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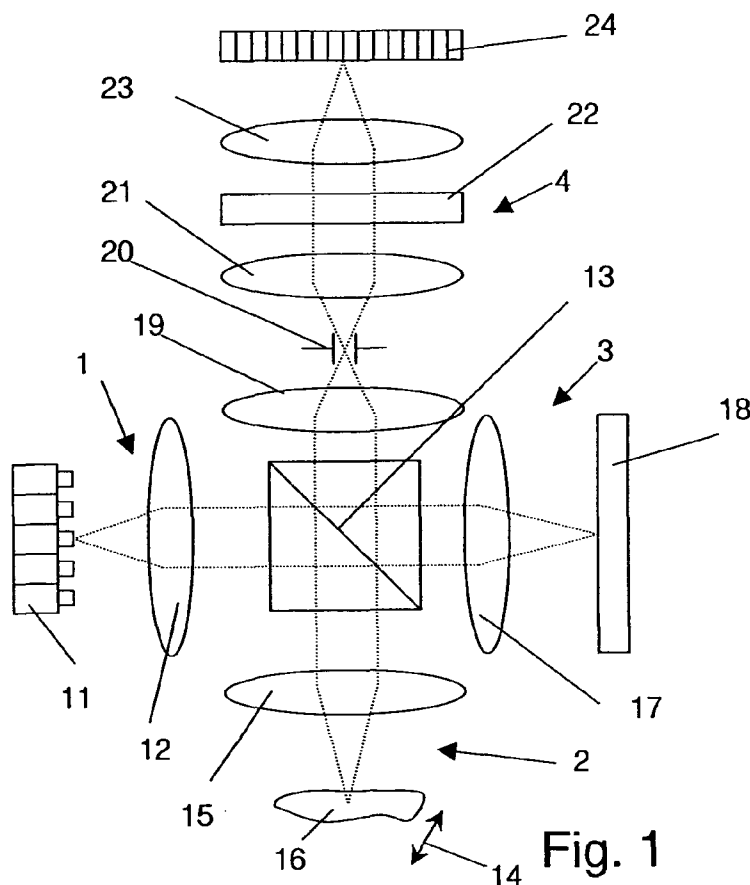
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(54) Title: OPTICAL COHERENCE TOMOGRAPHY SENSOR



(57) Abstract: The optical coherence tomography system according to the invention comprises - a plurality of radiation sources; - an optical system configured to split radiation emitted by the radiation sources into a sample radiation field and a reference radiation field, to direct the sample radiation field on a sample, and to recombine radiation field portions from the sample with radiation field portions of the reference radiation field to yield a measurement radiation field; - wherein the optical system is configured to direct radiation fields originating from at least two of said plurality of radiation sources onto different places on the sample; - and a detector unit for receiving the measurement radiation field; - wherein the optical system is configured to direct measurement radiation field portions that include radiation field portions from different places of the sample onto different places of said detector unit.

WO 2008/148237 A1



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OPTICAL COHERENCE TOMOGRAPHY SENSOR

FIELD OF THE INVENTION

The invention is in the field of optical coherence tomography. It more particularly relates to an optical coherence tomography system and an optical coherence tomography apparatus.

5 BACKGROUND OF THE INVENTION

Optical coherence tomography (OCT) is a method for non-contact optical imaging of objects, especially of biological tissue. It features the advantage of offering millimeter penetration into biological tissue with micrometer or even sub-micrometer axial and lateral resolution.

- 10 Optical coherence tomography is based on low-coherence interferometry. Light from a light source is split between a beam illuminating the (for example biological) sample and a reference beam illuminating a reference mirror. The beam reflected and/or backscattered by the sample and the reference beam (which usually is reflected back from a reference mirror) are brought into interference with each other.
- 15 In order to achieve a high axial resolution (i.e. a high resolution in with respect to the

- 2 -

optical axis, which is often direction perpendicular to the tissue surface), a wide bandwidth light source is required. Often, superluminescent light emitting diodes (SLEDs) are used for this purpose. As an alternative, the use of thermal light sources (such as halogen lamps) or of ultrashort laser pulses (which, due to the time-frequency uncertainty relation, have a broad bandwidth) have also been proposed.

Among OCT systems, there are Time-Domain OCT (TD-OCT) systems, and Fourier-Domain OCT (FD-OCT) systems. TD-OCT systems are based on temporal variations of the reference beam path. The amplitude of the interference signal between the backscattered light from the sample and the radiation reflected by the reference mirror is detected. In FD-OCT, the reference beam path is not scanned. Here, the depth profile is obtained from a Fourier transform of the spectrum recorded from the two interfering beams. This has the advantage to increase the speed of the depth profile acquisition compared to TD-OCT. Indeed, in TD-OCT the speed is usually limited by the reference beam path mechanical scanning system, while in FD-OCT the speed is only limited by the detector frame rate. A 2D- or 3D-image may then be obtained by scanning the light beam with respect to the sample. Usually, galvanometers are used to scan the sample under test. However, such galvanometers tend to be bulky and may transmit vibration in the system.

Approaches of parallel OCT for example using CCD cameras have also been proposed. An example of such an approach has been described by B. Grajciar et al. in *Optics Express* 13, 1131-1137 (2005). These approaches, however, suffer from a dilemma shown by Karamata et al. (*Optics Letters* 27, p. 736-738): The spatial coherence of the known high power sources such as, e.g., short pulse lasers, leads to an increased cross-talk across the sample. This causes the lateral (i.e. transverse) resolution to be reduced. Thermal sources do not exhibit this disadvantage; however, the power delivered into a single spatial mode is not high enough for high sensitivity real-time imaging with these sources.

SUMMARY OF THE INVENTION

It is a first object of the invention to provide an optical coherence tomography system that overcomes drawbacks of prior art optical coherence tomography systems, for example parallel systems. In particular, there is a need to provide an optical coherence tomography system that provides two-dimensional, for example cross-sectional, or three-dimensional images with high resolution and high sensitivity. The optical coherence tomography system should preferably allow data processing speeds that enable real-time recording of two-dimensional images. It is another object of the invention to provide an optical coherence tomography system that includes less moving parts than some non-parallel prior art optical coherence tomography systems and that achieve a better resolution than some parallel prior art OCT systems. It is another object of the invention to provide an optical coherence tomography system based on Fourier Domain optical coherence tomography with an extended depth scan range.

15 The optical coherence tomography system according to the invention comprises

- a plurality of radiation sources;
- an optical system configured to split radiation emitted by the radiation sources into a sample radiation field and a reference radiation field, to direct the sample radiation field on a sample, and to recombine radiation field portions from the sample with radiation field portions of the reference radiation field to yield a measurement radiation field;
- wherein the optical system is configured to direct radiation fields originating from at least two of said plurality of radiation sources onto different places on the sample;

- 4 -

- and a detector unit for receiving the measurement radiation field;
 - wherein the optical system is configured to direct measurement radiation field portions that include radiation field portions from different places of the sample onto different places of said detector unit.
- 5 The radiation field portions from the sample and the corresponding (i.e. originating from the same radiation source) reference radiation field portions interfere when being combined.

