacoustic response from the tissue (60). The photoacoustic sensor(s) (22) sense the photoacoustic response of the tissue (60).

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FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, 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).

— *as to the applicant's entitlement to claim the priority of the
earlier application (Rule 4.17(iii))*

Declarations under Rule 4.17:

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

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— *before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments*

TISSUE ABLATION DEVICE
WITH PHOTOACOUSTIC LESION FORMATION FEEDBACK

The present invention generally relates to a tissue ablation device of any type for
5 forming lesion in tissue. The present invention specifically relates to obtaining a
photoacoustic lesion formation feedback from the tissue ablation device.

Atrial fibrillation (“AF”) ablation is recognized as a growth opportunity for device
and imaging vendors due to the increasing number of procedures. Tissue ablation device
technologies based on cryo (freezing), laser and high intensity focused ultrasound (“HIFU”)
10 tissue destruction promise to simplify the placement of circumferential lesions, which are
used to electrically isolate the pulmonary veinous ostia and thereby cure AF. However,
methods for clinical monitoring and assessment of the lesion formation do not yet exist,
precluding live feedback during the therapeutic procedure with regard to lesion size, depth
and, hence, transmural. To overcome this problem, the present invention provides a tissue
15 ablation device which enables real-time assessment of ablation lesions using the
photoacoustic effect. Specifically, this tissue ablation device ablates the cardiac tissue as
known in the art and is equipped in accordance with the present invention with a
photoacoustic response sensor which continuously monitors the acoustic tissue response and
hence the ablation process.

20 One form of the present invention is a tissue ablation device comprising one or more
energy emitters and one or more photoacoustic sensors in a cooperative arrangement for
applying a tissue ablation therapy to a tissue. In operation, the energy emitter(s) emit a tissue
ablation beam into a target portion of the tissue to form a lesion therein, and alternatively or
concurrently emit a photoexcitation beam into the target portion of the tissue to excite a
25 photoacoustic response from the tissue whereby the photoacoustic sensor(s) sense the
photoacoustic response of the tissue.

A second form of the present invention is a system comprising a tissue ablation
therapy control system and the aforementioned tissue ablation device. In operation, the tissue
ablation therapy control system controls the emissions of the tissue ablation beam and the
30 photoexcitation beam by the energy emitter(s), and monitors the formation of the lesion
within the tissue based on the photoacoustic response of the tissue sensed by the
photoacoustic sensor(s).

A third form of the present invention is a method of performing a tissue ablation therapy of a tissue. The method comprises an emission of a tissue ablation beam into the tissue wherein a lesion is formed in the tissue, an emission of a photoexcitation beam into the tissue wherein a photoacoustic response is generated within the tissue; and a sensing of the photoacoustic response of the tissue wherein a formation of the lesion in the tissue is monitored.

The foregoing forms and other forms of the present invention as well as various features and advantages of the present invention will become further apparent from the following detailed description of various embodiments of the present invention read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present invention rather than limiting, the scope of the present invention being defined by the appended claims and equivalents thereof.

FIGS. 1 and 2 illustrate a block diagram of an embodiment of a tissue ablation system in accordance with the present invention.

FIG. 3 illustrates a flowchart representative of a tissue ablation therapy method with photoacoustic lesion formation feedback in accordance with the present invention.

FIGS. 4-6 illustrate a first exemplary embodiment of a balloon laser ablation catheter in accordance with the present invention.

FIGS. 7-9 illustrate a second exemplary embodiment of a balloon laser ablation catheter in accordance with the present invention.

Referring to FIGS. 1 and 2, a tissue ablation system 10 of the present invention employs a tissue ablation device 20 having one or more energy emitters 21, and one or more photoacoustic sensors 22. Generally, one or more of the emitter(s) 21 of device 20 are driven by a laser ablation controller 30 for ablating a tissue 60. Alternatively or concurrently, one or more of the emitter(s) 21 of device 20 are driven by a photoexcitation controller 40 for generating a photoacoustic response by tissue 60. In turn, the photoacoustic sensor(s) 22 of device 20 sense such a photoacoustic response by tissue 60 and a photoacoustic monitor 50 generates a photoacoustic image of a lesion 61 being formed in tissue 60 based on the photoacoustic response as sensed by the photoacoustic sensor(s) 22 of device 20.

Specifically, tissue ablation system 10 implements a flowchart 70 as shown in FIG. 3 that is representative of a tissue ablation therapy method with photoacoustic lesion formation feedback in accordance with the present invention.

Referring to FIG. 3, a stage S72 of flowchart 70 encompasses laser ablation controller 30 driving one or more of the energy emitter(s) 21 of device 20 to emit a tissue ablation beam TA into a target portion of tissue 60 as best shown in FIG. 1. In practice, tissue ablation beam TA may be generated from any source (e.g., a laser, a RF source, or a high intensity ultrasound source), may be generated in any form (e.g., a single long pulse, a continuous wave beam or a series of short pulses), and may be modulated as needed.

A stage S74 of flowchart 70 encompasses photoexcitation controller 40 driving one or more of the emitter(s) 21 of device 20 to emit a photoexcitation beam PE into an ablated target portion of tissue 60 as best shown in FIG. 2. In practice, photoexcitation beam PE may be generated from any source (e.g., a laser, a RF source, or a high intensity ultrasound source), may be generated in any form (e.g., a single long pulse, a continuous wave beam or a series of short pulses), and may be modulated as needed. Further, tissue ablation beam TA and photoexcitation beam PE may be interleavingly or sequentially emitted by the same emitter(s) 21 of device 20 into the same target portion of tissue 60, or concurrently emitted by different emitters 21 of device 20 into different target portions of tissue 60 (e.g., one target portion of tissue 60 is ablated by tissue ablation beam TA while another previously ablated target portion of tissue 60 is being excited by photoexcitation beam PE).

A stage S76 of flowchart 70 encompasses the photoacoustic sensor(s) 22 of device 20 sensing a photoacoustic response PR by tissue 60 responsive to photoexcitation beam PE as known in the art. In practice, the photoacoustic sensor(s) 22 of device 20 may have any structural form (e.g., ultrasound piezo sensors, P-MUTS, C-MUTs, Fabry-Perot optical interference or optical resonator based transducers).

A stage S78 of flowchart 70 encompasses photoacoustic monitor 50 generating a photoacoustic image of lesion 61 as formed in tissue 60 based on the sensed photoacoustic response PR of tissue 60 whereby the photoacoustic image is utilized to determine whether or not to continue with the ablation therapy of tissue 60. In one embodiment, the decision is an automated feature of monitor 50 whereby monitor 50 will terminate flowchart 70 upon the photoacoustic image indicating the lesion 61 has threshold features (e.g., a predetermined size and/or depth). In an alternative embodiment, the decision is a manual feature of monitor 50 whereby monitor 50 displays the photoacoustic image with a current listing of threshold features of lesion 61 to facilitate a user of system 10 in determining whether or not to terminate the ablation therapy of tissue 60.

