(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 435 835 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
11.02.2009 Bulletin 2009/07

(21) Application number: **02805927.7**

(22) Date of filing: **09.10.2002**

(51) Int Cl.:
A61B 5/00 *(2006.01)* ***A61B 8/12*** *(2006.01)*
G01N 29/06 *(2006.01)* ***G01N 21/47*** *(2006.01)*

(86) International application number:
PCT/US2002/032277

(87) International publication number:
WO 2003/055383 (10.07.2003 Gazette 2003/28)

(54) **SYSTEM AND METHOD FOR PROCESSING SIGNALS FROM AN INTERFEROMETER BY AN ULTRASOUND CONSOLE**

SYSTEM UND VERFAHREN ZUR VERARBEITUNG VON SIGNALEN VON EINEM INTERFEROMETER ÜBER EIN ULTRASCHALLPULT

SYSTEME ET PROCEDE POUR LE TRAITEMENT DE SIGNAUX PROVENANT D'UN INTERFEROMETRE PAR UNE CONSOLE A ULTRASONS

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR IE IT LI LU MC NL PT SE SK TR

(30) Priority: **18.10.2001 US 20040**

(43) Date of publication of application:
14.07.2004 Bulletin 2004/29

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- **WARREN S ET AL: "COMBINED ULTRASOUND AND FLUORESCENCE SPECTROSCOPY FOR PHYSICO- CHEMICAL IMAGING OF ATHEROSCLEROSIS" IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, IEEE INC. NEW YORK, US, vol. 42, no. 2, 1 February 1995 (1995-02-01), pages 121-132, XP000556788 ISSN: 0018-9294**

Printed by Jouve, 75001 PARIS (FR)

Description

Related Applications

[0001] The present application is a continuation-in-part of U.S. Patent Application Serial No. 09/909,357, filed on July 18, 2001, and U.S. Patent Application Serial No. 09/906,903, filed on July 16, 2001, which are assigned to the assignee of the present application.
This application is related to U.S. Patent Application Serial No. 10/017,534, titled DIFFRACTION GRATING BASED INTERFEROMETRIC SYSTEMS AND METHODS, filed on the same day as the present application and assigned to the assignee of the present application.

Field of the Invention

[0002] The invention relates generally to imaging systems and methods, and, more particularly, to the processing of data from Optical Coherence Tomographic systems.

Background of the Invention

[0003] Ultrasound medical imaging is a commonly used procedure to produce images of internal body cavities such as blood vessels and surrounding tissue. In ultrasound imaging of a blood vessel, an Intravascular Ultrasound ("IVUS") catheter is typically inserted into the blood vessel in a known manner. The IVUS catheter comprises an elongated member with an ultrasound transducer located at a distal end of the elongated member. The elongated member is inserted into the blood vessel, and the ultrasound transducer is positioned at a desired location in the blood vessel. The transducer emits ultrasound waves in the blood vessel or other such cavity when excited by a pulse. A portion of the emitted ultrasound waves is reflected back to the ultrasound transducer by tissue boundaries. The reflected ultrasound waves induce an echo signal at the ultrasound transducer. The echo signal is transmitted from the ultrasound transducer to an ultrasound console, which typically includes an ultrasound image processor, such as a computer, and a display. The display may comprise a monitor and/or a printer. The ultrasound console uses the received echo signal to image the cavity.
[0004] The echo signal is a serial amplitude modulated signal in which the amplitude of the signal varies with time. A typical echo signal has a time length of 3 μs, which corresponds to an image depth of approximately 6 millimeters from the ultrasound transducer. The echo signal carries both image brightness information and image depth information, where depth may be taken with respect to the ultrasound transducer. The image brightness information is provided by the amplitude of the echo signal. The image depth information is provided by the time position within the echo signal. An earlier time position in the echo signal corresponds to a lower image depth than a later time position in the echo signal.
[0005] In order to produce a radial cross-sectional image of a blood vessel and surrounding tissue, the ultrasound transducer is typically rotated along the axis of the elongated member. As the ultrasound transducer is rotated, the ultrasound transducer emits ultrasound waves in different radial directions. The resulting echo signals from the different radial directions are processed by the ultrasound console to produce a radial cross-sectional image of the blood vessel and the surrounding tissue. Alternatively, the ultrasonic transducer may be mounted in an assembly together with a reflective member (mirror), where the transducer emits ultrasonic energy in a substantially axial direction and the mirror is oriented to deflect the emitted ultrasonic energy in a radial direction.
[0006] Optical Coherence Tomography ("OCT") is a type of optical coherence-domain reflectometry that uses low coherence interferometry to perform high resolution ranging and cross-sectional imaging. In OCT systems, a light beam from a low coherence light source is split into a reference light beam and a sample light beam. A diffraction grating may be used to provide a time delay. The sample light beam is directed onto a sample and the light scattered from the sample is combined with the reference light beam. The combination of the sample and reference light beams results in an interference pattern corresponding to the variation in the sample reflection with the depth of the sample, along the sample beam. The sample beam typically suffers a high loss of energy due to its interaction with the sample. The reference beam serves as a local oscillator to amplify the interference pattern to a detectable level and therefore must have a much higher energy level than the sample light beam. The interference pattern is detected by a photo detector, whose output is processed to generate a cross-sectional image of the sample. High resolution (less than 10 micrometer) imaging of the cross-sections of the sample by OCT is useful in biological and medical examinations and procedures, as well as in materials and manufacturing applications. An advantage of the above-described OCDR system is that the array of photo detectors is able to capture image brightness information at multiple image depths in one instance. This enables the OCT system to produce images at true video rates, e.g., 30 frames per second
[0007] OCT based systems may be implemented with fiber optics and an optical fiber carrying the sample light beam may be incorporated into a catheter or an endoscope for insertion into internal body cavities and organs, such as blood

vessels, the gastrointestinal tract, the gynecological tract and the bladder, to generate images of internal cross-sections of the cavities or organs. The sample beam is typically emitted from the distal end of the instrument, where a prism or a mirror, for example, directs the sample light beam towards a wall of the cavity. The optical fiber and the prism or mirror may be rotated by a motor to facilitate examination of the circumference of the cavity.

[0008] An example of a fiber optic OCT system is shown in U.S. Patent No. 5,943,133 ("the 133 patent"), where sample and reference light beams are carried in respective optical fibers to a diffraction grating, which introduces a time delay and also combines the sample and reference light beams. Fig. 1 is a schematic diagram of a system 10 disclosed in the '133 patent. The system includes a light source 12 optically coupled to a 50/50 beam splitter 14 through an optical fiber 16. The beam splitter 14 splits the incident light beam equally into a sample light beam and a reference light beam. The sample light beam is carried by an optical fiber 18 to a focusing lens 20, which focuses the sample light beam onto a sample 22. The optical fiber 18 may be contained within a catheter (not shown) for insertion into a body cavity, such as a blood vessel, for examination of the tissue of the wall of the cavity. Light received from the tissue is focused by the lens 20 and coupled back into the optical fiber. The received light travels back to the beam splitter 14, where it is split again. A portion of the received light is directed into another optical fiber 24, which conveys the light to a first collimator 26. The reference light beam travels through an optical fiber 28 to a second collimator 30. The first and second collimators 26, 30 direct the sample and reference light beams onto the same region of a diffraction grating 32. The diffracted, combined light beam is conjugated on the detector plane of a multi channel linear diode array detector 34 by a conjugating 36 lens. A neutral density filter (not shown) is provided to decrease the energy in the reference beam to prevent saturation of the detector.

[0009] The sample light beam suffers a significant loss of energy due to its interaction with the sample. The second pass through the 50/50 beam splitter further reduces the already attenuated light beam. In addition, the interaction of the light beams with the diffraction grating causes a further loss in both the sample light beam and the reference light beam of about 50% of the incident light in the first order. The diffraction grating also introduces noise. As a result, the system of the '133 patent has a low signal-to-noise ratio.

[0010] Another interferometric system using a diffraction grating is described in "Nonmechanical grating-generated scanning coherence microscopy", Optics Letters, Vol. 23, No. 23, December 1, 1998. Fig. 2 is a schematic diagram of the disclosed system 50. A light source 52 provides light to a 50/50 beam splitter 54 that splits the energy in the light beam equally into a sample light beam 55 and a reference light beam 56. The sample light beam 55 is directed to a focusing lens 58 that focuses the sample light beam onto a sample 60. The light received by the focusing lens 58 from the sample 60 is returned to the beam splitter 54. The reference light beam 56 is directed to a diffraction grating 62 in a littrow configuration. The diffracted reference light beam is also returned to the beam splitter 54. The sample and reference light beams are then combined in the beam splitter 54 and directed to a charge-coupled device (CCD) array 64 for detection and processing by a computer 66. The reference light beam needs to be suppressed here, as well.

[0011] Here, only the reference light, beam is diffracted, making the system 50 more efficient than the system 10 of the '133 patent, shown in Fig. 1. However, the sample and reference arms in the system 50 of Fig. 2 cannot both be implemented with fiber optics. The diffraction grating introduces a time delay that is spatially spread across the width of the beam. The detector is a multi-element detector at least as wide as the light beam. Each element of the detector receives a portion of the beam corresponding to its position on the diffraction grating. If the reference light beam is conveyed by an optical fiber from the diffraction grating to the detector, the spatial order is lost. If the sample arm is implemented in fiber optics but the reference arm is not, the length of the reference arm would be inconveniently long.

[0012] US Patent No. 5,830, 145 discloses methods and systems for obtaining three-dimensional reconstruction of an organ or other internal structure using intraluminal ultrasound (ILUS) or optical coherence tomography (OCT) imaging. It would be desirable to provide an imaging system that can process both ultrasound imaging data and optical interferometric imaging data with the same signal processor to display both ultrasound images and OCDR images, thereby reducing costs.

[0013] The present invention consists of an imaging system comprising:

an ultrasound console having a serial input, an ultrasound image processor and a display;
an interferometer comprising a multi-element photo detector having a plurality of parallel outputs; and
an ultrasound device with an output coupled to the ultrasound console, characterised by:
a parallel to serial converter electrically coupling the plurality of parallel outputs of the multi-element photo detector to the serial input of the ultrasound console,
wherein the ultrasound console processes data provided by the interferometer to form an image for display.

[0014] Another embodiment of the present invention comprises a method of analyzing a surface comprising the steps of:

using an ultrasound device having an ultrasound transducer to emit ultrasound waves which are reflected by the surface and induce an echo signal at the ultrasound transducer;

transmitting the echo signal from the ultrasound transducer to an ultrasound console, which comprises a serial input, an ultrasound image processor and a display;
forming a sample light beam and a reference light beam with an interferometer, conveying the sample light beam to the surface, combining light received from the surface with the reference light beam into a combined light beam and detecting the combined light beam with a multi-element detector to output a plurality of parallel electrical signals, characterised by:
coupling the interferometer to the ultrasound console;
processing data from the interferometer by the ultrasound processor comprising:
converting the processed parallel electrical signals into a serial signal; and
providing the serial signal to the ultrasound processor for processing into an image.

Brief Description Of The Drawings

[0015] Fig. 1 is a schematic diagram of a prior art OCT system;
[0016] Fig. 2 is a schematic diagram of another prior art OCT system;
[0017] Fig. 3 is a schematic diagram of an interferometric system connected to an ultrasound console in accordance with one embodiment of the invention;
[0018] Fig. 4a is a schematic diagram of a diffraction grating based fiber optic interferometric system in accordance with another embodiment;
[0019] Fig. 4b is a schematic diagram of a diffraction grating based interferometric system with a similar arrangement to the system of fig. 4a, where both beam splitters are 50/50 beam splitters;
[0020] Fig. 5 is a schematic diagram of an interferometric system with a similar arrangement to the system of fig. 4a, where the diffraction grating is a transparent diffraction grating;
[0021] Fig. 6 is a schematic diagram of another embodiment of the invention, including an optical circulator and a first, non 50/50 beam splitter;
[0022] Fig. 7 is a schematic diagram of the system of Fig. 6, including polarization filters for use in detecting polarization related information;
[0023] Fig. 8 is a schematic diagram of the system of Fig. 6, including multiple light sources;
[0024] Fig. 9 is a schematic diagram of the system of Fig. 6, including an optical circulator and two non 50/50 beam splitters;
[0025] Fig. 10 is an enlarged view of the reference light beam being diffracted by the diffraction grating, indicating the time delay;
[0026] Fig. 11 is a schematic diagram of an interferometric system in accordance with another embodiment, wherein an acousto-optic modulator ("AOM") acts as both a transparent diffraction grating to introduce a time delay and as a modulator;
[0027] Fig. 12 is a schematic diagram of an AOM based interferometric system, as in the embodiment of Fig. 11, coupled to an ultrasound console; and
[0028] Fig. 13 shows an interferometric system in accordance with the embodiment of Fig. 4a, contained within a housing for use with a interferometric catheter and an ultrasound console.

Detailed Description Of The Preferred Embodiments

[0029] Fig. 3 is a schematic diagram of an embodiment of an imaging system 390 comprising an interferometric system 391 including a photo detector array 392 with a plurality of parallel outputs 394 connected to an ultrasound console 396 through a parallel to serial converter 398. The ultrasound console may be an intravascular ultrasound ("IVUS") console, including a signal processor, such as a computer, a microprocessor or a microcontroller, and a display to display generated images, as is known in the art. An ultrasound device 399 with an output 399a is also provided. The output 399a of the ultrasound device 399 is connected to the ultrasound console, in the same or a different input than the interferometer 391. A doctor or technician may thereby use either the interferometer 391 for optical imaging or the ultrasound device 399 for ultrasound imaging, with the same ultrasound console. An ultrasound system including an ultrasound image processor and display is available from Boston Scientific Corporation, Natick, Massachusetts. The ultrasound device 399 may be an IVUS catheter. IVUS catheters are described in U.S. Patent No. 5,715,825 entitled Acoustic Imaging Catheter and the Like. Interferometric systems 391 are described in more detail below.
[0030] The parallel to serial converter 398 may be one of the electronic interfaces described in U.S. Patent Application Serial No. 09/909,357 ("the ’357 application"), entitled "Electronics Interface for an Ultrasound Console", filed on July 18, 2001, assigned to the assignee of the invention.
[0031] As described in the ’357 application, the ultrasound console 402 may be configured to receive either an analog or a digital input. In one example of an electronics interface disclosed in the ’357 application for receiving a analog input,

the electronics interface comprises a plurality of channel processors, each coupled to one of the parallel channel outputs of the photo array. Each channel processor comprises an analog processor, an A/D converter, a First-In-First-Out ("FIFO") memory buffer, and a data bus coupled to the FIFO memory buffer of each one of the channel processors. A single FIFO memory buffer is coupled to the data bus and a D/A converter is coupled to the output of the single FIFO memory buffer. The output of the D/A converter is coupled to the input of the ultrasound console. A controller coupled to an ultrasound motor encoder synchronizes the operation of the electronics interface with the ultrasound console. The operation of the interface is described in more detail in the ’357 application.

[0032] Where the ultrasound console is adapted to receive a digital input, the serial digital data sequence from the single FIFO memory is provided to the input of the console through control logic that controls the transfer of the digital data sequence, as is also described in the ’357 application.

[0033] The photo detector array may be a multiplexed photo detector array. Electrical interfaces for single and double channel multiplexed photo detector arrays are also described in the ’357 application.

[0034] Other electronic interfaces for converting the parallel output of the array of photo detectors into a serial analog or digital data stream, may also be used.

[0035] In OCT systems using an array of photo detectors, the array captures image brightness information at multiple image depths in one instance. Since the detected spatial information may be read and stored, the parallel channel outputs of the photo detector array of the interferometric system may be processed into a serial analog or serial digital signal by a parallel to serial converter. The resulting serial signal carries image brightness information and image depth information in a similar manner as a typical echo signal. The time length and/or frequency of the serial signal may be adjusted to better match the time length and/or frequency of a typical echo signal that the ultrasound console is configured to receive by synchronizing the signal to the sweep speed of the ultrasound scanner and to the propagation velocity of sound. This enables an ultrasound console to process the serial analog signal into an image, in the same way ultrasound data is processed. The same ultrasound console may thereby be used to process both ultrasound based images derived from data received from an ultrasound catheter and optical interferometric based images derived from data received from an interferometric catheter, thereby reducing costs.

[0036] The interferometric system 391 may be any OCT interferometric system. For example, the systems of U. S. Patent No. 5, 943,133, and "Nonmechanical grating-generated scanning coherence microscopy", Optics Letters, Vol. 23, No. 23, December 1, 1998, discussed above, may be used. Additional interferometric systems are described below.

[0037] Fig. 4a is a schematic diagram of one embodiment of a diffraction grating based fiber optic interferometric system 100 that may be used in the imaging system 390 of fig. 3, shown connected to the IVUS console 396 through the parallel to serial converter 398. The system 100 comprises a light source 102 optically coupled to a fiber optic beam splitter 104 by an optical fiber 106. The fiber optic beam splitter 104 is preferably approximately a 50/50 beam splitter. More preferably, the beam splitter 104 is a 50/50 beam splitter. An optical fiber 108 is optically coupled to the fiber optic beam splitter and to a focusing lens 110.

[0038] An optical fiber 111 is also optically coupled to the fiber optic beam splitter 104 such that light entering the beam splitter from the optical fiber 108 is coupled into the optical fiber 110. The optical fiber 111 is also optically coupled to a first collimator 112. Another optical fiber 114 is optically coupled to the first beam splitter 104 and to a second collimator 116.

[0039] The optical fibers 108 and 110 comprise first and second parts of a sample arm, respectively, of the interferometric system 100. The optical fiber 114 comprises a reference arm of the system 100. Light from the light source 102 passes through the fiber optic beam splitter 104 and is split into a sample light beam and a reference light beam, each having half of the energy of the initial light beam provided from the light source 102 to the fiber optic beam splitter 104. The sample light beam is directed into the optical fiber 108 of the first part of the sample arm and the reference light beam is directed into the optical fiber 114 of the reference arm. The sample light beam is focused by the focusing lens 110 onto a sample of interest 119. which may be tissue within a body cavity, for example. Light scattered by the sample is focused by the focusing lens 110 to form a second sample light beam and is coupled back into the optical fiber 108 of the sample arm. That light passes back through the first beam splitter 104, where the light beam is split again. A light beam having half of the energy of the received light beam is coupled into the optical fiber 110 of the second part of the sample arm.

[0040] The second collimator 116 collimates the reference light beam and directs the reference light beam onto a diffraction grating 118 at an angle α. The diffraction grating 118 introduces an optical path difference to the reference light beam and reflects the diffracted reference light beam onto a second, open space beam splitter 120. The first collimator 112 also collimates the second sample light beam and directs it onto the second beam splitter 120.