The radiation sources of the plurality of radiation sources do not have a statistic correlation between them. The radiation sources are preferably a well-defined
10 number of individual radiation sources, which sources optionally may, however, comprise common elements such as a common substrate, common layers etc. The plurality of radiation sources may be a plurality of broadband radiation sources, such as a plurality of superluminescent light emitting diodes (SLEDs), a plurality of pulsed lasers, a plurality of pumped optical fibers, a plurality of Light Emitting
15 Diodes etc. The skilled person will know other radiation generating means, which may also be used for a system according to the invention.

The use of an array of SLEDs is especially preferred. It permits to provide the optical power required to image at high sensitivity and at high speed, and the optical power of each individual radiation source is approximately reduced by a factor equal to the
20 number of radiation sources, in comparison with a system that contains a single radiation source. This allows focusing the design of SLED light sources towards ultrabroad spectral bandwidth.

- 5 -

The radiation sources of the plurality of radiation sources may be substantially identical, or may alternatively comprise radiation sources of different types, for example radiation sources of different spectral emission characteristics. Instead of emitting broadband radiation, the sources may comprise means for spectrally scanning and thus encoding the optical frequency in time. The plurality of radiation sources may be viewed as together forming a multichannel radiation source. The multichannel radiation source may optionally include radiation re-direction means such as optical waveguides etc.

The optical system may be functioning as an optical imaging system that images an output pattern of the multichannel radiation source on the sample and that directs a radiation field emitted by the sample into a region where it interferes with the reference radiation field and images the thus generated interference radiation field (or measurement radiation field) onto the detector unit.

The detector unit may be a two-dimensional array of detector cells such as Complementary Metal-Oxide-Semiconductor (CMOS) sensors, charge coupled devices (CCDs) or other 2D-detector devices, e.g. based on thermal detection (bolometers, Golay cells, thermopiles).

The approach according to the invention features the substantial advantage that it makes possible the acquisition of at least two-dimensional images without the need for any moving parts. Thus, for acquiring three-dimensional images, at most the possibility of a movement in one direction is required. This is a significant advantage for the realization of a miniaturized device, although the invention is equally suited for non-miniaturized devices. In the case of use of sources that encode the optical frequency in time (spectrally scanned), 3D images can be acquired without moving parts, except possibly the part that scans the light source.

- 6 -

As an alternative or in addition, the invention may make an enhanced depth resolution for Fourier domain OCT possible by the parallel use of reference paths of different optical beam path lengths, where the radiation for the different reference beam paths originate from different radiation sources.

- 5 A further advantage is that the multichannel radiation source constituted by the radiation sources arranged in an array is that each radiation source has no statistic correlation with the other one. This makes a high lateral resolution combined with a high sensitivity (due to the high power) and high axial resolution (due to the large bandwidth of the individual radiation sources) possible.
- 10 According to an embodiment, the optical coherence tomography system is configured to record radiation spectra, so that depth dependent images (thus information relating to sample properties as a function of the distance to the sample surface on which the sample radiation field impinges) may be obtained by calculation according to the Fourier-Domain Optical Coherence Tomography
- 15 method.

Such spectral information may according to a first possibility be obtained by having, as previously mentioned, the multichannel radiation source conducting a spectral scan and by synchronously recording the measurement radiation in a time-dependent manner by the detector unit.

- 20 As an alternative, the optical system may comprise an optical disperser, such as a diffraction grating, a waveguide dispersion means or a prism. The detector unit then may resolve a spatial variation of the measurement signal, and therefrom the spectral information may be extracted. For example, the multichannel radiation source may

- 7 -

comprise a linear array of radiation sources that is imaged onto a line on the sample, where different points of this line are imaged onto places distanced with respect to each other in a first direction on the detector unit. The dispersive element then directs radiation of different frequencies onto different places on the detector along a second
5 direction different from the first direction.

As yet another alternative, the detector cells may themselves spectrally resolve the radiation incident on them, for example by being yet to develop voltage-tunable wavelength-selective photodetectors.

According to these embodiments, the OCT system may be viewed as including an
10 imaging system and an imaging spectrometer. The imaging system images the radiation source pattern (usually a line or an area) defined by the arrangement of radiation sources onto the sample to yield an (illuminated) sample radiation pattern. It is also capable of superposing, via a reference path, the image of the radiation source pattern on the sample radiation pattern in a manner that radiation portions
15 originating from one particular radiation source thrown back by the sample and radiation portions from the reference path (from the same radiation source), respectively are brought together and may interfere. The imaging spectrometer conserves the lateral resolution with respect to at least one spatial direction and in addition provides a spectral resolution.

20 In addition or according to an alternative to recording spectra, the OCT system is configured to image a two-dimensional array radiation source onto the sample. According to this alternative embodiment, the OCT system may be viewed as comprising an imaging system and a camera. The imaging system images the two-dimensional radiation source pattern (also called "area" in this text, meaning an area
25 of discrete light sources; the area is not limited to a rectangular shape, but the area

- 8 -

can have any shape) defined by the arrangement of radiation sources onto the sample to yield an (illuminated) sample radiation pattern. It is also capable of superposing, via a reference path, the image of the radiation source pattern on the sample radiation pattern in a manner that radiation portions originating from one particular radiation source thrown back by the sample and radiation portions from the reference arm, respectively are brought together and may interfere. The camera is capable of recording an image of an area where the radiation portions from the sample and from the reference path are superposed.

In accordance with this alternative embodiment, the OCT system may be but need not be a TD-OCT-system (i.e., the OCT system may but need not be a system where the reference path is scanned).

The invention also concerns a Fourier-domain optical coherence tomography apparatus comprising

- A linear array of superluminescent light emitting diodes;
- 15 - an interferometer including
 - an optical system comprising a plurality of lenses, at least one beam splitter and at least one mirror, the beam splitter being configured to split radiation emitted by the superluminescent light emitting diodes into a sample radiation field and a reference radiation field, the optical system directing the sample radiation field on a sample, and recombining radiation field portions from the sample with radiation field portions of the reference radiation field and causing them to interfere to yield a measurement radiation field;

- 9 -

- wherein the optical system is configured to direct radiation fields originating from different ones of said plurality of superluminescent radiation emitting diodes onto different places on the sample;
- the optical system further comprising a radiation decomposer decomposing the measurement radiation field into portions of different frequencies to yield a decomposed measurement radiation field;
- the interferometer further including a detector unit that comprises a two-dimensional array of detector cells for receiving the decomposed measurement radiation field;
- wherein the optical system is configured to direct portions of the decomposed measurement radiation field that include radiation field portions from different places of the sample onto places of said detector unit which are distanced with respect to each other in a first direction;
- and wherein the optical system is further configured to direct measurement radiation field portions of different frequencies that include radiation field portions from a same place of the sample onto places of said detector unit which are distanced with respect to each other in a second direction different from the first direction.