Tissue ablation controller 30, photoexcitation controller 40 and photoacoustic image monitor 50 constitute a tissue ablation therapy control system. In practice, this system may have any structural configuration incorporating controller 30, controller 40 and monitor 50 as needed to control a tissue ablation device of the present invention.

5 To facilitate a further understanding of the present invention, a description of a balloon laser ablation device 120 (FIGS. 4-6) and a balloon laser ablation device 220 (FIGS. 7-9) will now be provided herein in the context of forming a circumferential lesion 63 within a tissue 61 (e.g., a pulmonary vein vessel tissue).

Referring to FIGS. 4-6, balloon laser ablation device 120 employs a catheter 121
10 having an inflatable balloon 122 affixed thereto and housing an endoscope 123, an ultrasound piezo sensor 124 and a laser emitter 125. To perform the laser ablation therapy, balloon 122 is filled with a suitable optoacoustic medium 122 which enables a laser beam from laser emitter 122 to travel to lesion 63 and enables ultrasound waves from tissue 62 to travel back to ultrasound piezo sensor 124. More particular, the material composition of balloon 122 and
15 medium 126 may match that acoustic impedance of tissue 62 to facilitate an optimal signal propagation of a laser beam from laser emitter 125 to tissue 62 and of a photoacoustic response back to ultrasound piezo sensor 124 (e.g., a saline medium 126 filed within a latex balloon 122). In practice, medium 126 may be periodically flushed to maintain a constant temperature within balloon 122.

20 After the inflation of the balloon, a continual rotation of catheter 121 is started and endoscope 123 is used to locate a target portion of tissue 62 as best shown in FIG. 4. Upon locating the target portion of tissue 62, a laser ablation beam LA in the form of high energy light pulses or a high power continuous wave beam is emitted from laser emitter 125 through medium 126 to the target portion of tissue 62 to form lesion 63 in tissue 62 as best shown in
25 FIG. 5. Interleaved with or subsequent to laser ablation beam LA, a photoexcitation beam PE in the form of a low-energy near-infrared laser pulses on the order of microseconds are used to illuminate tissue 62 to thereby induce a photoacoustic response PR sensed by ultrasound piezo sensor 124 as best shown in FIG. 6. In practice, laser ablation beam LA (FIG. 5) and photoexcitation beam PE (FIG. 6) may be deflected as needed to improve targeting of an
30 ablation lesion 63 using electromechanically actuated lenses or mirrors.

Referring to FIGS. 7-9, balloon laser ablation device 220 employs a catheter 221 having an inflatable balloon 222 affixed thereto and housing a fish-eye endoscope 223, a

sensor arrays 224 having multiple ultrasound piezo elements, and a laser array 224 having multiple laser emitters. To perform the laser ablation therapy, balloon 222 is filled with a suitable optoacoustic medium 226 which enables a laser beam from laser array 222 to travel to lesion 63 and enables ultrasound waves from tissue 62 to travel back to sensor array 224.

5 More particular, the material composition of balloon 222 and medium 226 may match that acoustic impedance of tissue 62 to facilitate an optimal signal propagation of a laser beam from laser array 225 to tissue 62 and of a photoacoustic response back to sensor array 224 (e.g., a saline medium 226 filed within a latex balloon 222). In practice, medium 226 may be periodically flushed to maintain a constant temperature within balloon 222.

10 After the inflation of the balloon, catheter 221 is held stationary and endoscope 223 is used to locate a target portion of tissue 62 as best shown in FIG. 7. Upon locating the target portion of tissue 62, a laser ablation beam LA in the form of high energy light pulses or a high power continuous wave beam is emitted from laser array 225 through medium 226 to the target portion of tissue 62 to form lesion 63 in tissue 62 as best shown in FIG. 8.

15 Interleaved with or subsequent to laser ablation beam LA, a photoexcitation beam PE in the form of a low-energy near-infrared laser pulses on the order of microseconds are used to illuminate tissue 62 to thereby induce a photoacoustic response PR sensed by ultrasound piezo sensor array 224 as best shown in FIG. 9. In practice, laser ablation beam LA (FIG. 8) and photoexcitation beam PE (FIG. 9) may be deflected as needed to improve targeting of an
20 ablation lesion 63 using electromechanically actuated lenses or mirrors.

In additional embodiments of a balloon laser ablation device of the present invention, a combination of rotating components (FIGS. 4-6) and stationary components (FIGS. 7-9) may be incorporated therein. For example, the laser emitter may be a static lens assembly which allows for beam refraction for focusing and reflection/deflection for steering, and the
25 photoacoustic sensor may be rotated for purposes of photoacoustic imaging the lesion formed within the tissue. By further example, the laser emitter may be a rotating lens assembly which allows for beam refraction for focusing and reflection/deflection for steering, and the photoacoustic sensor may be static for purposes of photoacoustic imaging the lesion formed within the tissue.

30 Referring to FIG. 1-9, those having ordinary skill in the art will appreciate a tissue ablation device of the present invention can be utilized in numerous applications, and in practice, the actual structural configuration of a tissue ablation device of the present invention

will be dependent upon the specifics of an explicit application of the device. Thus, the present invention does not contemplate any particular type of best structural configuration of a tissue ablation device in accordance with the present invention among the numerous potential applications.

5 Still referring to FIGS. 1-9, experiments have proven the photoacoustic imaging of a tissue lesion in accordance with the present invention can distinguish normal tissue over ablated tissue. For example, for a cardiac tissue including normal tissue and an ablated tissue formed from a full laser power of 123mJ/cm^2 with a 800nm laser, a scan over a lesion formation area of 22 mm x 20 mm involving twenty (20) B-mode slices of the cardiac tissue
10 at 1 mm separation in the scan direction shows the ablated tissue being visibly distinct from the normal tissue. A combination of the B-mode slices reconstructed a C-mode image of the lesion formation.

 While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the
15 spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

Claims

1. A tissue ablation device, comprising:
at least one energy emitter (21) and at least one photoacoustic sensor (22) in a cooperative arrangement for applying a tissue ablation therapy to a tissue (60);
wherein the at least one energy emitter (21) is operable to emit a tissue ablation beam (TA) into a target portion of the tissue (60) to form a lesion (61) therein;
wherein the at least one energy emitter (21) is further operable to emit a photoexcitation beam (PE) into the target portion of the tissue (60) to excite a photoacoustic response from the tissue (60); and
wherein the at least one photoacoustic sensor (22) is operable to sense the photoacoustic response of the tissue (60).
2. The tissue ablation device (20) of claim 1, further comprising:
an endoscope (123, 223) for illuminating the target portion of the tissue (60).
3. The tissue ablation device (20) of claim 1, further comprising:
a catheter (121, 221) housing the at least one energy emitter (21) and the at least one photoacoustic sensor (22); and
an inflatable balloon (122, 222) affixed to the catheter (121, 221) and encircling the at least one energy emitter (21) and the at least one photoacoustic sensor (22), wherein the balloon (122, 222) is operable to be inflated via the catheter (121, 221) with an optoacoustic transfer medium (126, 226).
4. The tissue ablation device (20) of claim 1, wherein at least one of the at least one energy emitter (21) and the at least photoacoustic sensor (22) is rotated during the application of the tissue ablation therapy.
5. The tissue ablation device (20) of claim 1, wherein:
the tissue (60) is a pulmonary vein vessel tissue; and
the lesion (61) is a circumferential lesion formed within the pulmonary vein vessel tissue.

