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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 November 2007 (22.11.2007)

PCT

(10) International Publication Number
WO 2007/133961 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/US2007/068214

(22) International Filing Date: 4 May 2007 (04.05.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/799,511 10 May 2006 (10.05.2006) US

(71) Applicant (*for all designated States except US*): **THE GENERAL HOSPITAL CORPORATION** [US/US]; 55 Fruit Street, Boston, MA 02114 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **YUN, Seok-Hyun** [KR/US]; 30 Cambridge Park Drive, Apt. 4128, Cambridge, MA 02140 (US). **DE BOER, Johannes, F.** [NL/US]; 60C Marshall Street, Somerville, MA 02145 (US).

(74) Agents: **ABELEV, Gary** et al.; Dorsey & Whitney LLP, 250 Park Avenue, New York, NY 10177 (US).

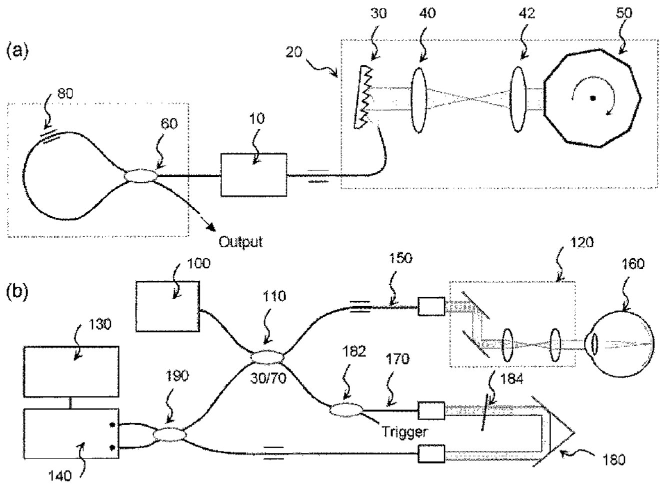
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP,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

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: PROCESSES, ARRANGEMENTS AND SYSTEMS FOR PROVIDING FREQUENCY DOMAIN IMAGING OF A SAMPLE



(57) Abstract: Apparatus, arrangement and method are provided for obtaining information associated with an anatomical structure or a sample using optical microscopy. For example, a radiation can be provided which includes at least one first electro-magnetic radiation directed to be provided to an anatomical sample and at least one second electro-magnetic radiation directed to a reference. A wavelength of the radiation can vary over time, and the wavelength is shorter than approximately 1150 nm. An interference can be detected between at least one third radiation associated with the first radiation and at least one fourth radiation associated with the second radiation. At least one image corresponding to at least one portion of the sample can be generated using data associated with the interference. In addition, at least one source arrangement can be provided which is configured to provide an electro-magnetic radiation which has a wavelength that varies over time. A period of a variation of the wavelength of the first electro-magnetic radiation can be shorter than 1 millisecond, and the wavelength is shorter than approximately 1150 nm.

WO 2007/133961 A2

PROCESSES, ARRANGEMENTS AND SYSTEMS FOR PROVIDING FREQUENCY DOMAIN IMAGING OF A SAMPLE

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is based upon and claims the benefit of priority from U.S. Patent Application Serial No. 60/799,511, filed May 10, 2006, the entire disclosure of which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

The research leading to the present invention was supported, at least in part, by National Institute of Health – National Cancer Institute, Grant number R33 214033. Thus, the U.S. government may have certain rights in the invention.

FIELD OF THE INVENTION

The present invention relates to processes, arrangements and systems which obtain information associated with an anatomical structure or a sample using optical microscopy, and more particularly to such methods, systems and arrangements that provide optical frequency domain imaging of the anatomical structure/sample (e.g., at least one portion of an eye).

BACKGROUND INFORMATION

Optical frequency domain imaging ("OFDI"), which may also be known as swept source optical coherence tomography ("OCT"), is a technique associated with OCT concepts that generally uses a wavelength-swept light source to probe the amplitude and phase of back scattering light from tissue. Exemplary OFDI techniques and systems are described in International Application No. PCT/US04/029148. Method and system to determine polarization properties of tissue is described in International Application No. PCT/US05/039374. The OFDI technique can offer intrinsic signal-to-noise ratio ("SNR") advantage over the time-domain techniques because the interference signal can be effectively integrated through a Fourier transform. With the recently developed rapidly tunable lasers in the 1300-nm range, the OFDI technique has enabled significant improvements in, e.g., imaging speed, sensitivity, and ranging depth over the conventional time-domain OCT systems. For example, such OFDI procedures/techniques can be used for imaging skin, coronary artery, esophagus, and anterior eye segments.

While retinal imaging is an established clinical use of the OCT techniques, this application has not been implemented using the OFDI procedures because the optical absorption in the human eye at 1300 nm may be too large. The standard spectral range of the conventional ophthalmic OCT techniques has been between 800 nm and 900 nm where the humors in the eye are transparent and broadband super-luminescent-diode ("SLD") light sources are readily available. It has been has suggested that the 1040-nm spectral range can be a viable alternative operating window for a retinal imaging, and can potentially offer a deeper penetration into the choroidal layers below the highly absorbing and scattering retinal pigment epithelium. The spectral domain ("SD") OCT systems, also known as Fourier domain OCT systems, that use broadband light sources at 800 nm and arrayed spectrometers have been provided to facilitate a three-dimensional retinal imaging in vivo with a superior image acquisition speed and a sensitivity to conventional time-domain OCT techniques.

As compared to the SD-OCT techniques, the OFDI procedures offer several advantages, such as an immunity to motion-induced signal fading, simple polarization-sensitive or diversity scheme, and long ranging depth. However, a clinical-viable OFDI system for imaging posterior eye segments has previously been unavailable, primarily due to the lack of a wide-tuning rapidly-swept light source in a low water absorption window. Indeed, despite the widespread use of the conventional OCT for retinal disease diagnostics, imaging posterior eye segment with OFDI has not been possible.

Accordingly, there is a need to overcome the deficiencies as described herein above.

OBJECTS AND SUMMARY OF EXEMPLARY EMBODIMENTS

To address and/or overcome the above-described problems and/or deficiencies, exemplary embodiments of systems, arrangements and processes can be provided that are capable of, e.g., utilizing the OFDI techniques to image at least one portion of the eye.

Thus, an exemplary embodiment of OFDI technique, system and process according to the present invention for imaging at least one portion of an eye can be provided. For example, a high-performance swept laser at 1050 nm and an ophthalmic OFDI system can be used that offers a high A-line rate of 19 kHz, sensitivity of >92 dB over a depth range of 2.5 mm with an optical exposure level of 550 μW, and a deep penetration into the choroid. Using the exemplary systems, techniques and arrangements according to the present invention, it is possible to perform comprehensive human retina, optic disk, and choroid imaging *in vivo*. This can enable a display of a choroidal vasculature *in vivo*, without exogenous fluorescence contrasts, and may be beneficial for evaluating choroidal as well as retinal diseases. According to another exemplary embodiment of the present invention, an OFDI system can be utilized which uses a swept laser in the 815-870 nm range, which can be used in clinical ophthalmic imaging and molecular contrast-based imaging.

Thus, according to one exemplary embodiment of the present invention, a method, apparatus and software arrangement can be provided for obtaining information associated with an anatomical structure or a sample using optical microscopy. For example, a radiation can be provided which includes at least one first electro-magnetic radiation directed to be provided to an anatomical sample and at least one second electro-magnetic radiation directed to a reference. A wavelength of the radiation can vary over time, and the wavelength is shorter than approximately 1150 nm. An interference can be detected between at least one third radiation associated with the first radiation and at least one fourth radiation associated with the second radiation. At least one image corresponding to at least one portion of the sample can be generated using data associated with the interference.

For example, a period of a variation of the wavelength of the first electro-magnetic radiation can be shorter than 1 millisecond. The anatomical sample can include at least one section of the posterior segment of an eye. The section can include a retina, a choroid, an optic nerve and/or a fovea. The wavelength may be shorter than approximately 950 nm. The wavelength can also vary by at least 10 nm over a period of a variation of the wavelength of the first electro-magnetic radiation. At least one fourth arrangement can also be provided which is capable of scanning the first electro-magnetic radiation laterally across the anatomical sample. The image may be associated with the anatomical structure of the sample and/or a blood and/or a lymphatic flow in the sample.

In one exemplary variant, the third arrangement may be capable of (i) obtaining at least one signal associated with at least one phase of at least one frequency component of the interference signal over less than an entire sweep of the wavelength, and (ii) comparing the at least one phase to at least one particular information. The particular information can be associated with a further signal obtained from a sweep of the wavelength that is different from the sweep of the wavelength of the signal. The particular information may be a constant, and/or can be associated with at least one phase of at least one further frequency component of the interference signal over less than an entire sweep of the wavelength. The frequency components may be different from one another.

In another exemplary variant, the third arrangement may be capable of generating a two-dimensional fundus-type reflectivity profile of the anatomic sample and/or a two-dimensional fundus-type image of the anatomic sample based the signal. Another arrangement may be provided which is capable of receiving the first or second electro-magnetic radiations, and providing at least one fifth electro-magnetic radiation associated with the first electro-magnetic radiation and/or the second electro-magnetic radiation The second arrangement may be further capable of detecting a further interference signal between the fifth radiation and the fourth radiation. The second arrangement may be further capable of obtaining at least one reference signal associated with a further phase of at least one first frequency component of the further interference signal over less than an entire sweep of the wavelength. The particular information may be the further phase.

According to another exemplary embodiment of the present invention, at least one source arrangement can be provided which is configured to provide an electro-magnetic radiation which has a wavelength that varies over time. A period of a variation of the wavelength of the one first electro-magnetic radiation can be shorter than 1 millisecond, and the wavelength is shorter than approximately 1150 nm. A control arrangement which is capable of modulating at least one of an optical gain or an optical loss in the at least one source arrangement over time can be provided. The optical gain may be facilitated by a semiconductor material. Another arrangement can be provided which is configured to effect a gain and/or a loss as a function of the wavelength. The wavelength may vary by at least 10 nm over the period and/or may be shorter than approximately 950 nm.

In yet another exemplary embodiment of the present invention, a method, apparatus and software arrangement can be provided. For example, first data can be received for a three-dimensional image of at least one portion of a sample. The first data may be associated with an optical interferometric signal generated from signals obtained from the sample and a reference. A region that is less than an entire portion of the first data can be converted to second data to generate a two-dimensional image which is associated with the portion of the sample. The region can be automatically selected based on at least one characteristic of the sample The entire portion may be associated with an internal structure within the sample (e.g., an anatomical structure). For example, the region may be at least one portion of a retina and/or a choroid. The two-dimensional image may be associated with an integrated reflectivity profile of the region and/or at least one of a blood or a lymphatic vessel network. The region can be automatically selected by determining at least one location of at least one section of the region based a reflectivity in the region.