The invention further concerns a system for optical coherence tomography, the system comprising

- a plurality of uncorrelated radiation sources;
- an optical system configured to split radiation emitted by the radiation sources into a sample radiation field and a reference radiation field, to direct the sample

- 10 -

radiation field on a sample, and to recombine radiation field portions from the sample with radiation field portions of the reference radiation field to yield a measurement radiation field;

- and a detector unit including a two-dimensionally resolvable detection area
5 arranged so as to receive the measurement field.

Still further, a Fourier domain optical coherence tomography system is provided, the system comprising

- a plurality of uncorrelated radiation sources;
- an optical system configured to split radiation emitted by the radiation
10 sources into a sample radiation field and a reference radiation field, to direct the sample radiation field on a sample, and to recombine radiation field portions from the sample with radiation field portions of the reference radiation field to yield a measurement radiation field;
- wherein the optical system is configured to direct reference radiation field
15 portions originating from at least two of said plurality of radiation sources along beam paths of different optical beam path lengths, and to direct sample radiation field portions originating from said at least two radiation sources onto neighboring locations on the sample;
- A radiation decomposer for decomposing the measurement radiation field
20 into portions of different frequencies to yield a decomposed measurement radiation field;

and detector unit including a two-dimensionally resolvable detection area arranged so as to receive the decomposed measurement field.

In this text, the terms “optical”, “light” etc. relate to electromagnetic radiation in general, in particular to infrared, visible, and ultraviolet radiation, and combinations
5 of these. A “superluminescent light emitting diode” is, as is known in the field, a superluminescent radiation emitting device, wherein the radiation is either infrared radiation, visible light, or possibly near ultraviolet radiation, or even far ultraviolet radiation, or has a frequency spectrum that includes radiation proportions of a combination of these.

10 The foregoing and other features and advantages of the invention will be further described in the following more particular description of preferred embodiments of the invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

- Fig. 1 is a schematic illustration of a first embodiment of the invention;
- 15 - Fig. 2 illustrates the detection arm of the embodiment of Fig. 1 in a view in a plane perpendicular to a detection arm plane of the view of Fig. 1;
- Fig. 3 illustrates a view analogous to the view of Fig. 2 for an alternative embodiment of the detection arm;

- 12 -

- Fig. 4 shows yet another embodiment of the system according to the invention;
- Fig. 5 is a schematic illustration of a further embodiment of the invention;
- Fig. 6 illustrates the detection arm of the embodiment of Fig. 5 in a view in a plane perpendicular to a detection arm plane of the view of Fig. 5;
- 5 - Fig. 7 shows a Fourier-domain optical coherence tomography (FD-OCT) apparatus yielding an extended depth scan range;
- Fig. 8 illustrates the detection arm of the embodiment of Fig. 7 in a view in a plane perpendicular to a detection arm plane of the view of Fig. 7;
- Fig. 9 shows a variant of the Fourier-domain optical coherence tomography (FD-
10 OCT) apparatus of Fig. 7 with some lateral resolution; and
- Fig. 10 shows very schematically a top view of a multichannel light source, namely, a 1D- array of SLEDs.

In the Figures, same reference numerals denote same components.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 13 -

The system illustrated in **Fig. 1** comprises a radiation source arm 1, a sample arm 2, a reference arm 3, and a detection arm 4. Radiation incident from the source arm 1 is split, by a beamsplitter 13, between a proportion directed to the sample arm 2 and a proportion directed to the reference arm 3. The radiation of the reference arm is re-
5 directed to the beamsplitter 13 and brought into interference with radiation radiated back from the sample 16 in the detection arm 4 and thereafter directed to a spectrometer with spatial resolution.

The radiation source arm 1 includes a multichannel radiation source 11 that comprises a plurality of superluminescent light emitting diodes (SLEDs) – depicted
10 very schematically in the figure – arranged in an array-like manner. In the depicted embodiment, the SLEDs are arranged in a linear, thus one-dimensional array of equidistant SLEDs. The linear arrangement defines a radiation source line.

Such an array of radiation sources can be incorporated by any arrangement of radiation sources. For example, an array of light radiation can be formed as an
15 unseparated bar of SLEDs with a common substrate as illustrated very schematically in **Fig. 10**. The thus depicted multichannel radiation source 11 comprises a common body 41 which includes a common n-contact (or p-contact) for all SLEDs and may also include at least a part of the heterostructure. The p-contacts (or n-contacts, respectively) may be individual, as illustrated by reference numeral 42 in the figure.
20 The waveguides 43 of the different SLEDs of the SLED bar are essentially parallel.

The radiation source arm also comprises radiation influencing means, illustrated as first lens 12 in the figure. The sample arm 2 also includes radiation influencing means, illustrated as second lens 15 in the figure. The radiation influencing means of the radiation source arm 1 and of the sample arm 16, together with the beamsplitter
25 13 form a first part of the optical system of the optical coherence tomography

- 14 -

system. The first part of the optical system is capable of imaging the radiation source line onto a sample radiation line on the sample 16.

The sample throws back, due to reflection and scattering (and possibly also due to luminescence, which portions, however, do not contribute to the final result), radiation portions when the sample radiation impinges on it. As is known in the art, if the sample surface is not completely nontransparent to the radiation, the emitted radiation includes portions originating from different depths underneath the sample surface.

Also the reference arm 3 comprises radiation influencing means, illustrated as a third lens 17 in the figure. The reference arm 3 also includes a mirror 18 or other radiation re-directing means (such as a system of fibers) for re-directing the radiation from the beamsplitter back to beamsplitter 13. The optical path length (the actual path length, multiplied by the index of refraction of the medium/media the radiation travels in) from the beamsplitter 13 via the re-directing means back to the beamsplitter 13 essentially corresponds to the optical path length from the beamsplitter 13 to the sample 16 and back to the beamsplitter. The system may optionally include means for adjusting the optical path length and/or for correcting dispersion in the reference arm and/or in the sample arm, for example by displacing the mirror 18 and/or the sample 16, respectively. The radiation re-directing means of the reference arm and the beamsplitter 13 are capable of directing radiation travelling on the reference path in a manner that it interferes with radiation portions emitted by the sample. More particularly, they image the radiation source line in a such manner on the beamsplitter 13 that radiation portions originating from one particular radiation source (SLED) thrown back by the sample 16 and the radiation re-directing means, respectively are brought together and may interfere in the detection arm 4.

- 15 -

The detection arm 4 comprises first detection arm radiation influencing means, here including a fourth lens 19, a slit 20, and a fifth lens 21. A diffraction grating 22 serves as radiation decomposer for decomposing the radiation field in the detection arm 4 – the measurement radiation field, which includes the radiation portions from the sample 16 and from the reference arm 3 interfering – into portions of different frequencies. The first detection arm radiation influencing means are capable of imaging the sample radiation line (and, via the radiation re-directing means, also directly the superposed radiation source line) onto the slit. The following radiation influencing means (lenses 21 and 23) perform an image of the slit onto the detector unit 24. A diffraction grating 22 is placed between lenses 21 and 23. Usually lenses 21 and 23 are placed in a way that the beams illuminating the diffraction grating are parallel to the optical axis. If the diffraction grating comprises essentially parallel grating lines defining a grating line direction, the direction of the imaged sample radiation line on the grating is not perpendicular to and for example (but not necessarily) parallel or nearly parallel (with an angle between -30° and 30°) to the grating line direction. By the diffraction grating, therefore, the radiation is spread in the dimension perpendicular to the plane in which the radiation line propagates. The spread measurement radiation field impinges on the detector unit 24 which comprises a two-dimensional array of detector cells. In this way, a two-dimensional cross-section image of the sample is mapped on the two-dimensional detector unit. One dimension of the detector unit maps the imaged sample line (lateral position), and the perpendicular dimension maps the depth of the image (axial position).