6. A tissue ablation system, comprising:
 - a tissue ablation therapy control system; and
 - a tissue ablation device (20) including:
 - at least one energy emitter (21) and at least one photoacoustic sensor (22) in a cooperative arrangement for applying a tissue ablation therapy to a tissue (60);
 - wherein the at least one energy emitter (21) is controllable by the tissue ablation therapy control system to emit a tissue ablation beam (TA) into a target portion of the tissue (60) to form a lesion (61) therein;
 - wherein the at least one energy emitter (21) is further controllable by the tissue ablation therapy control system to emit a photoexcitation beam into the target portion of the tissue (60) to excite a photoacoustic response from the tissue (60); and
 - wherein the at least one photoacoustic sensor (22) is operable to sense the photoacoustic response of the tissue (60) to facilitate a generation of a photoacoustic image of the lesion (61) by the tissue ablation therapy control system.
7. The tissue ablation system of claim 6, further comprising:
 - an endoscope (123, 223) for illuminating the target portion of the tissue (60).
8. The tissue ablation system of claim 6, further comprising:
 - a catheter (121, 221) housing the at least one energy emitter (21) and the at least one photoacoustic sensor (22); and
 - an inflatable balloon (122, 222) affixed to the catheter (121, 221) and encircling the at least one energy emitter (21) and the at least one photoacoustic sensor (22), wherein the balloon (122, 222) is operable to be inflated via the catheter (121, 221) with an optoacoustic transfer medium (126, 226).
9. The tissue ablation system of claim 6, wherein at least one of the at least one energy emitter (21) and the at least photoacoustic sensor (22) is rotated during the application of the tissue ablation therapy.
10. The tissue ablation system of claim 6, wherein:

the tissue (60) is a pulmonary vein vessel tissue; and
the lesion (61) is a circumferential lesion formed within the pulmonary vein vessel tissue.

11. The tissue ablation system of claim 6, wherein the tissue ablation control system includes:

a tissue ablation controller (30) operable to control an emission of the tissue ablation beam (TA) by the at least one emitter (21);

a photoexcitation controller (40) operable to control an emission of the photoexcitation beam (PE) PE by the at least one emitter (21); and

a photoacoustic image monitor (50) operable to monitor a formation of the lesion (61) within the tissue (60) based on a photoacoustic response of the tissue (60) as sensed by the at least one photoacoustic sensor.

12. A method of performing a tissue ablation therapy of a tissue (60), the method comprising:

emitting a tissue ablation beam (TA) into the tissue (60), wherein a lesion (61) is formed in the tissue (60);

emitting a photoexcitation beam (PE) into the tissue (60), wherein a photoacoustic response is generated within the tissue (60); and

sensing the photoacoustic response of the tissue (60), wherein a formation of the lesion (61) in the tissue (60) is monitored.

13. The method of claim 12, wherein the emissions of the tissue ablation beam (TA) and the photoexcitation beam (PE) are concurrent.

14. The method of claim 12, wherein the emissions of the tissue ablation beam (TA) and the photoexcitation beam (PE) are interleaved.

15. The method of claim 12, wherein the emissions of the tissue ablation beam (TA) and the photoexcitation beam (PE) are sequential.