According to a further exemplary embodiment of the present invention, is possible to cause a radiation to be provided which includes at least one first electro-magnetic radiation directed to a sample and at least one second electro-magnetic radiation directed to a reference. A wavelength of the radiation varies over time. An interference signal can be detected between at least one third radiation associated with the first radiation and at least one fourth radiation associated with the second radiation. At least one signal associated with at least one phase of at least one frequency component of the interference signal can be obtained over less than an entire sweep of the wavelength. The phase may be compared to at least one particular information.

In one exemplary variant, the first electro-magnetic radiation may be scanned laterally across the sample, which may include at least one section of a posterior segment of an eye. The section can include a retina, a choroid, an optic nerve and/or a fovea. The interference signal may be associated with an integral fraction of the entire sweep of the wavelength. The fraction of the sweep may be a half or a quarter of the sweep. The signal may be associated with a flow velocity and/or an anatomical structure in the sample. The particular information may be associated with a further signal obtained from a sweep of the wavelength that is different from the sweep of the wavelength of the signal. The particular information may be a constant and/or may be associated with at least one phase of at least one further frequency component of the interference signal over less than an entire sweep of the wavelength. The frequency components may be different from one another.

These and other objects, features and advantages of the present invention will become apparent upon reading the following detailed description of embodiments of the invention, when taken in conjunction with the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects, features and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying figures showing illustrative embodiments of the invention, in which:

FIGURE 1(a) is a block diagram of an exemplary embodiment of a wavelength-swept laser system according to the present invention;

FIGURE 1(b) is a block diagram of an exemplary embodiment of an interferometric system according to the present invention;

FIGURE 2(a) is a graph illustrating measured output characteristics of a peak-hold output spectrum and an optical absorption in water for a particular propagation distance corresponding to a roundtrip in typical human vitreous;

FIGURE 2(b) is a graph illustrating measured output characteristics of a time-domain output trace;

FIGURE 3 is a graph illustrating point spread functions measured at various path length differences;

FIGURE 4 is an exemplary image of retina and choroid obtained from a healthy volunteer using the exemplary embodiment of the . system, process and arrangement according to the present invention;

FIGURE 5(a) is a first exemplary OFDI image at fovea and optic nerve head of a patient A produced by an exemplary system at one location;

FIGURE 5(b) is a second exemplary OFDI image at the fovea and the optic nerve head of the patient A produced by another exemplary system at such location;

FIGURE 5(c) is a first exemplary SD-OCT image at the fovea and the optic nerve head of the patient A as a similar location produced by an exemplary system according to the present invention;

FIGURE 5(d) is a second exemplary SD-OCT image at the fovea and the optic nerve head of the patient A as the location of FIGURE 5(c) produced by an exemplary system according to the present invention;

FIGURE 5(e) is a third exemplary OFDI image obtained from a patient B produced by another exemplary system according to the present invention;

FIGURE 5(f) is a fourth exemplary OFDI image obtained from the patient B produced by a further exemplary system according to the present invention;

FIGURE 6A is an exemplary two-dimensional reflectance image of the retinal and choroidal vasculature extracted from the three-dimensional OFDI data set associated with the image of FIGURE 4 obtained by a conventional full-range integration method;

FIGURE 6B is an exemplary fundus-type reflectivity image obtained using an exemplary embodiment of an axial-sectioning integration technique;

FIGURE 6C is an exemplary retinal reflectivity image showing a shadow of a blood vasculature;

FIGURE 6C is an exemplary reflectivity image obtained from an upper part of the choroids;

FIGURE 6E is an exemplary image of an exemplary reflectivity image integrated from a center of the choroid showing a choroidal vasculature;

FIGURE 7(a) is a schematic diagram of an exemplary embodiment of the wavelength-swept laser arrangement according to the present invention;

FIGURE 7(b) is a graph of a peak-hold output spectrum of the signals generated using the exemplary embodiment of FIGURE 7(a);

FIGURE 7(c) is a graph of a oscilloscope trace generated using the exemplary embodiment of FIGURE 7(a);

FIGURE 8(a) is a graph of a sensitivity measured as a function of a reference power;

FIGURE 8(b) is a graph of a sensitivity measured as a function of a depth;

FIGURE 9 is an exemplary OFDI image of a Xenopus laevis tadpole in vivo acquired using another exemplary embodiment of the system, arrangement and process according to the present invention;

FIGURE 10(a) is a graph of an exemplary output of a shaped spectra without a gain/loss modulation generated as a function of wavelength using another exemplary embodiment of the system, arrangement and process according to the present invention;

FIGURE 10(b) is a graph of an exemplary output of the shaped spectra with the gain/loss modulation generated as a function of wavelength using an exemplary embodiment of the system, arrangement and process according to the present invention;

FIGURE 11 is a flow diagram of a conventional method to obtain Doppler OFDI signals;

FIGURE 12 is a flow diagram of an exemplary embodiment of a process to obtain Doppler OFDI signals by processing a portion of an interference fringe according to the present invention;

FIGURE 13(a) is an exemplary single image of the retina which includes the fovea and optic disk obtained from a healthy volunteer consecutively acquired at a large number of frames; and

FIGURE 13(b) is an exemplary integrated fundus image of the retina generated from multiple cross-sectional images covering an area by integrating the intensity in each depth profile.

Throughout the figures, the same reference numerals and characters, unless otherwise stated, are used to denote like features, elements, components or portions of the illustrated embodiments. Moreover, while the subject invention will now be described in detail with reference to the figures, it is done so in connection with the illustrative embodiments. It is intended that changes and modifications can be made to the described embodiments without departing from the true scope and spirit of the subject invention as defined by the appended claims.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

First Exemplary Embodiment of Laser Source System

FIGURE 1(a) depicts an exemplary embodiment of a laser source system (e.g., which can include a 1050 nm swept laser source) provided in a linear cavity configuration according to the present invention. As shown in this figure, a gain medium 10 can be provided, such as a bi-directional semiconductor optical amplifier (QPhotonics, Inc., QSOA-1050) which may be driven at an injection current level of 400 mA. One port of the amplifier can be coupled to a wavelength-scanning filter 20 that may comprise a diffraction grating 30 (1200 lines/mm), a telescope consisting of two lenses 40, 42 with respective focal lengths of 100 and 50 mm, and a polygon mirror scanner 50 (e.g., Lincoln Lasers, Inc., 40 facets). The design bandwidth and free spectral range of the filter can be approximately 0.1 nm and 61 nm, respectively. The amplifier's other port can be spliced to connect to a loop mirror which may include a 50/50 coupler 60. A Sagnac loop 70 can also act as an output coupler.

The reflectivity and output coupling ratio can be complementary, and may be optimized by adjusting a polarization controller 80 to tune the amount of the birefringence-induced non-reciprocity in the loop. The linear-cavity configuration can also be used instead of or together with conventional ring cavity designs, since low-loss low-cost circulators and isolators may not be readily available at 1050 nm. Sweep repetition rates of up to 36 kHz may be achieved with 100% duty cycle, which may represent a significant improvement over previously demonstrated swept lasers in the 1050 nm region that offered tuning rates of <1 kHz. In an OFDI system according to one exemplary embodiment of the present invention, the laser can be operated at a wavelength sweep rate of about 18.8 kHz, thus producing a polarized output with an average output power of 2.7 mW.

Exemplary Embodiment of Imaging System

FIGURE 1(b) depicts an exemplary embodiment of an optical frequency domain imaging (OFDI) system according to the present invention. For example, it is possible to use a swept laser can be used as a light source 100. This exemplary system further comprises a fiber-optic interferometer 110, a beam scanner 120, a detector 130 and a computer140. A sample arm 150 (e.g., 30% port) can be connected to a two-axis galvanometer scanner apparatus 120 which may be designed for a retinal imaging. A focal beam size can be approximately 10 μm in tissue (e.g., index = 1.38). The optical power level at an entrance pupil of an eye 160 can be measured to be about 550 μW, which is well below the 1.9-mW maximum exposure level at λ=1050 nm according to the ANSI laser safety standards. A reference arm 170 (e.g., 70% port) can utilize a transmission-type variable delay line 180 and a 10% tap coupler 182 to generate sampling trigger signals for acquiring data.

As shown in FIGURE 1(b), a neutral density (ND) attenuator 184 may be used to obtain an optimal reference-arm power. Light returning from the sample can be combined with the reference light at a 50/50 coupler 190. Resulting interference signals can be measured using an InGaAs dual-balanced detector 140 (e.g., New Focus, Inc., 1811). A signal provided by the balanced detector 140 can be further amplified (e.g., by 10 dB), low-pass filtered, and digitized at 10 MS/s using, e.g., a 12-bit data acquisition board (National Instruments, Inc., PCI-6115). For example, when sampling a 512 samples during each A-line scan, the imaging depth range determined by the spectral sampling interval can be about 2.44 mm in air.

Exemplary Laser Output Characteristics

Figure 2(a) depicts an exemplary output spectrum measured using an optical spectrum analyzer in peak-hold mode (with resolution = 0.1 nm). The exemplary output spectrum spanned from 1019 to 1081 nm over a range of 62 nm determined by the free spectral range of the filter. The spectral range coincided with a local transparent window of the eye. The roundtrip optical absorption in human vitreous and aqueous humors can be estimated to be between about 2dB and 5 dB based on known absorption characteristics of water (as shown in FIGURE 2(a)). Using a variable-delay Michelson interferometer, it is possible to measure the coherence length of the laser output, defined as the roundtrip delay resulting in 50% visibility, to be approximately 4.4 mm in air. From this value, it is possible to determine an instantaneous line width of laser output to be 0.11 nm. In FIGURE 2(a), a peak-hold output spectrum 200 and an optical absorption curve 205 are provided in water for a 42-mm propagation distance corresponding to a roundtrip in a typical human vitreous.

Figure 2(b) shows a graph of a time domain exemplary oscilloscope output trace 210 of a laser output indicating 100% tuning duty cycle at 18.8 kHz (single shot, 5-MHz detection bandwidth). The y-axis of the trace graph of FIGURE 2(b) represents an instantaneous optical power. The total power of amplified spontaneous emission (ASE) in the output, measured by blocking the intracavity beam in the polygon filter, is shown as about 1.1 mW. Since ASE is significantly suppressed during lasing, it is expected that the ASE level in the laser output may be negligible. The laser output exhibited significant intensity fluctuations (~10%pp) due to an etalon effect originating from relatively large facet reflections at the SOA chip with a thickness equivalent to 2.5 mm in air. In the exemplary embodiment of the imaging system, the etalon effect can cause ghost images (-30 dB) by optical aliasing.

Exemplary Sensitivity and Resolution of Imaging System

An exemplary embodiment of the OFDI system and exemplary optimized operating parameters can be provided to maximize the SNR using a partial reflector (neutral density filter and metal mirror) as a sample. An exemplary preferable reference arm power for maximal SNR may be 2.6 μW at each detection port. This relatively low value can be attributed to the relatively large intensity noise of the laser that may not be completely suppressed in the dual balanced detection. Exemplary data processing according to an exemplary embodiment of the present invention can include reference subtraction, envelope apodization or windowing, interpolation to correct for nonlinear k-space tuning, and dispersion correction. For example, subtracting the reference from the interference signals can eliminate image artifacts due to a non-uniform spectral envelope of the laser source. Apodizing the interference fringes by imposing a appropriate windowing technique can decrease the sidebands of point spread functions and improve image contrast.