The decomposing into radiation of different frequencies can better be seen in **Fig. 2**, which shows a part of the detection arm 4 in a view perpendicular to the view shown in Fig. 1. The path of radiation of two different frequencies – illustrated by dashed and dash-dotted lines, respectively – are schematically shown.

- 16 -

The slit 20, the fifth lens 21, the diffraction grating 22, the sixth lens 23 and the detector unit 24 may be viewed as together forming an imaging spectrometer. Of course, other implementations of spectrometers than the shown embodiment may be used, provided radiation portions originating from different places of the sample are distinguished, here by being directed onto different places on the detector unit.

The pattern of detector cells may be adapted to the geometry of the optical system. For example, the spectrometer of the shown embodiment may be designed in such a way that in the plane defined by the sample radiation line, the radiation field portions from one lateral position on the sample and its corresponding reference radiation field, from one radiation source, are focused onto one column of the two-dimensional detector cell array. In other words, to each radiation source corresponds a transverse position illuminated on the sample and a column ("vertical" line) of the detector cell array. If the grating lines are exactly parallel to the plane defined by the sample radiation line, in this plane the diffraction grating DG has no effect on the beams. In the plane perpendicular thereto ("the vertical plane"), the spectrometer is designed so that for each radiation source the radiation is spectrally dispersed by the diffraction grating DG, and is focused onto the rows of the photosensor array, at its corresponding column.

The transverse range of the sample investigated, along the sample line, is set by the radiation influencing means, here including the lenses 15, 19, 21, 23, and the detector unit dimension in the plane parallel to the radiation line source. Of course the radiation influencing means in the illuminating arm 1 should be chosen in such a way that the radiation source line illuminates the area of the sample investigated. The axial (depth) scan range z is directly related to the central wavelength of the radiation sources λ_0 and to the resolution of the spectrometer $\delta\lambda$, by: $z = \frac{\lambda_0^2}{4\delta\lambda}$. The spectrometer resolution is usually set by the entrance slit 20 width in the plane

- 17 -

perpendicular to the radiation line source, the radiation influencing means in the spectrometer (here especially lenses 21, 23), the dispersive power of the diffraction grating 22, and the pixel pitch of the detector unit (i.e. the distance between two detector cell centers). In order to set the lateral and axial scan ranges independently,
5 the lenses within the spectrometer 21, 23 may both be a set of two cylindrical lenses, or a combination of symmetric lenses with cylindrical lenses.

The transverse (lateral) resolution is set by the radiation influencing means 15, 19, 21, 23, and the size of the detector cell in the plane parallel to the sample line. The entrance slit 20 of the spectrometer may either be a slit or an array of pinholes (i.e.
10 one pinhole associated to one radiation source), this latter giving better results for the transverse resolution.

In this configuration, due to the principles underlying FD-OCT, a two-dimensional cross-sectional image of the sample is mapped onto the area of the photosensor array. At each transverse position on the sample corresponds one column of the
15 photosensor array, and the depth (axial) information of the sample at this transverse position is obtained by detecting the radiation spectrally dispersed on the rows. The depth information is retrieved by Fourier transformation of these data. The image is acquired at the detector unit data readout rate, which can be very high with today available photosensors (several tens of frames per second).

20 The system may further comprise a scanner for changing the relative position of the sample radiation line and the sample with respect to each other, especially in directions different from (for example perpendicular to) the sample radiation line direction. Such a scanner may include radiation directing means, a sample moving means, a means for displacing the entire optical system (including multichannel
25 radiation source and detector), or a combination of these, etc. In Fig. 1, a means for

- 18 -

displacing the sample 16 perpendicular to the drawing plane is illustrated very schematically by a double arrow 14.

By the additional means of the scanner, one may obtain a plurality of two-dimensional cross-sectional images adjacent to each other and thus ultimately three-dimensional images of the sample.

Whereas in the shown embodiment, the beamsplitter also serves for recombining the radiation portions from the sample with the reference radiation field portions, this need not be the case. Rather, different physical means may be used for splitting and recombining the radiation fields.

10 **Fig. 3** depicts a variant of the detection arm 4, wherein the diffraction grating 22 of the transmission type of Figs. 1 and 2 is replaced by a diffraction grating 32 of the reflection type. Otherwise, the functionality is unchanged compared to the above-described embodiment.

15 Other means for spectrally dispersing the measurement radiation field may be used, such as a prism, a bundle of different optical fibers, etc. As an alternative, yet other means for decomposing the measurement field into its spectral components may be used, such as all solid-state spectrometers.

20 The embodiment shown in **Fig. 4** is distinct from the above-described embodiments in that it comprises a multichannel radiation source that includes a two-dimensional arrangement 31 of individual radiation sources, such as individual SLEDs, SLED-arrays, or VCSEL arrays . The two-dimensional arrangement is depicted in Fig. 4 only very schematically. The optical system that in the shown embodiment is made

- 19 -

up of the lenses 12, 15, 17, 19, 21, 23, the slit 20, the beamsplitter 13 and the re-direction means 38 is capable of imaging the radiation source area defined by the two-dimensional arrangement of radiation sources onto the sample to yield an (illuminated) sample radiation area. It is also capable of imaging the sample radiation area onto the detector unit 24 and of superposing, via the reference arm 3, the image
5 of the radiation source area in a manner that radiation portions originating from one particular radiation source (SLED) thrown back by the sample 16 and the radiation re-directing means, respectively are brought together and may interfere in the detection arm 4 and may be detected by a pixel of the detector unit.

10 Due to this construction, the system according to Fig. 4 yields a two-dimensional image of the irradiated area of the sample at a particular depth. The depth depends on the exact relationship between the optical path lengths in the sample arm 2 and in the reference arm 3. By scanning the optical path length on the reference arm and/or the sample arm, one may obtain a plurality of two-dimensional images representing two-
15 dimensional images taken at different depths in the sample and thus ultimately also three-dimensional images of the sample structure.

In Fig. 4, the radiation re-directing means is shown as a movable mirror 38. By moving the movable mirror 38, one may vary the optical path length in the reference arm to slightly deviate from the optical path length in the sample arm and thus to
20 perform the depth scan.

The fourth, fifth, and sixth lens 19, 21, 23 together with the (optional) slit 20 and the detector unit together may be viewed as forming a camera for recording an image of the interference pattern formed by the superposed (via the beamsplitter 13) sample radiation area with the reference radiation area. The skilled person will know a lot of
25 other embodiments of cameras or devices having a similar functionality, i.e. imaging

- 20 -

a two-dimensional image onto a sensor unit and recording the image for further processing.

