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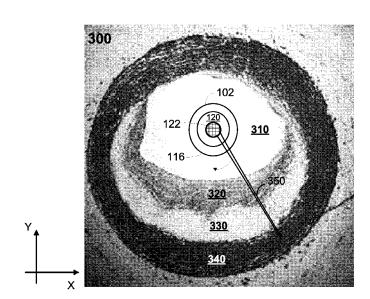


FIG. 3

(57) Abstract: A method for acoustic tomography within a patient may include generating a focused ultrasonic signal using a transducer is provided; the ultrasonic signal forming a path within the patient. The method includes directing the ultrasonic signal on a spot within the patient; scanning the spot in a predetermined pattern about a volume within the patient; receiving an ultrasonic echo in the transducer; converting the ultrasonic echo into a voltage; selecting a frequency band from the voltage; amplifying the voltage in the selected frequency band with a processing circuit; and generating an image of the volume within the patient structure utilizing the amplified voltage. A method for recanalization of a blood vessel including the above acoustic tomography steps is also provided.



Method for Focused Acoustic Computed Tomography (FACT)

Field of the Invention

The present disclosure relates generally to ultrasound imaging inside the living body and, in particular, to a focused intravascular ultrasound (IVUS) imaging catheter that produces high resolution intravascular imaging using a polymer based transducer.

Description of Related Art

Intravascular ultrasound (IVUS) imaging is widely used in interventional cardiology as a diagnostic tool for a diseased vessel, such as an artery, within the human body to determine the need for treatment, to guide the intervention, and/or to assess its effectiveness. IVUS imaging uses ultrasound echoes to create an image of the vessel of interest. Ultrasound waves pass easily through most tissues and blood, but they are partially reflected from discontinuities arising from tissue structures (such as the various layers of the vessel wall), red blood cells, and other features of interest. The IVUS imaging system, which is connected to the IVUS catheter by way of a patient interface module (PIM), processes the received ultrasound echoes to produce a cross-sectional image of the vessel where the catheter is placed.

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Current IVUS solutions do not provide resolution capable of differentiating structures without significant training in image interpretation. Structures requiring clearer images might include plaque burden, stent apposition, lipid pool identification, thrombus, and stent endothelization. While Optical Coherence Tomography (OCT) devices offer improved resolution, they require flushing to produce the image, and due to limitations of light penetration they do not allow for visualization of the vessel morphology beyond the surface of the vessel. While existing IVUS catheters deliver useful diagnostic information, there is a need for enhanced image quality to provide more valuable insight into the vessel condition. For further improvement in image quality in rotational IVUS, it is desirable to use a transducer with broader bandwidth and to incorporate focusing into the transducer.

What is needed is a method for high resolution ultrasound imaging to assess lesions, characterize vessels or to monitor other structures within a patient's body.

Summary

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According to embodiments disclosed herein, a method for acoustic tomography within a patient may include generating a focused ultrasonic signal using a transducer, the ultrasonic signal forming a path within the patient; directing the ultrasonic signal on a spot within the patient; scanning the spot in a predetermined pattern about a volume within the patient; receiving an ultrasonic echo in the transducer; converting the ultrasonic echo into a voltage; selecting a frequency band from the voltage; amplifying the voltage in the selected frequency band with a processing circuit; and generating an image of the volume within the patient structure utilizing the amplified voltage.

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Further according to some embodiments, a method for recanalization of a blood vessel may include positioning a flexible member within the blood vessel proximal to a pre-selected area of interest; generating a focused ultrasonic signal using a transducer, the ultrasonic signal forming a path within the blood vessel; directing the ultrasonic signal on a spot within the blood vessel; scanning the spot in a predetermined pattern about a volume within the patient; receiving an ultrasonic echo in the transducer; converting the ultrasonic echo into a voltage; selecting a frequency band from the voltage; amplifying the voltage in the selected frequency band with a processing circuit; and recanalizing a lumen in the blood vessel based on the image.

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These and other embodiments of the present invention will be described in further detail below with reference to the following drawings.

Brief Description of the Drawings

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FIG. 1A is a schematic illustration of an intravascular ultrasound (IVUS) imaging system, according to some embodiments.

FIG. 1B is a cross-sectional side view of a distal portion of a catheter used in an IVUS imaging system, according to some embodiments.

- FIG. 2A is a partial illustration of a focusing transducer, according to some 5 embodiments.
 - FIG. 2B is a partial illustration of a focusing transducer, according to some embodiments.
- FIG. 3 is a cross-sectional illustration of an IVUS catheter inside a blood vessel, according to some embodiments.
 - FIG. 4 is a longitudinal illustration of an IVUS catheter inside a blood vessel, according to some embodiments.
- FIG. 5 is a longitudinal illustration of an IVUS catheter inside a blood vessel, according to some embodiments.
- FIG. 6 is a flow chart illustrating steps in a method for focused acoustic computed tomography (FACT), according to some embodiments.
 - FIG. 7 is a flow chart illustrating steps in a method for recanalization of a blood vessel using FACT, according to some embodiments.
- In the figures, elements having the same reference number have the same or similar functions.

Detailed Description

For the purposes of promoting an understanding of the principles of the present disclosure, reference will now be made to the embodiments illustrated in the drawings, and specific language will be used to describe the same. It is nevertheless understood that no limitation to the scope of the disclosure is intended. Any alterations and further modifications to the described devices, systems, and methods, and any further application of the principles of the present disclosure are fully

contemplated and included within the present disclosure as would normally occur to one skilled in the art to which the disclosure relates. In particular, it is fully contemplated that the features, components, and/or steps described with respect to one embodiment may be combined with the features, components, and/or steps described with respect to other embodiments of the present disclosure. For the sake of brevity, however, the numerous iterations of these combinations will not be described separately.

In a typical rotational IVUS catheter, a single ultrasound transducer element is located at the tip of a flexible driveshaft that spins inside a plastic sheath inserted into the vessel of interest. The transducer element is oriented such that the ultrasound beam propagates generally perpendicular to the axis of the catheter. A fluid-filled sheath protects the vessel tissue from the spinning transducer and driveshaft while permitting ultrasound signals to freely propagate from the transducer into the tissue and back. As the driveshaft rotates (typically at 30 revolutions per second), the transducer is periodically excited with a high voltage pulse to emit a short burst of ultrasound. The same transducer then listens for the returning echoes reflected from various tissue structures, and the IVUS imaging system assembles a two dimensional display of the vessel cross-section from a sequence of several hundred of these pulse/acquisition cycles occurring during a single revolution of the transducer. In some embodiments, software may be used to provide reconstruction three-dimensional (3D) images of tissue structures by storing two-dimensional data collected from a rotational IVUS catheter.

In the rotational IVUS catheter, the ultrasound transducer is typically a piezoelectric element with low electrical impedance capable of directly driving an electrical cable connecting the transducer to the imaging system hardware. In this case, a four wire (or quad cable) can be used to carry the transmit pulse from the system to the transducer and to carry the received echo signals from the transducer back to the imaging system by way of a patient interface module ("PIM") where the echo signals can be assembled into an image. To transport the electrical signal across a rotating mechanical junction some embodiments include an electromechanical interface where the electrical signal traverses the rotating junction. In some

embodiments of a rotational IVUS imaging system a rotary transformer, slip rings, and rotary capacitors, may be used to create an electrical interface between the PIM and the catheter.

As described in more detail below, ultrasound transducers may be formed to emit a focused beam. Utilizing a focused beam and/or alternate piezoelectric materials allow Focused Acoustic Computed Tomography (FACT) technologies to provide sub 50 µm resolution without compromising depth or penetration. Thereby generating an image which is useful for defining vessel morphology, beyond surface characteristics. Reference will now be made to a particular embodiment of the concepts incorporated into an intravascular ultrasound system. However, the illustrated embodiments and uses thereof are provided as examples only, without limitation on other systems and uses, such as but without limitation, imaging within any vessel, artery, vein, lumen, passage, tissue or organ within the body. Embodiments of focused acoustic computed tomography methods as disclosed herein may also be used for renal denervation applications.