[0041] The second beam splitter 120 combines the second sample light beam and the reference light beam and directs a portion of the combined light beam onto a photo detector 122, through a conjugating lens 124. The photo detector 112 is preferably a multi-element photo detector, such as a photo diode array. An array of avalanche mode photo diodes may be used, for example. A charge coupled-device ("CCD") may be used, as well. The conjugating lens 124 projects the image of the combined beam on the plane of the second beam splitter onto the detector plane..

[0042] In accordance with this first embodiment, the open space beam splitter 120 directs less than half of the light energy in the reference beam and more than half of the energy in the second sample light beam into the combined beam directed toward the detector 122. Preferably, substantially more than half of the energy in the second sample light beam, such as 75% or more, is directed into the combined beam and substantially less than half of the energy in the reference light beam, such as 25% or less, is directed into the combined light beam. More preferably, at least about 90% or more of the energy of the sample light beam and about 10% or less of the energy of the reference light beam are directed into the combined beam. For example, the second beam splitter may be a 10/90, /95, 2/98 or 1/99 beam splitter. In the embodiment of Fig. 3, the reference light beam is transmitted through the second beam splitter 120 while the sample light beam is reflected by the second beam splitter 120. Alternatively, the sample light beam may be transmitted through the second beam splitter 120 and the reference light beam may be reflected by the second beam splitter.

[0043] As is known in the art, in order for there to be constructive interference between the sample and reference light beams in this and the other embodiments of the invention, the optical path lengths of the sample light beam (the initial sample light beam and the second light beam) and the reference light beam from the first beam splitter 104 to the second beam splitter 120 need to be equal to within the coherence length of the light source 102. The refractive index of the optical fibers and the open space traversed by the light beams, as well as the refractive index of the sample material, need to be considered in determining appropriate path lengths.

[0044] The interference pattern resulting from the combination of the sample and reference light beams contains both depth information and brightness information. The brightness information is provided by the light intensities of the interference pattern. Since the portion of the second sample light beam that is received in the sample arm from a certain depth from the sample interferes with a portion of the diffracted reference beam at a spatial position corresponding to the optical path difference for this position, the depth information is provided by the spatial position within the interference pattern. The photo detectors of the array 122 are arranged so that each photo detector element detects the light intensity of the interference pattern at a certain spatial position within the interference pattern, as is known in the art. Thus, the output of each photo detector element provides image brightness information for a certain image depth. The array 122 outputs the information along parallel channels (not shown), where each channel corresponds to the output of one of the photo detector elements. The outputs of the parallel channels of the photo array 122 are provided to the IVUS console 396 through the parallel to serial converter 398 to produce an image of the sample depth reflection along the sample light beam for display. Preferably, the multi-element detector 122 is a photo diode array and a heterodyne detection technique is used.

[0045] As discussed above, if the detector is a photo diode array and a heterodyne detection method is used, low frequency modulation is required. A modulator 117, such as a fiber stretcher or an acousto-optic modulator, is therefore provided along the optical fiber 114. The modulator 117 may be provided along the optical fibers 108 or 111 to modulate the sample light beam, as well.

[0046] Use of two beam splitters enables the reference light beam to be conveyed to the diffraction grating 118 by an optical fiber 114. Since the second sample light beam is not combined with the reference light beam on the diffraction grating in this embodiment, additional loss and noise is not introduced to the second sample light beam. Since the optical path from the diffraction grating 118 to the detector 122 is open space, spatial information in the reference and sample light beams is preserved.

[0047] The optical fiber 108 of the first part of the sample arm is preferably incorporated in a catheter adapted to be positioned in a body cavity or organ by standard catheter intervention procedures. For example, the catheter may be inserted into a blood vessel or the heart by guiding the flexible catheter through various blood vessels along a circuitous path, starting, for example, by percutaneous introduction through an introducer sheath disposed in a perforation of the femoral artery. Alternatively, the catheter can be introduced directly into a body cavity or body tissue, such as an organ. The optical fiber may be coupled to a motor for causing rotation of the fiber within the catheter. Catheters and endoscopes for use in the optical imaging of blood vessels and other internal body cavities are known in the art and are described in U.S. Patent No. 6,134,003, U.S. Patent No. 5,321,501 and International Publication No. WO 98/38907 published on September 11, 1998, for example. As disclosed in those references, a mirror or prism may be provided to reflect the sample light beam onto biological tissue parallel to the optical fiber and to reflect light received from the tissue into the optical fiber. By rotating the optical fiber, tissue along the circumference of the cavity may be examined.

[0048] While it is preferred that the second beam splitter 120 in Fig. 4a be a non 50/50 beam splitter, it is not required. Fig. 4b is a schematic diagram of an interferometric system 100' that is similar to the system of fig. 4a, except that the second beam splitter 120' is a 50/50 beam splitter. A neutral density filter or other such attenuator may be provided as needed to suppress the reference light beam to prevent saturation of the detector 124. Components common to the embodiment of fig. 4a are commonly numbered.

[0049] Fig. 5 is a schematic diagram of another interferometric system 150 that may be used in the imaging system 390. The interferometric system 150 has a similar arrangement to the system 100 of Fig. 4a, except that the diffraction grating is a transparent diffraction grating 152. Components common to the configuration of Fig. 4a are commonly numbered in Fig. 5. The second collimator 116 is arranged to direct the reference light beam on a rear side of the diffraction grating 152 at an angle α. The diffracted reference beam is directed onto the open space beam splitter 120, for combination with the second sample light beam, as discussed above. The combined light beam is directed through the conjugating lens 124 and onto the multi-element detector 122, also es described above. The ability to use either a reflective diffraction grating 118 or a transparent diffraction grating 152 in the interferometric systems of the invention, adds flexibility to the design of the interferometer in practical applications. Any of the embodiments described herein can use either a reflective or a transparent diffraction grating.

[0050] Fig. 6 is a schematic diagram of another embodiment of an interferometric system 200 that can be used in the imaging system 390, wherein more than half of the light energy is directed into the sample light beam and less than half of the light energy is directed into the reference light beam by use of a non 50/50 fiber optic beam splitter. Preferably, substantially more than half of the light energy incident on the beam splitter, such as 75% of the energy, is directed into the sample light beam and substantially less than half of the incident light energy, such as 25%, is directed into the reference light beam. More preferably, at least about 90% of the incident light energy is directed into the sample light beam and about 10% or less is directed into the reference light beam.

[0051] In this embodiment, the sample light beam is directed to and from the sample under examination through an optical circulator instead of a beam splitter, as in the embodiment of Fig. 4a and in the prior art of Figs. 1 and 2. Therefore, the first beam splitter need not be approximately a 50/50 beam splitter.

[0052] Components common to the embodiment of Fig. 4a are commonly numbered in Fig. 6. A light source 102 provides light to a 90/10 beam splitter 202 through an optical fiber 106. The 90/10 fiber optic beam splitter 202 provides 90% of the energy of the light incident to the beam splitter 202 into the sample light beam and 10% of the energy of the light into the reference light beam.

[0053] An optical circulator 204 is provided with three ports, Port 1, Port 2 and Port 3. Light entering the optical circulator 204 through Port 1 is directed out of the circulator through port 2. Light entering the optical circulator 204 through Port 2 is directed out of the circulator through Port 3. An optical fiber 206 is optically coupled to the first beam splitter 202 to Port 1 of the optical circulator 204 to convey the sample light beam to the circulator.

[0054] An optical fiber 208 is optically coupled to Port 2 of the optical circulator 204 and to a focusing lens 110. An optical fiber 210 is optically coupled to Port 3 of the optical circulator 204 and to a first collimator 112. The sample light beam is conveyed from the first beam splitter 202 to Port 1 of the optical circulator 204 through the optical fiber 206. The sample light beam is directed to Port 2 of the optical circulator, where it exits the circulator and is conveyed to the focusing lens 110 by the optical fiber 208. The focusing lens focuses the sample light beam onto the sample 119. Light received from the sample is focused and coupled into the optical fiber 108, forming a second sample light beam to be returned to Port 2 of the optical circulator. The second sample light beam is directed from Port 2 to Port 3 of the optical circulator, where it is conveyed by the optical fiber 204 to the first collimator 112.

[0055] An optical fiber 220 is also optically coupled to the beam splitter 202 and to a second collimator 116, as in the embodiment of Fig. 4a. A reference light beam having 10% of the energy of the light conveyed to the 90/10 beam splitter 202 from the light source 102 is directed into the optical fiber 220. The second collimator 116 directs the reference light beam onto a reflective diffraction grating 118. The diffraction grating 118 introduces an optical path difference to the reference light beam and reflects the diffracted reference light beam onto the open space beam splitter 120. A transparent diffraction grating 152 could be used instead of the reflective diffraction grating 118, as discussed above. The first collimator 112 also directs the second sample light beam onto the open space beam splitter 120 for combination with the reference light beam.

[0056] In this embodiment, the second beam splitter 120 is approximately a 50/50 beam splitter 222. Preferably, the second beam splitter 120 is a 50/50 beam splitter. Two combined sample/reference beams, each having half of the energy of the second sample light beam and half of the energy of the reference light beam, are formed. Two photo detectors 224, 226, which are preferably multi-element photo detectors, are provided, one along the path of each combined light beam. Because two detectors are provided, the 50/50 beam splitter 222 does not cause a loss of energy and information in the second sample light beam. Respective conjugating lenses 228, 230 are provided between each detector 224, 226 and the second beam splitter 222. The outputs of individual detectors in corresponding spatial positions in each array are combined by analog circuitry 227. The parallel output of the analog circuitry 227 is provided to the IVUS console 396 through the parallel to serial converter 398, for processing into an image in a manner known in the art. Two detectors may be readily provided in the embodiment of Fig. 4b, as well, in the same manner.

[0057] Preferably, about 90% or more of the light energy is directed into the sample light beam and about 10% or less of the light energy is directed into the reference light beam by the first beam splitter 202. The amount of energy provided to the sample and reference beams may be controlled by selection of the characteristics of the fiber optic beam splitter 202 so that only the necessary amount of light energy is provided to the reference light beam to sufficiently amplify the sample light beam for imaging without saturating the multi-element photo detectors 224, 226. The remainder of the energy is directed to the sample light beam. A 2/98, a 95/5 or a 1/99 or other such beam splitter may also be used, for example.

[0058] Directing the second sample light beam received from the sample 119 through the optical 204 circulator 204 instead of back through the first beam splitter 202 avoids a significant source of loss in the second sample beam. The loss in the optical circulator is between about 0.5 decibels ("db") to about 1.1db each way. The two way loss in the optical circulator is therefore about 1.0db to about 2.2db (about 37%). The loss in a 50/50 beam splitter 222, by contrast, is 50% each way or 75% if the sample beam travels through the 50/50 beam splitter twice.

[0059] The detectors 224, 226 may be tuned to detect light at the same wavelength band or at different wavelength bands. The ability to detect more than one wavelength band is useful for spectroscopy and for reducing aliasing in the image.

[0060] The two combined sample/reference light beams in the embodiment of Fig. 6 may contain polarization related information. Birefringence measurements may be made by providing a polarization filter along each light beam, where each filter allows passage of light having a different polarization. In Fig. 7, polarizations filters 240, 242 are shown between each of the conjugating lenses 228, 230 and the detectors 224, 226, respectively. The detectors are preferably multi-element photo detectors. Two parallel to serial converters 398a, 398b may be provided, one to receive the parallel outputs from each multi-element detector. The outputs from the parallel to serial converters 398a, 398b may be provided in parallel to the IVUS console 396. Two images may be generated and compared. Differential measurements may be made by comparing the signals at each detector as a function of spatial position and relative intensity, as is also known in the art. Variations in intensity versus position are an indication of polarity sensitive areas of target tissue. The optical fiber used in this embodiment is preferably a polarization maintaining (high birefringence) optical fiber, as is known in the art. A polarization filter 243, shown in phantom, may also be provided between the light source 102 and the fiber optic beam splitter 202 instead of the polarization filters 240, 242, to polarize the light beam emitted by the light source to a desired polarization. Instead of the polarization filter 243, the second beam splitter 222 may be a polarization beam splitter. A single detector, as in the embodiments of Figs. 3 and 4, may also be used to detect a light beam of a particular polarization.

[0061] Polarization filters may be provided in other interferometric systems where two combined beams are formed, as well. For example, a 50/50 beam splitter may also be provided between the diffraction grating 32 and the detector 34 in the system of the '133 patent shown in Fig. 1, to form two combined beams. A second detector, two polarization filters and two conjugating lenses may then be provided, as in Fig. 7, to conduct birefrigence measures.

[0062] In another variation in the embodiment of Fig. 6, a second light source 103 may be provided, as shown in Fig. 8. Additional light sources may also be provided. Each light source may emit light at a different wavelength. For example, the first light source can emit light at 800 nanometers and the second light source can emit light at 1200 nanometers. The light from the second light source 103 may be coupled into the optical fiber 106 by a wavelength division multiplexor, for example. One of the detectors 224, 226 may be tuned to detect light at a wavelength corresponding to the first light source 102 and the other detector may be tuned to detect light at a wavelength band corresponding to the second light source 103. If more than two light sources are provided, the individual photo detectors in each array can be tuned to detect light at different wavelength bands. As in the embodiment of Fig. 7, two parallel to serial converters 398a, 398b may be provided with separate outputs to the IVUS console 396. Images at each wavelength band may be generated. The interference patterns at each wavelength band may be compared as a function of spatial position and intensity at each wavelength band. The difference in intensity at the same position in the interference patterns may indicate wavelength dependent attenuation or absorption of the sample. Bandpass filtering, detector response and the fiber characteristics of each "detection channel" may be selected to optimize the use of specific wavelengths.

[0063] Fluorescence of tissue is known to be dependant upon tissue type and tissue constituents. One of the light sources in fig. 8 may be in the blue or ultraviolet range, for example, to induce fluorescence in the tissue. One of the detectors 224, 226 may be tuned to the ultraviolet, blue or other wavelength band at which the target tissue is expected to fluoresce to detect the intensity of the emitted fluorescent light.

[0064] In another embodiment using an optical circulator 204, neither the first fiber optic beam splitter nor the second open space beam splitter is a 50/50 beam splitter. In the system 280 of fig. 9, the first beam splitter, 282 is a 95/5 beam splitter, for example, that directs 95% of the light energy provided to the beam splitter into the sample light beam and 10% into the reference light beam. The second open space beam splitter 284 is a 10/90 beam splitter, for example, directing 90% of the light energy in the second sample light beam and 10% or less of the light energy in the reference light beam toward a single detector 286 in the combined beam. Varying the characteristics of both beam splitters 282, 284 provides additional flexibility in optimizing the energy distribution between the sample and reference light beams. Components of the system 280 common to the embodiments of Figs. 6 and 4a are commonly numbered.

[0065] To determine the theoretical percentage of the light source energy reaching the detector from the sample arm in the various embodiments of the invention and in the prior art, the sample under examination may be replaced by a mirror. The table below shows the percentage of the light source energy in the sample and reference arms at the sample, at the diffraction grating and at the detector in the prior art interferometer of fig. 1 and in the example interferometers of Figs. 4a, 5 and 6, if the sample light beam is reflected by a mirror (suffers no loss due to interaction with the sample).

Figure	Percentage of light source energy incident on:				
	Sample	Diffraction Grating		Detector/Detectors	
	Sample Arm	Sample Arm	Reference Arm	Sample Arm	Reference Arm
Fig. 1	50	25	50	12.5	25
Fig. 4a	50	NA	50	22.5	2.5
Fig. 5	50	NA	50	22.5	2.5
Fig. 6	90	NA	10	56.7	5

[0066] In the prior art of Fig. 1, the light energy in the reference light beam incident on the detector is 25% of the light energy from the source and is higher than the sample light energy. To prevent saturation of the detector, the reference beam has to be suppressed. In the embodiments of Figs. 4a and 5, in the sample arm, the light source energy is reduced by 75% by two passes through the 50/50 beam splitter and then by 10% by the 10/90 beam splitter. In the reference arm, the light source energy is reduced by 50% by the first beam splitter, 50% by the diffraction grating and 90% by the second beam splitter. In the embodiment of fig. 6, in the sample arm, the light source energy is reduced by 10% by the 90/10 beam splitter and by 37% by two passes through the optical circulator. The loss caused by the 50/50 beam splitter does not reduce the total energy of the sample light beam because the total energy of the light incident on both detectors by the sample light beam is the same as the energy of the sample light beam incident on the beam splitter. In the reference arm, the light is reduced to 10% of the light energy from the source by the 10/90 beam splitter and then by 50% by the diffraction grating. In the embodiments of Figs. 4a, 5 and 6, the proportion of the initial light energy in the reference light beam incident on the detector is much lower than in the prior art and the proportion of the light energy in the sample light beam is higher. Saturation of the detector or detectors may be readily avoided by suitable selection of the characteristics of the beam splitters. A neutral density filter may be provided along the reference arm for more precise control over the energy of the reference light beam, if necessary. Since more of the light energy from the source may be allocated to the sample light beam, where it is most needed, less energy is wasted in the system.

[0067] Fig. 10 is an enlarged view of the reference light beam R emitted by the collimator 116 being diffracted by the diffraction grating 118, showing the maximum optical path difference δ across the diffracted reference light beam Rd for the embodiment of Fig. 4a. The second sample light beam S received from the sample is shown being emitted by the collimator 112. The second beam splitter 120 is also shown. The optical path difference δ varies gradually across the diffracted reference light beam Rd such that the difference at one side of the beam cross-section "a" is about zero and the difference at the opposite side of the beam "b" is the maximum difference δ. The maximum optical path difference δ is typically chosen to enable measurement of the light scattered from the desired depth. Since the optical paths of the reference and sample light beams have to be substantially equal, the optical path difference δ corresponds to the depth of the image in the second sample light beam S, corrected by the refractive index of the media in which the depth is measured. The maximum optical path difference δ is a function of the width Wd of the diffracted light beam and the angle of incidence α:

$$\delta = Wd \times \sin\alpha. \qquad (1)$$

[0068] The depth Δ is a function of the maximum optical path difference δ. Since it takes a two-way sample beam path to determine the depth versus a one way reference beam path to define the maximum optical path difference, the depth is half of the maximum optical path difference δ. Since the depth Δ is measured in a material other than air, it is also a function of the refraction coefficient of the sample material η:

$$\Delta = \delta / 2\eta. \qquad (2)$$

[0069] The angle of incidence α of the reference light beam on the diffraction grating is a function of the diffraction grating parameter p (distance between adjacent grooves) and the light wavelength λ. The diffraction grating formula is:

$$\mathrm{Sin}\ \alpha = \lambda / \mathrm{p}. \qquad (3)$$

[0070] Also, as shown in Fig. 10, the width Wref of the reference light beam R is less than the width Wd of the diffracted reference light beam Rd. Preferably, the width Wd of the diffracted reference light beam is the same as the width Ws of the second sample light beam S. The combined light beam (not shown) has the same width. The width Wref of the reference light beam is therefore preferably:

$$\mathrm{Wref} = \mathrm{Ws} / \mathrm{Cos}\ \alpha \qquad (4)$$

[0071] The width of the detector array or arrays should the same or slightly greater than the width of the combined light beam. Preferably, the first collimator 112, that collimates the second sample light beam S received from the sample, has the same dimensions as that of the detection array.