As yet another variant, the relationship between the optical path lengths on sample arm 2 and on the reference arm 3 may be kept constant, and to each of the pixels of the camera – thus the detector cells – a spectrometer is attributed. This may for
5 example be done by an array of fibers (one fiber corresponding to each pixel), each re-directing a radiation portion to a spectrometer, or by a detector unit where each detector cell includes a means for resolving the spectrum of incident radiation, such as a voltage-tunable wavelength-selective photodetector cell.

10 The system illustrated in **Fig. 5** and **Fig. 6** is similar in its functionality to the system illustrated in Fig. 1 and Fig. 2. However, in contrast thereto system, the radiation influencing means are of a different kind. The first, second, third, fourth and fifth lenses 12, 15, 17, 19, and 21 of the system of Figs. 1 and 2 are replaced by linear
15 arrays of microlenses 12', 15', 17', 19', and 21'. After the grating 22, cylindrical lens 27 is arranged, which only has an effect in the, according to the above definition, “vertical” plane (for beams that are spread by the grating). Thereafter, radiation reaches the detector unit 24 through an array of cylindrical microlenses 23' that only has an effect in the “horizontal” plane.

20 The number and arrangement of the microlenses may be adapted to the array of radiation sources and/or to the detector cells. For example, each microlens in the arrays of microlenses 12', 15', 17', 19', and 21', and the array of cylindrical microlenses 23' may correspond to one radiation source.

- 21 -

The slit 20, in this embodiment, only has an effect in the vertical plane, i.e. influences the resolution of the spectrometer (axial scan range). A linear array of pinholes can be used instead of the slit, with one hole per light source.

The invention also concerns a Fourier-domain optical coherence tomography (FD-OCT) apparatus yielding an extended depth scan range. Indeed, standard FD-OCT systems have a depth scan range limited by the spectrometer resolution. By means of the principle of the invention, it is also possible to overcome this limitation by replacing the reference mirror by an echelon mirror as shown schematically in **Fig. 7**. The system is similar to the one presented in Figure 4, with the following modifications:

- A reference radiation field separated in a multitude of reference fields with different path lengths. This can be realized for example by replacing the reference mirror by an echelon mirror 58 that contains a multitude of mirrors located at different depths, related to the optical axis.
- 15 - The mirrors of the echelon are irradiated by radiation portions originating from different radiation sources. For example each radiation source illuminates one mirror of the echelon, or groups of radiation sources illuminate different mirrors of the echelon.
- 20 - Every radiation source illuminates the sample on the same area, i.e. the light portions from different radiation sources are directed to places on the sample that are very close to each other (and can for example overlap). This can be realized by choosing a focal length of lens L2 much shorter than the focal length of lens L3.
- 25 - In this configuration, each vertical column of the photosensor detects the radiation field from one reference path length and from the sample field,

- 22 -

corresponding to one (dimensional) depth profile in the sample at a distance set by the related reference path length.

- If the difference path lengths between the echelons are chosen equal to the depth scan range limited by the spectrometer resolution, the total depth scan range of the system is multiplied by the number of steps.

Fig. 8 shows a vertical view of the detection arm, in analogy to Figures 2 and 6.

It has to be noted that in the embodiment of Figs. 7 and 8 the extended depth scan range is realized at the cost of the lost of the second dimension of the image. In case also a transversal resolution is desired, a scan unit 14 of the system may therefore cause a relative movement of the reference arm and the sample (or a deflection of the beam or other means causing the spot of incidence on the sample to be systematically varied) in two spatial directions, thereby yielding a three-dimensionally resolved image with an enhanced depth resolution, where the lateral/transverse resolution, however, is somewhat influenced by the optical system:

- 15 The transverse resolution of this system, noted Δx in Fig. 7, is given by the area of the sample illuminated by the multitude of radiation sources. In the ideal case, every radiation sources should illuminates the same position of the sample and the resolution would only be limited by the spot size of the radiation field. In the practical case, the resolution is strongly dependent of the focal length of the lens 15 (or lens system) focussing the incident radiation onto the sample 16. The shorter this focal length, the better the transverse resolution.

In the case the difference path lengths between the multitudes of reference fields is in the range of a fraction of the radiation field wavelength, a phase sensitive system can be realized.

It is also possible to add some transversal resolution to the variant with the enhanced
5 depth resolution, at least in one dimension, with parallel measurement of the
different lateral positions. One possibility of doing so is illustrated in **Fig. 9**. The
echelon mirror 68 of this embodiment is distinct from the one of Figure 7 in that it
contains a plurality of “staircases” (i.e. stepped sections 68.1 each containing a
plurality of mirrors at different depths). Each stepped section 68.1 of the echelon
10 reference mirror corresponds to a small area Δx on the sample which is depth
resolved by the combination of the steps and the spectral decomposition, as taught
referring to Fig. 7. The number of (transversally resolved) depth scans corresponds to
the number of stepped sections.

The system may further optionally comprise a scan unit 14 to transversally scan in
15 one or two lateral directions.

Other variants of combinations of the concept of Fig. 7 with a transversal resolution
are conceivable.

In all embodiments including an echelon, the stepping does not necessarily need to
be monotonous; in principle the different mirrors at different depths could be
20 arranged in arbitrary sequence. The software calculating a depth resolution just has to
contain the information on the stepping.

- 24 -

In all embodiments including an echelon, the combination with a transversal resolution (be it parallel or sequential by scanning or both) is advantageous in systems where the transversal resolution may be limited or where the sample varies only comparably slowly in the transversal direction. This is often the case in reality,
5 as the variation perpendicular to the body surface is often much stronger as the variation parallel thereto.

Various other embodiments may be envisaged without departing from the scope and spirit of the invention.

WHAT IS CLAIMED IS:

1. A system for optical coherence tomography, the system comprising
 - a plurality of radiation sources;
 - an optical system configured to split radiation emitted by the radiation
5 sources into a sample radiation field and a reference radiation field, to direct
the sample radiation field on a sample, and to recombine radiation field
portions from the sample with radiation field portions of the reference
radiation field to yield a measurement radiation field;
 - wherein the optical system is configured to direct radiation fields originating
10 from at least two of said plurality of radiation sources onto different places
on the sample;
 - and a detector unit for receiving the measurement radiation field;
 - wherein the optical system is configured to direct measurement radiation
field portions that include radiation field portions from different places of
15 the sample onto different places of said detector unit.
2. The system according to claim 1 wherein the plurality of radiation sources is a
plurality of superluminescent light emitting diodes.
3. The system according to claim 2, wherein said superluminescent light emitting
diodes have a same frequency characteristics.