FIG. 1A is a schematic illustration of an intravascular ultrasound (IVUS) imaging system 100, according to some embodiments. IVUS imaging system 100 includes an IVUS catheter 102 coupled by a patient interface module (PIM) 104 to an IVUS control system 106. In some embodiments, a bedside utility box (BUB) or a Bedside Interface Box (BIB) may be used as an interface module. Control system 106 is coupled to a monitor 108 that displays an IVUS image (such as an image generated by the IVUS system 100).

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In some embodiments, IVUS catheter 102 is a rotational IVUS catheter, which may be similar to a Revolution® Rotational IVUS Imaging Catheter available from Volcano Corporation and/or rotational IVUS catheters disclosed in U.S. Patent No. 5,243,988 and U.S. Patent No. 5,546,948, both of which are incorporated herein by reference in their entirety, for all purposes. Catheter 102 includes an elongated, flexible catheter sheath 110 (having a proximal end portion 114 and a distal end portion 116) shaped and configured for insertion into a lumen of a blood vessel (not shown). A longitudinal axis LA of the catheter 102 extends between proximal end portion 114 and distal end portion 116. Catheter 102 is flexible such that it can adapt

to the curvature of the blood vessel during use. In that regard, the curved configuration illustrated in FIG. 1A is for exemplary purposes and in no way limits the manner in which the catheter 102 may curve in other embodiments. Generally, catheter 102 may be configured to take on any desired straight or arcuate profile when in use.

In some embodiments a rotating imaging core 112 extends within sheath 110. Accordingly, in some embodiments imaging core 112 may be rotated while sheath 110 remains stationary. Imaging core 112 has a proximal end portion 118 disposed within the proximal end portion 114 of sheath 110 and a distal end portion 120 disposed within the distal end portion 116 of sheath 110. Distal end portion 116 of sheath 110 and the distal end portion 120 of imaging core 112 are inserted into the vessel of interest during operation of IVUS imaging system 100. The usable length of catheter 102 (for example, the portion that can be inserted into a patient, specifically the vessel of interest) can be any suitable length and can be varied depending upon the application. The proximal end portion 114 of sheath 110 and the proximal end portion 118 of imaging core 112 are connected to PIM 104. Proximal end portions 114, 118 are fitted with a catheter hub 124 that is removably connected to PIM 104. Catheter hub 124 facilitates and supports a rotational interface that provides electrical and mechanical coupling between catheter 102 and PIM 104.

Distal end portion 120 of imaging core 112 includes a transducer assembly 122. Transducer assembly 122 is configured to be rotated (either by use of a motor or other rotary device) to obtain images of the vessel. Transducer assembly 122 can be of any suitable type for visualizing a vessel and, in particular, a stenosis in a vessel. In the depicted embodiment, transducer assembly 122 includes a piezoelectric micromachined ultrasonic transducer ("PMUT") and associated circuitry, such as an application-specific integrated circuit (ASIC). An exemplary PMUT used in IVUS catheters may include a polymer piezoelectric membrane, such as that disclosed in U.S. Patent No. 6,641,540, and co-pending applications entitled "Preparation and Application of a Piezoelectric Film for an Ultrasound Transducer," Attorney Docket No. 44755.1062, "Focused Rotational IVUS Transducer Using Single Crystal Composite Material," Attorney Docket No. 44755.931, and "'Transducer Mounting

Arrangements and Associated Methods for Rotational Intravascular Ultrasound (IVUS) Devices," Attorney Docket No. 44755.960, each hereby incorporated by reference in its entirety. The PMUT may provide greater than about 70% bandwidth, or about 75% bandwidth for optimum resolution in a radial direction, and a spherically-focused aperture for optimum azimuthal and elevation resolution. In some embodiments, a bandwidth of about 75% may be sufficient to obtain high quality images. That is, in some embodiments a transducer assembly fabricated using a PMUT material according to embodiments as disclosed herein may have a response bandwidth that is more than 100% of the center frequency of the response band. For example, if the response band of transducer assembly 122 is 20 MHz, a response bandwidth may be about 20 MHz or more. Thus, the response bandwidth of such transducer assembly may include frequencies from about 10 MHz to about 30 MHz.

Transducer assembly 122 may also include a housing having the PMUT and associated circuitry disposed therein. In some embodiments the housing has an opening that ultrasound signals generated by the PMUT transducer travel through. Alternatively, transducer assembly 122 may include a capacitive micro-machined ultrasonic transducer ("CMUT"). Accordingly, some embodiments may use a flat transducer assembly 122 with an acoustic lens positioned adjacent to the transducer assembly, for beam focusing. In yet another alternative embodiment, transducer assembly 122 could include an ultrasound transducer array (for example, arrays having 16, 32, 64, or 128 elements are utilized in some embodiments) utilizing focus transducer assemblies.

The rotation of imaging core 112 within sheath 110 is controlled by PIM 104. For example, PIM 104 provides user interface controls that can be manipulated by a user. In some embodiments PIM 104 may receive and analyze information received through imaging core 112. It will be appreciated that any suitable functionality, controls, information processing and analysis, and display can be incorporated into PIM 104. Thus, PIM 104 may include a processor circuit 154 and a memory circuit 155 to execute operations on catheter 102 and receive, process, and store data from catheter 102. In some embodiments PIM 104 receives data from ultrasound signals (echoes) detected by imaging core 112 and forwards the received echo data to control

system 106. Control system 106 may include a processor circuit 156 and a memory circuit 157 to execute operations on catheter 102 and receive, process, and store data from catheter 102. In some embodiments PIM 104 performs preliminary processing of the echo data prior to transmitting the echo data to control system 106. PIM 104 may perform amplification, filtering, and/or aggregating of the echo data, using processor circuit 154 and memory circuit 155. PIM 104 can also supply high- and low-voltage DC power to support operation of catheter 102 including the circuitry within transducer assembly 122.

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In some embodiments, wires associated with IVUS imaging system 100 extend from control system 106 to PIM 104. Thus, signals from control system 106 can be communicated to PIM 104 and/or vice versa. In some embodiments, control system 106 communicates wirelessly with PIM 104. Further according to some embodiments, catheter 102 may communicate wirelessly with PIM 104. Similarly, it is understood that, in some embodiments, wires associated with the IVUS imaging system 100 extend from control system 106 to monitor 108 such that signals from control system 106 can be communicated to monitor 108 and/or vice versa. In some embodiments, control system 106 communicates wirelessly with monitor 108.

The piezoelectric micro-machined ultrasound transducer (PMUT) fabricated using a polymer piezoelectric material, such as disclosed in U.S. Patent 6,641,540 that is hereby incorporated by reference in its entirety, offers greater than about 70% bandwidth, or about 75% bandwidth for optimum resolution in the radial direction, and a spherically-focused aperture for optimum azimuthal and elevation resolution. The electrical impedance of the transducer may be reduced to efficiently drive the electrical cable coupling the transducer to the IVUS imaging system by way of the PIM.

FIG. 1A illustrates a 3-dimensional (3D) Cartesian coordinate system XYZ oriented such that the Z-axis is aligned with the LA. In further descriptions of embodiments disclosed herein, a reference to a Cartesian plane or coordinate may be made in relation to FIG. 1A. One of ordinary skill will recognize that the particular choice of coordinate axes in FIG. 1A is not limiting of embodiments as disclosed herein. The choice of coordinate axes is done for illustration purposes only.