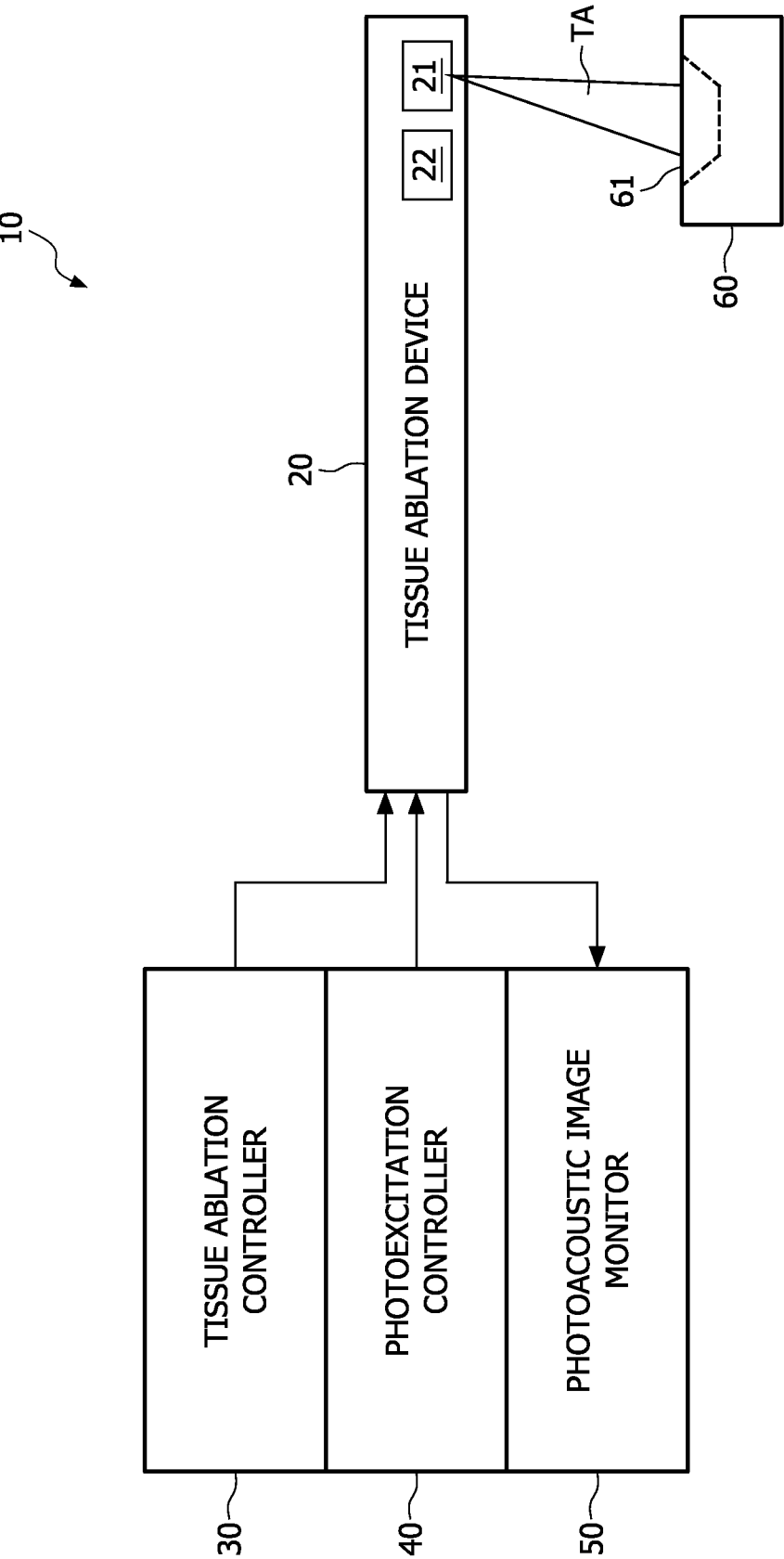


FIG. 1

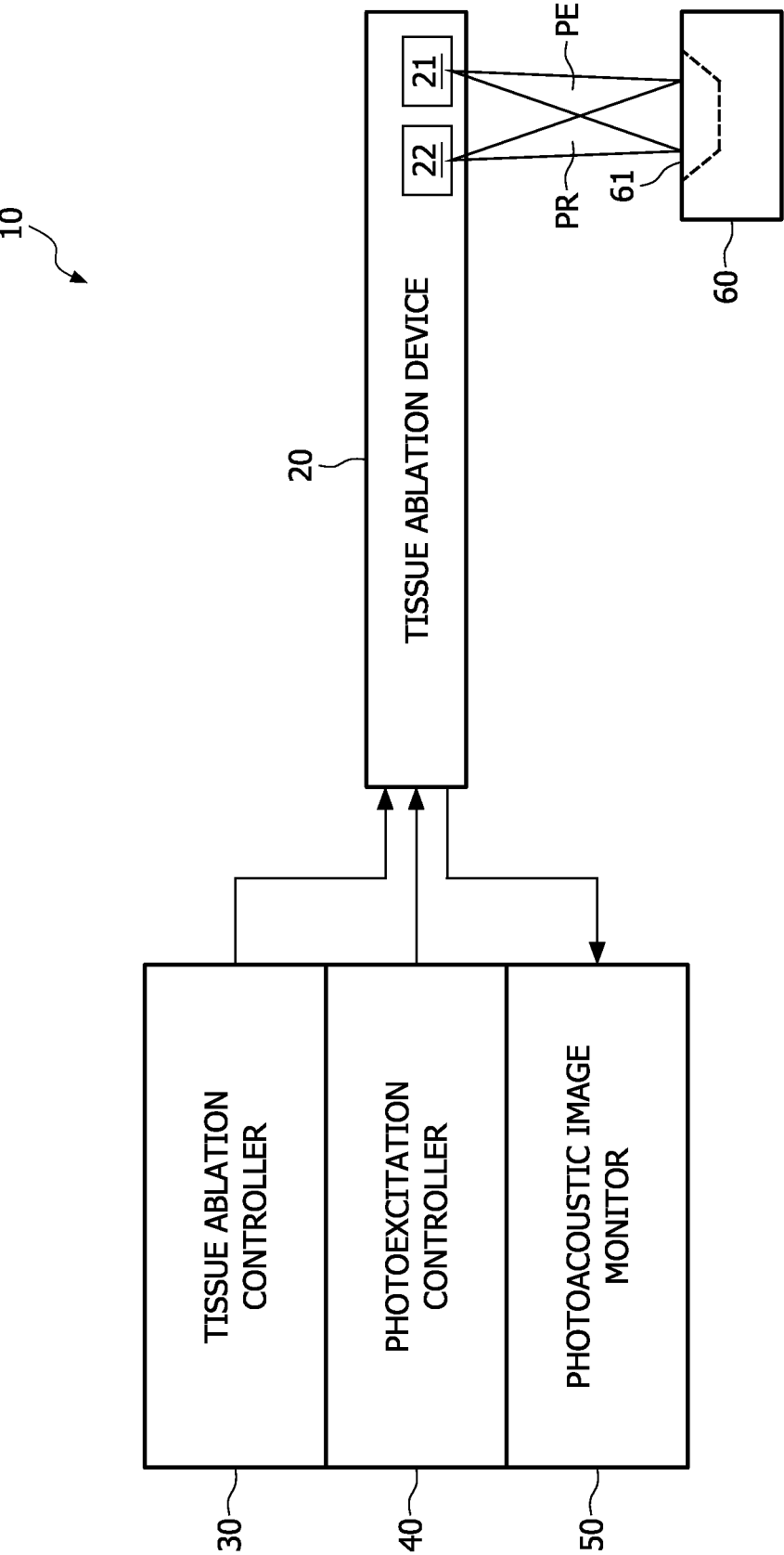


FIG. 2

