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(54) Apparatus for OCT imaging with axial line focus for improved resolution and depth of field

OCT Einrichtung mit axialem Linienfokus für verbesserte Auflösung und Tiefenschärfe

Dispositif d'imagerie OCT avec une ligne focale axiale pour meilleure résolution et profondeur de champ

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- **SERGEI YU POPOV, ARI T. FRIBERG: "Apodization of generalized axicons to produce uniform axial line images", * IOPSCIENCE * LOGIN * CREATE ACCOUNT * ATHENS/ INSTITUTIONAL LOGINIOPSCIENCEPURE AND APPLIED OPTICS: JOURNAL OF THE EUROPEAN OPTICAL SOCIETY PART A, vol. 7, no. 3, May 1998 (1998-05), pages 537-548, XP002616303, DOI: 10.1088/0963-9659/7/3/014**
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Description

FIELD OF THE INVENTION

[0001] The present invention relates to apparatus for imaging tissue samples using optical coherence tomography and incorporating an optical element to improve transverse resolution and depth of focus.

BACKGROUND OF THE INVENTION

[0002] Currently, the use of optical coherence tomography (OCT) is limited to the visualization of architectural morphological structures within biological tissues. The imaging of sub-cellular features with OCT has not been well demonstrated because of the relatively poor transverse resolution required to preserve depth of focus. The capability to perform high transverse resolution, large depth of field cross-sectional OCT imaging would permit application to early diagnosis of epithelial cancers and other biomedical imaging diagnostics that require sub-cellular level resolution.

[0003] To date, there are no known optical coherence tomography configurations that can perform high transverse resolution imaging over a large depth of field. It would be desirable to have a simple device for performing high transverse resolution, large depth of field optical coherence tomography. In addition, by allowing light delivery through a single optical fiber, this device would be also be easily incorporated into catheters or endoscopes. These properties would make this device an enabling technology for performing optical coherence tomography in applications requiring sub-cellular resolution imaging at remote sites within biological systems.

[0004] F. Lexer et al, "Dynamic coherent focus for transversal resolution enhancement of OCT", Proceedings of the SPIE, vol. 3251, April 1998, p. 85-90, describes an optical design for OCT.

[0005] J.A. Izatt et al, "Optical Coherence Tomography and Microscopy in Gastrointestinal Tissues,", IEEE Journal of Selected Topics in Quantum Electronics, vol. 2 no. 4, December 1996, p. 1017-1028, describes techniques for non invasive biomedical imaging based on low-coherence interferometry.

[0006] S.Y. Popov and A.T. Friberg, "Apodization fo generalized axicons to produce uniform axial line images", Pure Appl. Opt. 7; describes a way to improve the trade-off between depth of focus and lateral resolution for three dimensional imaging applications by using apodization.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The invention is illustrated in the drawings in which like reference characters designate the same or similar parts throughout the figures of which:

Fig. 1 is a schematic view describing focusing using a refractive axicon. A collimated beam, incident from the left, is focused to an axial line with a narrow width and large depth.

Fig. 2 is a schematic view of an OCT system with axicon optic in sample arm.

Fig. 3 is a schematic view of the relationship between axial location and annulus of illumination.

Fig. 4A is a schematic view of the image formation.

Fig. 4B is a schematic view of the translation of the entire optical assembly in the y-direction. Part C of Fig. 4B is a schematic view of the rotation of the entire optical assembly. Part D of Fig. 4B is a schematic view of the angular deflection of the axial line focus in the x-y plane.

Fig. 5 is a schematic view of a system used to perform high transverse resolution ranging with a high depth of field.

Fig. 6 is a schematic view of an offset fiber array.

Fig. 7 is a schematic of a fiber array, microlens array and diffraction grating.

Fig. 8 is a schematic view of an embodiment of an apodized pupil plane filter.

Fig. 9 is a schematic view of the use of an apodizer in front of an imaging lens.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Definitions

[0008] "Axicon" shall mean any optic element (or combination thereof) capable of generating an axial line focus. Refractive, diffractive, and reflective axicons have been demonstrated. See, J.H. McLeod, J. Opt. Soc. Am 44, 592 (1954); J.H. McLeod, J. Opt Soc. Am 50, 166 (1960); and J.R. Rayces, J. Opt Soc. Am. 48, 576 (1958).