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FIG. 1B is a cross-sectional side view of a distal portion of a catheter used in an IVUS imaging system, according to some embodiments. In particular, Fig. 1B shows an expanded view of aspects of the distal portion of imaging core 112. In this exemplary embodiment, imaging core 112 is terminated at its distal tip by a housing 126 having a rounded nose and a cutout 128 for the ultrasound beam 150 to emerge from the housing. In some embodiments, a flexible driveshaft 132 of imaging core 112 is composed of two or more layers of counter wound stainless steel wires, welded, or otherwise secured to housing 126 such that rotation of the flexible driveshaft also imparts rotation to housing 126. In the illustrated embodiment, a PMUT MEMS transducer layer 121 includes a spherically focused portion facing cutout 128. In some embodiments, transducer assembly 122 may include applicationspecific integrated circuit (ASIC) 144 within distal portion 120 of imaging core 112. ASIC 144 is electrically coupled to transducer layer 221 through two or more connections. In that regard, in some embodiments of the present disclosure ASIC 144 may include an amplifier, a transmitter, and a protection circuit associated with PMUT MEMS layer 121. In some embodiments, ASIC 144 is flip-chip mounted to a substrate of the PMUT MEMS layer 121 using anisotropic conductive adhesive or suitable alternative chip-to-chip bonding method. When assembled together PMUT MEMS layer 121 and ASIC 144 form an ASIC/MEMS hybrid transducer assembly 122 mounted within housing 126. An electrical cable 134 with optional shield 136 may be attached to transducer assembly 122 with solder 140. Electrical cable 134 may extend through an inner lumen of the flexible driveshaft 132 to proximal end 118 of imaging core 112. In proximal end 118, cable 134 is terminated to an electrical connector portion of a rotational interface coupling catheter 102 to PIM 104 (cf. FIG. 1A). In the illustrated embodiment, transducer assembly 122 is secured in place relative to the housing 126 by an epoxy 148 or other bonding agent. Epoxy 148 may serve as an acoustic backing material to absorb acoustic reverberations propagating within housing 126 and as a strain relief for the electrical cable 134 where it is soldered to transducer assembly 122.

FIG. 2A is a partial illustration of a focusing transducer 122A, according to some embodiments. Transducer 122A includes a polymeric layer 221 having a first adjacent conductive layer 222a and a second adjacent conductive layer 222b.

Polymeric layer 221 includes a piezo-electric polymer material made into a concave shape as depicted in FIG. 2A. In some embodiments, the polymer used in polymeric layer 221 may be a ferroelectric polymer such as polyvinylidene fluoride (PVDF). Further according to some embodiments, polymeric layer 221 may include PVDF-co-trifluoroethylene (PVDF-TrFE) as a piezo-electric material. A voltage 230 (V) is applied between conductive layers 222a and 222b in order to generate focused ultrasound beam 250A. Likewise, in some embodiments an incident ultra-sound beam 250A may impinge on polymeric layer 221 and produce a deformation leading to a voltage difference V 230 between conductive layers 222a and 222b.

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In some embodiments, the concavity of transducer 122A may be a section of a sphere. In some embodiments, the concavity of transducer 122A is directed radially outward, in a plane perpendicular to the LA (i.e., XY-plane in FIG. 2A). Accordingly, in rotational IVUS embodiments, transducer 122A rotates about the LA, thus sweeping focused beam 250A radially in the XY plane. In some embodiments, while transducer 122A may include a planar polymeric layer, an acoustic 'lens' may be placed adjacent to transducer 122A. Thus, focused acoustic beam 250A may be generated by acoustic wave refraction. Still further, the material forming sheath 110 may have an acoustic impedance, thereby focusing the acoustic wave propagating through sheath 110.

FIG. 2B is a partial illustration of a focusing transducer 122B, according to some embodiments. Transducer 122B may have a polymeric layer 221 with a concavity oriented along the LA. Focusing transducer 122B includes a rotating reflective element 225 to direct focusing ultrasonic beam 250B radially out of axial direction LA. According to some embodiments, focused ultrasonic beam 250B may be generated substantially along the blood vessel, or the LA axis. Then, beam 250B may be deflected radially outward by rotating reflective element 225, as shown in FIG. 2B.

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Still further, the output of the transducer or a reflecting element may be oriented to generally align with the longitudinal axis LA. These devices may be swept through an arc to generate forward looking images.

Focused ultrasonic beams 250A, 250B have a focal distance 210 (f) converging into a focal waist 220 (ω). Accordingly, the focal waist has a diameter that may be less than 50 μm. Focal distance 210 is determined from the curvature of the surface formed by transducers 122A, 122B, and the refractive index of the propagation medium of focused acoustic beam 250. Typically, the propagation medium is blood, plasma, a saline solution, or some other bodily fluid. In some embodiments, focal distance 'f' may be as long as 10 mm, or more. Thus, the tissue penetration depth of focused ultrasonic beams 250A, 250B may be 5 mm, 10 mm, or more.

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Focal distance 210 and focal waist 220 may also be determined by the curvature of the aperture. In some embodiments focused acoustic beam 250A, B may include a plurality of acoustic frequencies in a frequency bandwidth. The frequency bandwidth may be determined by the polymer material and the shape of polymeric layer 221. The structure of the transducer assembly including backing, electrodes, and matching layers may determine the acoustic frequency bandwidth of transducers 122A, 122B. The viscoelastic properties of the polymer material may also determine the acoustic frequency bandwidth of transducers 122A, 122B.

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Accordingly, some embodiments have a polymeric layer 221 such that an ultrasonic signal produced by transducers 122A, 122B includes a frequency bandwidth from about 5 to about 135 Mega Hertz (MHz, 1 MHz = 10^6 Hz). Embodiments of catheters 102 including a transducer such as transducers 122A, 122B allow for a better image resolution since ultrasonic beams 250A, 250B are focused.

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Further according to some embodiments, the material and shape of distal portion 116 of sheath 110 may be selected to match the acoustic impedance of the materials in transducer 122 and the target structure (e.g., blood vessel wall). Impedance matching of the acoustic signal across all elements in the distal portion of catheter 102 is desirable to enhance the response of transducer 122 to the acoustic echo coming from the blood vessel wall. Embodiments of materials and shapes of distal portion 116 of sheath 110 to match the acoustic impedance in transducer 122 may be as disclosed in co-pending U.S. Patent Application entitled "Intravascular Ultrasound Catheter for Minimizing Image Distortion," Attorney Ref. No. 44755.938,

hereby incorporated by reference in its entirety, for all purposes. Impedance matching layers can also be used to modify impedance match

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FIG. 3 is a cross-sectional illustration of an IVUS catheter 102 inside a blood vessel 300, according to some embodiments. Blood vessel 300 includes a lumen 310, typically filled with a blood flow. FIG. 3 also shows a stenosed segment in blood vessel 300. The stenosis may include a plaque formed by a fibrous cap 320 adjacent to a necrotic core 330 formed in an interior side of a layer adventitia340. Accordingly, methods for using an IVUS catheter in FACT enable the classification of a plaque in a stenosed segment of a blood vessel, such as illustrated in FIG. 3. For example, a plaque may be classified as 'vulnerable' to rupture, based on the size, configuration, and nature of its components. A component of a plaque within a vessel may be fibrous cap 320, and necrotic core 330. In some configurations a component of a plaque within a vessel may include fat cell tissue and macrophage cells. The nature of a component of a plaque within a vessel may include substances such as elastin, collagen and cholesterol. The viscoelastic properties of the substances and the configuration of the different components included in a plaque within a vessel provide a differentiated acoustic response. Thus, interaction with a focused ultrasound beam 350 may produce an image that clearly differentiates the components of the plaque, their nature, and their configuration (size and shape).

FIG. 3 depicts a focused ultrasonic beam 350 directed axially from catheter 102 toward the wall of blood vessel 300. Ultrasonic beam 350 is generated by transducer 122 inside distal end portion 120 of imaging core 112, and passes through distal end portion 116 of sheath 110 and blood plasma or a saline solution in lumen 310. According to some embodiments, focused ultrasonic beam 350 may be rotating about the LA of catheter 102, in a trajectory projected as a circle in the XY plane in FIG. 3.