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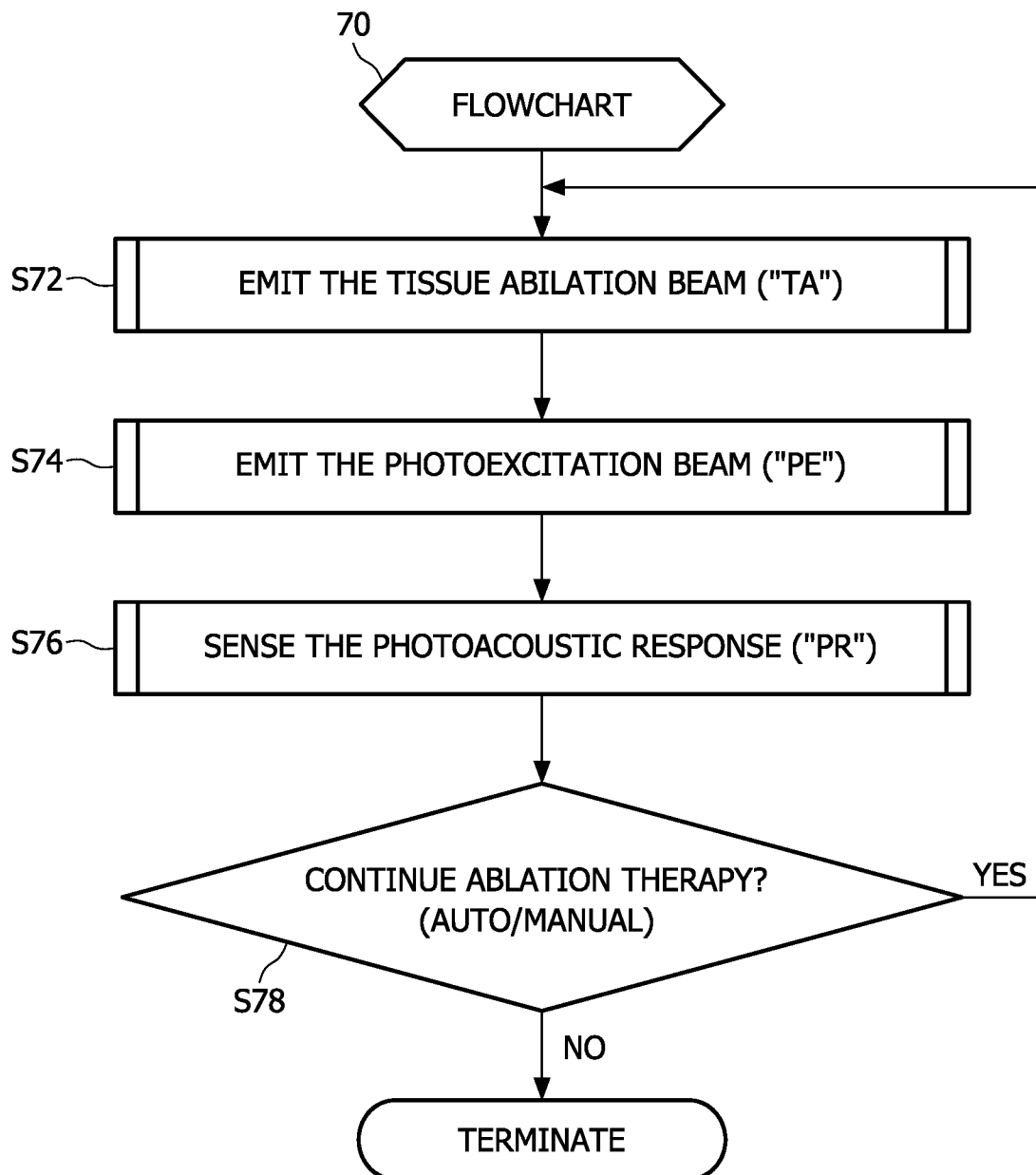