This exemplary embodiment of the process according to the present invention may come at a resolution loss and SNR (due to a reduced integration time). It is possible to use a Gaussian window to yield a desirable compromise in contrast and resolution (e.g., at 1050-nm). Since the detector signal may not be sampled in constant time intervals, whereas the tuning curve of our laser was not linear in k-space, interpolating the interference signal may be preferable to reduce or avoid image blurring. Upon completing the exemplary interpolation, the signal may be further corrected for the chromatic dispersion in the interferometer as well as in the sample, e.g., by multiplying a predetermined phase function.

FIGURE 3 shows exemplary A-line profiles and/or point spread functions 220 measured at various path length differences of the interferometer. For this measurement, we used a neutral density attenuator (73 dB) and gold-coated mirror in the sample arm, and the path length was varied by moving the reference mirror. The maximum SNR is 25 dB that corresponds to a maximum sensitivity of 98 dB. The theoretical shot-noise limit of sensitivity is calculated to be 109 dB; the 11-dB deficiency in sensitivity of our system seems reasonable, considering that the residual laser intensity noise, imperfect polarization alignment between the sample and reference light, and Gaussian windowing, among many other practical details, contributed to SNR loss. For example, to facilitate the exemplary SNR analysis, each exemplary curve plotted was obtained by an average over 500 consecutive scans at a constant depth, and a simple numerical subtraction was performed to make the noise floor flat. Ghost artifacts marked as asterisks 230 were caused by the etalon effect in the laser source are shown in this figure.

As indicated in FIGURE 3, the sensitivity was decreased to 92 dB as the path length increased to a depth of 2.4 mm, due to the finite coherence length of the laser output. As compared to the conventional time-domain systems that use a broadband source at 1040 nm, the exemplary embodiment of the system according to the present invention provides a higher sensitivity, e.g., at a 100-fold faster image acquisition speed and one sixth of sample arm power. The high sensitivity and depth range of the exemplary embodiment of the system according to the present invention compare favorably with exemplary SD-OCT systems that use broadband sources in the 800 – 900 nm spectral range. Due to the absorption by water in the eye, the actual SNR for the human retina is likely 3-4 dB lower than the values measured with the mirror sample. Based on the source spectrum (as shown in FIGURE 2(a)) and the Gaussian window function used, the theoretical axial resolution can be determined to be about 13 μm in air; the measured values may be 14 - 16 μm, increasing with the depth. Errors in interpolation and dispersion compensation due to higher order terms may account for the discrepancy.

Exemplary Video-rate Imaging of Retina, Optic Disk, and Choroid in vivo

Exemplary OFDI imaging was conducted on two healthy volunteers (A: 36-year-old Asian male, B: 41-year-old Caucasian male) using the exemplary embodiments of the system, process and arrangement according to the present invention. The exemplary OFDI system acquired 18,800 A-lines continuously over 10-20 seconds as the focused sample beam was scanned over an area of 6 mm (horizontal) by 5.2 mm (vertical) across the macular region in the retina. Figure 4 shows a sequence 250 of images of the fovea and optic disk of the sample recorded from volunteer A at a frame rate of 18.8 Hz in 10.6 seconds. Each image frame was constructed from 1,000 A-line scans with an inverse grayscale table mapping to the reflectivity range over 47 dB, with each frame spanning over 6.0 mm (horizontal) and 1.8 mm (depth) in tissue. For example, 200 frames were acquired in 10.6 seconds to screen a tissue area with a vertical span of 5.2 mm. The anatomical layers in the retina are visualized and correlate well with previously published OCT images and histological findings.

Figure 5A depicts an expanded exemplary image of fovea extracted from the three-dimensional data set using the exemplary embodiments of the system, process and arrangement according to the present invention. The exemplary OFDI image of FIGURE 5A indicates a deep penetration into the choroid nearly up to the interface with the sclera, visualizing densely-packed choroidal capillaries and vessels.

To assess the penetration of the exemplary embodiments of the system, process and arrangement according to the present invention, the two volunteers A and B can be three-dimensionally imaged using both the OFDI system and the SD-OCT system previously developed for video-rate retinal imaging. The SD-OCT system employed a super luminescent diode with a center wavelength of 840 nm and a 3-dB spectral bandwidth of 50 nm, offering an axial resolution of 8 - 9 nm in air. At an A-line rate of 29 kHz and a sample arm power level of 600 μW, the SD-OCT system offered a peak sensitivity of 98 dB at zero delay that decreased to 82 dB at the maximum ranging depth of 2.2 mm in air.

Figures 5A-5F illustrate side-by-side comparisons of the OFDI and SD-OCT images near the foveae and optic disks of the two volunteers A and B. For example, FIGURES 5A and 5C shows OFDI images at fovea and optic nerve head from the volunteer A. FIGURES 5B and 5D illustrate SD-OCT images from the same person at similar tissue locations. FIGURES 5E and 5F provide the OFDI and SD-OCT images, respectively, obtained from volunteer B. For example, as shown, the OFDI images exhibit considerably deeper penetration in tissue than the SD-OCT images in most if not in all data sets. Such large penetration depth may stem from both the high system sensitivity and long source wavelength. Despite the relatively large axial resolution of ~11 μm in tissue, the OFDI system can visualize the anatomical layered structure in the retina (as shown in FIGURE 5A), RNFL, retinal nerve fiber layer, IPL, inner plexiform layer, INL; inner nuclear layer, OPL; outer plexiform layer, ONL; outer nuclear layer, IPRL; interface between the inner and outer segments of the photoreceptor layer, RPE; retinal pigmented epithelium, and C; choriocapillaris and choroid.

As shown in these figures, the OFDI images exhibit considerably deeper penetration into the choroid compared to the SD-OCT images, whereas the higher axial resolution in the SD-OCT images provide better contrast between retinal layers. The lower absorption and scattering in RPE at 1050 nm than 840 nm may account for the apparently superior penetration of the OFDI system to the SD-OCT system with a comparable sensitivity.

Visualization of Retinal/Choroidal Vasculature with OFDI Techniques/Systems

With the three-dimensional tomographic data of the eye's posterior segment, the pixel values along the entire depth axis can be integrated to produce a two-dimensional fundus-type reflectivity image. FIGURE 6A shows an exemplary integrated reflectivity image generated from the entire OFDI image sequence shown in FIGURE 4, with the image being two-dimensional reflectance image (5.3 x 5.2 mm^2) obtained with the conventional full-range integration method. The exemplary image shows the exemplary optical nerve head, fovea, retinal vessels, and an outline of the deep choroidal vasculature. However, the depth information is not indicated. To address this deficiency of the image generated by a conventional method, it is possible to integrate only selective regions according to using the exemplary embodiment of the system, process and arrangement of the present invention.

For example, according to one exemplary embodiment of the present invention, in order to visualize the retinal vasculature with a maximum contrast, it is possible to integrate the reflectivity in the range between IPRL and RPE 260, 270 as shown in FIGURE 6B. This figure shows an Illustration of an exemplary embodiment of a axial-sectioning integration technique for producing fundus-type reflectivity images. The shadow or loss of signal created by the retinal vessels above can appear most distinctly. Integrating over the entire retina including the vessel often results in a lower contrast in the vasculature because retinal blood vessels produce large signals by strong scattering. Automatic image processing conveniently allowed for automatic segmentations of the IPRL and RPE layers 260, 270.

FIGURE 6C depicts an exemplary reflectivity image (shadow) of a blood vasculature (3.8 x 5.2 mm^2) of the retina vessels . Using the thin integration region below the RPE, it is also possible to obtain fundus-type reflectivity images of the choriocapillary layer containing abundant small blood vessels and pigment cells obtained from an upper part of the choroid, as shown in FIGURE 6D. To obtain an image of the complete choroidal region, it is possible to utilize an integration range indicated by references 280 and 290 of FIGURE 6B. The choroidal vasculature is shown in the exemplary resulting reflectivity image of FIGURE 6E which is an exemplary reflectivity image integrated from the center of the choroid revealing the choroidal vasculature. Reflectivity images with similar qualities can be obtained from volunteer B.

Exemplary Implementation of Exemplary Embodiments of Invention

Experimental results show that the images generated using the exemplary OFDI techniques at 1050 nm can provide a comprehensive imaging of the human retina and choroid with high resolution and contrast. However, the exemplary embodiment of the OFDI system according to the exemplary embodiments of the present invention may provide an order-of-magnitude higher image acquisition speed than with the use of the conventional time-domain OCT systems, and avails the choroid images with an enhanced contrast in comparison to the SD-OCT system at 840 nm. The enhanced penetration makes it possible to obtain depth-sectioned reflectivity images of the choroid capillary and vascular networks. Fundus camera or scanning laser ophthalmoscope have been conventionally used to view vasculatures. However, such methods may require fluoresce in or indocyanine green angiography to have access to the choroid except for patients with significantly low level of pigmentations.

The exemplary OFDI system according to the present invention includes a wavelength-swept laser produced using, e.g., a commercial SOA and custom-built intracavity scanning filter. such laser's output power, tuning speed and range may yield a sensitivity of about 98 dB, A-line rate of 19 kHz, and resolution of 10 μm in tissue. Increasing the saturation power and gain of SOA and reducing the extended-cavity loss can possibly further improve the sensitivity and resolution (tuning range). For example, the power exposure level of the exemplary embodiment of the system according to the present invention can be only 550 μW, whereas the maximum ANSI limit at 1050 nm is likely to be 1.9 mW.

<u>Exemplary Embodiment of Swept Laser Source</u>

FIGURE 7(a) shows another exemplary embodiment of a swept laser source arrangement according to the present invention, e.g., in the 815-870 nm spectral range. The swept laser source arrangement can include a fiber-optic unidirectional ring cavity 300 with a free-space isolator 310. The gain medium 320 may be a commercially-available semiconductor optical amplifier (e.g., SOA-372-850-SM, Superlum Diodes Ltd.). An intracavity spectral filter 330 can be provided which may comprise a diffractive grating (e.g., 830 grooves/mm) 332, two achromatic lenses 334, 336 in the $4f$ configuration, and a 72-facet polygon mirror 340 (Lincoln lasers, Inc.). The polygon can be rotated at about 600 revolutions per second to produce unidirectional sweeps from short to long wavelengths at a repetition rate of 43.2 kHz.

The free-space collimated beam in the cavity may have a size of about 1 mm FWHM (full width at half maximum). The beam incident angle to the grating normal can be 67 deg. The focal lengths of the two lenses 334, 336 in the telescope can be 75 (f_1) and 40 (f_2) mm, respectively. It is possible to predict a free-spectral range of 55 nm and FWHM filter bandwidth of 0.17 nm. The laser output can be obtained via a 70% port of a fiber-optic coupler 350. Two polarization controllers 360, 362 can be used to maximize the output power and tuning range.