In some embodiments, focused ultrasonic beam 350 may be reflected from the wall of blood vessel 300 towards transducer 122 in distal end portion 120 of imaging core 112. Thus, a reflected ultrasound signal may be recorded by PIM 104, providing information about the tissue in the wall of blood vessel 300. The reflected ultrasound signal may be the echo of a focused ultrasound signal projected onto the wall of blood

vessel 300 from transducer 122 in the distal end 120 of imaging core 112. Beam 350 sweeps about the LA forming an arc, scanning a volume of the patient's tissue.

FIG. 4 is a longitudinal illustration of an IVUS catheter 102 inside a blood vessel 300, according to some embodiments. Focused ultrasound beam 450 is directed radially onto blood vessel wall 340 in a direction forming an azimuthal angle 455 (θ) with axis LA (along the Z-axis). Accordingly, angle 455 may have any value between zero (0°) and ninety (90°) degrees. In some embodiments, angle 455 may be larger than 90°, and close to 180°. FIG. 4 shows a blood 410 flowing in a direction substantially away from distal end 116 of catheter 102. In some embodiments, blood 410 may be flowing in a direction substantially away from a proximal end of catheter 102 (i.e., opposite of what is shown in FIG. 4). In general, blood flow is substantially parallel to the LA (Z-axis in FIG. 4), either along the +Z direction, or along the -Z direction.

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In some embodiments as illustrated in FIG. 4, angle 455 may be 90° so that a transverse scan is obtained as focused ultrasound beam 450 is rotated about the LA. Thus, a transverse plane scan substantially parallel to the XY-plane may be obtained.

In some embodiments angle 455 is not perpendicular (90°) to the LA. For example, in some embodiments angle 455 may be less than 90° in a forward looking IVUS catheter. In configurations where angle 455 is not perpendicular, a component of the blood flow velocity along the direction of focused ultrasound beam 450 may be different from zero (0). When this is the case, an acoustic echo received from blood vessel wall 340 may be slightly shifted in frequency, by virtue of the Doppler effect. The frequency shift of the ultrasonic echo is related to the component of the flow velocity along the direction of focused ultrasound beam 450. For example, a frequency shift of the ultrasonic echo signal may be directly proportional to the magnitude of the component of the flow velocity along the direction of focused ultrasound beam 450. Thus, using knowledge of angle 455 and measuring the frequency shift of the echo signal, a blood flow speed may be obtained.

FIG. 5 is a longitudinal illustration of an IVUS catheter 102 inside a blood vessel 300, according to some embodiments. According to FIG. 5, IVUS catheter 102

axially advances along blood vessel 300. Blood vessel 300 may include a stenosed segment 500, having a plaque. The plaque within vessel 300 may include fibrous cap 320 on top of necrotic tissue 330. Blood vessel 300 also includes muscle cell tissue 340, as described in detail above (cf. FIGS. 3-4).

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Focused ultrasound beam 350 forms a predetermined pattern 550 as it rotates around LA and catheter 102 is displaced in the +Z direction. For example, in some embodiments consistent with the present disclosure a predetermined pattern 550 may be a helicoid trajectory. In some embodiments, transducer 122 is retracted from, or pulled back through blood vessel 300. That is, distal end 116 is displaced in the -Z direction, according to some embodiments. Advancing and retracting transducer 122 along vessel 300 may be accomplished manually or with an automated system. Without limiting embodiments of the present disclosure, a retracted displacement (along the -Z direction) of transducer 122 will be assumed hereinafter.

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As transducer 122 is retracted through the blood vessel 300, ultrasound echo signals collected along pattern 550 may be used to create an image of the blood vessel wall. The image of the blood vessel wall may be a 3D image including a plurality of cross sections of the blood vessel wall. The cross sections of the blood vessel wall may be substantially aligned with planes XY perpendicular to the Z-axis (i.e., the LA direction), along different points on the Z-axis. The image generated from pattern 550 may be processed by PIM 104 and control system 106 using an image characterization application, or code. The image characterization application may render a characterized tissue component map. In some embodiments, the image characterization application performs a spectral analysis of ultrasound echo information for a vessel cross-section. Thus, different plaque components may be determined and distinguished in the characterized tissue component map. example, the characterization application may use a classification criterion including a rule based upon a location of a confluence of necrotic core 330 within the vessel cross-section in relation to a border between the lumen 310 and a plaque. A classification criterion may include a rule, based upon a location, in relation to a lumen-plaque border, of confluent necrotic core within the vessel cross-section; and rendering, in response to the classification, a plaque classification associated with the vessel cross-section. For example, a classification criterion may use the thickness of

fibrous cap 320 to determine the vulnerability of a plaque, and the likelihood of plaque rupture and thrombosis.

FIG. 6 is a flow chart illustrating steps in a method 600 for focus acoustic computed tomography (FACT), according to some embodiments. According to some embodiments, method 600 may be performed by control system 106 using processor circuit 156 and memory circuit 157 and/or PIM 104 using processor circuit 154 and memory circuit 155, based on scan data provided by transducer assembly 122 (cf. FIG. 1). Accordingly, some steps in method 600 may be performed by control system 106 and some steps in method 600 may be performed by PIM 104. A reconstructed image plane in method 600 may be provided to a user in display 108.

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Step 610 includes generating an ultrasonic signal. In some embodiments, the ultrasonic signal may be generated from a transducer assembly (e.g., transducer assembly 122, cf. FIG. 1) in the form of an ultrasound acoustic beam following a path. The ultrasound acoustic beam path may be a focused path (e.g., focused acoustic beam 350, cf. FIG. 3) to produce a focal region of high acoustic intensity in a target portion of a tissue. Step 610 may include providing a voltage pulse to a transducer element (e.g., V 230, cf. FIGS. 2A, B). Accordingly, voltage pulse V 230 may be provided by PIM 104 to transducers 122A, B for a pre-selected period of time in step 610. Furthermore, voltage pulse V 230 may be provided in a series of pulses produced at a preselected frequency, in step 610.

Step 620 includes scanning the ultrasonic signal in a predetermined pattern about the interior wall of a structure. In some embodiments, step 620 may include sweeping the ultrasonic signal continuously in a predetermined pattern about the interior vessel wall. According to some embodiments, the sweeping is accomplished by rotating the transducer or a reflective surface which deflects the signal from the transducer within a catheter. The catheter may remain substantially stationary while the transducer is rotated and the acoustic signal is swept around the LA of the catheter. In some embodiments, the transducer is moved longitudinally, as it rotates about the LA to create a helical pattern (e.g., pattern 550, FIG. 5). In some embodiments, step 620 may be performed manually by an operator, or automatically through a motor included in PIM 104.

Step 630 includes receiving an ultrasonic echo from the interior wall of the structure. According to some embodiments, step 630 may be performed using a transducer, such as transducers 122A, 122B described in detail above, in relation to FIGS. 2A and 2B. Thus, upon receiving the ultrasonic echo from the interior wall of the structure, a deformation induced in a piezo-electric material in the transducer may result in a voltage signal. The transducer may further be configured to couple the voltage signal out of a vessel region into a processor circuit, such as processor circuit 154 in PIM 104.

In some embodiments, step 630 may be performed during a period of time between two voltage pulses from step 610. Thus, according to some embodiments in step 610 a voltage signal travels from processor circuit 154 in PIM 104 into transducer assembly 122 along catheter 102 (cf. FIG. 1). Further according to some embodiments, in step 630 a voltage signal travels from transducer assembly 122 to processor circuit 154 in PIM 104. In some embodiments, step 630 may include selecting a frequency band from the voltage received in the PIM. Accordingly, the high-bandwidth of transducer 122 may enable the selection of different frequency bands within the response band of the transducer. Selecting a specific frequency band enables PIM 104 to reconstruct images from selected portions of the tissue structure. For example, the focal distance of a focused acoustic beam may be selected by selecting a frequency band in the voltage received from the transducer in step 630. Thus, the penetration depth of the acoustic echo signal may be selected in PIM 104 by selecting the frequency band of receive amplifier 114 in step 630.