FIG. 3

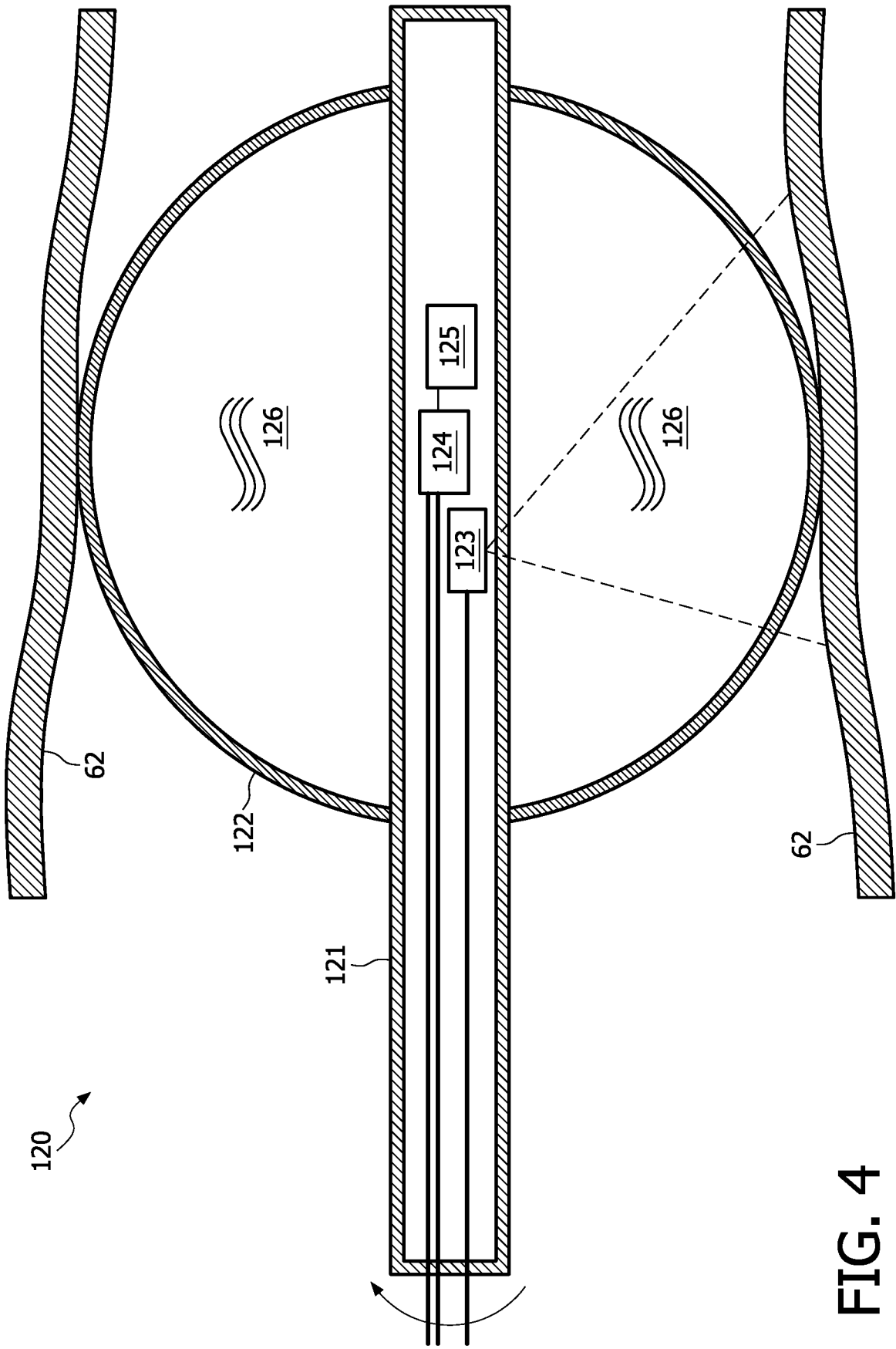


FIG. 4

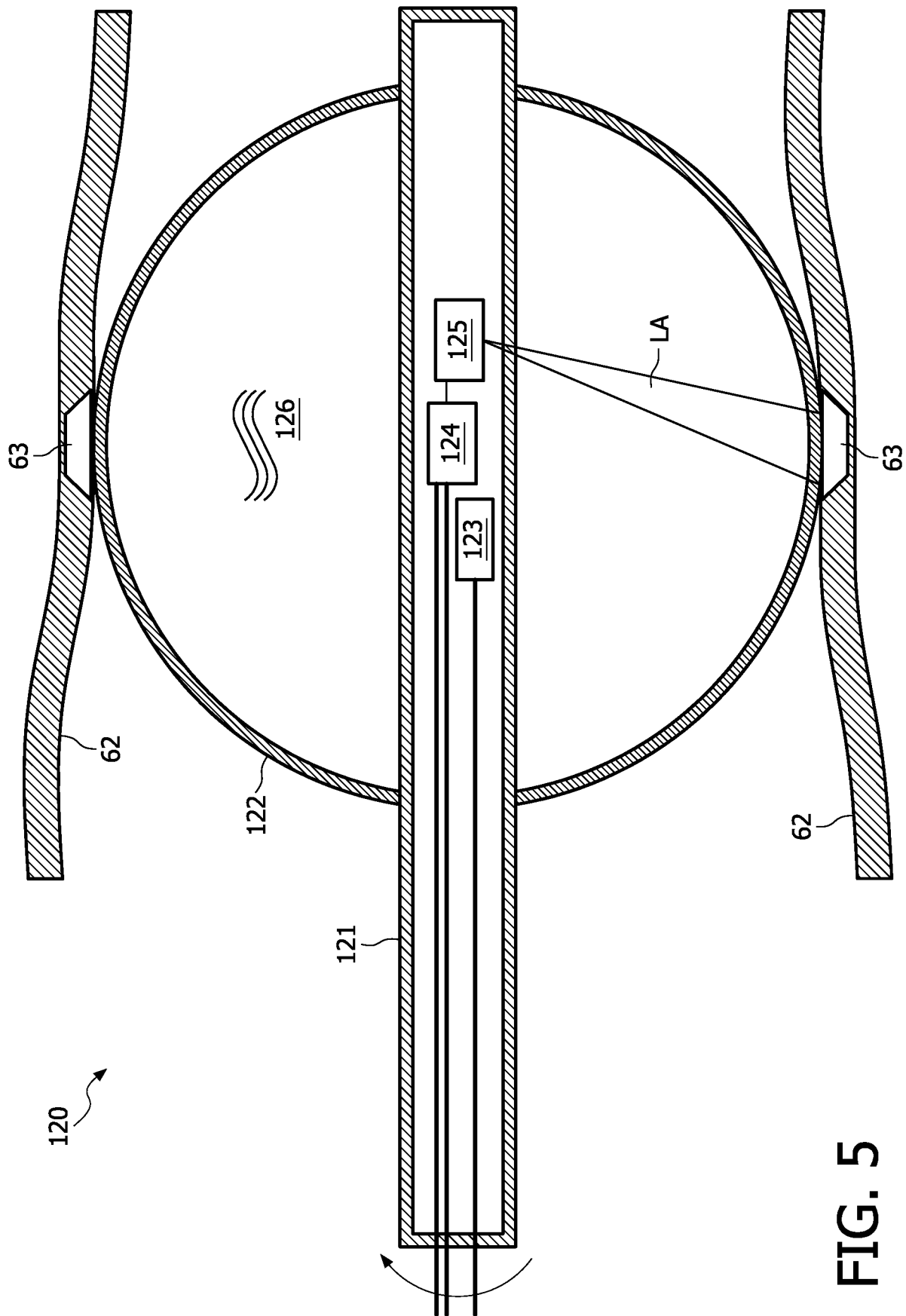


FIG. 5

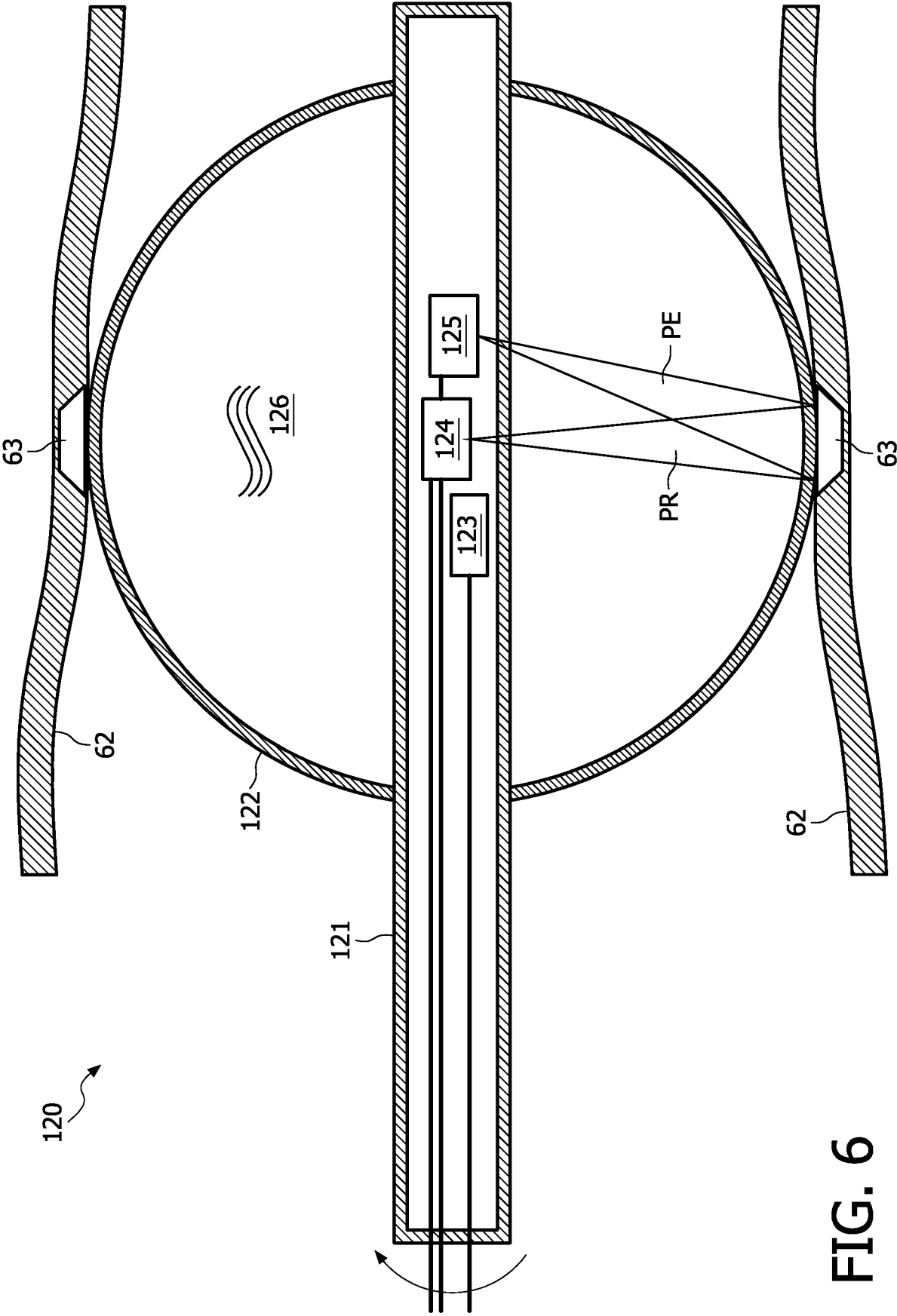


FIG. 6

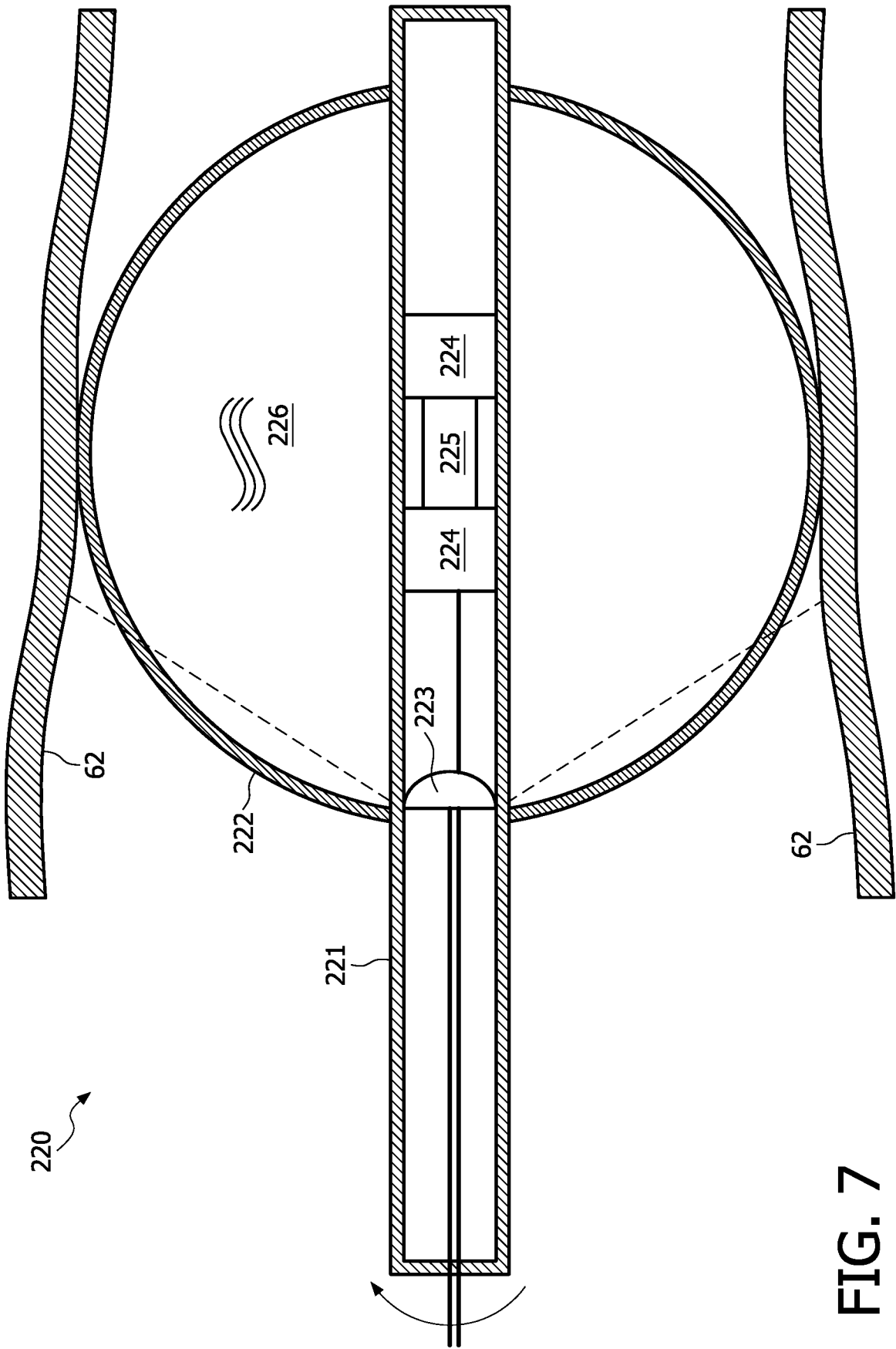


FIG. 7

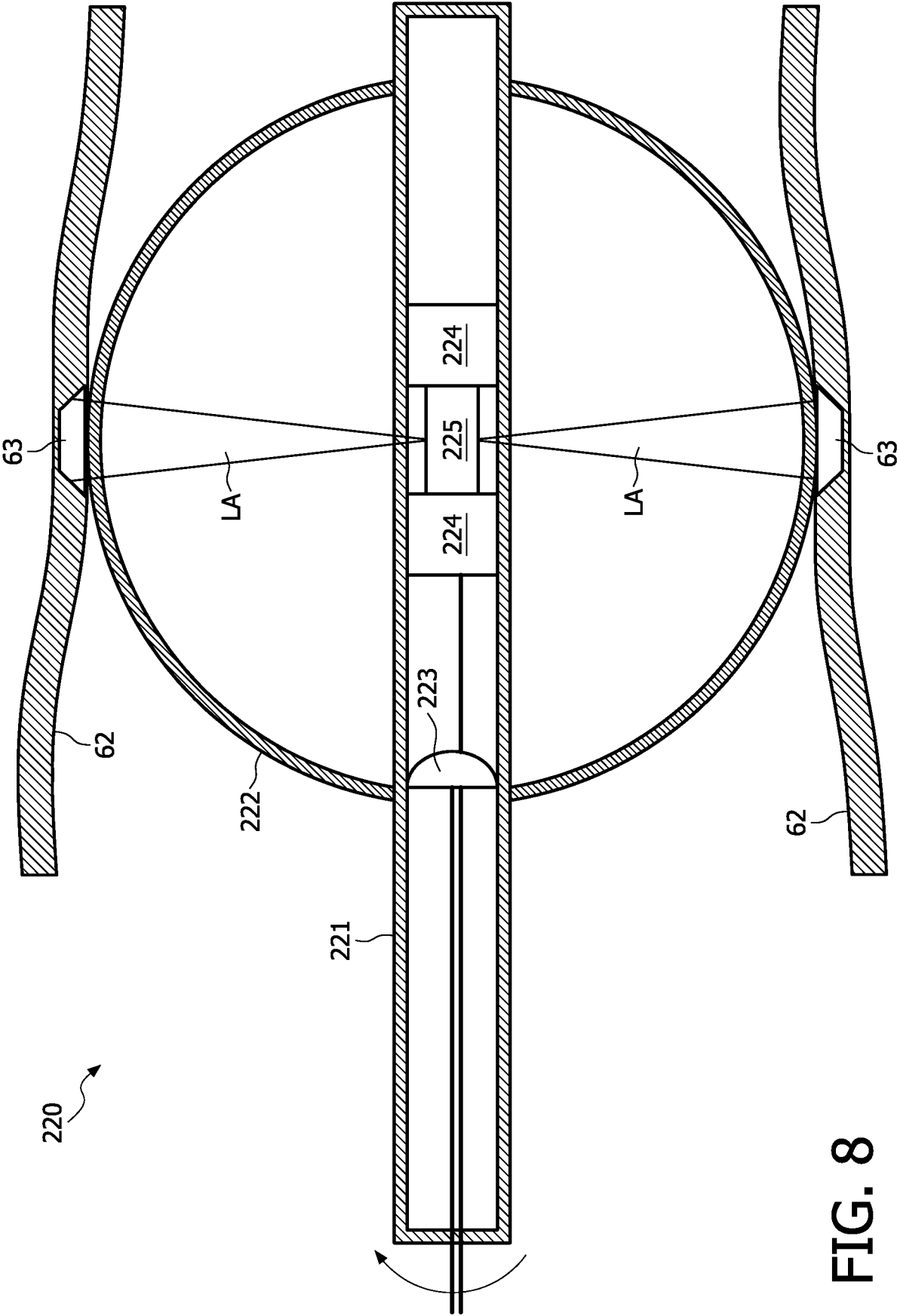


FIG. 8

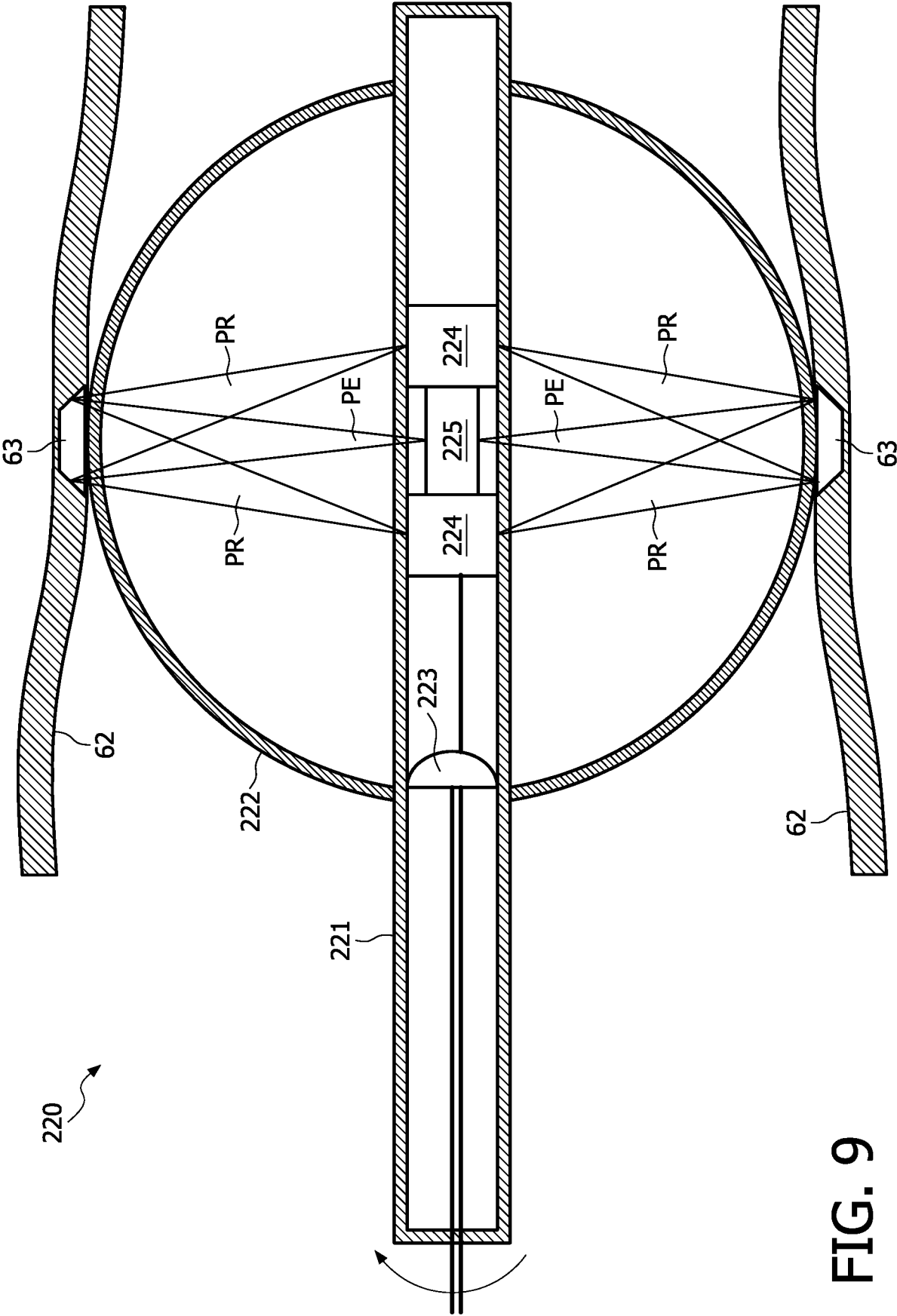


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2008/055312

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B5/00 A61B18/24
ADD. A61B17/00 A61B19/00

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 199 16 653 A1 (LUBATSCHOWSKI HOLGER [DE]) 19 October 2000 (2000-10-19) column 2, lines 34-45 column 3, lines 3-24 column 3, line 60 - column 4, line 29 figures claims 1,3,4,6,8 ----- -/--	1-2,6-7, 11

☒ 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.
- *G* document member of the same patent family