For example, it is possible to measure the spectral and temporal characteristics of the laser output at a sweep rate of about 43.2 kHz. The SOA may be driven with an injection current of about 110 mA. FIGURE 7(b) shows an exemplary output spectrum 380, 385 measured with an exemplary optical spectrum analyzer in a peak-hold mode at a resolution bandwidth of 0.1 nm. The total tuning range is 55 nm from 815 to 870 nm with a FWHM bandwidth of 38 nm. A stability of the output power is provided in the single-shot oscilloscope trace 390 as shown in FIGURE 7(c) provided at a about 43.2 kHz sweep rate and 7mW averaged power. The peak power variation across tuning cycles may be less than 1%. The instantaneous laser emission can contain multiple longitudinal modes.

An exemplary measurement of the coherence length (as shown in FIGURE 3(b)) can indicate that the FWHM line width may be approximately 0.17 nm corresponding to the filter bandwidth. The intensity noise characteristic of the laser output may further be characterized by using an electrical spectrum analyzer (e.g., Model, Agilent) and low-gain Silicon detector. The measured relative intensity noise can range from about −125 dB/Hz to −135 dB/Hz decreasing with the frequency in the frequency range of about 2 MHz to 10 MHz. The noise peaks due to longitudinal mode beating can appear at 91 MHz. The time-average output power may be about 6.9 mW.

The large output coupling ratio of the exemplary embodiment of the laser source arrangement, e.g., about 70%, can ensure that the peak power at the SOA does not exceed about 20 mW, e.g., the specified optical damage threshold of the SOA. When this condition is not satisfied, a sudden catastrophic or slowly progressing damage may occur at the output facet of SOA chip. Increasing the optical damage threshold of the 800-nm SOA chips, e.g., by new chip designs, can improve the tuning range as well as the long-term reliability. The output may contain a broadband amplified spontaneous emission that can occupy ~8% (about 0.56 mW) of the total average power.

Exemplary Imaging System

An exemplary embodiment of the OFDI system according to the present invention can be provided using the exemplary wavelength-swept laser arrangement. The configuration of the exemplary system can be similar to the system shown in FIGURE 1(b). The laser output can be split into two paths in an interferometer by a 30/70 coupler. In one path (e.g., 30% port, termed "sample arm") may illuminate a biological sample via a two-axis galvanometer scanner (e.g., Model, Cambridge Technologies). The other path, "reference arm," generally provides a reference beam. The signal beam returning from the sample by backscattering is combined with the reference beam at, e.g., a 50/50 coupler, thus producing interference.

The interference signal may be detected with a dual-balanced silicon receiver (e.g., DC-80 MHz, 1807-FS, New Focus). The receiver output is low-pass filtered (35 MHz) and digitized at a sampling rate of 100 MS/s with a 14-bit data acquisition board (e.g., DAQ, NI-5122, National Instruments). A small portion (10%) of the reference beam can be tapped and detected through a grating filter to provide triggers to the DAQ board. During each wavelength sweep or A-line scan, a large number, e.g., 2048 samples can be acquired. The sampled data may initially be stored in an on-board memory or on another storage device.

Upon collecting a desired number of A-line scans, the data set may be transferred to a host personal computer, either to the memory/storage arrangement for on-line processing and/or display or to the hard disk for post processing. When only a single frame is acquired at a time, the exemplary system is capable of processing and displaying the image frame in real time at a frame refresh rate of about 5 Hz. For larger data sets, an exemplary 256 MB on-board memory provides for acquisition of up to 65,536 A-line scans consecutively for about 1.3 sec. This corresponds to about 128 image frames, each consisting of 512 A-lines. Post data processing techniques can include reference subtraction, apodization, interpolation into a linear k-space, and dispersion compensation prior to Fourier transforms.

To characterize and optimize the exemplary embodiment of the system, process and arrangement according to the present invention, it is possible to use an axial point spread function (or A-line) by using a partial mirror as the sample (-50 dB reflectivity). FIGURE 8(a) shows a graph 400 of the sensitivity of the exemplary system measured as a function of the reference optical power. The reference power can be varied by using a variable neutral density (ND) filter in the reference arm. Throughout this measurement, for example, the path length difference between the sample and reference arms may be about 0.6 mm, and the optical power returning from the attenuated sample mirror can be 3.3 nW at each port of the 50/50 coupler. The sensitivity values may be determined by adding the sample attenuation (e.g., about 50 dB) to the measured signal-to-noise ratios (SNR). The reference power can be measured at one of the ports of the 50/50 coupler, corresponding to the time-average reference power at each photodiode. At reference powers between about 30 μW and 200 μW, a maximum sensitivity of ~96 dB may be obtained.

The sensitivity in the unit of decibel may be expressed as: $S_{dB} = S_0 - 10\log_{10}(1 + a/P_r + P_r/b) - \Delta$, where S_0 denotes the shot-noise limited sensitivity, P_r is the reference power level, a and b correspond to the reference power levels at which the thermal and intensity noise, respectively, become equal to that of the shot noise in magnitude, and Δ can be a fitting parameter associated with other factors contributing to the loss of sensitivity. Taking into account amplified spontaneous emission, S_0 may be about 107 dB. For example, a = 17 μW from the detector noise level (e.g., 3.3 pA/√Hz) and conversion efficiency (e.g., 1 A/W). Based on the relative intensity noise of the laser (e.g., -130 dB/Hz) and an 18-dB common-noise suppression efficiency of the balanced receiver, b = 280 μW. For example, the best fit to the experimental data 410 of FIGURE 8(b) can be obtained with Δ = 8 dB. FIGURE 8(b) shows a graph of the sensitivity 420 measured as a function of depth. This exemplary value may be largely attributed to the simplified model assuming a flat reference spectrum, a polarization mismatch between the sample and the reference light, and the apodization step in data processing, each possibly contributing to a loss of sensitivity by a couple of dB's.

Due to a finite coherence length of the laser source, the sensitivity can decrease as the interferometric delay increases. It is possible to measure axial point spread functions at various depth locations of the sample mirror by changing the delay in the reference arm while maintaining the reference power at about 100 μW per photodiode, as shown in the graph of FIGURE 8(b). For example, each axial profile can be calibrated by measuring the noise floor obtained by blocking the sample arm, and then matching the noise floor to a 50 dB level. In this manner, the modest frequency or depth dependence (~ 2 dB) of the noise floor can be reduced or eliminated. Thus, the sensitivity can drop by about 6 dB at a depth of about 1.9 mm. From a Gaussian fit (dashed line), the instantaneous laser line width may be about 0.17 nm. The FWHM of the axial profile, or the axial resolution in air, can be about 8 μm in the depth from zero to B mm. This corresponds to an axial resolution of ~6 μm in tissue imaging (e.g., refractive index, $n \approx 1.35$).

As an example, to confirm and demonstrate the capabilities of the exemplary embodiment of the system, process and arrangement according to the present invention for high-speed high-resolution biological imaging, images of *Xenopus laevis* tadpoles may be obtained *in vivo* by scanning the sample beam (B-mode scan). The sample beam can have a confocal parameter of about 250 µm and a FWHM beam size of approximately 7 µm at the focus in air (n = 1). The optical power on the sample may be about 2.4 mW. During the imaging procedure, the tadpole (stage 46) can be under anesthesia in a water bath by a drop of about 0.02% 3-aminobenzoic acid ethyl ester (MS-222).

Figure 9 shows a sequence of images 450 obtained as the beam is scanned in one dimension repeatedly over the ventricle in the heart. The image sequence was acquired at a frame rate of 84.4 Hz (512 A-lines per frame) in the duration of 1.2 s, but is displayed at a reduced rate of 24 frames per second. Each frame, cropped from the original (500 x 1024 pixels), has 400 x 200 pixels and spans a dimension of 3.3 mm (horizontal) by 1.1 mm (depth, n = 1.35). The motion of the ventricle including trabeculae can be seen. The ability to image the beating heart with high spatial and temporal resolution may be useful for investigating normal and abnormal cardiac developments *in vivo*. Combined with contrast agents such ICG and gold nano particles developed in the 800-nm region, the exemplary embodiment of the OFDI system, process and arrangement according to the present invention can enable high-speed functional or molecular imaging.

Exemplary Laser Current Modulation

An exemplary preferred light source arrangement for OFDI imaging generally has a flat output spectrum. To obtain such desired spectral profile, it is possible to modulate the gain or loss of a gain medium or a filter inside or outside a laser cavity. The filter may be a broadband variable attenuator, and its transmission may be controlled synchronously with laser tuning. The exemplary filter may be a passive spectral filter with a desired transmission spectrum. The gain medium can preferably be a semiconductor optical amplifier, and its gain may be varied by modulating the injection current to the amplifier synchronously with filter tuning. FIGURES 10(a) and 10(b) illustrate graphs of exemplary output tuning traces 480, 490 without and with the use of an exemplary embodiment of a modulation method according to the present invention, respectively. This exemplary method can also be effective to maximize or at least increase the output power and tuning range for a given optical damage threshold of the semiconductor gain chip.

Exemplary Flow Measurement

The ability to detect and quantify the blood flow in the eye retina and choroid can have impacts in several clinical applications such as for an evaluation of age-related macular degeneration. Several methods of extracting the flow information from the phase of the OFDI signals are known in the art. These exemplary conventional methods, however, require a significant beam overlap between two consecutive A-line scans- over sampling, thus causing undesirable compromise between the phase accuracy and image acquisition speed. Using the exemplary embodiment of the system, process and arrangement according to the present invention, instead of comparing the phase values of two A-line scans, it is possible to extract multiple phase values corresponding to different time points or wavelengths within a single A-line and compare the values with reference phase values. This exemplary procedure provides for a measurement of the flow velocity at multiple time points during a single A-line scan, permitting a faster beam scan and image acquisition speed. Such procedure can be used at decreased phase or velocity measurement accuracy, which is likely to be acceptable in many applications.

FIGURE 11 illustrates a flow diagram of a conventional method to extract the phase and velocity information from an entire dataset obtained during each wavelength scan. As shown in FIGURE 10, A-line scans, k-th through (k+1)-th are provided. In step 510, DFT from each of such scans is received, and utilized in the formulas $A_k(z)e^{i\varphi k(z)}$ and $A_k(z)e^{i\varphi k+1(z)}$, respectively. Then, using the determined results in step 510, the following determination is made in step 520: $\Delta(z) = \varphi_{k+1}(z) - \varphi_k(z)$. Then, in step 530, a phase image is overlayed to an intensity image if A(z) is larger than a particular threshold. Here, $A_m(z)$ denotes the signal amplitude associated with the sample reflectance at a depth z at the m-th A-line scan, $\varphi_m(z)$ denotes the signal phase associated with a depth z at the m-th A-line scan, and $\Delta(z)$ represents a difference between the phases.