Step 640 includes amplifying the ultrasonic echo in a processor circuit. The processor circuit in step 640 may be as processor circuit 154 in PIM 104 (cf. FIG. 1). According to some embodiments, the processor circuit in step 640 may include an ASIC provided adjacent to the transducer, in a distal portion of the catheter (e.g., ASIC 144, cf. FIG. 1B). Step 650 includes producing an image from the ultrasonic echo. According to some embodiments, step 650 may be performed partially by PIM 104. In some embodiments, step 650 may be performed partially by control system 106. According to some embodiments, step 650 includes producing a 2-dimensional image (2D-image) of a cross section of the blood vessel wall. The cross-section may

be substantially parallel to an XY-plane perpendicular to a LA oriented along the blood vessel. In some embodiments, step 650 includes producing a 3-dimensional image (3D-image) of the blood vessel wall from a plurality of 2D-images. According to embodiments as described herein, step 650 may include forming an image with axial resolution better than $50 \, \mu m$.

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In some embodiments, step 650 may include complementing the image obtained from the IVUS catheter with an image obtained using an optical beam scanning technique, such as optical coherence tomography (OCT). For example, using an OCT system a high resolution image of a deep tissue structure may be obtained. Such a deep tissue image may be complemented with an IVUS image of tissue portions close to the catheter, including blood stream in a blood vessel.

Step 660 includes classifying the image from the ultrasonic echo. Step 660 may be performed by processor circuit 156 and memory circuit 157 in control system 106. In some embodiments, step 660 is performed by processor circuit 156 executing commands, retrieving and storing data, the commands and the data being stored in memory circuit 157. For example, in some embodiments the commands executed by processor circuit 156 in control system 106 may be included in an image characterization application stored in memory circuit 157. The image characterization application may be as described in detail above, in relation to FIG. 5. Image characterization applications as used in step 660 may be as disclosed in US PAT. No. 7,627,156 entitled "Automated lesion analysis based upon automatic plaque characterization according to a classification criterion," US PAT. No. 7,175,597 entitled "Non-Invasive Tissue Characterization System and Method," and US PAT. No. 6,200,268 entitled "Vascular Plaque Characterization," each incorporated herein by reference in its entirety, for all purposes.

FIG. 7 is a flow chart illustrating steps in a method 700 for recanalization of a blood vessel using FACT, according to some embodiments. According to some embodiments, method 700 may be performed partially by system 100 and an external operator handling a recanalization tool. Steps performed by system 100 may be partially executed by control system 106 using processor circuit 156 and memory circuit 157. In some embodiments, steps performed by system 100 may be partially

executed by PIM 104 using processor circuit 154 and memory circuit 155 based on scan data provided by transducer assembly 122 (cf. FIG. 1). A reconstructed image plane in method 700 may be provided to the external operator in display 108. Thus, the external operator makes a decision of whether or not to excise a portion of the stenosed segment of the blood vessel using a recanalization tool based on the reconstructed image plane on display 108. According to some embodiments the recanalization tool may be a physical instrument having a sharp end on an abrasive surface. In some embodiments, the recanalization tool may be a laser beam susceptible of being directed to a point in the blood vessel and ablate a tissue portion.

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Step 710 includes positioning a flexible member within a blood vessel. A flexible member in step 710 may be as catheter 102, including a rotating imaging core 112 and a sheath 110. Step 710 may further include positioning catheter 102 with its LA substantially aligned with the blood vessel, inside the lumen portion of the blood vessel. Step 720 includes generating an ultrasonic signal. Step 720 may be as step 610, described in detail above in relation to method 600. Step 730 includes scanning the ultrasonic signal in a predetermined pattern about the interior wall of a structure including a region of stenosis. In some embodiments, the predetermined pattern may be as pattern 550 described in detail above (cf. FIG. 5). The region of stenosis may also be as stenosed segment 500, described in detail above (cf. FIG. 5).

Step 740 includes receiving an ultrasonic echo from the interior wall of the structure. Accordingly, step 740 may be as step 630 described in detail above, in relation to method 600. Step 750 includes amplifying the ultrasonic echo in a processor circuit. Step 750 may be as step 640 described in detail above, in relation to method 600. Step 760 includes producing an image from the region of stenosis, and may be as step 650 described in detail above in relation to method 600. Step 770 includes classifying the image from the region of stenosis, and may be as step 660 described in detail above in relation to method 600.

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Step 780 includes querying whether or not the region of stenosis needs a recanalization procedure. A decision in step 780 may be made according to the detected vulnerability of a plaque that may be present in the region of stenosis. For example, when an image from the region of stenosis is classified as 'vulnerable

plaque' in step 770, a recanalization may be recommended in step 780. When an image from the region of stenosis is classified in a category other than 'vulnerable plaque,' method 700 may be repeated from step 710. Thus, catheter 102 may be repositioned at a different point along the blood vessel.

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Step 790 includes recanalizing the region of stenosis. According to some embodiments, step 790 may be performed prior to steps 720 through 760. In some embodiments, step 790 may be performed after steps 720 through 760. Further according to some embodiments, step 790 may be performed at any point during execution of any one of steps 720 through 760. In some embodiments step 790 may include providing heat to a target region (e.g., stenosed segment 500, cf. FIG. 5) to mitigate the stenosis. In some embodiments, step 790 may include ablation, use of an abrasive surface, drug delivery, stenting, and drilling, to remove the stenosis. For example, step 790 may include lightly rubbing an abrasive surface against the tissue to remove a stenosed segment.

Embodiments of the invention described above are exemplary only. One skilled in the art may recognize various alternative embodiments from those specifically disclosed. Those alternative embodiments are also intended to be within the scope of this disclosure. As such, the invention is limited only by the following claims.

Claims

What is claimed is:

1. A method for acoustic tomography within a patient, the method comprising:

generating a focused ultrasonic signal using a transducer, the ultrasonic signal forming a path within the patient;

directing the ultrasonic signal on a spot within the patient;

scanning the spot in a predetermined pattern about a volume within

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receiving an ultrasonic echo in the transducer;

converting the ultrasonic echo into a voltage;

selecting a frequency band from the voltage;

amplifying the voltage in the selected frequency band with a

processing circuit; and

generating an image of the volume within the patient structure utilizing the amplified voltage.

- The method of Claim 1 wherein the converting the ultrasonic echo into a
 voltage includes using an Application Specific Integrated Circuit (ASIC) proximal to the transducer.
 - 3. The method of Claim 2 wherein the ASIC and the transducer are positioned in a distal end of a catheter.

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- 4. The method of Claim 3 wherein the scanning the spot in a predetermined pattern about a volume comprises rotating an imaging core about a longitudinal axis inside the catheter.
- The method of Claim 4 wherein the rotating an imaging core comprises rotating a reflective element about a longitudinal axis of the catheter.

6. The method of Claim 1 wherein generating a focused ultrasonic beam comprises generating a focused beam having a bandwidth that is more than 70% of the center frequency.

- 5 7. Wherein the generating a focused ultrasonic signal comprises using a piezoelectric polymeric transducer.
 - 8. The method of Claim 1 wherein scanning the spot in a predetermined pattern includes forming a helical pattern.