- 26 -

4. The system according to any one of the previous claims, wherein the plurality of radiation sources is a one-dimensional or two-dimensional array of radiation sources, and wherein the optical system is configured to direct radiation fields originating any two of said plurality of radiation sources onto different places
5 on the sample.
5. The system according to any one of the previous claims, wherein the detector unit includes a plurality of detector cells arranged in a two dimensional pattern.
6. The system according to any one of the previous claims, wherein the optical system comprises a radiation decomposer for decomposing the measurement
10 radiation field into portions of different frequencies before it impinges on the detector unit.
7. The system according to claim 6 wherein the radiation decomposer includes a radiation disperser.
8. The system according to claim 7, wherein the radiation disperser comprises a
15 diffraction grating.
9. The system according to claim 8, wherein the diffraction grating comprises a plurality of parallel diffraction grating lines, wherein the plurality of radiation sources is arranged in a linear array defining a radiation source line, and wherein the optical system is capable of imaging the radiation source line onto
20 the diffraction grating so that the radiation source line is parallel to the grating lines.

- 27 -

10. The system according to claim 5, wherein each detector cell of the detector unit includes a spectrometer.
11. The system according to any one of the previous claims further comprising a scan unit for causing a region of incidence of the sample radiation field on the sample to be varied.
12. The system according to any one of the previous claims, wherein the optical system is configured to simultaneously direct reference radiation field portions originating from at least two of said plurality of radiation sources along beam paths of different optical beam path lengths.
13. A Fourier-domain optical coherence tomography apparatus comprising
- a linear array of superluminescent light emitting diodes;
 - an interferometer including
 - an optical system comprising a plurality of lenses, at least one beam splitter and at least one mirror, the beam splitter being configured to split radiation emitted by the superluminescent light emitting diodes into a sample radiation field and a reference radiation field, the optical system directing the sample radiation field on a sample, and recombining radiation field portions from the sample with radiation field portions of the reference radiation field and causing them to interfere to yield a measurement radiation field;

- 28 -

- wherein the optical system is configured to direct radiation fields originating from different ones of said plurality of superluminescent radiation emitting diodes onto different places on the sample;
 - the optical system further comprising a radiation decomposer decomposing the measurement radiation field into portions of different frequencies to yield a decomposed measurement radiation field;
 - the interferometer further including a detector unit that comprises a two-dimensional array of detector cells for receiving the decomposed measurement radiation field;
 - wherein the optical system is configured to direct portions of the decomposed measurement radiation field that include radiation field portions from different places of the sample onto places of said detector unit which are distanced with respect to each other in a first direction;
 - and wherein the optical system is further configured to direct measurement radiation field portions of different frequencies that include radiation field portions from a same place of the sample onto places of said detector unit which are distanced with respect to each other in a second direction different from the first direction.
14. A system for optical coherence tomography, the system comprising
- a plurality of uncorrelated radiation sources;
 - an optical system configured to split radiation emitted by the radiation sources into a sample radiation field and a reference radiation field, to direct the sample radiation field on a sample, and to recombine radiation field

- 29 -

portions from the sample with radiation field portions of the reference radiation field to yield a measurement radiation field;

- and a detector unit including a two-dimensionally resolvable detection area arranged so as to receive the measurement field.

5 15. The system according to claim 14, wherein the optical system is configured to direct radiation fields originating from at least two of said plurality of radiation sources onto different places on the sample, and wherein the optical system is configured to direct measurement radiation field portions that include radiation field portions from different places of the sample onto different places of said
10 detector unit.

16. The system according to claim 14 or 15, wherein the optical system is configured to direct reference radiation field portions originating from at least two of said plurality of radiation sources along beam paths of different optical beam path lengths.

15 17. The system according to claim 16, wherein the optical system includes a reference beam mirror, and wherein said reference beam mirror is an echelon mirror.

18. The system according to claim 16 or 17, wherein the plurality of radiation sources are arranged in a one-dimensional array of radiation sources.

20 19. A Fourier domain optical coherence tomography system comprising

- 30 -

- a plurality of uncorrelated radiation sources;
- an optical system configured to split radiation emitted by the radiation sources into a sample radiation field and a reference radiation field, to direct the sample radiation field on a sample, and to recombine radiation field portions from the sample with radiation field portions of the reference radiation field to yield a measurement radiation field;
- wherein the optical system is configured to direct reference radiation field portions originating from at least two of said plurality of radiation sources along beam paths of different optical beam path lengths, and to direct sample radiation field portions originating from said at least two radiation sources onto neighboring locations on the sample;
- A radiation decomposer for decomposing the measurement radiation field into portions of different frequencies to yield a decomposed measurement radiation field;
- and detector unit including a two-dimensionally resolvable detection area arranged so as to receive the decomposed measurement field.