[0072] For example, if the sample is biological tissue (η = 1.33) and the depth of measurement is Δ = 3mm, the maximum optical path difference from formula (2) would be: δ = 7.98mm. If the light source has a wavelength λ = 820nm and the diffraction grating parameter is p = 1/830mm, the angle α from formula (3) would be: Sin α = 0.697 (α = 44.2deg.). Then, the width Wd of the diffracted reference beam Rd, which is preferably equal to the width Ws of the second sample light beam received from the sample Ws from (1) would be Wd = 11.45mm. The width of the combined light beam is also Wd. The photo detector array would then also have a width of at least 11.45mm.

[0073] In the embodiments above, the light source 102 is a low coherence, broadband light source, such as a super luminescent diode. The coherence length of the light source may be from about 15 to about 30 microns, for example. The wavelength may be between about 800 to about 1500 nanometers, for use with biological tissue. The light source should emit light at a power of at least about 10 milliwatts for depth measurements of about 1 millimeter. The light source should emit light at a power of at least about 50 milliwatts for depth measurements of 2 - 3 millimeters. Superluminescent diodes for use in the embodiments may be obtained from Super Lume Diodes, Ltd. Moscow, Russia, or Hamamatsu Photonics K.K., Solid State Division, Hamamatsu City, Japan, ("Hamamatsu") for example.

[0074] The detector is preferably a multi-element photo detector, such as a photo diode array. An avalanche mode photo diode array may be used, for example The photodiode array preferably has at least 256 diodes. An array of 512 photo diodes or more is more preferred. Photo diode arrays may be obtained from Sensors Unlimited, Inc., Princeton, New Jersey and Hamamatsu, for example. A charge-coupled device ("CCD") may also be used.

[0075] Appropriate optical fibers and fiber optic beam splitters of desired characteristics are readily commercially available. They may be obtained from Corning Incorporated, Corning, New York, for example. Open space beam splitters of desired characteristics are also readily commercially available. They may be obtained from Edmunds Scientific, Tonawanda, New York, for example. The conjugating lenses and focussing lens may also be obtained from Edmunds Scientific, for example.

[0076] Fig. 11 is yet another embodiment of an interferometric system 300, that may be used in the imaging system 390 of Fig. 3, wherein an acousto-optic modulator ("AOM") 302 acts as both a transparent diffraction grating to introduce an optical path difference to the reference light beam and as a modulator to introduce a frequency shift. Otherwise, the system is the same as the embodiment of Fig. 4a. One AOM may be used for shallow depths of a few hundred microns, for example. Two modulators may be used for greater depths of 500 to 1,000 microns, for example. One AOM may also be used along with a transparent diffraction grating, as shown in US Patent No. 6,114,645. While one AOM may introduce a frequency of modulation higher than that desirable in an OCT system, two or more AOM's in series, each driven at different frequencies, may be used to achieve the desired frequency. The AOM 302 may be driven by a programmable signal generator, as is known in the art.

[0077] Since the projected interference pattern generated by the interferometric system of the invention is formed on the detector nearly instantaneously, pulsed imaging may also be implemented in any of the embodiments discussed above. Pulsed imaging allows for the use of higher peak power and lower average power (lower duty cycle), enabling increased penetration through attenuative structures while maintaining low average light energy for safe operation. A laser diode may be used in a pulsed mode as the light source in any of the embodiments. The laser diode may be smaller and less expensive than the superluminescent diode discussed above for continuous operation, because a small laser diode may produce a sufficient peak output at a wider bandwidth in a pulse mode without being destroyed.

[0078] Fig. 12 shows an imaging system 391 including an AOM based interferometric system 400, as in the embodiment of Fig. 11, wherein the first, fiber optic beam splitter 202 is a 90/10 beam splitter and the second, open space beam splitter 222 is a 50/50 beam splitter. Two photo detector arrays 224, 226 are provided, as in the embodiment of Fig. 6. The outputs of corresponding detectors in each of the parallel outputs from the photo detector arrays 224, 226 of the interferometric system 400 are combined by analog circuitry 227, as noted above. The parallel outputs of the analog circuitry 227 are input to the parallel to serial converter 398 that converts the parallel outputs into a serial amplitude modulated signal that can be processed by an ultrasound console. If only one detector is provided, as in the embodiment of Fig. 4a, for example, the analog circuitry 227 is not needed and the parallel outputs of the photo detector array 122 could be provided directly to the parallel to serial converter 398.

[0079] A computer 404 may optionally be provided to process the serial signal output by the parallel to serial converter. The serial signal is then provided to the IVUS console 396 through an input 405 for processing into an image for display. The interferometric system 400 may be selectively connected to the input 405 when optical imaging is desired. The ultrasound catheter 399 is also shown in Fig. 12, with an output 399a. The output 399a is connected to the input 405 or a separate input 417 of the IVUS console 396.

[0080] The optical fiber 208 of the sample arm is shown coupled to an optical fiber 407 within a catheter 403 through a rotary connector 410. A minor or prism 412 is shown for reflecting the sample light beam out of the catheter to tissue in a body cavity, as described above. The rotary connector 410 is driven by a motor, as is known in the art.

[0081] Fig. 13 shows a housing 420 containing an interferometer in accordance with the embodiment of Fig. 4a of the present invention for use with an interferometric catheter 408 and an IVUS console 396. Components common to the other embodiments are commonly numbered. The light source 102, the fiber optic beam splitter 104, the optical fibers 106, 108, 110 and 114, the diffraction grating 118, the collimators 112, 116, the open space beam splitter 120, the conjugating lens 124 and the multi-element detector 122 are shown. The rotary coupler 410 of fig. 11 is also shown. A motor 422 is provided in the housing 420 to rotate the rotary coupler 410 and the optical fiber 407 within the catheter 408. A motor controller 424 controls the operation of the motor 422. A power supply 426 is shown, as well. Data acquisition and processing boards 428 are provided, electrically connected to a cable 430 for connection to the IVUS console 396. The parallel to serial converter 398 may be included on the processing boards. A port 428 of the housing and a catheter adapter 430 for connection to the port are shown as well.

[0082] As mentioned above, any of the embodiments of the interferometric systems described herein, as well as other fiber optic and non fiber optic OCT systems using a multi-element photo detector, may be used in the imaging system 390.

[0083] While use of a multi-element photo detector array is preferred, a single element photo detector may also be used, in which case the width of the combined light beam could be moved across the detector or the detector could be moved across the width of the combined light beam.

[0084] Another interferometric system which may be used is described in U.S.S.N. 09/906,903, entitled "Electronically Scanned Optical Coherence Tomography with Frequency Modulated Signals", filed on July 16, 2001 and assigned to the assignee of the present invention. There, an interferometer uses a single element detector and image depth information is carried on multiple modulation frequencies, each corresponding to a different depth. The image depth information in the signal output by the detector may be resolved by tuning to the desired frequency. Interfaces for coupling interferometer with a single element detector to an IVUS console are also disclosed.

[0085] Alternatively, an oscillating minor or other such reflector may be used to scan a sample depth. For example, interferometers such as those described in U.S. Patent No. 6,134,003, U.S. Patent No. 6,111,645, U.S. Patent No. 5,459,570, U.S. Patent No. 5,321,501 and International Publication No. WO 98/38907 published on September 11, 1998, for example, may also be used in the imaging system with an interface disclosed in the '903 application or other such interfaces.

[0086] As was also mentioned above, the sample arm may be incorporated in an endoscope for insertion into the gastrointestinal tract, for example. The sample arm may also have a probe at its end for examining external biological tissue, such as the eye, or other types of samples, such as semiconductors.

[0087] While the preferred embodiments described above are implemented with fiber optics for use in examining internal biological tissue, such as biological tissue along internal body cavities and organs, the embodiments of the invention may be readily implemented with bulk optics or other optical components. In a non fiber optic implementation, one collimator is preferably provided between the light source and the first beam splitter.

[0088] While use of a multi-element photo detector array is prefered, a single element photo detector may also be used, in which case the width of the combined light beam could be moved across the detector or the detector could be moved across the width of the combined light beam.

[0089] Use of a focusing lens, first and second collimators and one or two conjugating lenses are also preferred, but not required.

[0090] While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that modifications may be made to those embodiments without going beyond the scope of the invention, as defined by the following claims and their equivalents.

Claims

1. An imaging system comprising:

   an ultrasound console (396) having a serial input, an ultrasound image processor and a display;
   an interferometer (391) comprising a multi-element photo detector (392) having a plurality of parallel outputs (394); and
   an ultrasound device (399) with an output (399a) coupled to the ultrasound console (396), **characterised by**:
   a parallel to serial converter (398) electrically coupling the plurality of parallel outputs (394) of the multi-element photo detector (392) to a serial input of the ultrasound console (396),
   wherein the ultrasound console (396) processes data provided by the interferometer (391) to form an image for display.

2. The imaging system of claim 1, wherein the interferometer (391)comprises a catheter.

3. The imaging system of claim 1, wherein the ultrasound device (399) comprises a catheter.

4. The imaging system of claim 1, wherein the ultrasound console (396) is configured to process analog serial data and the parallel to serial converter (398) is adapted to provide analog serial data to the ultrasound console(396).

5. The imaging system of claim 1, wherein the ultrasound console (396) is to process analog serial data and the parallel to serial converter (398) is adapted to provide digital serial data to the ultrasound console (396).

6. The imaging system of claim 1, wherein the interferometer (391) comprises two multi-element photo detectors (224, 226), each comprising a plurality of parallel outputs (394) coupled to the parallel to serial converter (398).

7. The imaging system of claim 1, wherein the interferometer (391) further comprises: a light source (102);

   means (104) for creating a sample light beam and a reference light beam from light from the light source (102);
   means for conveying the sample light beam to a sample;
   means for introducing a time delay into at least one of a second sample light beam received from the sample and the reference light beam; and
   means for combining the second sample light beam with the reference light beam to form a combined light beam for detection by the detector (392).

8. The imaging system of claim 7, wherein the means for combining the second sample light beam and the reference light beam is a beam splitter (120).

9. The imaging system of claim 7, wherein the means for introducing a time delay and the means for combining the second sample light beam and the reference light beam is a diffraction grating (118).

10. The imaging system of claim 7, wherein:

    the means for introducing a time delay is a diffraction grating (118) that introduces the time delay to the reference light beam; and
    the means for combining the second sample light beam and the reference light beam is a beam splitter (120).

11. The imaging system of claim 7, wherein the means for forming the sample and reference light beams is a first beam splitter (104) and the means for combining the second sample light beam and the reference light beam is a second beam splitter (120).

12. The imaging system of claim 1, wherein the interferometer (391) further comprises:

    a low coherence light source (102);
    a first beam splitter (104) in communication with the light source (102) to split light from the light source (102) into a first sample light beam to be directed onto a sample (119) and a reference light beam;
    a diffraction grating (118) in communication with the first beam splitter (104) to receive the reference light beam from the first beam splitter (104) and to diffract the reference light beam; and

a second beam splitter (120) positioned to receive a second sample light beam from the sample (119), the second beam splitter (120) being in communication with the diffraction grating (118) to receive the diffracted reference light beam, wherein the second sample light beam and the diffracted reference light beam are combined in the second beam splitter (120) to form a combined light beam; and
a detector (392) positioned to receive the combined light beam from the second beam splitter.

13. The imaging system of claim 12, wherein at least one of the first beam splitter (104) and the second beam splitter (120) is a non 50/50 beam splitter.

14. The imaging system of claim 13 wherein:

the first beam splitter (104) is an approximately 50/50 beam splitter; and
the second beam splitter (120) directs more than half of the light energy in the second sample light beam into the combined beam and directs less than half of the light energy in the reference light beam into the combined beam.

15. The imaging system of claim 14, wherein the second beam splitter (120) directs substantially more than half of the light energy in the second sample light beam into the combined light beam and directs substantially less than half of the light energy in the reference light beam into the combined beam.

16. The imaging system of claim 5, wherein the diffraction grating (118) is a reflective diffraction grating, a transparent diffraction grating or an acousto optic modulator.

17. The imaging system of claim 14, wherein the detector (392) is a multi-element photo detector comprising a plurality of parallel outputs (394), the system further comprising:

a parallel to serial converter (398) electrically coupled between the output (394) of the detector and the input of the ultrasound console(396),the parallel to serial converter comprising a plurality of inputs, each input being coupled to a respective one of the plurality of outputs (394) of the detector (392), to convert the parallel data output by the plurality of outputs (394)of the detector (392) into serial data,
the parallel to serial converter (398) having an output coupled to the input of the ultrasound console (396) to provide the serial data to the ultrasound console (396) to process into an image.

18. The imaging system of claim 12, wherein the first beam splitter (104) directs more than half of the light energy received from the light source (102) into the sample light beam and less than half of the light energy received from the light source (102) into the reference light beam.

19. The imaging system of claim 18, further comprising an optical circulator (204), wherein the sample light beam is directed to the sample through the optical circulator (204) and the second sample light beam is directed to the second beam splitter (120) through the optical circulator (204).

20. The imaging system of claim 19, wherein the second beam splitter (120) directs substantially more than half of the light energy received from the light source (102) into the sample light beam and substantially less than half of the light energy received from the light source (102) into the reference light beam.

21. The imaging system of claim 20, wherein the second beam splitter (120) is an approximately 50/50 beam splitter (222) and the second sample light beam and the reference light beam are combined in the second beam splitter (222) to form first and second combined light beams, the first light beam being detected by the first detector (224); and the interferometer further comprises a second detector (226) to detect the second light beam.

22. The imaging system of claim 21, wherein the first and second detectors (224, 226) are each multi-element photo detectors comprising a plurality of parallel outputs, the system further comprising:

a parallel to serial converter (398) electrically coupled between the output of the detector and the input of the ultrasound console (396), the parallel to serial converter (398) comprising a plurality of inputs, each input being coupled to a respective one of the plurality of outputs (394) of the detector, to convert the parallel data output by the plurality of outputs (394) of the detector into serial data,
the parallel to serial converter (398) having an output coupled to the input of the ultrasound console (396) to

provide the serial data to the ultrasound console (396) to process into an image.

23. The imaging system of claim 12, further comprising a focusing lens (110) to focus the sample light beam onto the sample and to focus the second sample light beam.

24. An imaging system as claimed in claim 1 wherein
the interferometer (391) further comprises:

a low coherence light source (102);
a first fiber optic beam splitter (104);
a first optical path optically coupling the light source (102) to the first beam splitter (104), wherein the first beam splitter (104) splits light received from the light source (102) into a sample light beam and a reference light beam;
a second optical path optically coupling the first beam splitter (104) to a sample and coupling a second sample light beam from the sample to the first beam splitter (104);
a second beam splitter (120);
a third optical path optically coupling the first beam splitter (104) to the second beam splitter (120) to convey the second sample light beam, at least in part, from the first beam splitter (104) to the second beam splitter (120);
a diffraction grating (118);
a fourth optical path optically coupling the first beam splitter (104) to the diffraction grating (118) to convey the reference light beam, at least in part, to the diffraction grating (118);
wherein the second beam splitter (120) is positioned to receive the diffracted reference light beam and the reference light beam and the second sample light beam are combined in the second beam splitter (120) to form a combined light beam; and
the multi-element photo detector being positioned to receive the combined light beam;
the parallel to serial converter (398) comprising a plurality of inputs, each input being coupled to a respective one of the plurality of outputs (394) of the detector (392), to convert the parallel data output by the plurality of outputs (394) of the detector (392) into serial data,
the parallel to serial converter (398) having an output coupled to the input of the ultrasound console (396) to provide the serial data to the ultrasound console (396) to process into the image.

25. The imaging system of claim 24, wherein:

the first beam splitter (104) is an approximately 50/50 beam splitter; and
the second beam splitter (120)directs more than half of the light energy received from the light source (102) into the sample light beam and less than half of the light energy received from the light source (102) into the reference light beam.

26. The imaging system of claim 25, further comprising a catheter and an optical fiber (108) within the catheter, wherein the second optical path is optically coupled to the optical fiber (108) within the catheter.

27. The imaging system of claim 24, further comprising a focusing lens (110), wherein the second optical path optically couples the first beam splitter (104) to the focusing lens (110), to focus the sample light beam onto the sample and to focus the second sample light beam.

28. An imaging system as claimed in claim 1 wherein;
the interferometer (391) further comprises:

a low coherence light source (102);
a first fiber optic beam splitter (202);
a first optical fiber (106) optically coupling the light source (102) to the first beam splitter (202), wherein the first beam splitter (202) splits light received from the light source (102) into a sample light beam and a reference light beam;
an optical circulator (204) having a first port, a second port and a third port, wherein light input to the first port exits the optical circulator (204) from the second port and light entering the second port exits the optical circulator (204) from the third port;
a second optical fiber (206) optically coupling the first beam splitter (202) to the first port of the optical circulator (204);
a third optical fiber (208) optically coupling the second port of the optical circulator (204) to the sample (119)

and optically coupling a second sample light beam from the sample (119) to the second port;
a second beam splitter (222);
a fourth optical fiber (210) optically coupling the third port of the optical circulator (204) to the second beam splitter (222), wherein the third optical fiber (208) conveys the second sample light beam, at least in part, from the third port to the second beam splitter (222);
a diffraction grating (118);
a fifth optical fiber (220) optically coupling the first beam splitter (202) to the diffraction grating (118) to convey the reference light beam, at least in part, to the diffraction grating (118);
the second beam splitter (222) being positioned to receive the diffracted reference light beam from the diffraction grating (118), wherein the reference light beam and the second sample light beam combine in the beam splitter (222) to form a combined light beam; and
the multi-element photo detector (392) positioned to receive the combined beam; and
the parallel to serial converter (398) comprising a plurality of inputs, each input being coupled to a respective one of the plurality of outputs of the detector, to convert the parallel data output by the plurality of outputs of the detector into serial data,
the parallel to serial converter (398) having an output coupled to the input of the ultrasound console (396) to provide the serial data to the ultrasound console (396) to process into the image.

29. The imaging system of claim 28, wherein the light received from the light source (102) has an energy and the first beam splitter (202) splits the light into a sample light beam having more than half of the energy of the light and a reference light beam having less than half of the energy of the light.