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- 9. The method of Claim 1, wherein the volume within a patient comprises a wall of a blood vessel; and the providing an image from the echo signal includes providing a cross section of the blood vessel.
- 15 10. The method of Claim 10, further comprising classifying a plaque within the wall of the blood vessel.
- The method of Claim 11 wherein classifying the plaque within the wall of the blood vessel comprises rendering a characterized tissue component map.
 - 12. The method of Claim 11 wherein rendering the characterized tissue component map comprises:

spectrally analyzing the ultrasonic echo;

distinguishing different plaque components in the characterized tissue component map;

assigning identifying values to the different plaque components; applying a classification criterion to spatially arranged data of the characterized tissue map; and

- rendering a plaque classification associated with the cross section of the blood vessel.
- 13. The method of Claim 1, wherein the ultrasonic signal has a

frequency in the range from 5 MHz to 135 MHz.

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14. The method of Claim 1 wherein the generating an image of the volume within the patient includes reconstructing a three-dimensional (3D) image using two-dimensional data.

- 15. The method of Claim 1, wherein the generating the ultrasonic signal comprises directing the ultrasonic signal along a direction substantially parallel to a longitudinal axis of the volume within the patient, and further comprising deflecting the ultrasonic signal transversally with respect to the longitudinal axis by a rotating reflective element.
- 16. The method of Claim 1, wherein the generating the ultrasonic signal comprises directing the ultrasonic signal transversally with respect to a longitudinal axis of the volume within the patient by a rotating transducer.
 - 17. The method of Claim 1, wherein the spot within the patient has a diameter of less than 50 μm .
- 20 18. The method of Claim 1 wherein the spot within the patient is located at a depth of about 10 mm, or less from a surface of a tissue structure within the patient.
- 19. The method of Claim 1, wherein the generating the ultrasonic signal comprises directing the ultrasonic signal at an angle from about 0° to about 180° relative to a longitudinal axis of the volume within the patient.
 - 20. The method of Claim 19 further comprising:

measuring a frequency shift in the ultrasonic echo signal relative to the generated focused ultrasonic signal; and

determining a flow rate of a fluid in a lumen of the volume within the patient using the measured frequency shift.

21.	The method of Claim 1 further comprising displacing the ultrasonic
	transducer along a longitudinal axis of the volume within the patient; and
	providing a plurality of cross-sectional images of the volume within
	the patient collected along the longitudinal axis.

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22. The method of Claim 21 wherein displacing the ultrasonic transducer comprises at least one of the steps selected from the group consisting of manually displacing the transducer and automatically displacing the transducer.

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- 23. The method of Claim 21 wherein displacing the ultrasonic transducer comprises at least one of the steps selected from the group consisting of retracting the transducer and advancing the transducer.
- 15 24. A method for recanalization of a blood vessel, the method comprising:

positioning a flexible member within the blood vessel proximal to a pre-selected area of interest;

generating a focused ultrasonic signal using a transducer, the ultrasonic signal forming a path within the blood vessel;

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directing the ultrasonic signal on a spot within the blood vessel; scanning the spot in a predetermined pattern about a volume within the patient;

receiving an ultrasonic echo in the transducer;

converting the ultrasonic echo into a voltage;

selecting a frequency band from the voltage;

amplifying the voltage in the selected frequency band with a processing circuit; and

recanalizing a lumen in the blood vessel based on the image.

30 25. The method of Claim 24 wherein the pre-selected area of interest comprises a stenosed segment of the blood vessel; and

the predetermined pattern comprises the stenosed segment of the blood vessel.

26. The method of Claim 25 wherein the recanalizing the lumen in the blood vessel based on the image comprises at least one of the steps in the group consisting of:

directing an ablation laser to a point of interest;
removing a portion of the stenosed segment of the blood vessel
with an abrasive surface; and
delivering a drug to the point of interest.

- 10 27. The method of Claim 24, further comprising classifying a plaque within the wall of the blood vessel.
- 28. The method of Claim 27 wherein the recanalizing the lumen in the blood vessel is performed when the classifying a plaque indicates that the plaque is a vulnerable plaque.

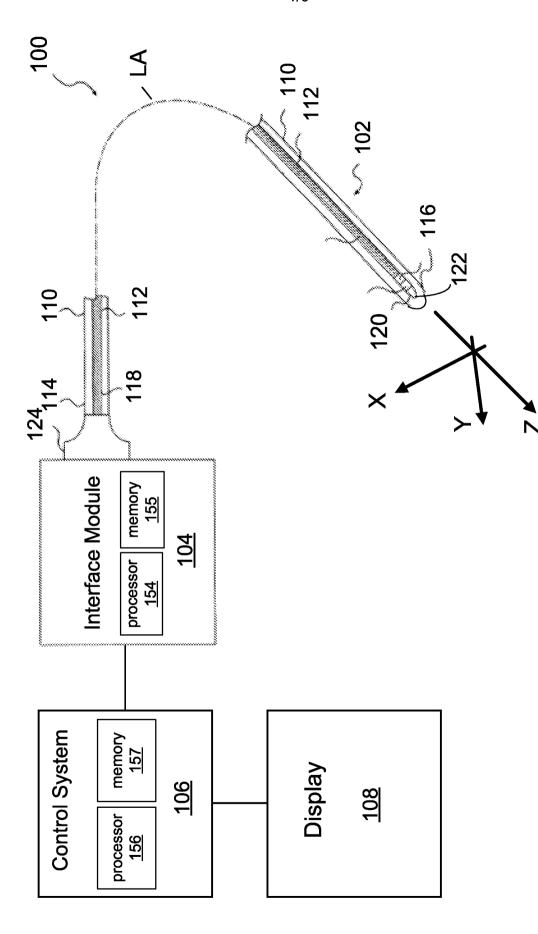
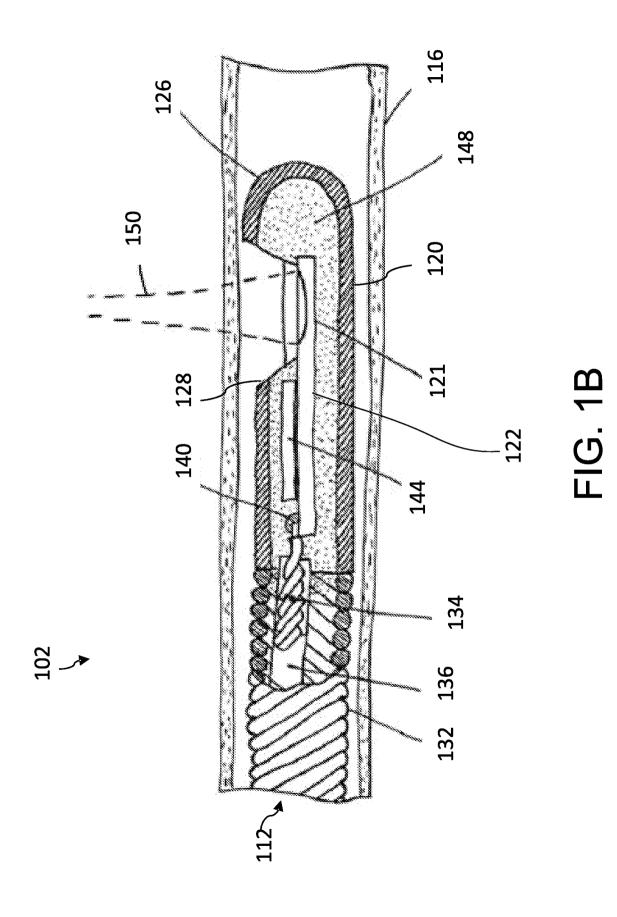
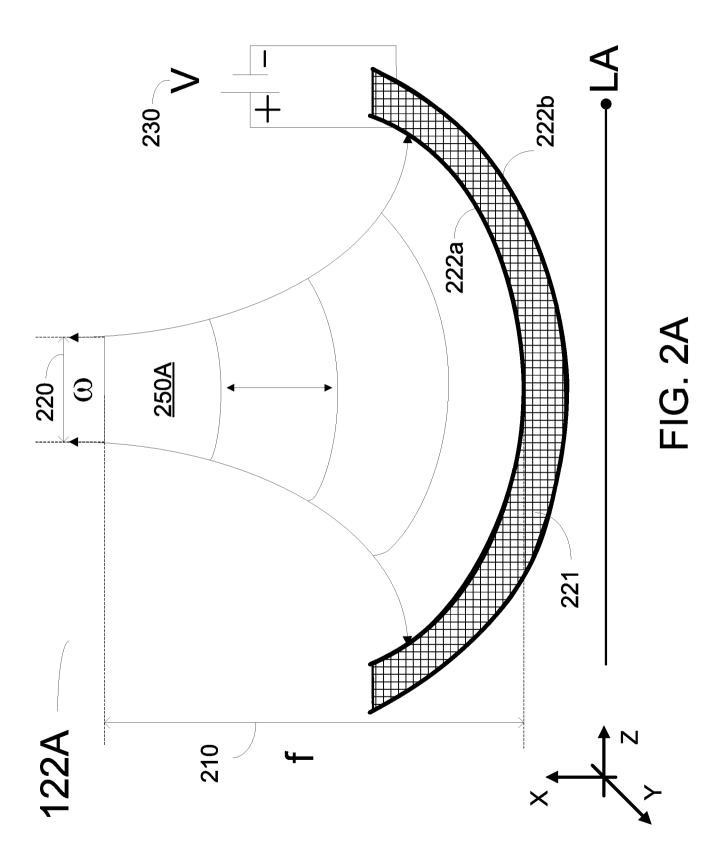
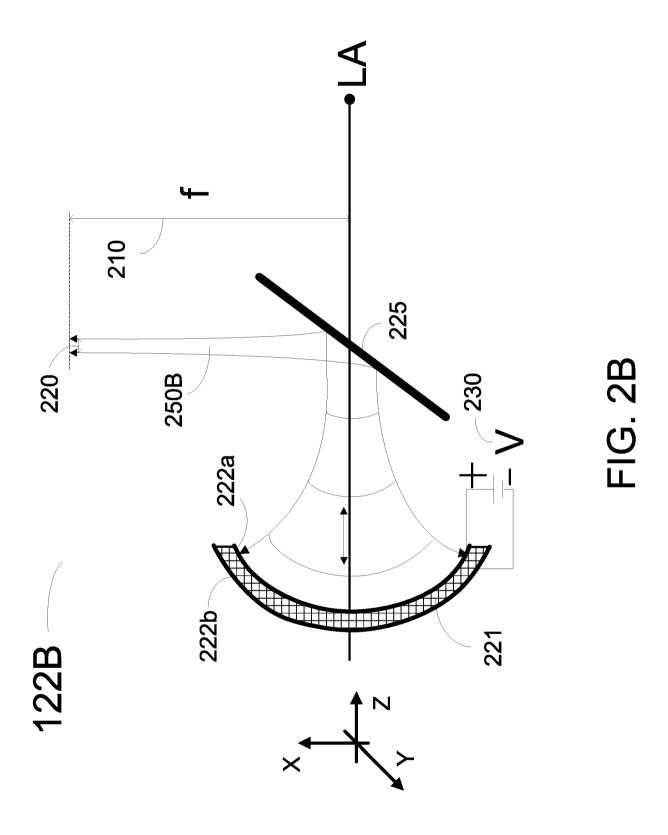