FIGURE 12 illustrates a flow diagram of the exemplary embodiment of the process according to the present invention which can be used to obtain the phase and flow information by processing a half of the interference fringe data. For example, similarly to the conventional method shown in FIGURE 11, A-line scans, k-th through (k+1)-th are provided. Then, in step 560, DFT from each of such scans is received, and utilized in the following formulas, respectively: $A_1(z)e^{i\varphi 1(z) - \varphi r,1 (z)}$, $A_2(z)e^{i\varphi 2(z) - \varphi r,2 (z)}$, etc. Using the results obtained from step 560, the following determination is made in step 570: $\Delta(z) = \varphi_1(z) - \varphi_2(z) + \varphi_{r,1}(z) - \varphi_{r,2}(z)$. Here, $A_1(z)$ and $A_2(z)$ denote the signal amplitudes obtained from the two different portions of the interference signal acquired in each A-line scan, $\varphi_1(z)$ and $\varphi_2(z)$ denote the signal phases obtained from the two different portions of the interference signal, and $\varphi_{r,1}(z)$ and $\varphi_{r,2}(z)$ denote reference phases that may be constants, phases obtained from an auxiliary interferometric signal, or phases associated with a different depth. By subtracting the reference phases from the signal phases, phase noise associated with sampling timing fluctuations and motion artifacts can be greatly reduced. Further, in step 580, a phase image is overlayed to an intensity image if A(z) is larger than a particular threshold. This exemplary process can also be applicable to beam-scanning phase microscopy.

FIGURES 13(a) and 13(b) show exemplary images image of the retina obtained from a healthy volunteer. For example, FIGURE 13(a) illustrates a single exemplary image from a large number of frames consecutively acquired using the exemplary embodiment of the system, process and arrangement according to the present invention. The image frame consists of about 1000 axial lines, and the exemplary image shows the fovea and optic disk of the patient. FIGURE 13(b) shows an exemplary Integrated fundus image produced from multiple cross-sectional images covering an area by integrating the intensity in each depth profile to represent a single point in the fundus image using the exemplary embodiment of the system, process and arrangement according to the present invention.

As shown in these figures, the retinal OFDI imaging was performed at 800-900 nm *in vivo on a* 41-year-old Caucasian male subject. The exemplary embodiment of the OFDI system, process and arrangement according to the present invention acquired 23 k A-lines continuously over 1-2 seconds as the focused sample beam was scanned over an area including the macular and optic nerve head region in the retina. Each image frame was constructed from 1,000 A-line scans with an inverse grayscale table mapping to the reflectivity range. The anatomical layers in the retina are clearly visualized and correlate well with previously published OCT images and histological findings.

The foregoing merely illustrates the principles of the invention. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. Indeed, the arrangements, systems and methods according to the exemplary embodiments of the present invention can be used with any OCT system, OFDI system, SD-OCT system or other imaging systems, and for example with those described in International Patent Application PCT/US2004/029148, filed September 8, 2004, U.S. Patent Application No. 11/266,779, filed November 2, 2005, and U.S. Patent Application No. 10/501,276, filed July 9, 2004, the disclosures of which are incorporated by reference herein in their entireties. It will thus be appreciated that those skilled in the art will be able to devise numerous systems, arrangements and methods which, although not explicitly shown or described herein, embody the principles of the invention and are thus within the spirit and scope of the present invention. In addition, to the extent that the prior art knowledge has not been explicitly incorporated by reference herein above, it is explicitly being incorporated herein in its entirety. All publications referenced herein above are incorporated herein by reference in their entireties.

What Is Claimed Is:

1. An apparatus comprising:

at least one first arrangement configured to provide a radiation which includes at least one first electro-magnetic radiation directed to an anatomical sample and at least one second electro-magnetic radiation directed to a reference, wherein a wavelength of the radiation provided by the at least one first arrangement varies over time, and the wavelength is shorter than approximately 1150 nm;

at least one second arrangement capable of detecting an interference between at least one third radiation associated with the at least one first radiation and at least one fourth radiation associated with the at least one second radiation; and

at least one third arrangement capable of generating at least one image corresponding to at least one portion of the sample using data associated with the interference.

2. The apparatus according to claim 1, wherein a period of a variation of the wavelength of the at least one first electro-magnetic radiation is shorter than 1 millisecond.

3. The apparatus according to claim 1, wherein the anatomical sample includes at least one section of the posterior segment of an eye.

4. The apparatus according to claim 3, wherein the at least one section includes at least one of a retina, a choroid, an optic nerve, or a fovea.

5. The apparatus according to claim 1, wherein the wavelength is shorter than approximately 950 nm.

6. The apparatus according to claim 1, wherein the wavelength varies by at least 10 nm over a period of a variation of the wavelength of the at least one first electro-magnetic radiation.

7. The apparatus according to claim 1, further comprising at least one fourth arrangement which is capable of scanning the at least one first electro-magnetic radiation laterally across the anatomical sample.

8. The apparatus according to claim 1, wherein the at least one image is associated with the anatomical structure of the sample.

9. The apparatus according to claim 8, wherein the at least one image is further associated with at least one of a blood or a lymphatic flow in the sample.

10. The apparatus according to claim 1, wherein the at least one third arrangement is capable of (i) obtaining at least one signal associated with at least one phase of at least one frequency component of the interference signal over less than an entire sweep of the wavelength, and (ii) comparing the at least one phase to at least one particular information.

11. The apparatus according to claim 10, wherein the at least one particular information is associated with a further signal obtained from a sweep of the

wavelength that is different from the sweep of the wavelength of the at least one signal.

12. The apparatus according to claim 10, wherein the at least one particular information is a constant.

13. The apparatus according to claim 10, wherein the at least one particular information is associated with at least one phase of at least one further frequency component of the interference signal over less than an entire sweep of the wavelength, and wherein the frequency components are different from one another.

14. The apparatus according to claim 1, wherein the at least one third arrangement is capable of generating a two-dimensional fundus-type reflectivity profile of the anatomic sample.

15. The apparatus according to claim 10, wherein the at least one third arrangement is capable of generating a two-dimensional fundus-type image of the anatomic sample based the at least one signal.

16. The apparatus according to claim 10, further comprising

at least on fourth arrangement capable of receiving the at least one of the first or second electro-magnetic radiations, and providing at least one fifth electro-magnetic radiation associated with the at least one of the first electro-magnetic radiation or the second electro-magnetic radiation, wherein the at least one second arrangement is further capable of detecting a further interference signal between the at least one fifth radiation and the at least one fourth radiation,

wherein the at least one second arrangement is further capable of obtaining at least one reference signal associated with a further phase of at least one first frequency component of the further interference signal over less than an entire sweep of the wavelength.

17. The apparatus according to claim 16, wherein the at least one particular information is the further phase.

18. A method comprising:

causing a radiation which includes at least one first electro-magnetic radiation directed to be provided to an anatomical sample and at least one second electro-magnetic radiation directed to a reference, wherein a wavelength of the radiation varies over time, and the wavelength is shorter than approximately 1150 nm;

detecting an interference between at least one third radiation associated with the at least one first radiation and at least one fourth radiation associated with the at least one second radiation; and

generating at least one image corresponding to at least one portion of the sample using data associated with the interference.

19. A software arrangement comprising:

a first set of instructions which, when executed by a processing arrangement, causes a radiation which includes at least one first electro-magnetic radiation directed to be provided to an anatomical sample and at least one second electro-magnetic radiation directed to a reference, wherein a wavelength of the radiation varies over time, and the wavelength is shorter than approximately 1150 nm;

a second set of instructions which, when executed by the processing arrangement, causes a detection of an interference between at least one third radiation associated with the at least one first radiation and at least one fourth radiation associated with the at least one second radiation; and

a second set of instructions which, when executed by the processing arrangement, causes the processing arrangement to generate at least one image corresponding to at least one portion of the sample using data associated with the interference.

20. An apparatus comprising:

at least one source arrangement configured to provide an electro-magnetic radiation which has a wavelength that varies over time,

wherein a period of a variation of the wavelength of the at least one first electro-magnetic radiation is shorter than 1 millisecond, and the wavelength is shorter than approximately 1150 nm.

21. The apparatus according to claim 20, further comprising a control arrangement which is capable of modulating at least one of an optical gain or an optical loss in the at least one source arrangement over time.

22. The apparatus according to claim 20, wherein the optical gain is facilitated by a semiconductor material

23. The apparatus according to claim 20, further comprising an arrangement which is configured to effect at least one of a gain or a loss as a function of the wavelength.

24. The apparatus according to claim 20, wherein the wavelength varies by at least 10 nm over the period.

25. The apparatus according to claim 20, wherein the wavelength is shorter than approximately 950 nm.

26. A process comprising:

providing an electro-magnetic radiation; and

providing an ability to vary a wavelength the electro-magnetic radiation over time, wherein a period of a variation of the wavelength of the at least one first electro-magnetic radiation is shorter than 1 millisecond, and the wavelength is shorter than approximately 1150 nm.

27. A software arrangement comprising:

a set of instructions which, when executed by a processing arrangement, causes an electro-magnetic radiation which has a wavelength that varies over time to be provided, wherein a period of a variation of the wavelength of the at least one first electro-magnetic radiation is shorter than 1 millisecond, and the wavelength is shorter than approximately 1150 nm.

28. An apparatus comprising:

at least one arrangement configured to receive first data for a three-dimensional image of at least one portion of a sample,

wherein the first data is associated with an optical interferometric signal generated from signals obtained from the sample and a reference,

wherein the at least one arrangement is further configured to convert a region that is less than an entire portion of the first data to second data to generate a two-dimensional image which is associated with the at least one portion of the sample,

wherein the at least one arrangement is still further configured to automatically select the region based on at least one characteristic of the sample, and

wherein the entire portion is associated with an internal structure within the sample.

29. The apparatus according to claim 28, wherein the sample is an anatomical structure.

30. The apparatus according to claim 28, wherein the region is at least one portion of at least one of a retina or a choroid.

31. The apparatus according to claim 28, wherein the two-dimensional image is associated with an integrated reflectivity profile of the region.

32. The apparatus according to claim 31, wherein the two-dimensional image is associated with at least one of a blood or a lymphatic vessel network.

33. The apparatus according to claim 28, wherein the at least one arrangement automatically selects the region by determining at least one location of at least one section of the region based a reflectivity in the region.

34. A process comprising:

receiving first data for a three-dimensional image of at least one portion of a sample, wherein the first data is associated with an optical interferometric signal generated from signals obtained from the sample and a reference;

converting a region that is less than an entire portion of the first data to second data to generate a two-dimensional image which is associated with the at least one portion of the sample; and

automatically select the region based on at least one characteristic of the sample, wherein the entire portion is associated with an internal structure within the sample.