30. The imaging system of claim 29, wherein the second beam splitter (222) is an approximately 50/50 beam splitter and the second sample light beam and the reference light beam are combined in the second beam splitter (222) to form first and second sample light beams, wherein the first combined light beam is received by the first multi-element photo detector (224); and
the interferometer further comprises a second multi-element photo detector (226) positioned to receive a second combined beam from the second beam splitter, the second multi-element photo detector (226) comprising a plurality of parallel outputs coupled to the parallel to serial converter.

31. The imaging system of claim 28 or claim 31, further comprising a catheter and an optical fiber (108) within the catheter, wherein the third optical fiber (208) is optically coupled to the optical fiber (108) within the catheter.

32. The imaging system of claim 28, further comprising a focusing lens (110) to focus the sample light beam from the third optical fiber (208) onto the sample and to focus the second sample light beam into the third optical fiber (208).

33. A method of analyzing a surface comprising the steps of:

using an ultrasound device having an ultrasound transducer to emit ultrasound waves which are reflected by the surface and induce an echo signal at the ultrasound transducer;
transmitting the echo signal from the ultrasound transducer to an ultrasound console, which comprises a serial input, an ultrasound image processor and a display;
forming a sample light beam and a reference light beam with an interferometer, conveying the sample light beam to the surface, combining light received from the surface with the reference light beam into a combined light beam and detecting the combined light beam with a multi-element detector to output a plurality of parallel electrical signals, **characterised by**:
coupling the interferometer to the ultrasound console;
processing data from the interferometer by the ultrasound processor comprising:
converting the processed parallel electrical signals into a serial signal; and
providing the serial signal to the ultrasound processor for processing into an image.

Patentansprüche

1. Abbildungssystem, welches aufweist:

eine Ultraschallkonsole (396) mit einem Serieneingang, einem Ultraschall-Bildprozessor und einer Anzeigevorrichtung;

ein Interferometer (391) aufweisend einen Multi-element-Fotodetektor (392) mit mehreren parallelen Ausgängen (394); und

eine Ultraschallvorrichtung (399) mit einem mit der Ultraschallkonsole (396) gekoppelten Ausgang (399a), **gekennzeichnet durch**:

einen Parallel/Serien-Wandler (398), der elektrisch die mehreren parallelen Ausgänge (394) des Multielement-Fotodetektors (392) mit einem seriellen Eingang der Ultraschallkonsole (396) koppelt,

wobei die Ultraschallkonsole (396) von dem Interferometer (391) gelieferte Daten verarbeitet, um ein Bild für die Anzeige zu bilden.

2. Abbildungssystem nach Anspruch 1, bei dem das Interferometer (391) ein Katheter aufweist.

3. Abbildungssystem nach Anspruch 1, bei dem die Ultraschallvorrichtung (399) ein Katheter aufweist.

4. Abbildungssystem nach Anspruch 1, bei dem die Ultraschallkonsole (396) ausgebildet ist zum Verarbeiten analoger serieller Daten, und der Parallel/Serien-Wandler (398) ausgebildet ist zum Liefern analoger serieller Daten zu der Ultraschallkonsole (396).

5. Abbildungssystem nach Anspruch 1, bei dem die Ultraschallkonsole (396) ausgebildet ist zum Verarbeiten analoger serieller Daten und der Parallel/Serien-Wandler (398) ausgebildet ist zum Liefern digitaler serieller Daten zu der Ultraschallkonsole (396).

6. Abbildungssystem nach Anspruch 1, bei dem das Interferometer (391) zwei Multielement-Fotodetektoren (224, 226) aufweist, von denen jeder mehrere parallele Ausgänge (394) aufweist, die mit dem Parallel/Serien-Wandler (398) gekoppelt sind.

7. Abbildungssystem nach Anspruch 1, bei dem das Interferometer (391) weiterhin aufweist:

eine Lichtquelle (102);

Mittel (104) zum Schaffen eines Abtastlichtstrahls und eines Bezugslichtstrahls aus dem Licht der Lichtquelle (102);

Mittel zum Befördern des Abtastlichtstrahls zu einer Probe;

Mittel zum Einführen einer Zeitverzögerung in zumindest einen von einem zweiten Abtastlichtstrahl, der von der Probe empfangen wurde, oder den Bezugslichtstrahl; und

Mittel zum Kombinieren des zweiten Abtastlichtstrahls mit dem Bezugslichtstrahl, um einen kombinierten Lichtstrahl zur Erfassung durch den Detektor (392) zu bilden.

8. Abbildungssystem nach Anspruch 7, bei dem die Mittel zum Kombinieren des zweiten Abtastlichtstrahls und des Bezugslichtstrahls ein Strahlenteiler (120) sind.

9. Abbildungssystem nach Anspruch 7, bei dem die Mittel zum Einführen einer Zeitverzögerung und die Mittel zum Kombinieren des zweiten Abtastlichtstrahls und des Bezugslichtstrahls ein Beugungsgitter (118) sind.

10. Abbildungssystem nach Anspruch 7, bei dem die Mittel zum Einführen einer Zeitverzögerung ein Beugungsgitter (118) sind, das die Zeitverzögerung in den Bezugslichtstrahl einführt; und die Mittel zum Kombinieren des zweiten Abtastlichtstrahls und des Bezugslichtstrahls ein Strahlenteiler (120) sind.

11. Abbildungssystem nach Anspruch 7, bei dem die Mittel zum Bilden des Abtast- und des Bezugslichtstrahls ein erster Strahlenteiler (104) sind und die Mittel zum Kombinieren des zweiten Abtastlichtstrahls und des Bezugslichtstrahls ein zweiter Strahlenteiler (120) sind.

12. Abbildungssystem nach Anspruch 1, bei dem das Interferometer (391) weiterhin aufweist:

eine Niedrigkohärenz-Lichtquelle (102);

einen ersten Strahlenteiler (104) kombiniert mit der Lichtquelle (102), um Licht von der Lichtquelle (102) in einen ersten Abtastlichtstrahl, der auf eine Probe (119) zu richten ist, und einen Bezugslichtstrahl teilt;

ein Beugungsgitter (118) in Verbindung mit dem ersten Strahlenteiler (104), um den Bezugslichtstrahl von dem ersten Strahlenteiler (104) zu empfangen und den Bezugslichtstrahl zu beugen;

und einen zweiten Strahlenteiler (120), der positioniert ist zum Empfangen eines zweiten Abtastlichtstrahls von der Probe (119), wobei der zweite Strahlenteiler (120) in Verbindung mit dem Beugungsgitter (118) ist, um den gebeugten Bezugslichtstrahl zu empfangen, wobei der zweite Abtastlichtstrahl und der gebeugte Bezugslichtstrahl in dem zweiten Strahlenteiler (120) kombiniert werden, um einen kombinierten Lichtstrahl zu bilden; und einen Detektor (392), der positioniert ist zum Empfangen des kombinierten Lichtstrahls von dem zweiten Strahlenteiler.

13. Abbildungssystem nach Anspruch 12, bei dem zumindest einer von dem ersten Strahlenteiler (104) oder dem zweiten Strahlenteiler (120) ein Nicht-50/50-Strahlenteiler ist.

14. Abbildungssystem nach Anspruch 13, bei dem: der erste Strahlenteiler (104) angenähert ein 50/50-Strahlenteiler ist; und
der zweite Strahlenteiler (120) mehr als die Hälfte der Lichtenergie in dem zweiten Abtastlichtstrahl in den kombinierten Strahl richtet und weniger als die Hälfte der Lichtenergie in dem Bezugslichtstrahl in den kombinierten Strahl richtet.

15. Abbildungssystem nach Anspruch 14, bei dem der zweite Strahlenteiler (120) im Wesentlichen mehr als die Hälfte der Lichtenergie in dem zweiten Abtastlichtstrahl in den kombinierten Lichtstrahl richtet und im Wesentlichen weniger als die Hälfte der Lichtenergie in dem Bezugslichtstrahl in den kombinierten Strahl richtet.

16. Abbildungssystem nach Anspruch 5, bei dem das Beugungsgitter (118) ein reflektierendes Beugungsgitter, ein durchlässiges Beugungsgitter oder ein akustooptischer Modulator ist.

17. Abbildungssystem nach Anspruch 14, bei dem der Detektor (392) ein Multielement-Fotodetektor ist, der mehrere parallele Ausgänge (394) aufweist, welches System weiterhin aufweist:

einen Parallel/Serien-Wandler (398), der elektrisch zwischen den Ausgang (394) des Detektors und den Eingang der Ultraschallkonsole (396) gekoppelt ist, welcher Parallel/Serien-Wandler
mehrere Eingänge aufweist, wobei jeder Eingang mit einem jeweiligen der mehreren Ausgänge (394) des Detektors (392) gekoppelt ist, um die von den mehreren Ausgängen (394) des Detektors (392) ausgegebenen parallelen Daten in serielle Daten umzuwandeln,
wobei der Parallel/Serien-Wandler (398) einen Ausgang hat, der mit dem Eingang der Ultraschallkonsole (396) gekoppelt ist, um die seriellen Daten zu der Ultraschallkonsole (396) zur Verarbeitung in ein Bild zu liefern.

18. Abbildungssystem nach Anspruch 12, bei dem der erste Strahlenteiler (104) mehr als die Hälfte der von der Lichtquelle (102) empfangenen Lichtenergie in den Abtastlichtstrahl richtet und weniger als die Hälfte der von der Lichtquelle (102) empfangenen Lichtenergie in den Bezugslichtstrahl richtet.

19. Abbildungssystem nach Anspruch 18, weiterhin aufweisend einen optischen Zirkulator (204), wobei der Abtastlichtstrahl durch den optischen Zirkulator (204) zu der Probe gerichtet wird und der zweite Abtastlichtstrahl durch den optischen Zirkulator (204) zu dem zweiten Strahlenteiler (120) gerichtet wird.

20. Abbildungssystem nach Anspruch 19, bei dem der zweite Strahlenteiler (120) im Wesentlichen mehr als die Hälfte der von der Lichtquelle (102) empfangenen Lichtenergie in den Abtastlichtstrahl und im Wesentlichen weniger als die Hälfte der von der Lichtquelle (102) empfangenen Lichtenergie in den Bezugslichtstrahl richtet.

21. Abbildungssystem nach Anspruch 20, bei dem der zweite Strahlenteiler (120) angenähert ein 50/50-Strahlenteiler (222) ist und der zweite Abtastlichtstrahl und der Bezugslichtstrahl in dem zweiten Strahlenteiler (222) kombiniert werden, um den ersten und den zweiten kombinierten Lichtstrahl zu bilden, wobei der erste Lichtstrahl durch den ersten Detektor (224) erfasst wird; und
das Interferometer weiterhin einen zweiten Detektor (226) aufweist, um den zweiten Lichtstrahl zu erfassen.

22. Abbildungssystem nach Anspruch 21, bei dem der erste und der zweite Detektor (224, 226) jeweils Multielement-Fotodetektoren, die mehrere parallele Ausgänge aufweisen, sind, welches System weiterhin aufweist:

einen Parallel/Serien-Wandler (398), der elektrisch zwischen den Ausgang des Detektors und den Eingang der Ultraschallkonsole (396) gekoppelt ist, welcher Parallel/Serien-Wandler (398) mehrere Eingänge aufweist, wobei jeder Eingang mit einem jeweiligen der mehreren Ausgänge (394) des Detektors gekoppelt ist, um die von den mehreren Ausgängen (394) des Detektors ausgegebenen parallelen Daten in serielle Daten umzuwandeln, wobei der Parallel/Serien-Wandler (398) einen Ausgang hat, der mit dem Eingang der Ultraschallkonsole (396) gekoppelt ist, um die seriellen Daten zu der Ultraschallkonsole (396) für die Verarbeitung in ein Bild zu liefern.

23. Abbildungssystem nach Anspruch 12, weiterhin aufweisend eine Fokussierlinse (110) zum Fokussieren des Abtastlichtstrahls auf die Probe und zum Fokussieren des zweiten Abtastlichtstrahls.

24. Abbildungssystem nach Anspruch 1, bei dem das Interferometer (391) weiterhin aufweist:

eine Niedrigkohärenz-Lichtquelle (102);
einen ersten faseroptischen Strahlenteiler (104);
einen ersten optischen Pfad, der die Lichtquelle (102) mit dem ersten Strahlenteiler (104) optisch koppelt, wobei der erste Strahlenteiler (104) von der Lichtquelle (102) empfangenes
Licht in einen Abtastlichtstrahl und einen Bezugslichtstrahl teilt;
einen zweiten optischen Pfad, der den ersten Strahlenteiler (104) mit einer Probe optisch koppelt und einen zweiten Abtastlichtstrahl von der Probe mit dem ersten Strahlenteiler (104) koppelt;
einen zweiten Strahlenteiler (120);
einen dritten optischen Pfad, der den ersten Strahlenteiler (104) mit dem zweiten Strahlenteiler (120) optisch koppelt, um den zweiten Abtastlichtstrahl zumindest teilweise von dem ersten Strahlenteiler (104) zu dem zweiten Strahlenteiler (120) zu befördern;
ein Beugungsgitter (118);
einen vierten optischen Pfad, der den ersten Strahlenteiler (104) mit dem Beugungsgitter (118) optisch koppelt, um den Bezugslichtstrahl zumindest teilweise zu dem Beugungsgitter (118) zu befördern;
wobei der zweite Strahlenteiler (120) positioniert ist zum Empfangen des gebeugten Bezugslichtstrahls, und der Bezugslichtstrahl und der zweite Abtastlichtstrahl in dem zweiten Strahlenteiler (120) kombiniert werden, um einen kombinierten Lichtstrahl zu bilden; und
der Multielement-Fotodetektor positioniert ist zum Empfangen des kombinierten Lichtstrahls;
wobei der Parallel/Serien-Wandler (398) mehrere Eingänge aufweist, von denen jeder Eingang mit einem jeweiligen der mehreren Ausgänge (394) des Detektors (392) gekoppelt ist, um die von den mehreren Ausgängen (394) des Detektors (392) ausgegebenen parallelen Daten in serielle Daten umzuwandeln,
und wobei der Parallel/Serien-Wandler (398) einen mit dem Eingang der Ultraschallkonsole (396) gekoppelten Ausgang hat, um die seriellen Daten für die Verarbeitung in ein Bild zu der Ultraschallkonsole (396) zu liefern.

25. Abbildungssystem nach Anspruch 24, bei dem: der erste Strahlenteiler (104) angenähert ein 50/50-Strahlenteiler ist; und der zweite Strahlenteiler (120) mehr als die Hälfte der von der Lichtquelle (102) empfangenen Lichtenergie in den Abtastlichtstrahl und weniger als die Hälfte der von der Lichtquelle (102) empfangenen Lichtenergie in den Bezugslichtstrahl richtet.

26. Abbildungssystem nach Anspruch 25, weiterhin aufweisend ein Katheter und eine optische Faser (108) innerhalb des Katheters, wobei der zweite optische Pfad mit der optischen Faser (108) innerhalb des Katheters optisch gekoppelt ist.

27. Abbildungssystem nach Anspruch 24, weiterhin aufweisend eine Fokussierlinse (110), wobei der zweite optische Pfad den ersten Strahlenteiler (104) mit der Fokussierlinse (110) optisch koppelt, um den Abtastlichtstrahl auf die Probe zu fokussieren und den zweiten Abtastlichtstrahl zu fokussieren.

28. Abbildungssystem nach Anspruch 1, bei dem das Interferometer (391) weiterhin aufweist:

eine Niedrigkohärenz-Lichtquelle (102);
einen ersten faseroptischen Strahlenteiler (202) ;
eine erste optische Faser (106), die die Lichtquelle (102) mit dem ersten Strahlenteiler (202) optisch koppelt, wobei der erste Strahlenteiler (202) von der Lichtquelle (102) empfangenes Licht in einen Abtaststrahl und einen Bezugslichtstrahl teilt;
einen optischen Zirkulator (204) mit einem ersten Port, einem zweiten Port und einem dritten Port, wobei in das erste Port eingegebenes Licht den optischen Zirkulator (204) durch das zweite Port verlässt und in das zweite Port eintretendes Licht den optischen Zirkulator (204) durch das dritte Port verlässt;
eine zweite optische Faser (206), die den ersten Strahlenteiler (202) mit dem ersten Port des optischen Zirkulators (204) optisch koppelt;
eine dritte optische Faser (208), die das zweite Port des optischen Zirkulators (204) mit der

Probe (119) optisch koppelt und einen zweiten Abtastlichtstrahl von der Probe (119) mit dem zweiten Port optisch koppelt;
einen zweiten Strahlenteiler (222);
eine vierte optische Faser (210), die das dritte Port des optischen Zirkulators (204) mit dem zweiten Strahlenteiler (222) optisch koppelt, wobei die dritte optische Faser (208) den zweiten Abtastlichtstrahl zumindest teilweise von dem dritten Port zu dem zweiten Strahlenteiler (222) befördert;
ein Beugungsgitter (118);
eine fünfte optische Faser (220), die den ersten Strahlenteiler (202) mit dem Beugungsgitter (118) optisch koppelt, um den Bezugslichtstrahl zumindest teilweise zu dem Beugungsgitter (118) zu befördern;
wobei der zweite Strahlenteiler (222) positioniert ist zum Empfangen des gebeugten Bezugslichtstrahls von dem Beugungsgitter (118), und der Bezugslichtstrahl und der zweite Abtastlichtstrahl in dem Strahlenteiler (222) kombiniert werden, um einen kombinierten Lichtstrahl zu bilden; und
der Multielement-Fotodetektor (392) positioniert ist zum Empfangen des kombinierten Strahls; und der Parallel/Serien-Wandler (398) mehrere Eingänge aufweist, von denen jeder Eingang mit einem jeweiligen der mehreren Ausgänge des Detektors gekoppelt ist, um die von den mehreren Ausgängen des Detektors ausgegebenen parallelen Daten in serielle Daten umzuwandeln, und
der Parallel/Serien-Wandler (398) einen mit dem Eingang der Ultraschallkonsole (396) gekoppelten Ausgang hat, um die seriellen Daten für die Verarbeitung in das Bild zu der Ultraschallkonsole (396) zu liefern.

29. Abbildungssystem nach Anspruch 28, bei dem das von der Lichtquelle (102) empfangene Licht eine Energie hat und der erste Strahlenteiler (202) das Licht in einen Abtastlichtstrahl mit mehr als der Hälfte der Energie des Lichts und einen Bezugslichtstrahl mit weniger als der Hälfte der Energie des Lichts teilt.

30. Abbildungssystem nach Anspruch 29, bei dem der zweite Strahlenteiler (222) ein angenähert 50/50-Strahlenteiler ist und der zweite Abtaststrahl und der Bezugslichtstrahl in dem zweiten Strahlenteiler (222) kombiniert werden, um einen ersten und einen zweiten Abtastlichtstrahl zu bilden, wobei der erste kombinierte Lichtstrahl von dem ersten Multielement-Fotodetektor (224) empfangen wird; und
das Interferometer weiterhin einen zweiten Multielement-Fotodetektor (226) aufweist, der positioniert ist zum Empfangen eines zweiten kombinierten Strahls von dem zweiten Strahlenteiler, welcher zweite Multielement-Fotodetektor (226) mehrere parallele Ausgänge aufweist, die mit dem Parallel/Serien-Wandler gekoppelt sind.