FIG. 1A

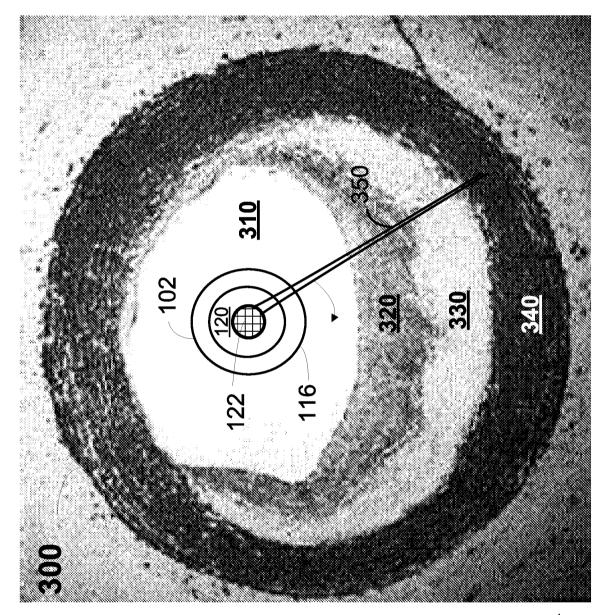


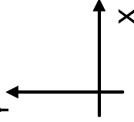


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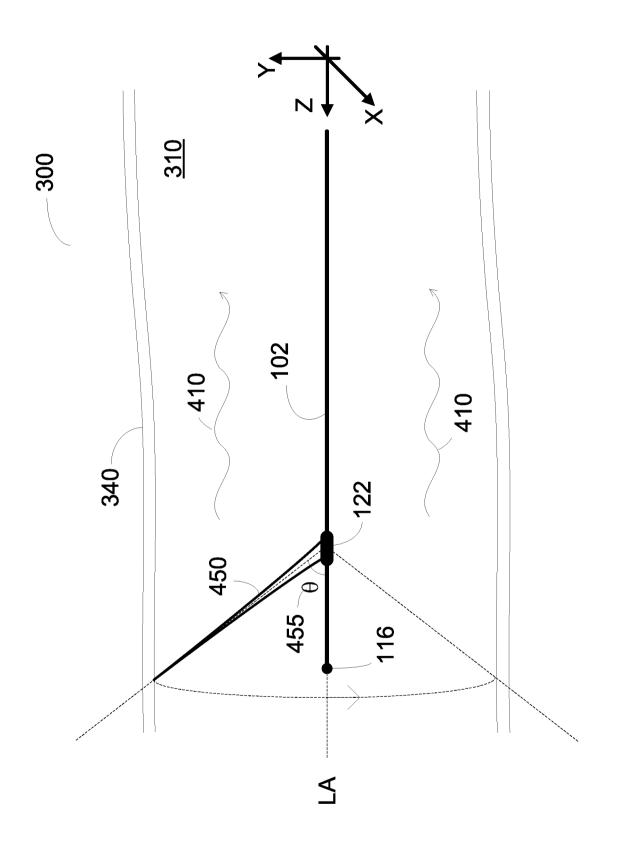