35. A software arrangement comprising:

a first set of instructions which, when executed by a processing arrangement, receives first data for a three-dimensional image of at least one portion of a sample, wherein the first data is associated with an optical interferometric signal generated from signals obtained from the sample and a reference;

a second set of instructions which, when executed by the processing arrangement, converts a region that is less than an entire portion of the first data to second data to generate a two-dimensional image which is associated with the at least one portion of the sample; and

a third set of instructions which, when executed by the processing arrangement, automatically selects the region based on at least one characteristic of the sample, wherein the entire portion is associated with an internal structure within the sample.

36. An apparatus comprising:

at least one first arrangement providing a radiation which includes at least one first electro-magnetic radiation directed to a sample and at least one second electro-magnetic radiation directed to a reference, wherein a wavelength of the radiation provided by the at least one first arrangement varies over time; and

at least one second arrangement capable of detecting an interference signal between at least one third radiation associated with the at least one first radiation and at least one fourth radiation associated with the at least one second radiation,

wherein the at least one second arrangement is capable of obtaining at least one signal associated with at least one phase of at least one frequency component of the interference signal over less than an entire sweep of the wavelength, and comparing the at least one phase to at least one particular information.

37. The apparatus according to claim 36, further comprising at least one third arrangement which is capable of scanning the at least one first electro-magnetic radiation laterally across the sample.

38. The apparatus according to claim 36, wherein the sample includes at least one section of a posterior segment of an eye.

39. The apparatus according to claim 36, wherein the at least one section includes at least one of a retina, a choroid, an optic nerve, or a fovea.

40. The apparatus according to claim 36, wherein the interference signal is associated with an integral fraction of the entire sweep of the wavelength.

41. The apparatus according to claim 36, wherein the fraction of the sweep is a half or a quarter of the sweep.

42. The apparatus according to claim 36, wherein the at least one signal is associated with at least one of a flow velocity or an anatomical structure in the sample.

43. The apparatus according to claim 36, wherein the at least one particular information is associated with a further signal obtained from a sweep of the wavelength that is different from the sweep of the wavelength of the at least one signal.

44. The apparatus according to claim 36, wherein the at least one particular information is a constant.

45. The apparatus according to claim 36, wherein the at least one particular information is associated with at least one phase of at least one further frequency component of the interference signal over less than an entire sweep of the wavelength, and wherein the frequency components are different from one another.

46. The apparatus according to claim 36, further comprising

at least on third arrangement capable of receiving the at least one of the first or second electro-magnetic radiations, and providing at least one fifth electro-magnetic radiation associated with the at least one of the first electro-magnetic radiation or the second electro-magnetic radiation,

wherein the at least one second arrangement is further capable of detecting a further interference signal between the at least one fifth radiation and the at least one fourth radiation,

wherein the at least one second arrangement is further capable of obtaining at least one reference signal associated with a further phase of at least one first frequency component of the further interference signal over less than an entire sweep of the wavelength.

47. The apparatus according to claim 46, wherein the at least one particular signal is the further phase.

48. A process comprising:

causing a radiation to be provided which includes at least one first electro-magnetic radiation directed to a sample and at least one second electro-magnetic radiation directed to a reference, wherein a wavelength of the radiation provided by the at least one first arrangement varies over time;

detecting an interference signal between at least one third radiation associated with the at least one first radiation and at least one fourth radiation associated with the at least one second radiation; and

obtaining at least one signal associated with at least one phase of at least one frequency component of the interference signal over less than an entire sweep of the wavelength, and comparing the at least one phase to at least one particular information.

49. A software arrangement comprising:

a first set of instructions which, when executed by a processing arrangement, causes a radiation to be provided which includes at least one first electro-magnetic radiation directed to a sample and at least one second electro-magnetic radiation directed to a reference, wherein a wavelength of the radiation provided by the at least one first arrangement varies over time;

a second set of instructions which, when executed by the processing arrangement, causes a detection of an interference signal between at least one third radiation associated with the at least one first radiation and at least one fourth radiation associated with the at least one second radiation; and

a third set of instructions which, when executed by the processing arrangement, obtains at least one signal associated with at least one phase of at least one frequency component of the interference signal over less than an entire sweep of the wavelength, and comparing the at least one phase to at least one particular information.

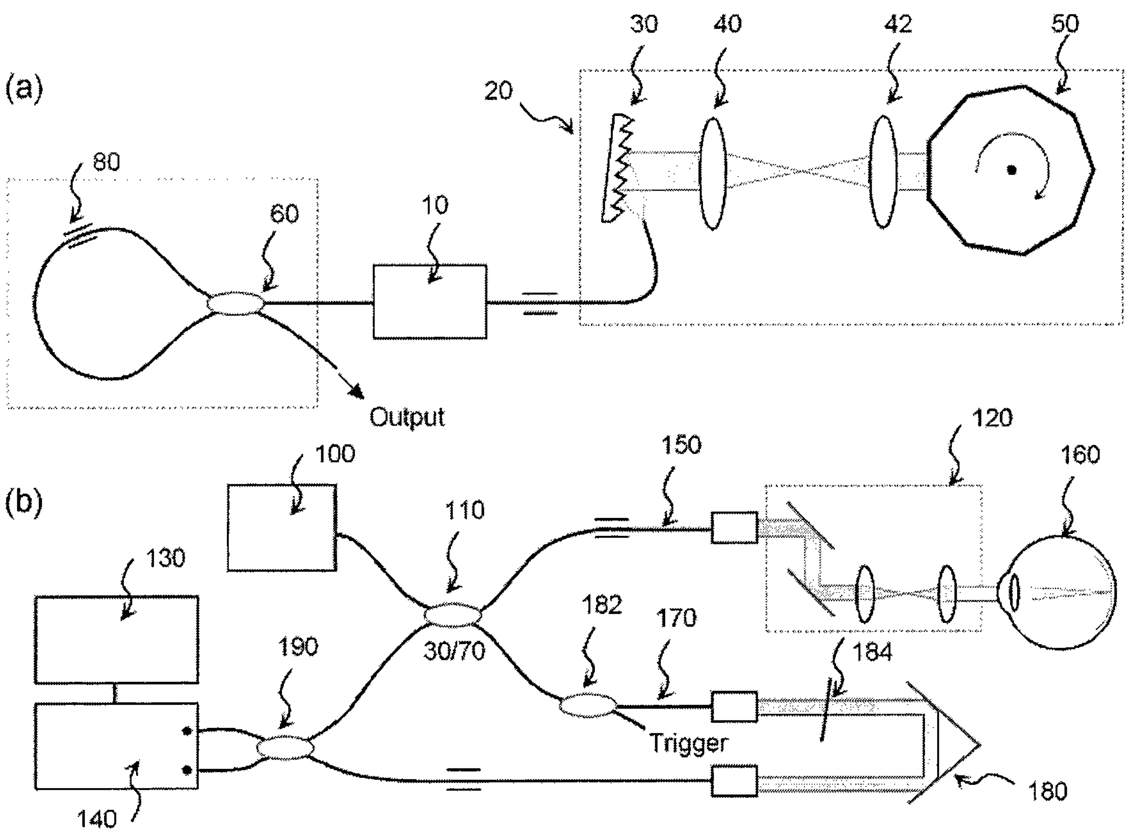


FIGURE 1

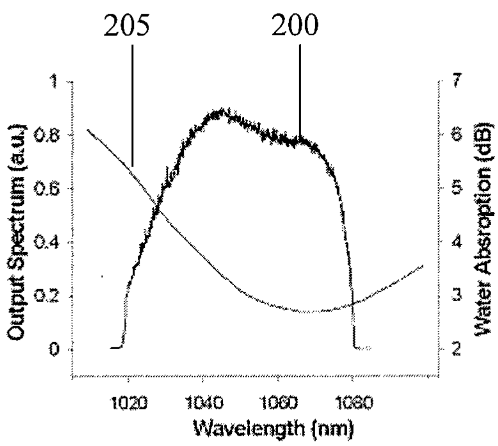


FIGURE 2(a)

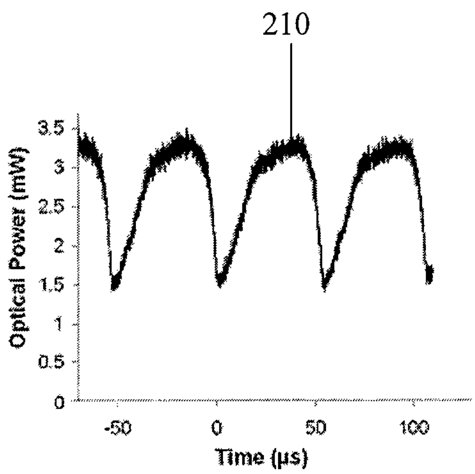


FIGURE 2(b)