31. Abbildungssystem nach Anspruch 28 oder Anspruch 31, weiterhin aufweisend ein Katheter und eine optische Faser (108) innerhalb des Katheters, wobei die dritte optische Faser (208) mit der optischen Faser (108) innerhalb des Katheters optisch gekoppelt ist.

32. Abbildungssystem nach Anspruch 28, weiterhin aufweisend eine Fokussierlinse (110) zum Fokussieren des Abtastlichtstrahls von der dritten optischen Faser (208) auf die Probe und zum Fokussieren des zweiten Abtastlichtstrahls in die dritte optische Faser (208).

33. Verfahren zum Analysieren einer Oberfläche, das die Schritte aufweist:

Verwenden einer Ultraschallvorrichtung mit einem Ultraschallwandler, um Ultraschallwellen zu emittieren, die von der Oberfläche reflektiert werden und ein Echosignal an dem Ultraschallwandler induzieren;
Übertragen des Echosignals von dem Ultraschallwandler zu einer Ultraschallkonsole, die einen Serieneingang, einen Ultraschall-Bildprozessor und eine Anzeigevorrichtung aufweist;
Bilden eines Abtastlichtstrahls und eines Bezugslichtstrahls mit einem Interferometer, Befördern des Abtastlichtstrahls zu der Oberfläche, Kombinieren von von der Oberfläche empfangenem Licht mit dem Bezugslichtstrahl in einen kombinierten Lichtstrahl, und Erfassen des kombinierten Lichtstrahls mit einem Multielement-Detektor, um mehrere parallele elektrische Signale auszugeben, **gekennzeichnet durch**:
Koppeln des Interferometers mit der Ultraschallkonsole;
Verarbeiten von Daten von dem Interferometer durch den Ultraschallprozessor, welches aufweist:
Umwandeln der verarbeiteten parallelen elektrischen Signale in ein Seriensignal; und Liefern des Seriensignals zu dem Ultraschallprozessor für die Verarbeitung in ein Bild.

Revendications

1. Système d'imagerie comprenant:

une console à ultrasons (396) ayant une entrée série, un processeur d'image d'ultrasons et un affichage ;
un interféromètre (391) comprenant un photodétecteur multiélément (392) ayant une pluralité de sorties parallèles (394) ; et
un dispositif à ultrasons (399) avec une sortie (399a) couplée à la console à ultrasons (396), **caractérisé par** :
un convertisseur parallèle-série (398) couplant électriquement la pluralité de sorties parallèles (394) du photodétecteur multiélément (392) à une entrée série de la console à ultrasons (396),
dans lequel la console à ultrasons (396) traite des données fournies par l'interféromètre (391) pour former une image pour l'affichage.

2. Système d'imagerie selon la revendication 1, dans lequel l'interféromètre (391) comprend un cathéter.

3. Système d'imagerie selon la revendication 1, dans lequel le dispositif à ultrasons (399) comprend un cathéter.

4. Système d'imagerie selon la revendication 1, dans lequel la console à ultrasons (396) est configurée pour traiter des données série analogiques et le convertisseur parallèle-série (398) est adapté pour fournir des données série analogiques à la console à ultrasons (396).

5. Système d'imagerie selon la revendication 1, dans lequel la console à ultrasons (396) sert à traiter des données série analogiques et le convertisseur parallèle-série (398) est adapté pour fournir des données série numériques à la console à ultrasons (396).

6. Système d'imagerie selon la revendication 1, dans lequel l'interféromètre (391) comprend deux photodétecteurs multiéléments (224, 226), chacun comprenant une pluralité de sorties parallèles (394) couplées au convertisseur parallèle-série (398).

7. Système d'imagerie selon la revendication 1, dans lequel l'interféromètre (391) comprend en outre :

une source de lumière (102) ;
un moyen (104) pour créer un faisceau lumineux d'échantillon et un faisceau lumineux de référence à partir de la lumière provenant de la source de lumière (102) ;
un moyen pour convertir le faisceau lumineux d'échantillon en un échantillon ;
un moyen pour introduire un retard temporel dans au moins un élément pris parmi un second faisceau lumineux d'échantillon reçu depuis l'échantillon et le faisceau lumineux de référence ; et
un moyen pour combiner le second faisceau lumineux d'échantillon avec le faisceau lumineux de référence pour former un faisceau lumineux combiné pour la détection par le détecteur (392).

8. Système d'imagerie selon la revendication 7, dans lequel le moyen pour combiner le second faisceau lumineux d'échantillon et le faisceau lumineux de référence est un séparateur de faisceau (120).

9. Système d'imagerie selon la revendication 7, dans lequel le moyen pour introduire un retard temporel et le moyen pour combiner le second faisceau lumineux d'échantillon et le faisceau lumineux de référence est un réseau de diffraction (118).

10. Système d'imagerie selon la revendication 7, dans lequel :

le moyen pour introduire un retard temporel est un réseau de diffraction (118) qui introduit le retard temporel sur le faisceau lumineux de référence ; et
le moyen pour combiner le second faisceau lumineux d'échantillon et le faisceau lumineux de référence est un séparateur de faisceau (120).

11. Système d'imagerie selon la revendication 7, dans lequel le moyen pour former le faisceau lumineux d'échantillon et le faisceau lumineux de référence est un premier séparateur de faisceau (104) et le moyen pour combiner le second faisceau lumineux d'échantillon et le faisceau lumineux de référence est un second séparateur de faisceau (120).

12. Système d'imagerie selon la revendication 1, dans lequel l'interféromètre (391) comprend en outre :

une source de lumière faible cohérence (102) ;

un premier séparateur de faisceau (104) en communication avec la source de lumière (102) pour séparer la lumière de la source de lumière (102) selon un premier faisceau lumineux d'échantillon qui doit être dirigé sur un échantillon (119) et un faisceau lumineux de référence ;
un réseau de diffraction (118) en communication avec le premier séparateur de faisceau (104) pour recevoir le faisceau lumineux de référence depuis le premier séparateur de faisceau (104) et pour diffracter le faisceau lumineux de référence ; et
un second séparateur de faisceau (120) positionné pour recevoir un second faisceau lumineux d'échantillon depuis l'échantillon (119), le second séparateur de faisceau (120) étant en communication avec le réseau de diffraction (118) pour recevoir le faisceau lumineux de référence diffracté, dans lequel le second faisceau lumineux d'échantillon et le faisceau lumineux de référence diffracté sont combinés dans le second séparateur de faisceau (120) pour former un faisceau lumineux combiné ; et
un détecteur (392) positionné pour recevoir le faisceau lumineux combiné depuis le second séparateur de faisceau.

13. Système d'imagerie selon la revendication 12, dans lequel au moins un élément pris parmi le premier séparateur de faisceau (104) et le second séparateur de faisceau (120) est un séparateur de faisceau non 50/50.

14. Système d'imagerie selon la revendication 13, dans lequel :

le premier séparateur de faisceau (104) est un séparateur de faisceau approximativement 50/50 ; et
le second séparateur de faisceau (120) dirige plus de la moitié de l'énergie lumineuse dans le second faisceau lumineux d'échantillon selon le faisceau combiné et dirige moins de la moitié de l'énergie lumineuse dans le faisceau lumineux de référence selon le faisceau combiné.

15. Système d'imagerie selon la revendication 14, dans lequel le second séparateur de faisceau (120) dirige sensiblement plus de la moitié de l'énergie lumineuse dans le second faisceau lumineux d'échantillon selon le faisceau lumineux combiné et dirige sensiblement moins de la moitié de l'énergie lumineuse dans le faisceau lumineux de référence selon le faisceau combiné.

16. Système d'imagerie selon la revendication 5, dans lequel le réseau de diffraction (118) est un réseau de diffraction réflectif, un réseau de diffraction transparent ou un modulateur acousto-optique.

17. Système d'imagerie selon la revendication 14, dans lequel le détecteur (392) est un photodétecteur multiélément comprenant une pluralité de sorties parallèles (394), le système comprenant en outre :

un convertisseur parallèle-série (398) couplé électriquement entre la sortie (394) du détecteur et l'entrée de la console à ultrasons (396), le convertisseur parallèle-série comprenant une pluralité d'entrées, chaque entrée étant couplée à l'un respectif de la pluralité de sorties (394) du détecteur (392) pour convertir la sortie de données parallèles par la pluralité de sorties (394) du détecteur (392) selon des données série,
le convertisseur parallèle-série (398) ayant une sortie couplée à l'entrée de la console à ultrasons (396) pour fournir les données série à la console à ultrasons (396) pour les traiter selon une image.

18. Système d'imagerie selon la revendication 12, dans lequel le premier séparateur de faisceau (104) dirige plus de la moitié de l'énergie lumineuse reçue depuis la source de lumière (102) selon le faisceau lumineux d'échantillon et moins de la moitié de l'énergie lumineuse reçue depuis la source de lumière (102) selon le faisceau lumineux de référence.

19. Système d'imagerie selon la revendication 18, comprenant en outre un circulateur optique (204), dans lequel le faisceau lumineux d'échantillon est dirigé sur l'échantillon au travers du circulateur optique (204) et le second faisceau lumineux d'échantillon est dirigé sur le second séparateur de faisceau (120) au travers du circulateur optique (204).

20. Système d'imagerie selon la revendication 19, dans lequel le second séparateur de faisceau (120) dirige sensiblement plus de la moitié de l'énergie lumineuse reçue depuis la source de lumière (102) selon le faisceau lumineux d'échantillon et sensiblement moins de la moitié de l'énergie lumineuse reçue depuis la source de lumière (102) selon le faisceau lumineux de référence.

21. Système d'imagerie selon la revendication 20, dans lequel le second séparateur de faisceau (120) est un séparateur

de faisceau approximativement 50/50 (222) et le second faisceau lumineux d'échantillon et le faisceau lumineux de référence sont combinés dans le second séparateur de faisceau (222) pour former les premier et second faisceaux lumineux combinés, le premier faisceau lumineux étant détecté par le premier détecteur (224) ; et
l'interféromètre comprend en outre un second détecteur (226) pour détecter le second faisceau lumineux.

22. Système d'imagerie selon la revendication 21, dans lequel les premier et second détecteurs (224, 226) sont chacun des photodétecteurs multiéléments comprenant une pluralité de sorties parallèles, le système comprenant en outre :

un convertisseur parallèle-série (398) couplé électriquement entre la sortie du détecteur et l'entrée de la console à ultrasons (396), le convertisseur parallèle-série (398) comprenant une pluralité d'entrées, chaque entrée étant couplée à l'une respective de la pluralité de sorties (394) du détecteur, pour convertir les données parallèles produites en sortie par la pluralité de sorties (394) du détecteur selon des données série,
le convertisseur parallèle-série (398) ayant une sortie couplée à l'entrée de la console à ultrasons (396) pour fournir les données série sur la console à ultrasons (396) pour les traiter selon une image.

23. Système d'imagerie selon la revendication 12, comprenant en outre une lentille de focalisation (110) pour focaliser le faisceau lumineux d'échantillon sur l'échantillon et pour focaliser le second faisceau lumineux d'échantillon.

24. Système d'imagerie selon la revendication 1, dans lequel l'interféromètre (391) comprend en outre :

une source de lumière faible cohérence (102) ;
un premier séparateur de faisceau à fibre optique (104) ;
un premier chemin optique couplant optiquement la source de lumière (102) au premier séparateur de faisceau (104), dans lequel le premier séparateur de faisceau (104), sépare la lumière reçue depuis la source de lumière (102) selon un faisceau lumineux d'échantillon et un faisceau lumineux de référence ;
un second chemin optique couplant optiquement le premier séparateur de faisceau (104) à un échantillon et couplant un second faisceau lumineux d'échantillon depuis l'échantillon au premier séparateur de faisceau (104) ;
un second séparateur de faisceau (120) ;
un troisième chemin optique couplant optiquement le premier séparateur de faisceau (104) au second séparateur de faisceau (120) pour convoyer le second faisceau lumineux d'échantillon, au moins en partie, depuis le premier séparateur de faisceau (104) jusqu'au second séparateur de faisceau (120) ;
un réseau de diffraction (118) ;
un quatrième chemin optique couplant optiquement le premier séparateur de faisceau (104) au réseau de diffraction (118) pour convoyer le faisceau lumineux de référence, au moins en partie, sur le réseau de diffraction (118) ;
dans lequel le second séparateur de faisceau (120) est positionné pour recevoir le faisceau lumineux de référence diffracté, et le faisceau lumineux de référence et le second faisceau lumineux d'échantillon sont combinés dans le second séparateur de faisceau (120) pour former un faisceau lumineux combiné ; et
le photodétecteur multiélément étant positionné pour recevoir le faisceau lumineux combiné ;
le convertisseur parallèle-série (398) comprenant une pluralité d'entrées, chaque entrée étant couplée à l'une respective de la pluralité de sorties (394) du détecteur (392), pour convertir les données parallèles produites en sortie par la pluralité de sorties (394) du détecteur (392) selon des données série,
le convertisseur parallèle-série (398) ayant une sortie couplée à l'entrée de la console à ultrasons (396) pour fournir les données série sur la console à ultrasons (396) pour les traiter selon l'image.

25. Système d'imagerie selon la revendication 24, dans lequel :

le premier séparateur de faisceau (104) est un séparateur de faisceau approximativement 50/50 ; et
le second séparateur de faisceau (120) dirige plus de la moitié de l'énergie lumineuse reçue depuis la source de lumière (102) selon le faisceau lumineux d'échantillon et moins de la moitié de l'énergie lumineuse reçue depuis la source de lumière (102) selon le faisceau lumineux de référence.

26. Système d'imagerie selon la revendication 25, comprenant en outre un cathéter et une fibre optique (108) à l'intérieur du cathéter, dans lequel le second chemin optique est couplé optiquement à la fibre optique (108) à l'intérieur du cathéter.

27. Système d'imagerie selon la revendication 24, comprenant en outre une lentille de focalisation (110), dans lequel le second chemin optique couple optiquement le premier séparateur de faisceau (104) à la lentille de focalisation (110), pour focaliser le faisceau lumineux d'échantillon sur l'échantillon et pour focaliser le second faisceau lumineux d'échantillon.

28. Système d'imagerie selon la revendication 1, dans lequel : l'interféromètre (391) comprend en outre :

une source de lumière faible cohérence (102) ;
un premier séparateur de faisceau à fibre optique (202) ;
une première fibre optique (106) couplant optiquement la source de lumière (102) au premier séparateur de faisceau (202), dans lequel le premier séparateur de faisceau (202) sépare la lumière reçue depuis la source de lumière (102) selon un faisceau lumineux d'échantillon et un faisceau lumineux de référence ;
un circulateur optique (204) ayant un premier port, un second port et un troisième port, dans lequel la lumière entrée sur le premier port sort du circulateur optique (204) depuis le second port et la lumière entrant dans le second port sort du circulateur optique (204) depuis le troisième port ;
la seconde fibre optique (206) couplant optiquement le premier séparateur de faisceau (202) sur le premier port du circulateur optique (204) ;
une troisième fibre optique (208) couplant optiquement le second port du circulateur optique (204) à l'échantillon (119) et couplant optiquement le second faisceau lumineux d'échantillon depuis l'échantillon (119) au second port ;
un second séparateur de faisceau (222) ;
une quatrième fibre optique (210) couplant optiquement le troisième port du circulateur optique (204) au second séparateur de faisceau (222), dans lequel la troisième fibre optique (208) convoie le second faisceau lumineux d'échantillon, au moins en partie, depuis le troisième port jusqu'au second séparateur de faisceau (222) ;
un réseau de diffraction (118) ;
une cinquième fibre optique (220) couplant optiquement le premier séparateur de faisceau (202) au réseau de diffraction (118) pour convoyer le faisceau lumineux de référence, au moins en partie, jusqu'au réseau de diffraction (118) ;
le second séparateur de faisceau (222) étant positionné pour recevoir le faisceau lumineux de référence diffracté depuis le réseau de diffraction (118), dans lequel le faisceau de référence et le second faisceau lumineux d'échantillon se combinent dans le séparateur de faisceau (222) pour former un faisceau lumineux combiné ; et
le photodétecteur multiélément (392) positionné pour recevoir le faisceau combiné ; et
le convertisseur parallèle-série (398) comprenant une pluralité d'entrées, chaque entrée étant couplée à l'une respective de la pluralité de sorties du photodétecteur, pour convertir les données parallèles produites en sortie par la pluralité de sorties du photodétecteur selon des données série,
le convertisseur parallèle-série (398) ayant une sortie couplée à l'entrée de la console à ultrasons (396) pour fournir les données série sur la console à ultrasons (396) pour les traiter selon l'image.

29. Système d'imagerie selon la revendication 28, dans lequel la lumière reçue depuis la source de lumière (102) a une certaine énergie et le premier séparateur de faisceau (202) sépare la lumière selon un faisceau lumineux d'échantillon ayant plus de la moitié de l'énergie de la lumière et un faisceau lumineux de référence ayant moins de la moitié de l'énergie de la lumière.

30. Système d'imagerie selon la revendication 29, dans lequel le second séparateur de faisceau (222) est un séparateur de faisceau approximativement 50/50 et le second faisceau lumineux d'échantillon et le faisceau lumineux de référence sont combinés dans le second séparateur de faisceau (222) pour former des premier et second faisceaux lumineux d'échantillons, dans lequel le premier faisceau lumineux combiné est reçu par le premier photodétecteur multiélément (224) ; et
l'interféromètre comprend en outre un second photodétecteur multiélément (226) positionné pour recevoir un second faisceau combiné depuis le second séparateur de faisceau, le second photodétecteur multiélément (226) comprenant une pluralité de sorties parallèles couplées au convertisseur parallèle-série.

31. Système d'imagerie selon la revendication 28 ou la revendication 31, comprenant en outre un cathéter et une fibre optique (108) à l'intérieur du cathéter, dans lequel la troisième fibre optique (208) est couplée optiquement à la fibre optique (108) à l'intérieur du cathéter.

32. Système d'imagerie selon la revendication 28, comprenant en outre une lentille de focalisation (110) pour focaliser le faisceau lumineux d'échantillon depuis la troisième fibre optique (208) sur l'échantillon et pour focaliser le second faisceau lumineux d'échantillon dans la troisième fibre optique (208).