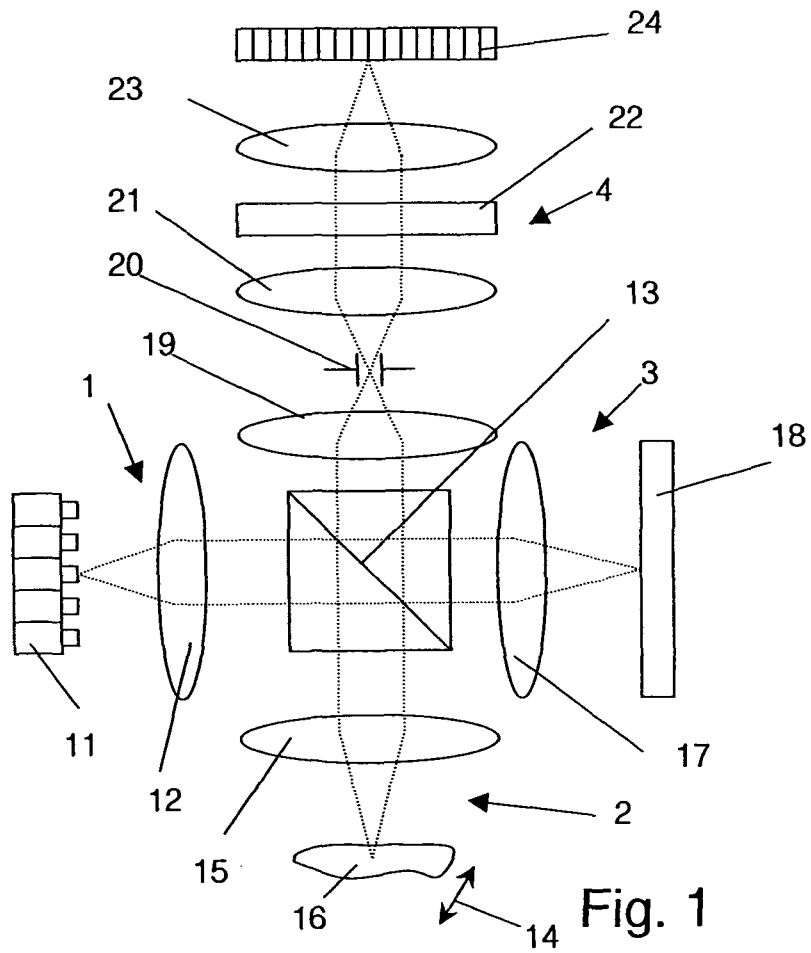


Fig. 1

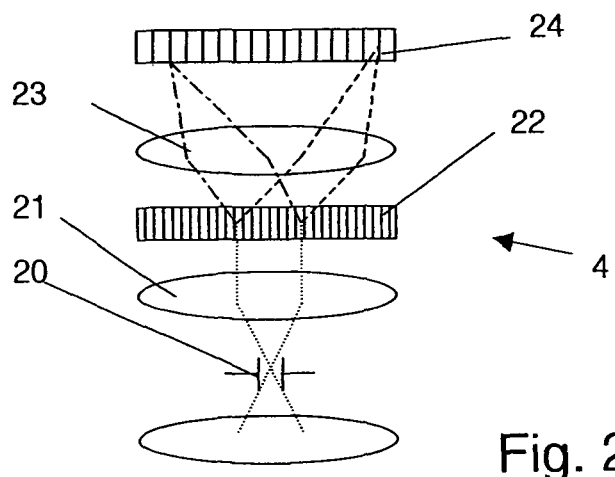


Fig. 2

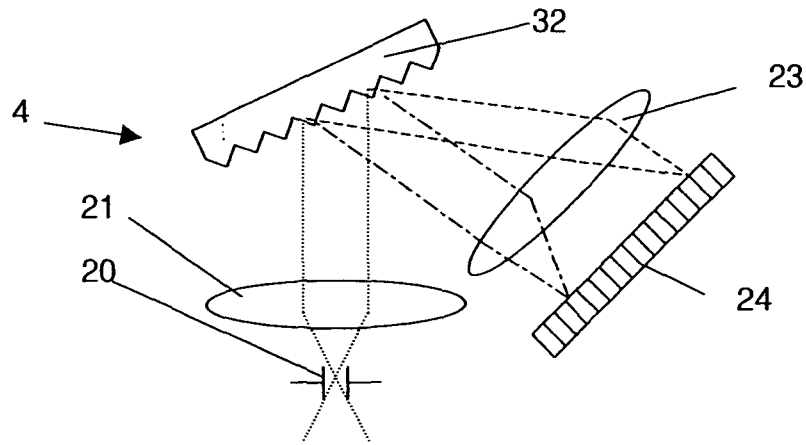


Fig. 3

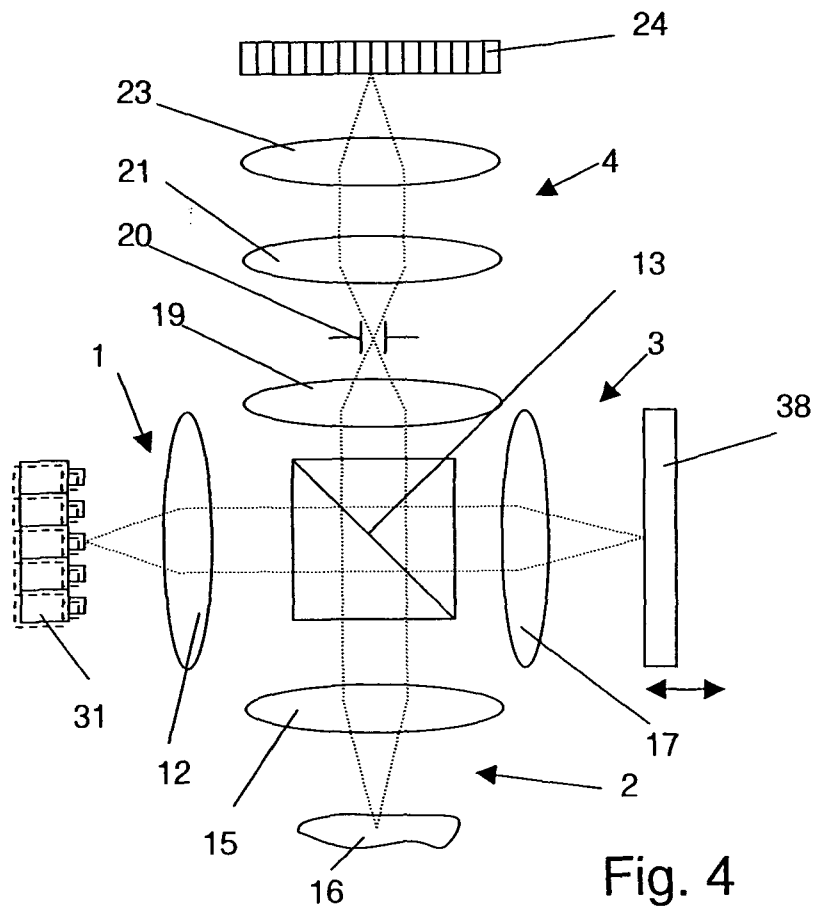


Fig. 4

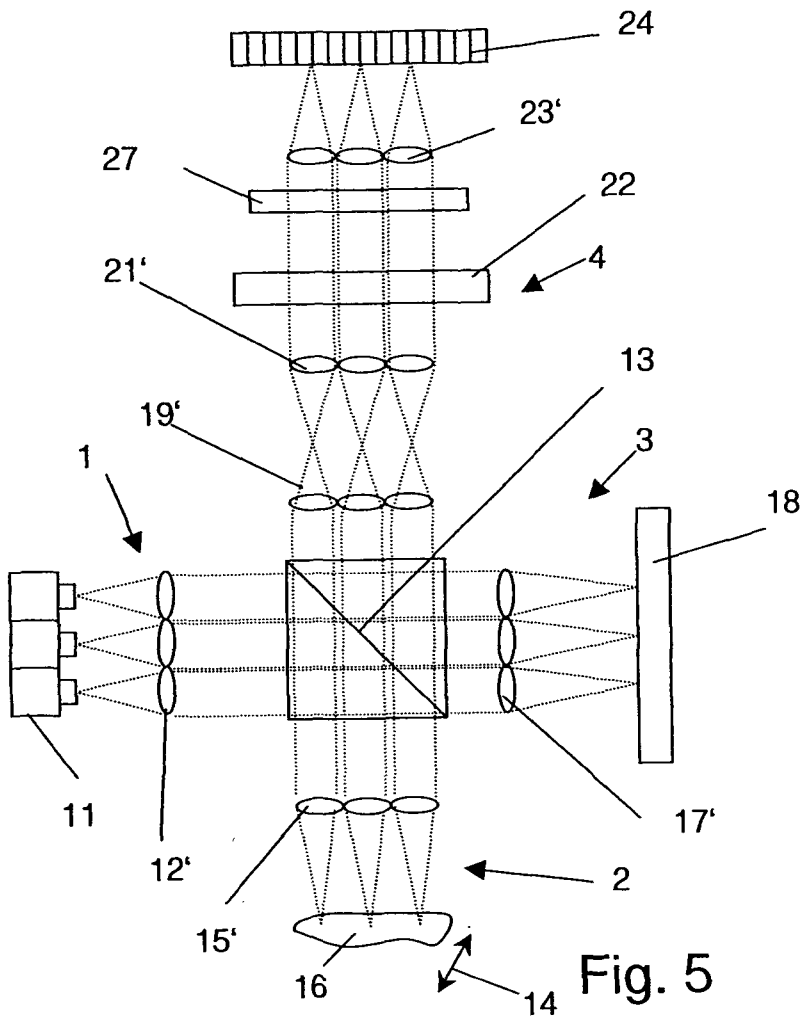


Fig. 5

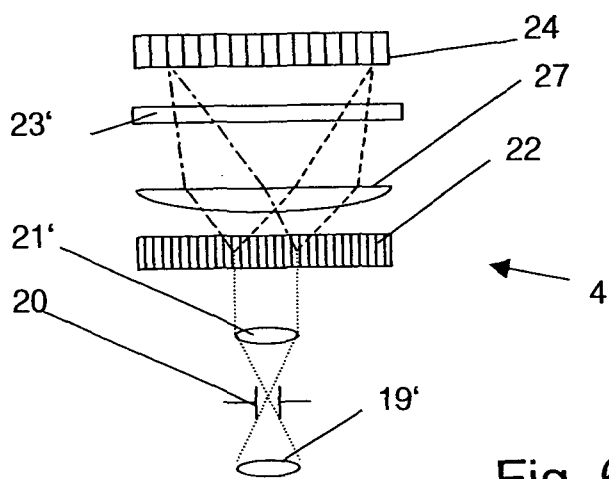


Fig. 6

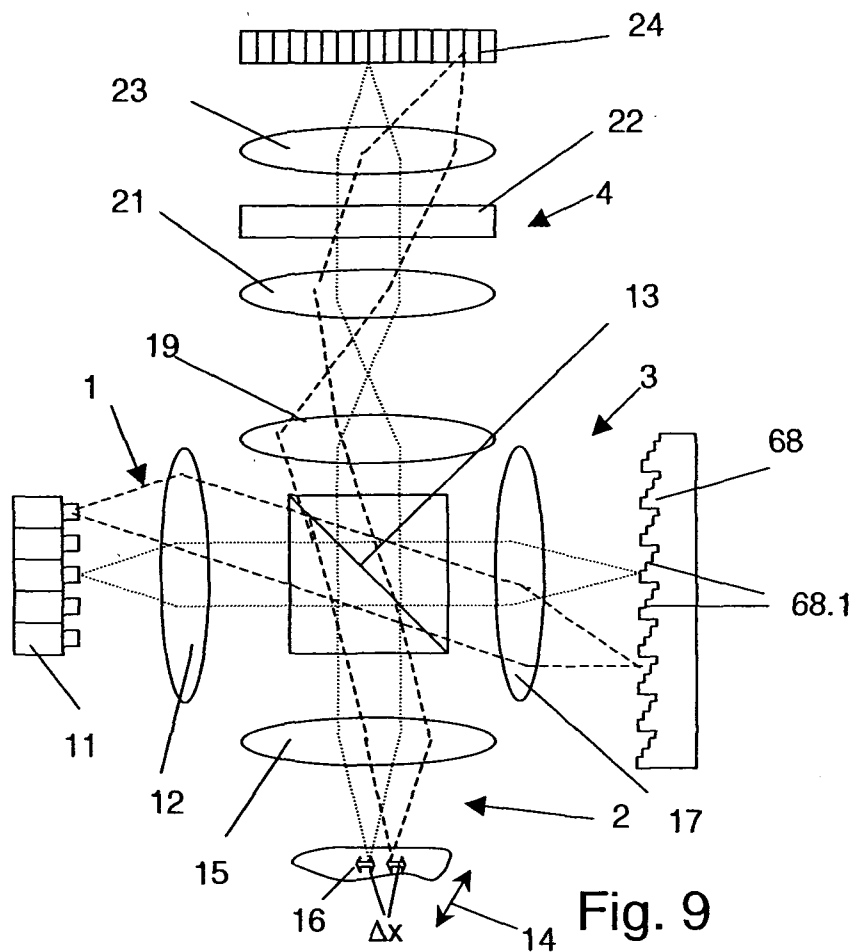


Fig. 9

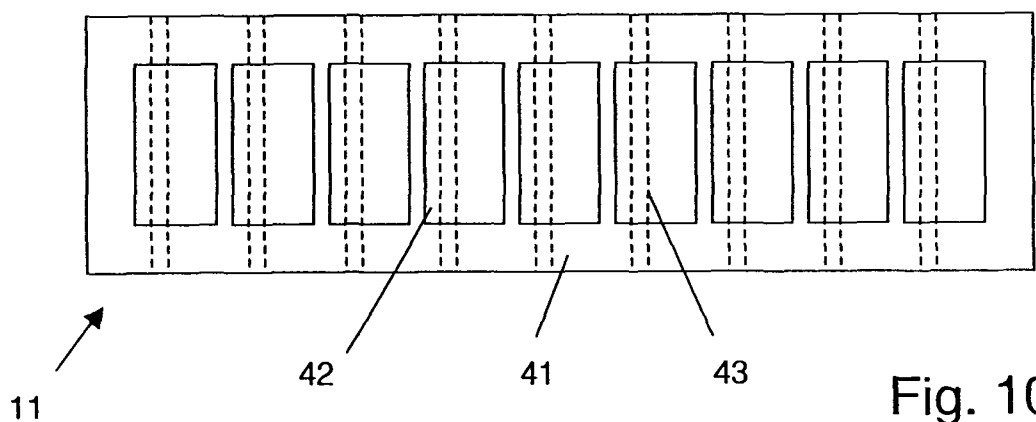


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/CH2008/000250

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B9/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01B

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, INSPEC, COMPENDEX

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2006/015717 A (ZEISS CARL MEDITEC AG [DE]; FERCHER ADOLF FRIEDRICH [AT]) 16 February 2006 (2006-02-16) page 7, line 1 - page 17, line 29 figures 1-9	1, 4-10, 12, 14-18
Y A	-----	11 2, 3
X	US 5 579 112 A (SUGIYAMA YUITI [JP] ET AL) 26 November 1996 (1996-11-26) column 12, line 27 - column 20, line 67 figures 1-6	1-5, 11, 14, 15
Y A	-----	11 6-10, 12, 16-18
Y	EP 0 498 541 A (HUGHES AIRCRAFT CO [US]) 12 August 1992 (1992-08-12) column 4, line 23 - column 6, line 12; figure 1	11

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :

<p>*A* document defining the general state of the art which is not considered to be of particular relevance</p> <p>*E* earlier document but published on or after the international filing date</p> <p>*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>*O* document referring to an oral disclosure, use, exhibition or other means</p> <p>*P* document published prior to the international filing date but later than the priority date claimed</p>	<p>*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>*&* document member of the same patent family</p>
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Date of the actual completion of the international search 12 August 2008	Date of mailing of the international search report 07/11/2008
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Kunz, Lukas
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CH2008/000250

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.
2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

see annex

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12,14-18

OCT where the interference pattern is not spectrally analysed in order to derive sample depth information.

2. claims: 13,19

FD-OCT where the interference pattern is spectrally analysed in order to derive sample depth information.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/CH2008/000250

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