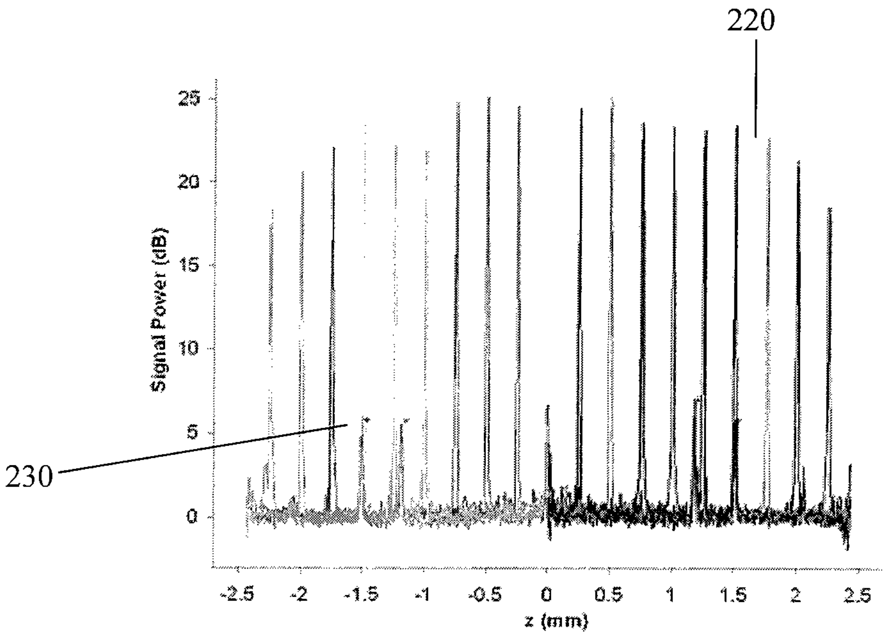


FIGURE 3

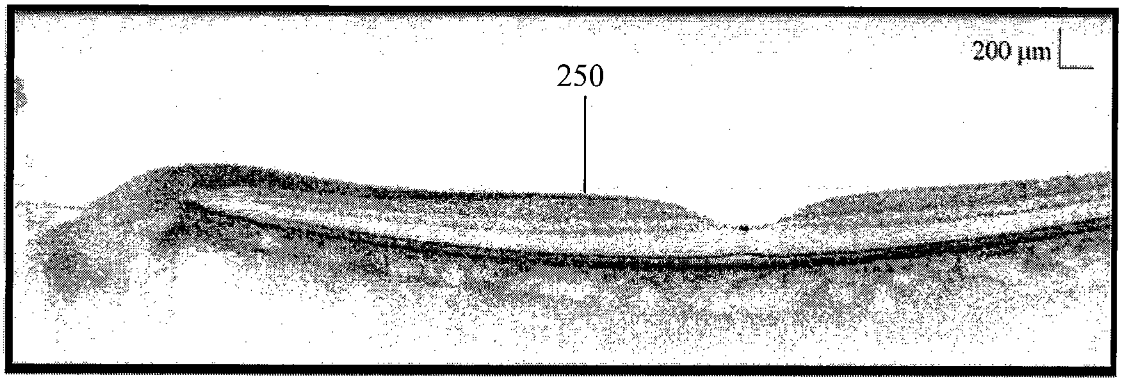


FIGURE 4

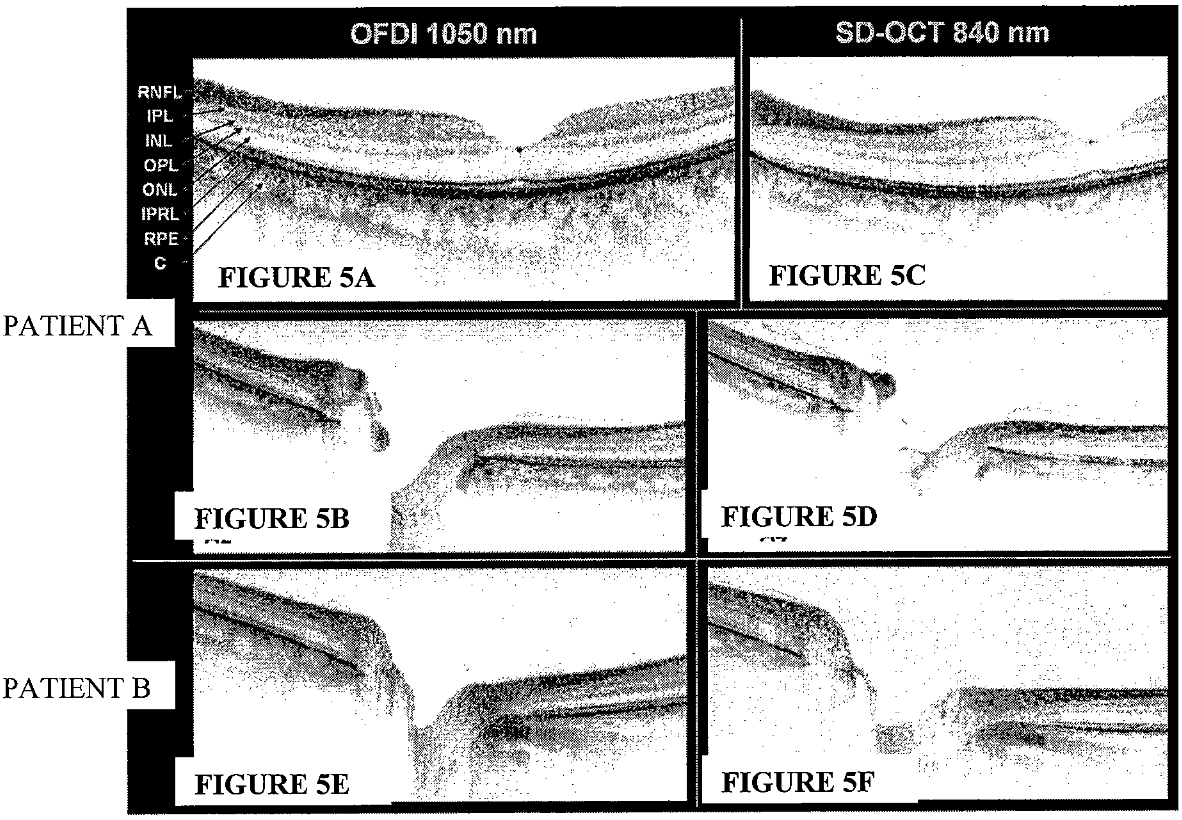


FIGURE 5A

FIGURE 5C

FIGURE 5B

FIGURE 5D

FIGURE 5E

FIGURE 5F

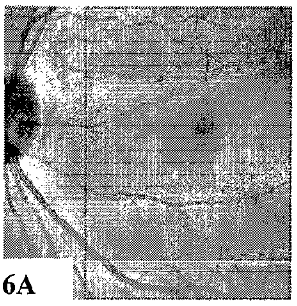


FIGURE 6A

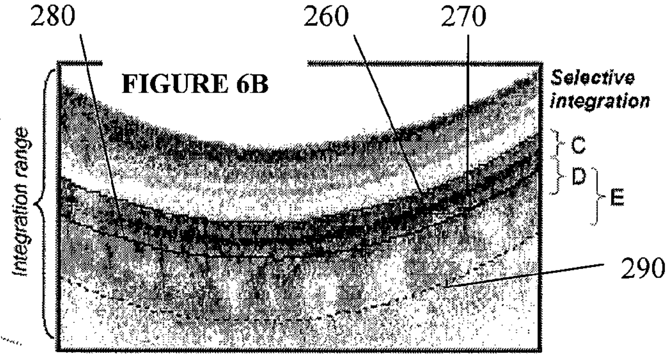


FIGURE 6B

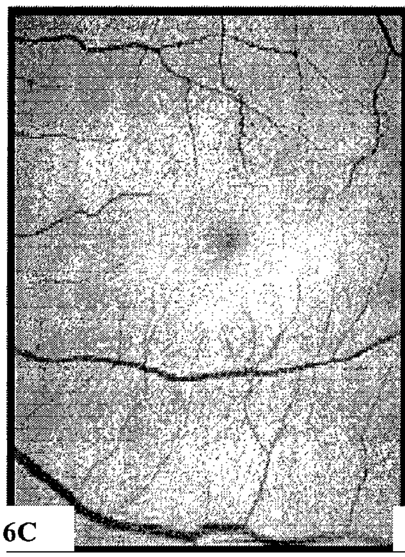


FIGURE 6C

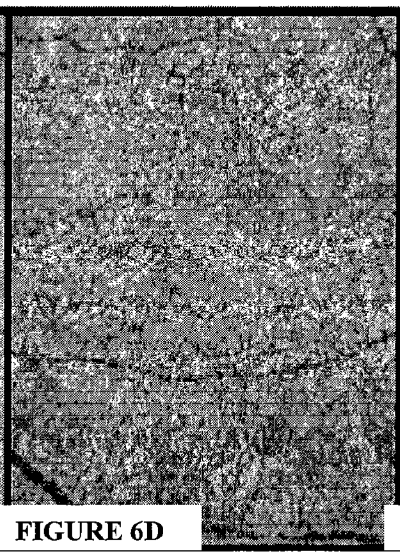


FIGURE 6D

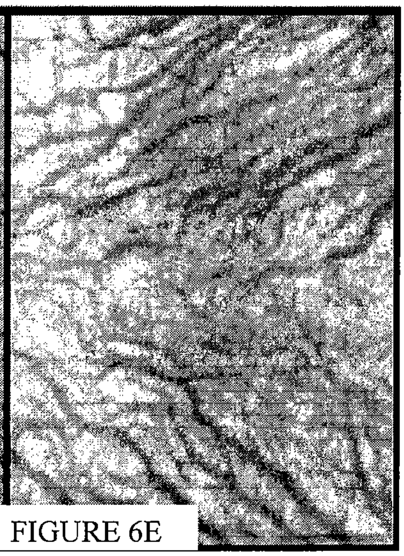


FIGURE 6E

FIGURE 7(a)

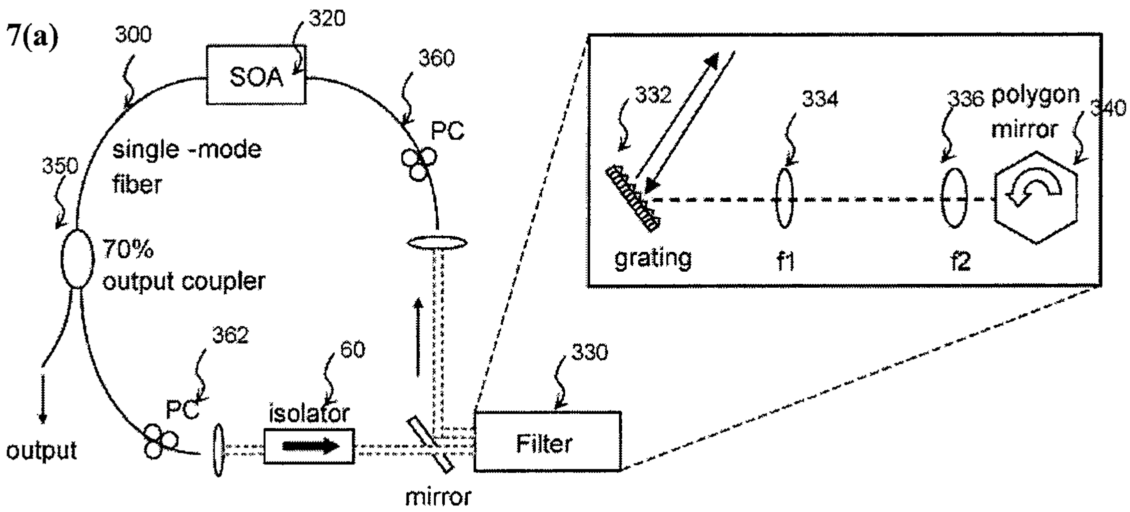


FIGURE 7(b)