33. Procédé pour analyser une surface, comprenant les étapes de :

utilisation d'un dispositif à ultrasons ayant un transducteur à ultrasons pour émettre des ondes ultrasonores qui sont réfléchies par la surface et pour induire un signal d'écho au niveau du transducteur à ultrasons ;
transmission du signal d'écho depuis le transducteur à ultrasons sur une console à ultrasons, laquelle comprend une entrée série, un processeur d'image d'ultrasons et un affichage ;
formation d'un faisceau lumineux d'échantillon et d'un faisceau lumineux de référence avec un interféromètre, convoyage du faisceau lumineux d'échantillon sur la surface, combinaison de la lumière reçue depuis la surface avec le faisceau lumineux de référence selon un faisceau lumineux combiné et détection du faisceau lumineux combiné avec un détecteur multiélément pour produire en sortie une pluralité de signaux électriques parallèles, **caractérisé par** :
le couplage de l'interféromètre à la console à ultrasons ;
le traitement des données depuis l'interféromètre par le processeur d'ultrasons comprenant :
la conversion des signaux électriques parallèles traités selon un signal série ; et
la fourniture du signal série au processeur d'ultrasons pour le traiter selon une image.

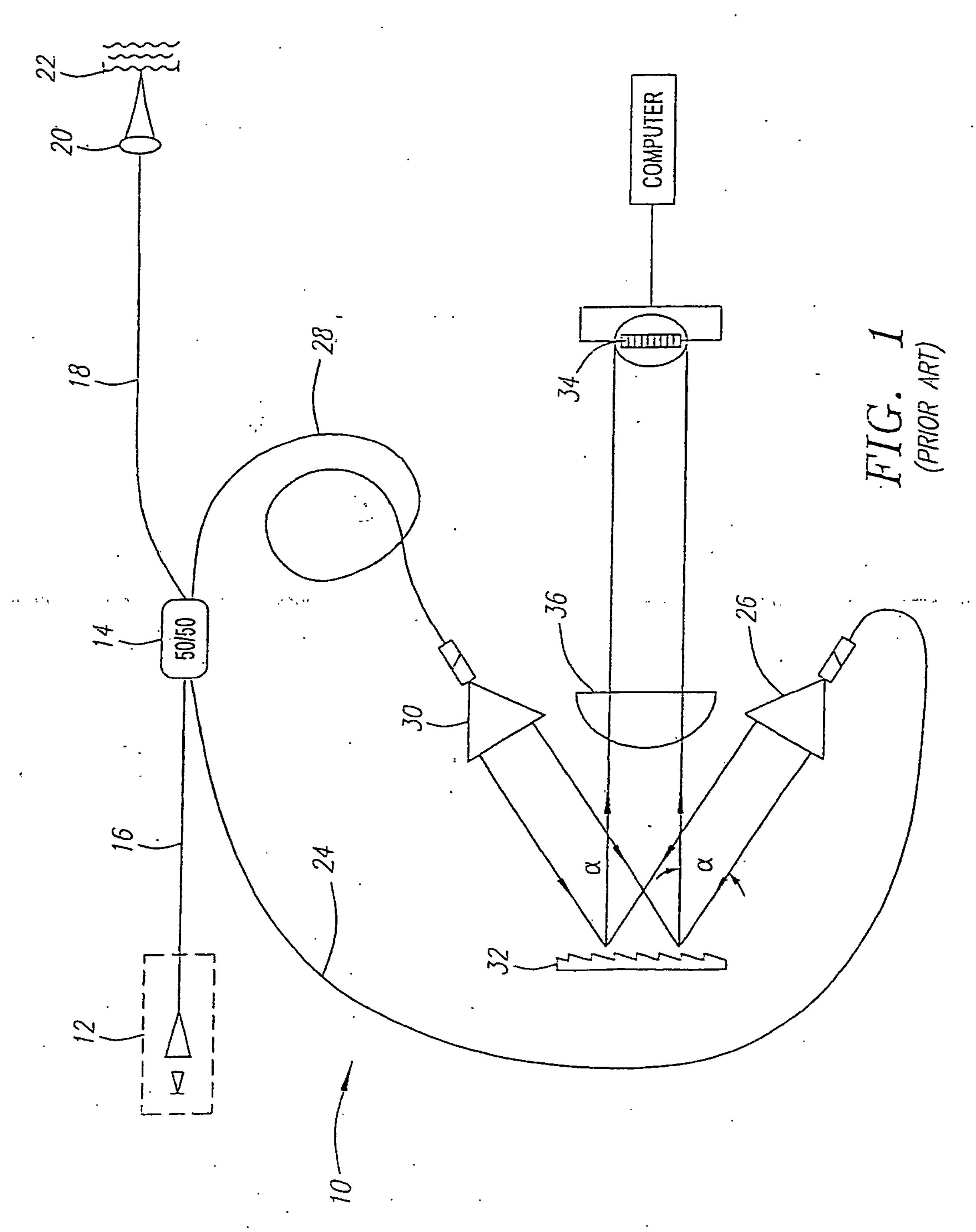


FIG. 1
(PRIOR ART)

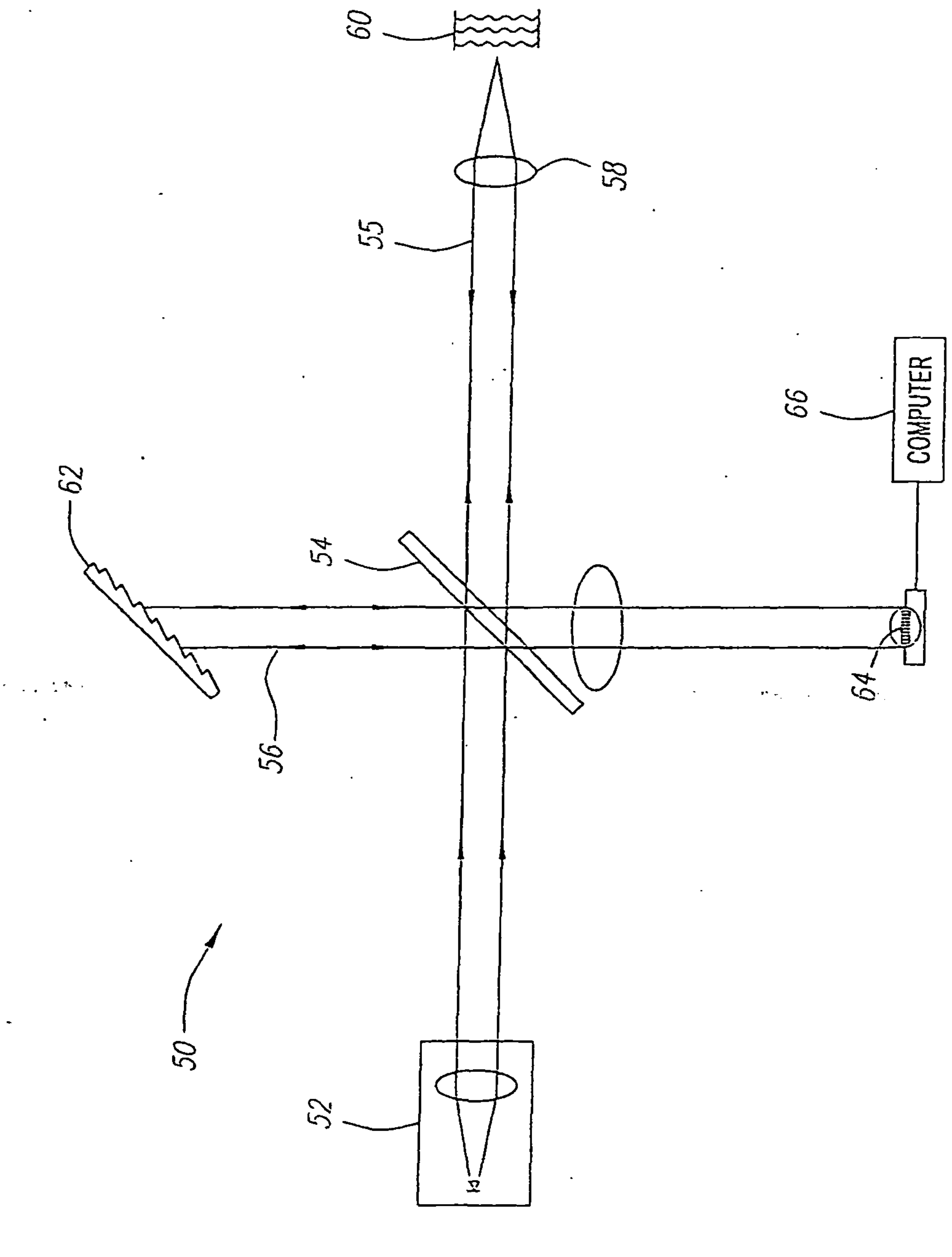


FIG. 2
(PRIOR ART)

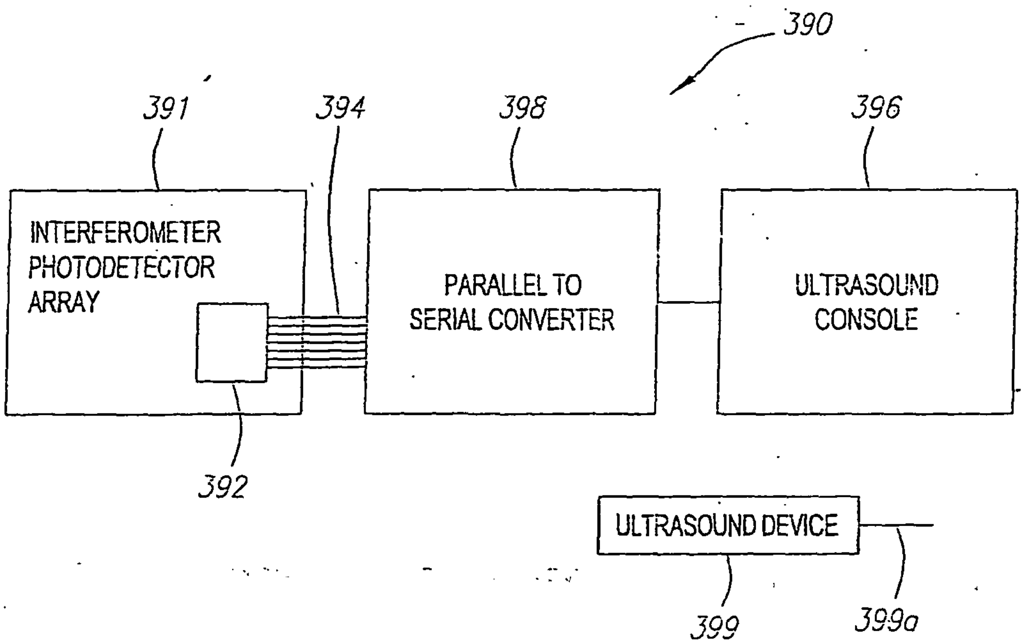

390
391
394
398
396
INTERFEROMETER
PHOTODETECTOR
ARRAY
PARALLEL TO
SERIAL CONVERTER
ULTRASOUND
CONSOLE
392
ULTRASOUND DEVICE
399
399a

FIG. 3

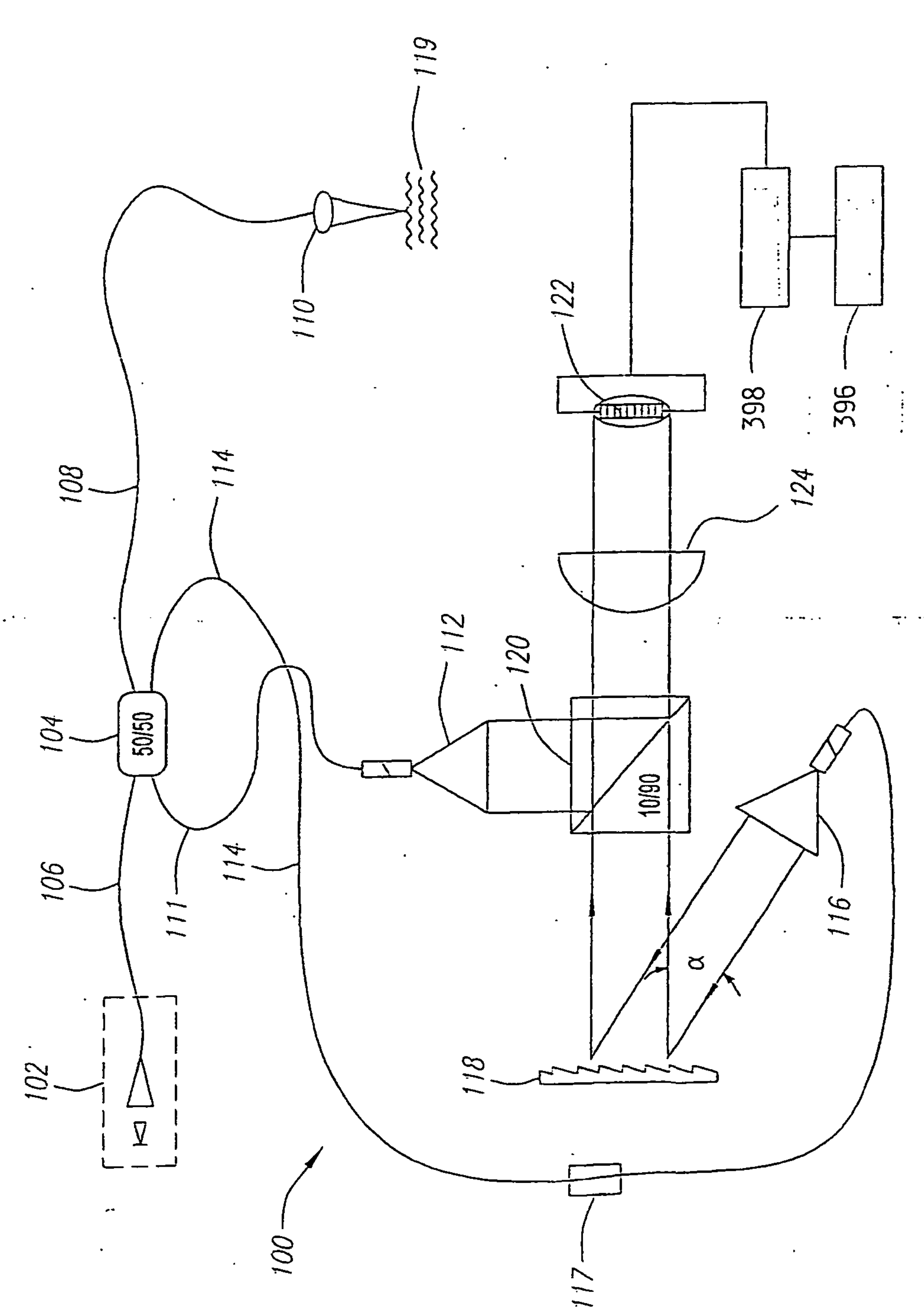

100
102
104
50/50
106
108
110
111
112
114
114
116
117
118
119
120
122
124
10/90
α
396
398

FIG. 4A

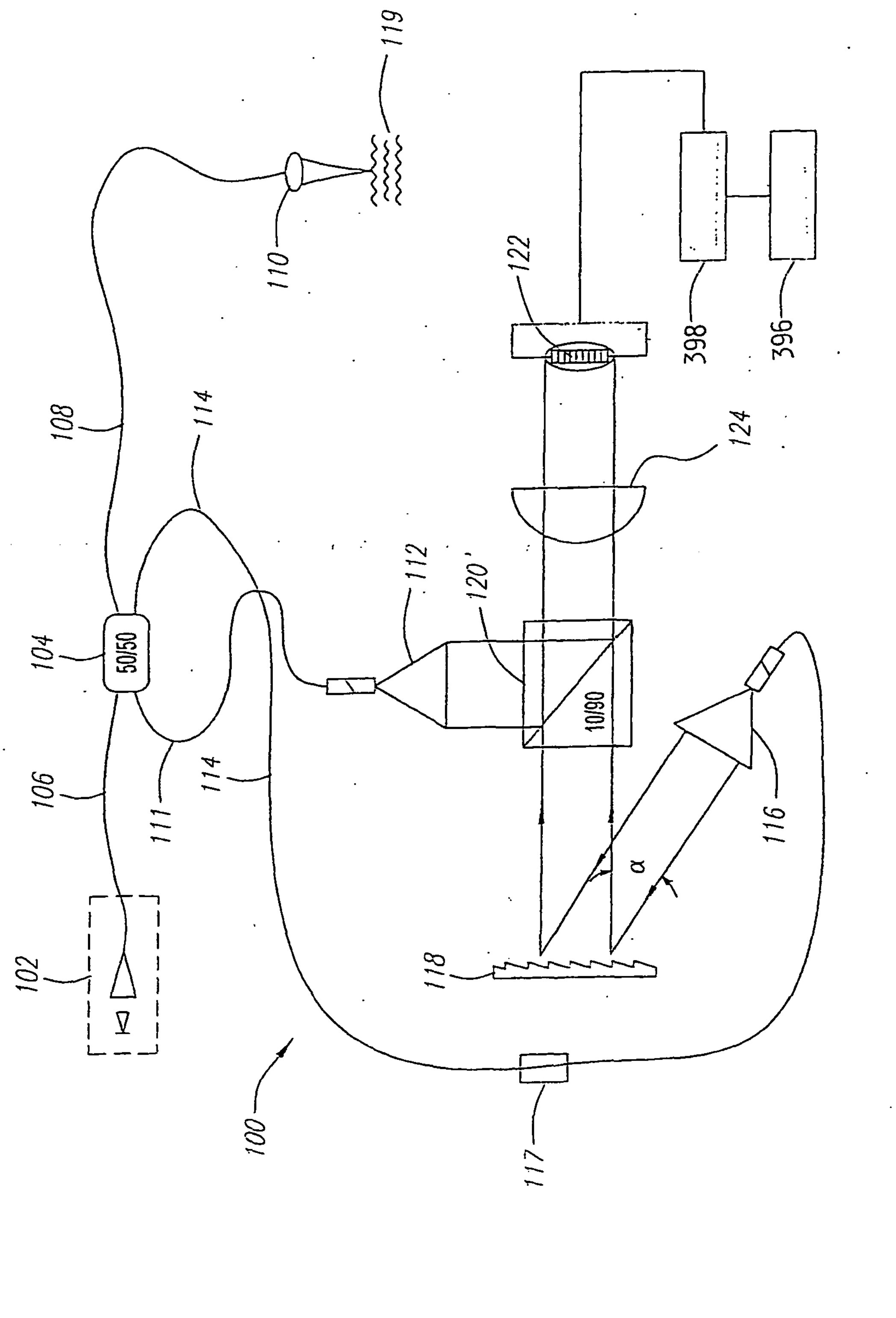

102
104
50/50
106
108
110
119
111
114
112
120'
10/90
122
124
398
396
116
α
118
117
100