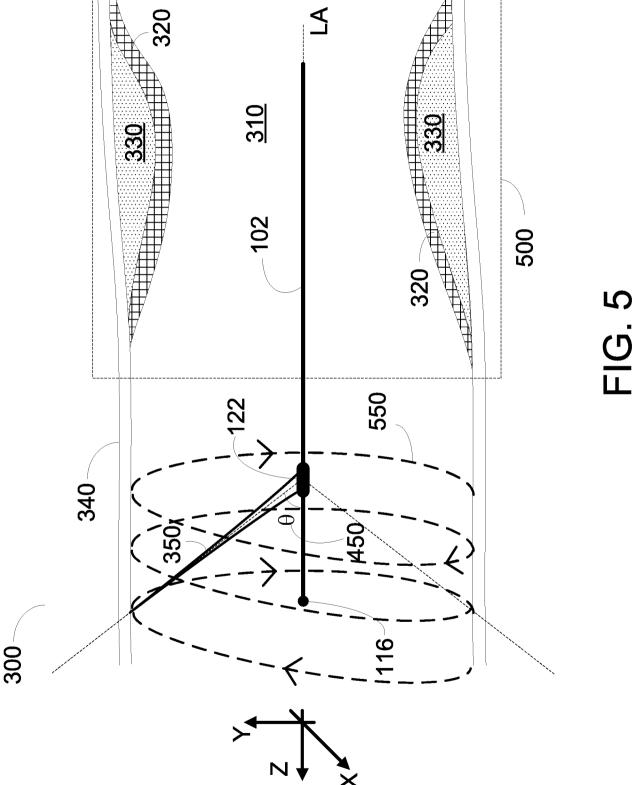












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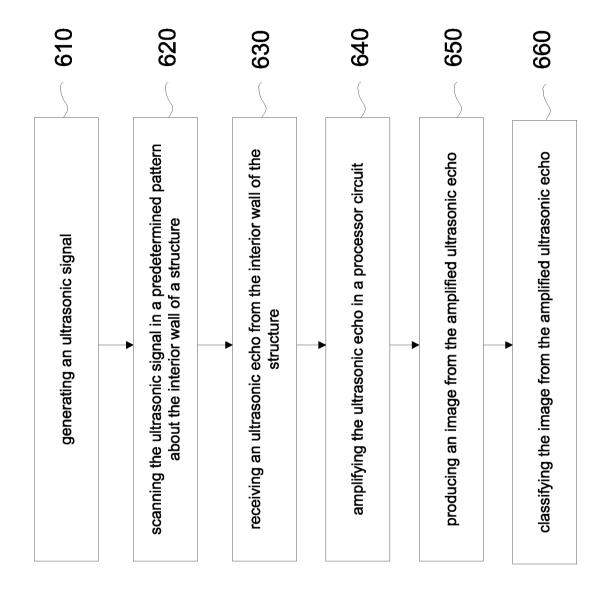


FIG. 6

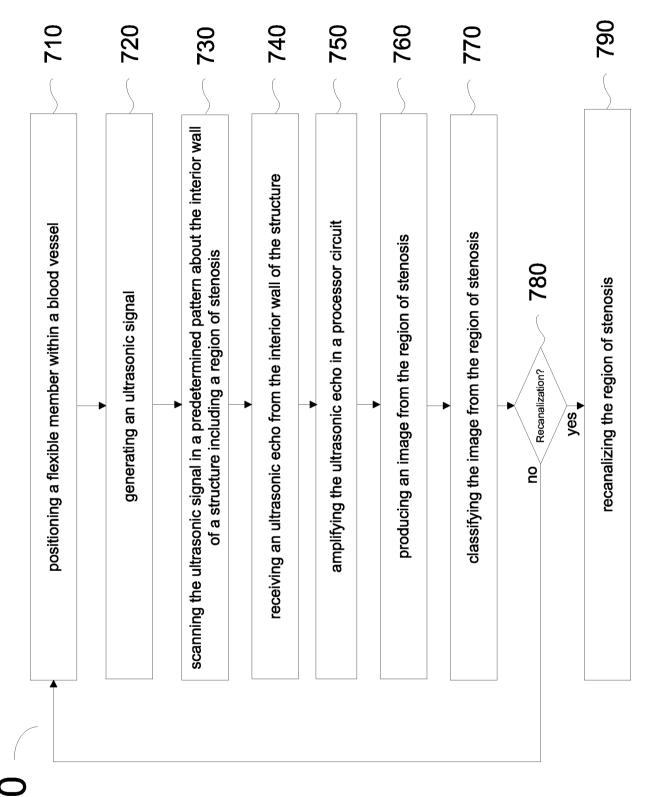


FIG. 7

International application No. **PCT/US2013/076215**

A. CLASSIFICATION OF SUBJECT MATTER

A61B 8/12(2006.01)i, A61B 8/13(2006.01)i

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 8/12; A61N 7/00; A61B 8/14; A61N 7/02; A61N 5/067; A61B 8/00; A61B 8/13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: focused-ultrasonic, volumetric, recanalization, intravascular, signal, FACT, ASIC, and imaging

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2012-136786 A1 (INSERM (INSTITUT NATIONAL DE LA SANT ET DE LA RECHERCHE MDICALE)) 11 October 2012 See abstract, page 16, claim 1, and figure 1.	1-23
A	US 2012-0271170 A1 (EMELIANOV, STANISLAV et al.) 25 October 2012 See abstract, claims 1-3, and figures 1A-5B.	1-23
A	US 2012-0220874 A1 (HANCOCK, ANDREW et al.) 30 August 2012 See abstract, and claims 30-37.	1-23
A	US 6544187 B2 (SEWARD, JAMES B.) 08 April 2003 See abstract, claims 1, 19-23 and figures 1-3.	1-23
A	US 2005-0277835 A1 (ANGELSEN, BJORN A.J. et al.) 15 December 2005 See abstract, and claims 34-39.	1-23

	Further documents are listed in the continuation of Box C.		\boxtimes	See patent family annex.
*	Special categories of cited documents:	"T"	later d	ocument published after the international filing date or priority
"A"	document defining the general state of the art which is not considered		date ar	nd not in conflict with the application but cited to understand
	to be of particular relevance		the pri	nciple or theory underlying the invention
"E"	earlier application or patent but published on or after the international	$^{"}X"$	docum	ent of particular relevance; the claimed invention cannot be
	filing date		consid	ered novel or cannot be considered to involve an inventive
"L"	document which may throw doubts on priority claim(s) or which is		step w	hen the document is taken alone
	cited to establish the publication date of another citation or other	"Y"	docum	ent of particular relevance; the claimed invention cannot be
	special reason (as specified)		consid	ered to involve an inventive step when the document is
"O"	document referring to an oral disclosure, use, exhibition or other		combin	ned with one or more other such documents, such combination
	means		being o	obvious to a person skilled in the art
"P"	document published prior to the international filing date but later	"&"	docum	ent member of the same patent family
	than the priority date claimed			
Date	of the actual completion of the international search	Date	of mai	lling of the international search report

Date of the actual completion of the international search
10 April 2014 (10.04.2014)

Date of mailing of the international search report
10 April 2014 (10.04.2014)

Name and mailing address of the ISA/KR
International Application Division

Authorized officer



International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2013/076215

Box No. II Observations where cert	ain 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:			
Claims 24-28 pertain to metho	matter not required to be searched by this Authority, namely: ods for treatment of the human body by surgery, and thus relate to a subject matter which this ority is not required, under Article 17(2)(a)(i) of the PCT and Rule 39.1(iv) of the Regulations			
	the international application that do not comply with the prescribed requirements to such an national search can be carried out, specifically:			
3. Claims Nos.: because they are dependent cl	aims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).			
Box No. III Observations where unit	y of invention is lacking (Continuation of item 3 of first sheet)			
This International Searching Authority	ound multiple inventions in this international application, as follows:			
As all required additional searce claims.	h fees were timely paid by the applicant, this international search report covers all searchable			
2. As all searchable claims could of any additional fees.	be searched without effort justifying an additional fees, this Authority did not invite payment			
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.:				
payme The ac	dditional search fees were accompanied by the applicant's protest and, where applicable, the ent of a protest fee. Idditional search fees were accompanied by the applicant's protest but the applicable protest as not paid within the time limit specified in the invitation. In the protest and the payment of additional search fees.			

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/076215

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012-136786 A1	11/10/2012	EP 2699316 A1 US 2014-024923 A1	26/02/2014 23/01/2014
US 2012-0271170 A1	25/10/2012	WO 2011-053931 A2 WO 2011-053931 A3	05/05/2011 25/08/2011
US 2012-0220874 A1	30/08/2012	US 2010-174190 A1 US 8187191 B2	08/07/2010 29/05/2012
US 6544187 B2	08/04/2003	US 2002-0128554 A1 US 2003-0171667 A1 US 6398736 B1	12/09/2002 11/09/2003 04/06/2002
US 2005-0277835 A1	15/12/2005	US 2004-0267129 A1 US 2004-0267130 A1 US 2006-0052699 A1 US 7641613 B2 US 8038616 B2	30/12/2004 30/12/2004 09/03/2006 05/01/2010 18/10/2011