Date of the actual completion of the international search

8 May 2009

Date of mailing of the international search report

25/05/2009

Name and mailing address of the ISA/

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Lohmann, Stefan

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2008/055312

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ROOME K A ET AL: "Towards a sideways looking intravascular laser-ultrasound probe" SENSORS AND ACTUATORS A, ELSEVIER SEQUOIA S.A., LAUSANNE, CH, vol. 76, no. 1-3, 30 August 1999 (1999-08-30), pages 197-202, XP004184437 ISSN: 0924-4247	1-2,4-7, 9-11
A	Par. 2., 5. abstract figure 1	3,8
X	WO 00/24315 A1 (UNIV TEXAS [US]) 4 May 2000 (2000-05-04) page 2, line 24 - page 3, line 20 claims 1,3,5,11,13,15-18,21 figures 2,3	1-2,5-7, 10-11
X	OBERHEIDE U ET AL: "OPTOACOUSTIC ONLINE CONTROL FOR LASER CYCLOPHOTOCOAGULATION" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, VA, US, vol. 4256, 23 January 2001 (2001-01-23), pages 53-60, XP001105011 ISSN: 0277-786X the whole document	1,6,11
X,P	EP 1 935 332 A2 (BIOSENSE WEBSTER INC [US]) 25 June 2008 (2008-06-25) paragraphs [0001] - [0003], [0036] - [0040], [0064] - [0067]	1-2,4-7, 9-11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2008/055312

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.: 12-15
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(iv) PCT – Method for treatment of the human or animal body by surgery and therapy
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.

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Information on patent family members

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