FIG. 4B

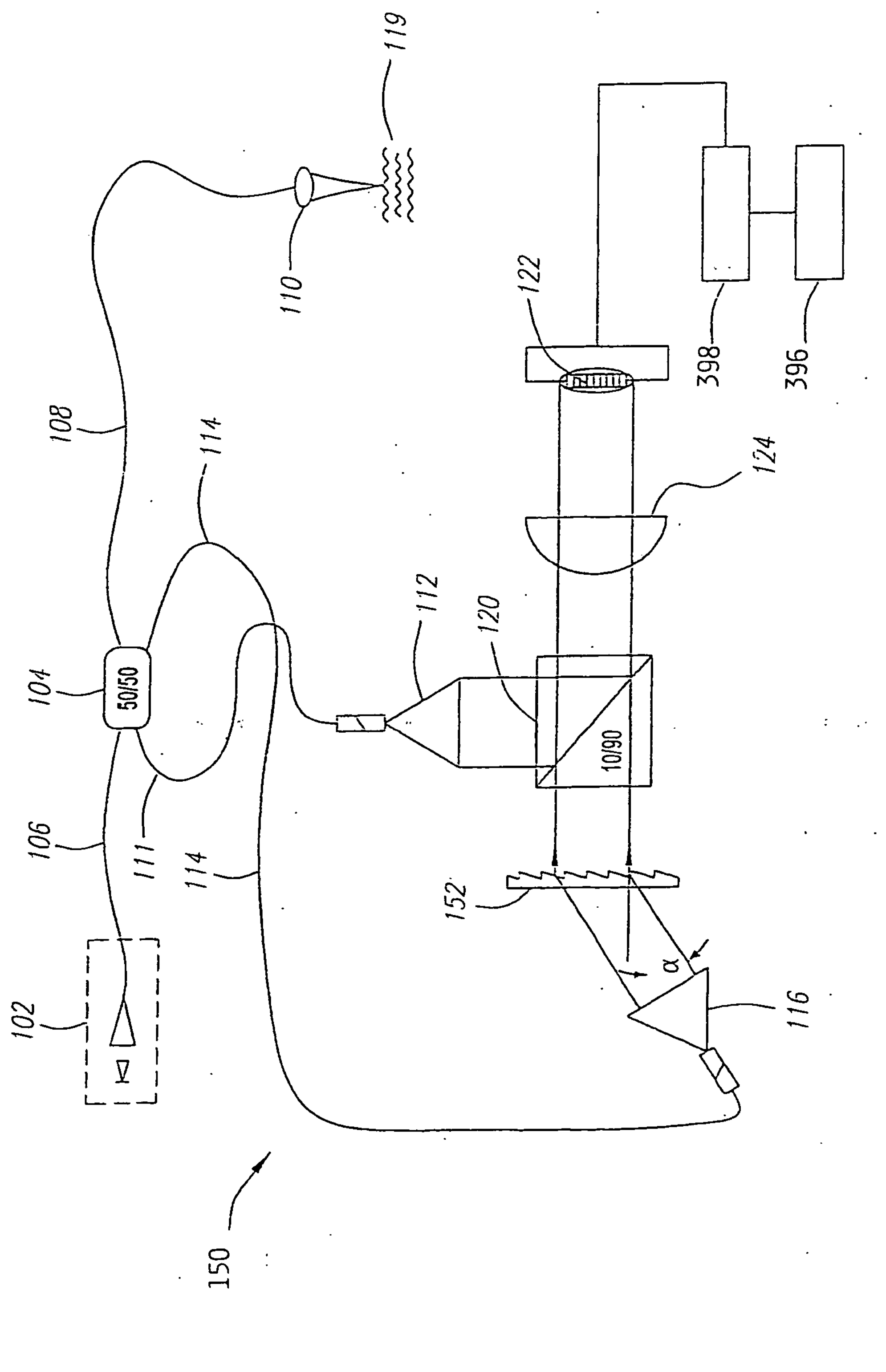

102
104
50/50
106
108
110
111
112
114
114
116
119
120
122
124
10/90
α
150
152
398
396

FIG. 5

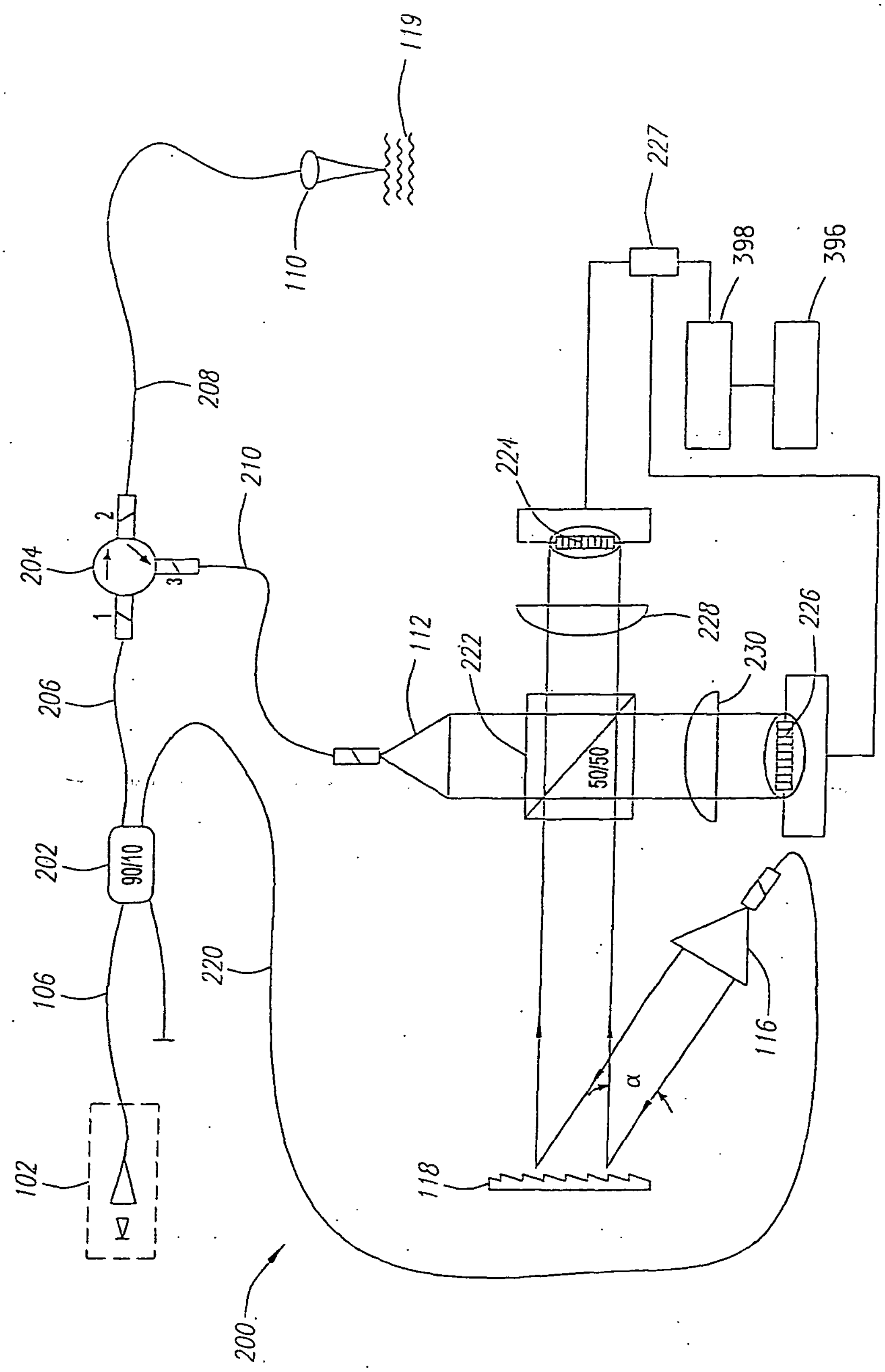
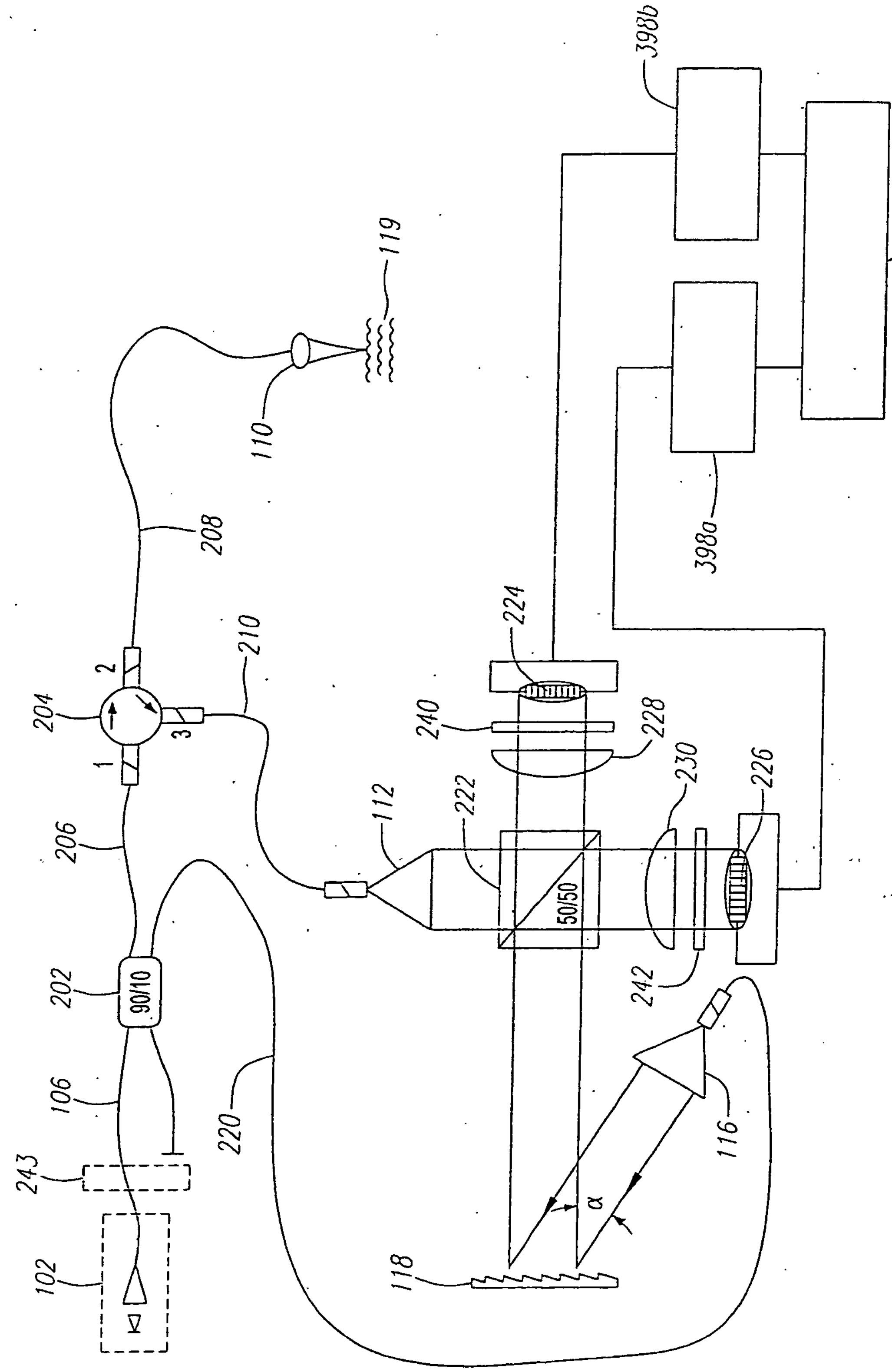

119
110
227
398
396
208
210
224
204
2
1
3
206
112
222
228
230
226
50/50
202
90/10
106
220
116
102
118
α
200

FIG. 6



102
243
106
202
90/10
206
204
1
2
3
208
210
110
119
112
222
50/50
224
240
228
230
226
242
220
116
118
α
398a
398b
396

FIG. 7

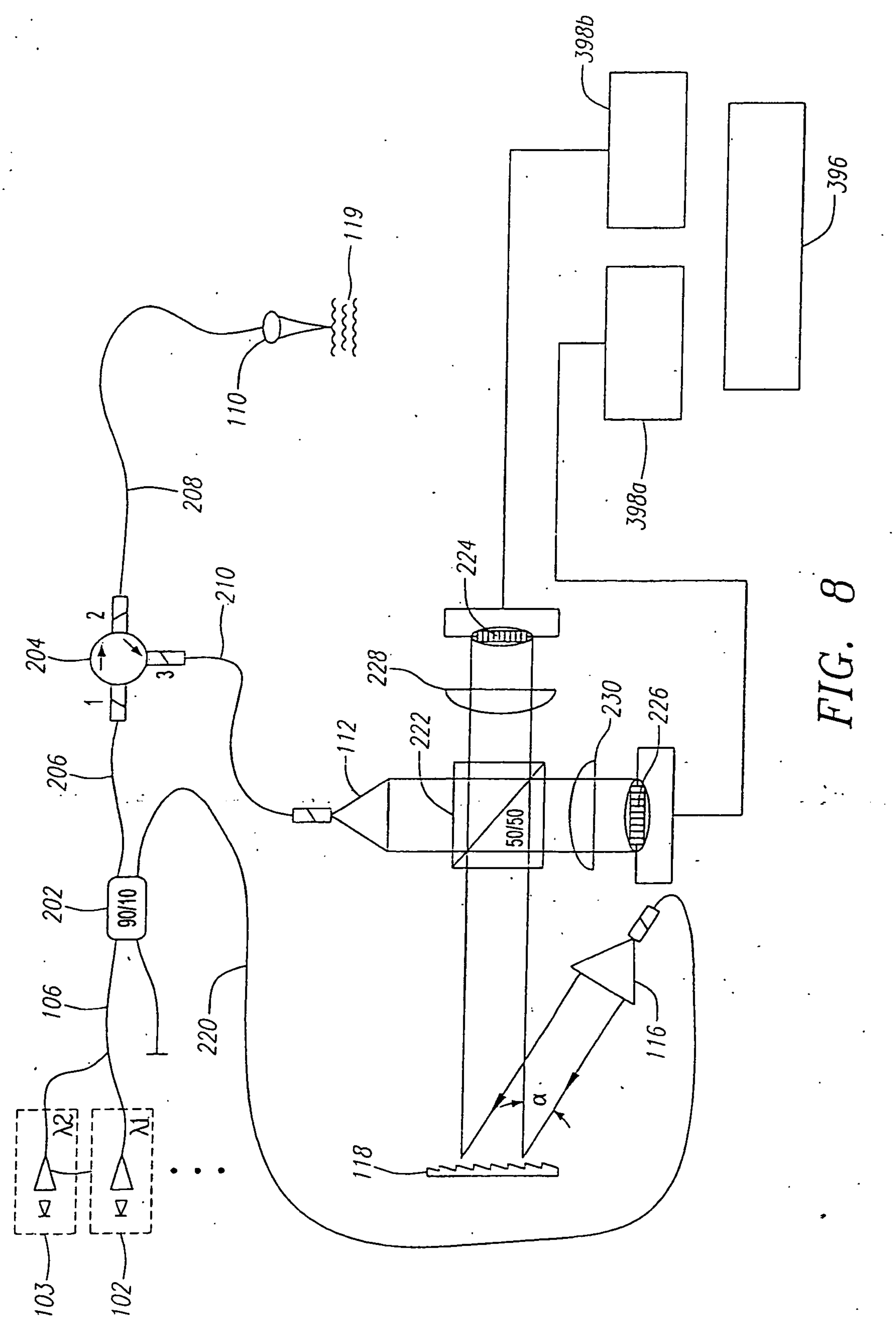

102
103
λ1
λ2
106
202
90/10
206
204
1
2
3
208
110
119
210
112
222
50/50
228
224
230
226
116
118
α
220
398a
398b
396

FIG. 8

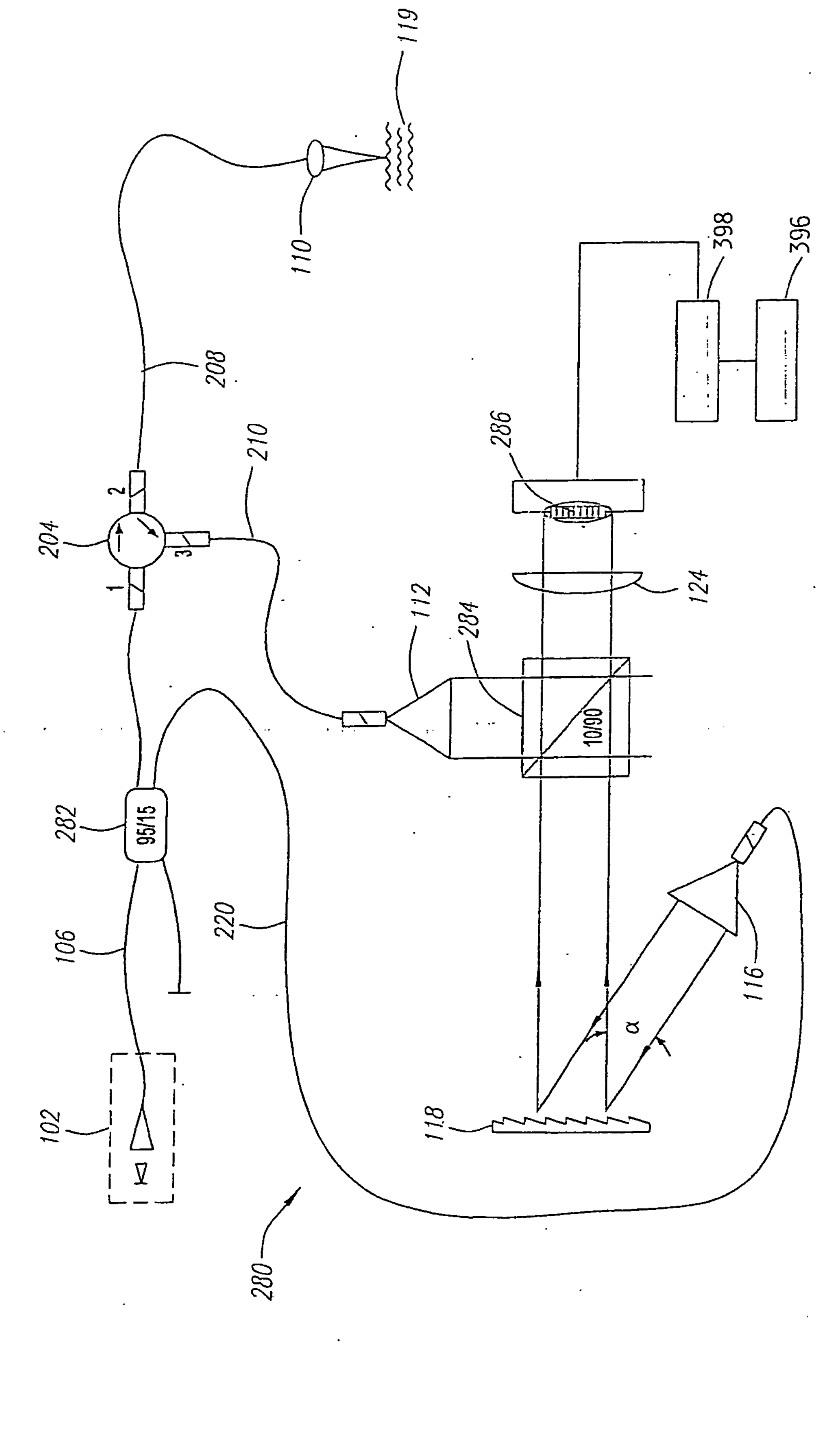

119
110
208
210
204
1
2
3
286
398
396
124
112
284
10/90
282
95/15
106
220
116
α
102
118
280