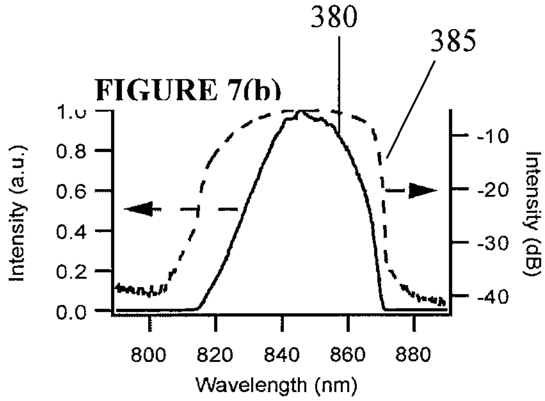
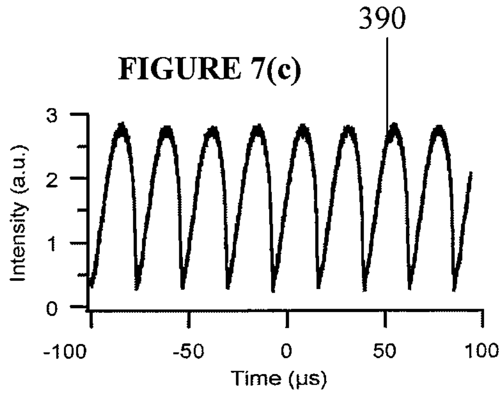
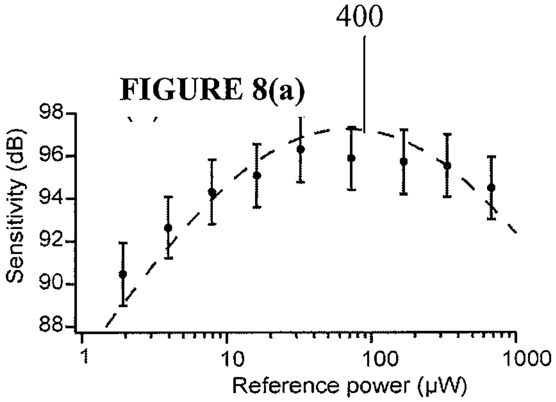
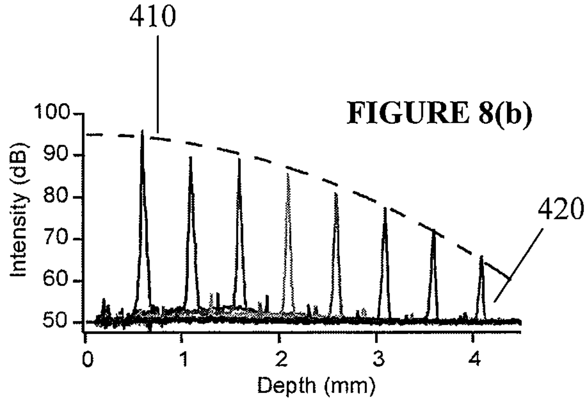


FIGURE 7(c)







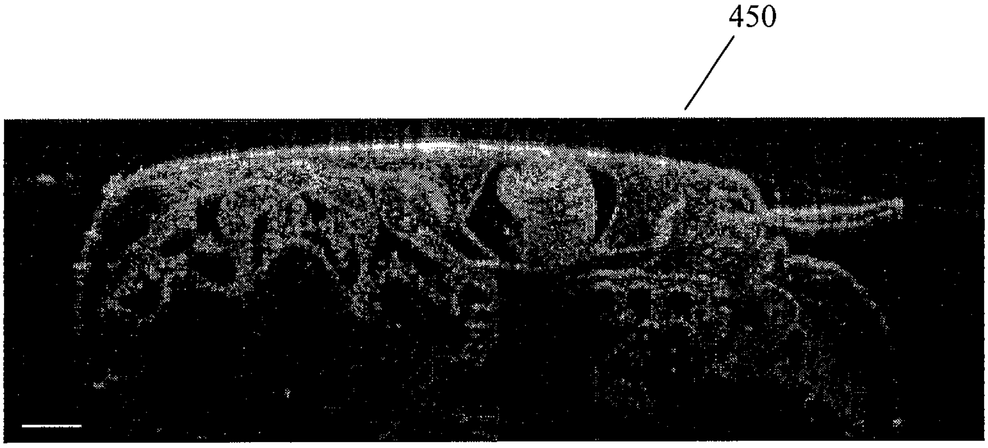


FIGURE 9

FIGURE 10(a)

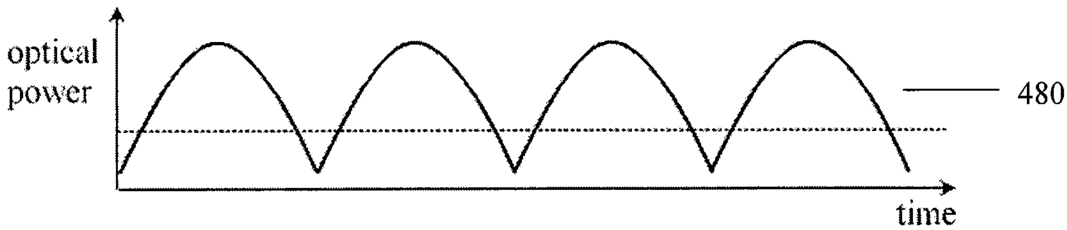
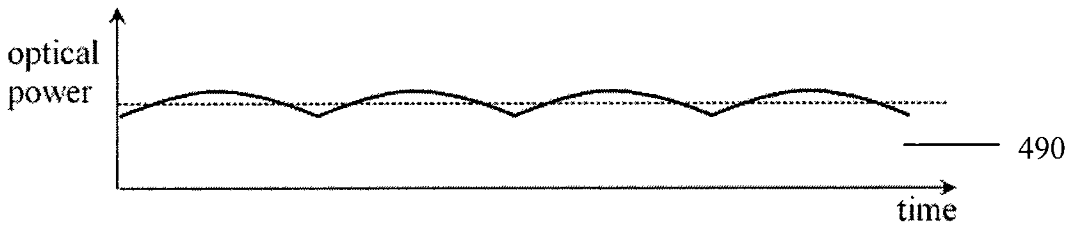


FIGURE 10(b)



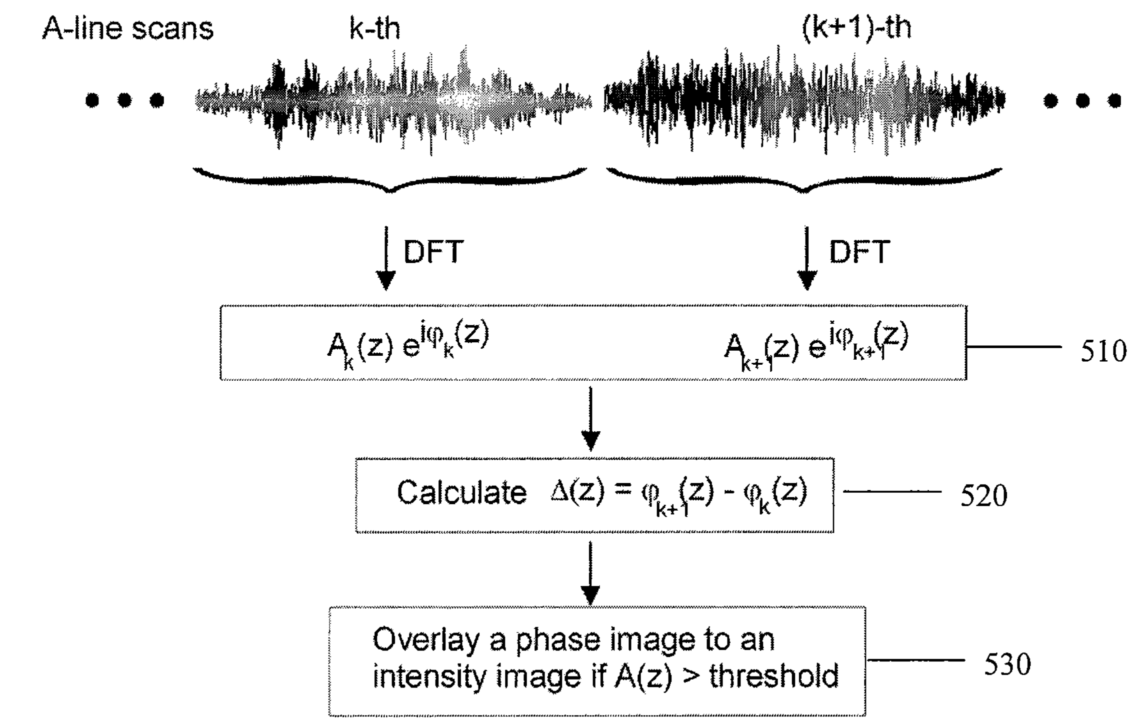


FIGURE 11 (PRIOR ART)

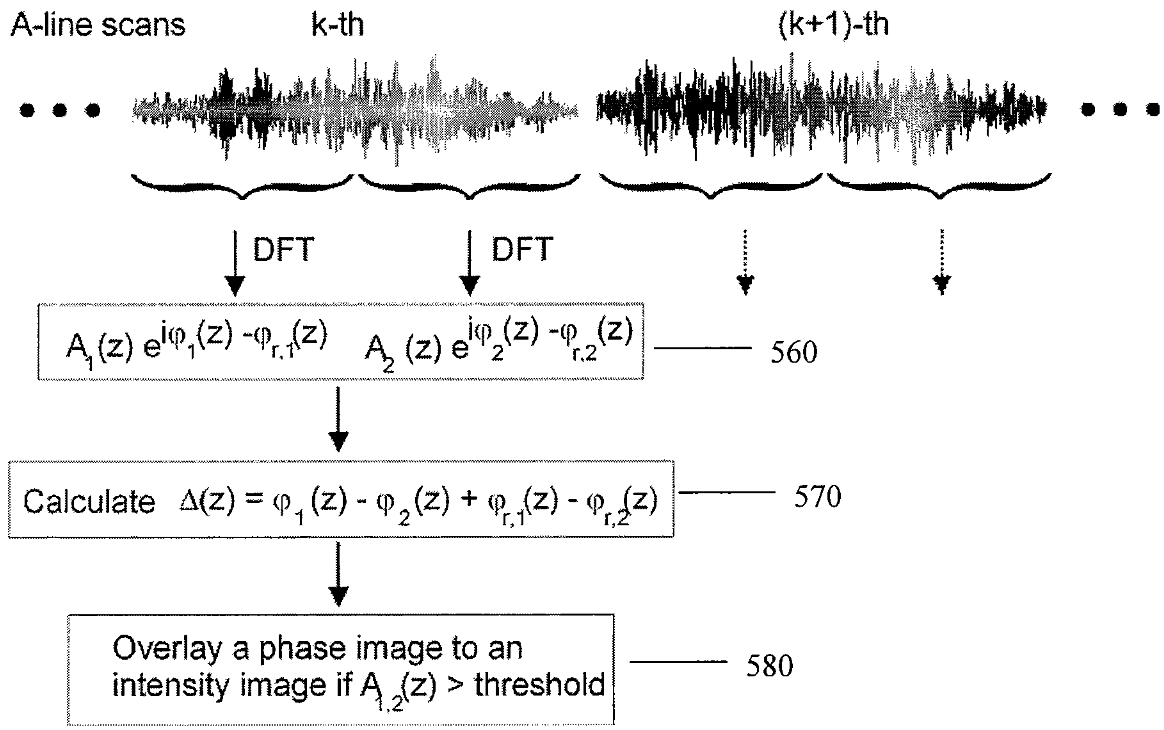


FIGURE 12

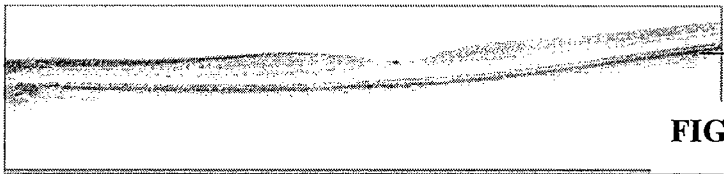


FIGURE 13(a)

FIGURE 13(b)

4828-9294-3105\1 4/20/2007 6:00 PM