FIG. 9

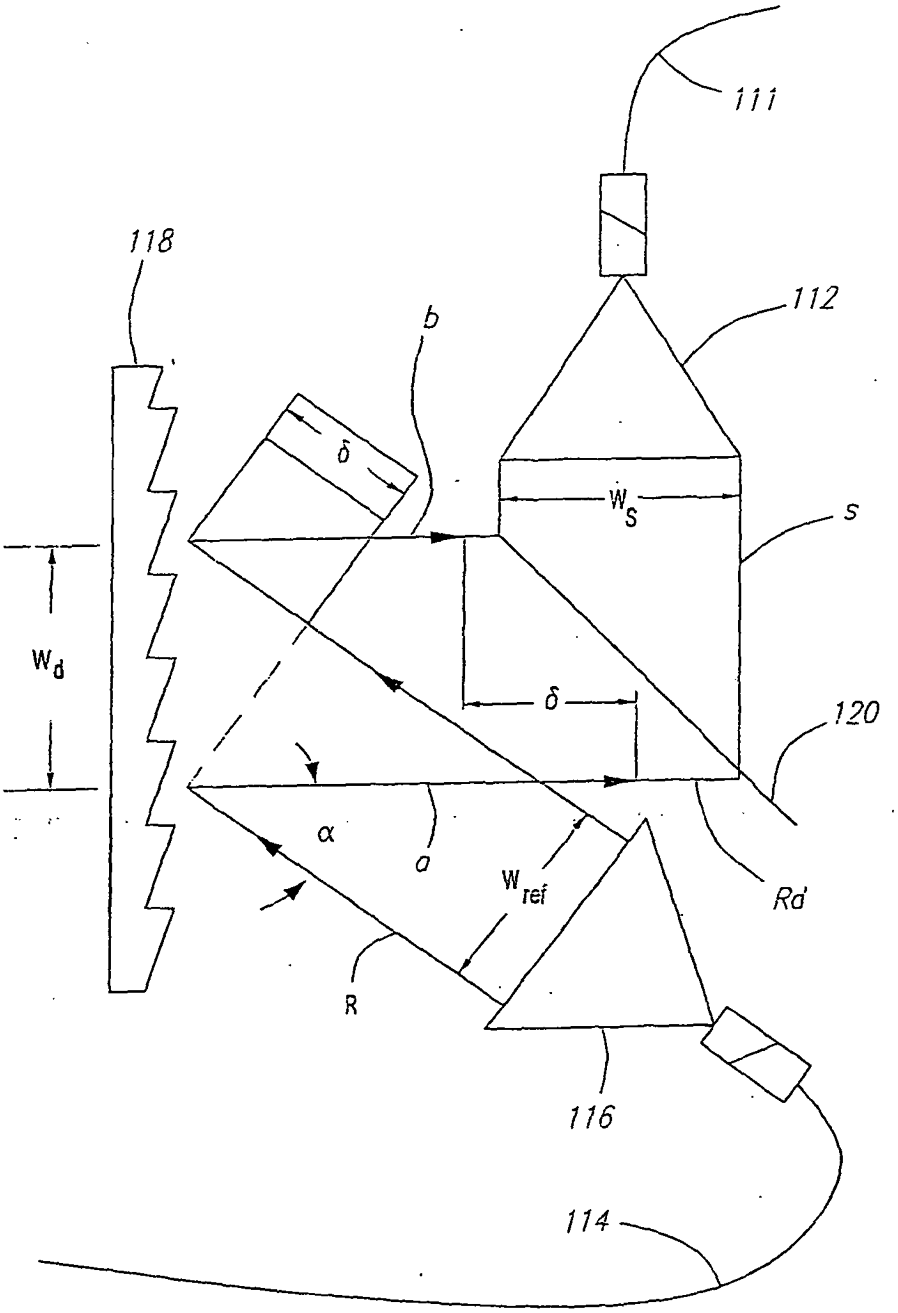


FIG. 10

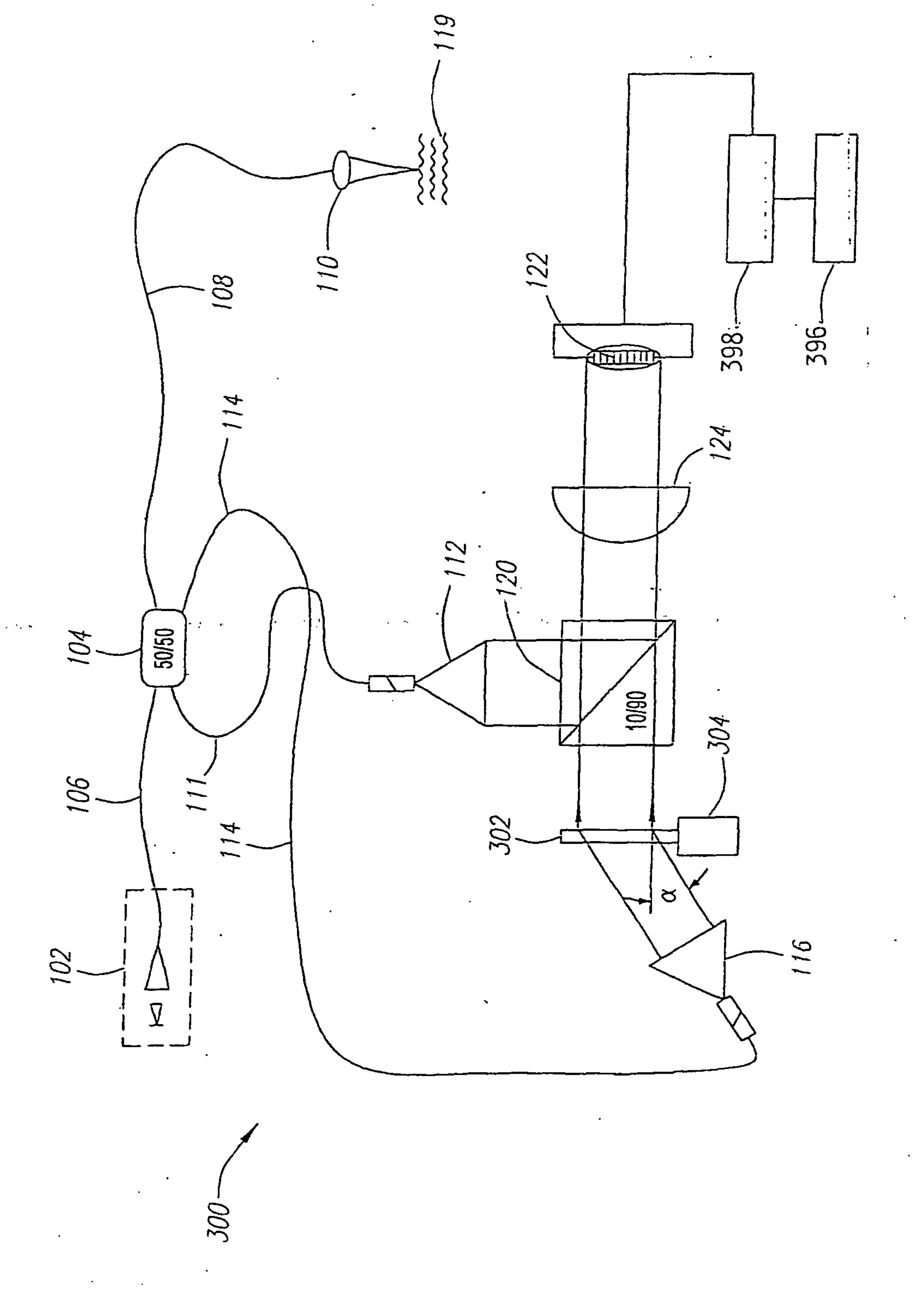

300
102
106
104
50/50
108
110
119
111
114
114
112
120
10/90
124
122
398
396
302
304
α
116

FIG. 11

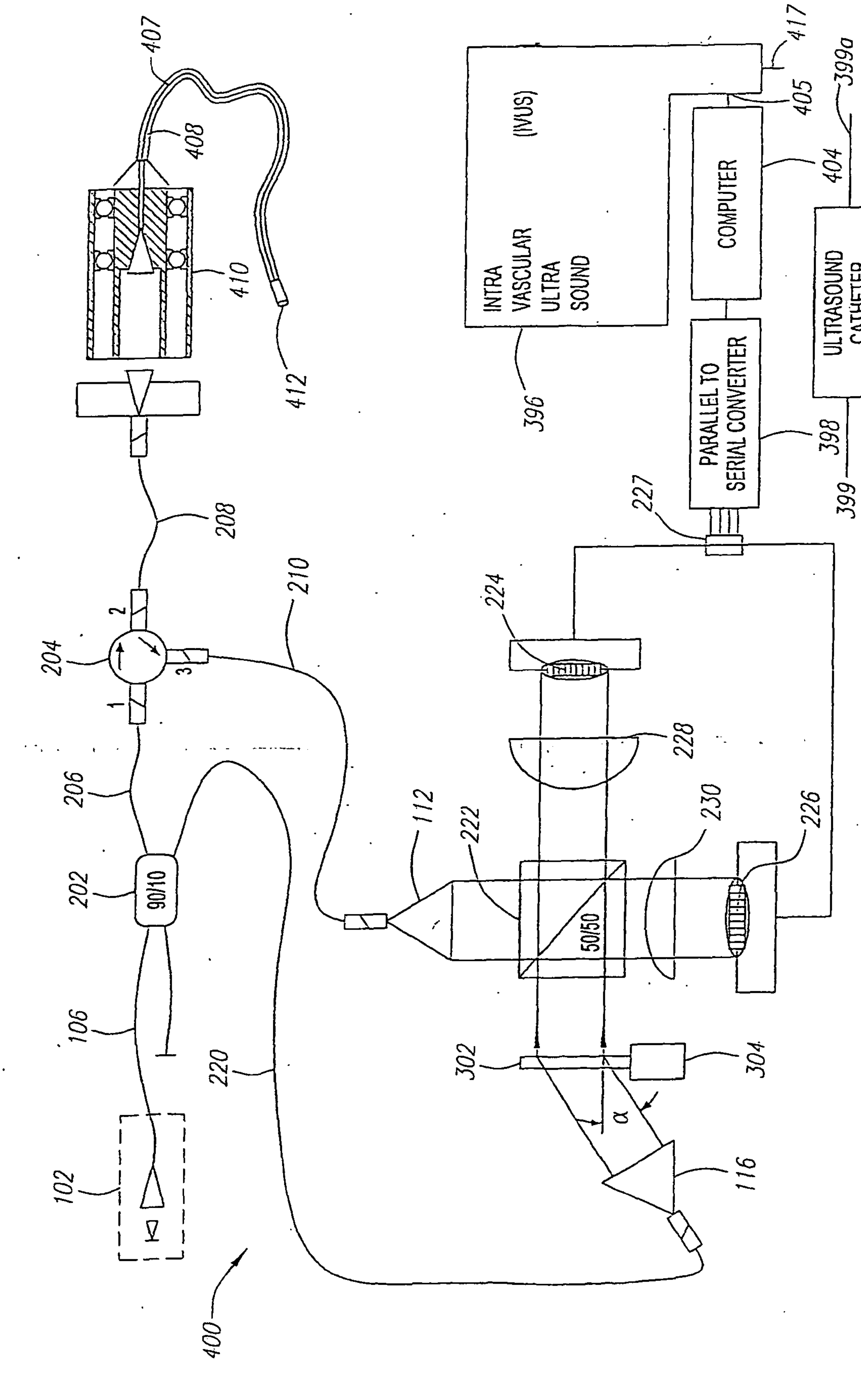

INTRA
VASCULAR
ULTRA
SOUND
(IVUS)
COMPUTER
PARALLEL TO
SERIAL CONVERTER
ULTRASOUND
CATHETER
90/10
50/50
α
1
2
3
102
106
112
116
202
204
206
208
210
220
222
224
226
227
228
230
302
304
396
398
399
399a
400
404
405
407
408
410
412
417

FIG. 12

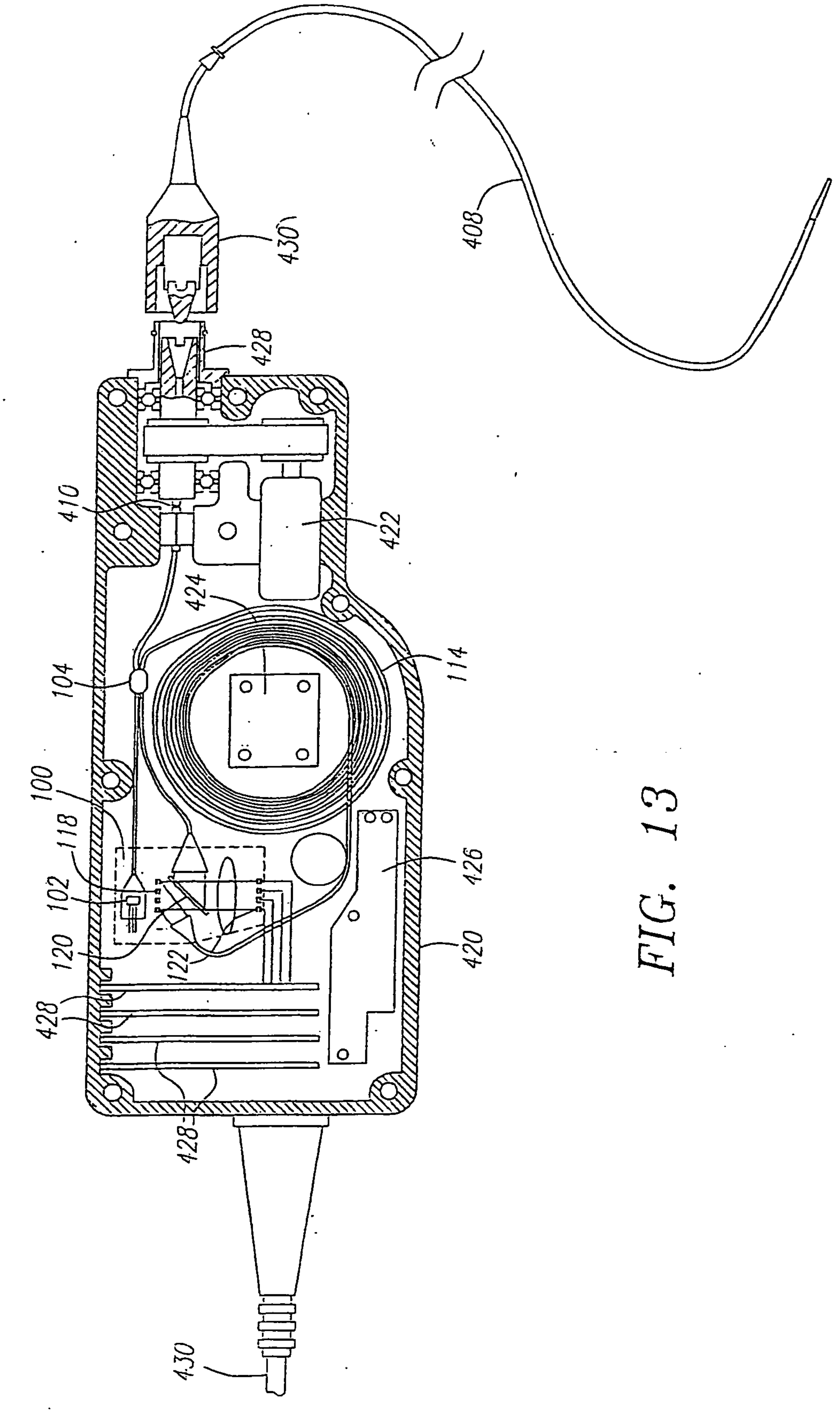

408
430
428
410
422
424
104
114
100
118
102
120
122
126
420
428
428
430

FIG. 13

REFERENCES CITED IN THE DESCRIPTION

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patsnap

专利名称(译)	用于通过超声控制台处理来自干涉仪的信号的系统和方法		
公开(公告)号	EP1435835B1	公开(公告)日	2009-02-11
申请号	EP2002805927	申请日	2002-10-09
申请(专利权)人(译)	SCIMED LIFE SYSTEMS INC.		
当前申请(专利权)人(译)	BOSTON SCIENTIFIC LIMITED		
[标]发明人	CROWLEY ROBERT J BARBATO LOUIS J OSTROVSKY ISAAC MODELL MARK D		
发明人	CROWLEY, ROBERT, J. BARBATO, LOUIS, J. OSTROVSKY, ISAAC MODELL, MARK, D.		
IPC分类号	A61B5/00 A61B8/12 G01N29/06 G01N21/47 G01N21/17 A61B8/00 G01B9/02 G01N29/22		
CPC分类号	A61B5/6852 A61B5/0066 A61B5/0095 A61B5/02007 A61B8/12 G01B9/02002 G01B9/02007 G01B9/02028 G01B9/0203 G01B9/02087 G01B9/02091 G01B2290/45 G01B2290/70 G01N29/06 G01N29/223 G01N2291/02416 G01N2291/02466		
优先权	09/020040 2001-10-18 US		
其他公开文献	EP1435835A1		
外部链接	Espacenet		

摘要(译)

成像系统包括干涉仪和超声控制台，其将来自干涉仪的信号处理成图像以供显示。干涉仪可以包括具有多个并行输出的一个或多个多元件光电检测器。在干涉仪的并行输出和超声控制台的输入之间提供并行到串行转换器，以将并行输出上提供的信号转换成串行信号，以供超声控制台分析。干涉仪可以选择性地耦合到超声控制台，并且系统还可以包括超声设备，该超声设备也可以选择性地耦合到控制台，向用户提供使用干涉仪或超声设备的选项。超声控制台还可以包括两个输入，一个用于干涉仪，另一个用于超声设备。干涉仪和超声装置都可以由导管携带，以插入体内腔体，例如血管。还公开了成像方法。

$$\delta = Wd \times \sin\alpha. \qquad (1)$$