[0009] "Depth of focus" shall mean the longitudinal distance over which the beam diameter increases by a factor ζ (typically ζ = sqrt(2) or 2). For a Gaussian beam, the sqrt(2) depth of focus is

$$2z_R = \frac{2\pi\left(\frac{d}{2}\right)^2}{\lambda}.$$

[0010] For a typical Gaussian spot size ($1/e^2$ diameter) of d = 5 μm, and a wavelength of 830 nm, the depth of focus is approximately 48 μm. The depth of focus for a uniform beam (3 dB full-width-half-maximum intensity response for a planar reflector moved through the longitudinal plane) may be defined as

$$z_R \approx \frac{.9\lambda}{NA^2}.$$

[0011] For a NA = 0.2, which produces a spot size of 5 μm, the depth of focus for a uniform beam is approximately 17 μm at 830 nm.

[0012] "Longitudinal" shall mean substantially parallel to the optical axis.

[0013] "Longitudinal resolution" shall mean the minimum distance, Δz, in the longitudinal direction that two points may be separated while still being differentiated by an optical detection means.

[0014] "Spot size" shall mean the transverse diameter of a focused spot. For a Gaussian beam, the spot size is defined as transverse width of the spot where the intensity at the focus has decreased by a factor of $1/e^2$. For a collimated Gaussian beam, the spot size, d, is defined as

$$d = \frac{4\lambda f}{\pi D},$$

where *D* is the beam diameter at the lens, *f* is the focal length of the lens and λ is the wavelength. For a flat top or uniform beam, the spot radius is defined as the transverse position of the first zero of the Airy disk,

$$w = \frac{1.22\lambda}{NA},$$

where

$$NA = n\sin\left(\tan^{-1}\left(\frac{D}{2f}\right)\right),$$

and *n* is the refractive index of the immersion medium.

[0015] "Transverse" shall mean substantially perpendicular to the optical axis.

[0016] "Transverse resolution" shall mean the minimum distance, Δr, in the transverse direction that two points may be separated while still being differentiated by an optical detection means. One commonly used approximation is $\Delta r =$

d (for a Gaussian beam) or Δr = w (for a uniform beam).

Basic Principle

[0017] An axial line focus, with a narrow transverse beam diameter and over a large length (or depth of focus), is generated. Used in conjunction with OCT, the diameter of the line focus determines the transverse resolution and the length determines the depth of field. As in standard OCT, the detection of light backreflected from sites along the axial focus is performed using a Michelson interferometer. When the light source has a finite spectral width, this configuration can be used to determine the axial location of the backreflection site. The axial resolution is determined by the coherence length of the light source.

[0018] Those of ordinary skill in the art will appreciate that there are a variety of known devices for generating a line focus. An axicon (reflective, transmissive, or diffractive optical element ("DOE")) is an acceptable model known to those skilled in the art for this and will be the method that is used in the present invention to demonstrate use of OCT with an axial line focus to achieve high resolution imaging over large depths of field. It is to be understood that this method is illustrative and not intended to be the exclusive model. Other known models include, but are not limited to, multi-focal lenses, such as the Rayleigh-Wood lens (Optical Processing and Computing, H.H Arsenault, T. Szoplik, and B. Macukow eds., Academic Press Inc., San Diego, CA, 1989), the use of chromatic aberration to produce an array of wavelength dependent foci along the longitudinal axis, and the like.

Resolution

[0019] The following section discusses the physical principles of a representative axicon that uses refraction, as shown in Fig. 1. The intensity distribution of light transmitted through a refractive axicon lens (see R. Arimoto, C. Saloma, T. Tanaka, and S. Kawata, Appl. Opt. 31, 6653 (1992)) is given by Equation (1):

$$I(r,z)=\frac{4\pi^2E^2(R)}{\lambda}\frac{RSin(\beta)}{Cos^2(\beta)}J_0^2\left(\frac{2\pi rSin(\beta)}{\lambda}\right), \tag{1}$$

where $E^2(R)$ is the intensity of the light incident on the axicon as a function of the radius R, λ is the wavelength of the light, and β is the half angle of the light transmitted through the axicon. The cone angle α is related to β and the depth of focus, z_D, by Equations (2a) and (2b):

$$nSin(\alpha)=Sin(\alpha+\beta), \tag{2a}$$

$$z_D=R(Cot(\beta)-Tan(\alpha)), \tag{2b}$$

where n is the refractive index of the axicon. The above equations can be used to determine the diameter of the axial line focus. For plane wave illumination the focus diameter is given by Equation (3):

$$d_0=0.766\frac{\lambda}{\beta}. \tag{3}$$

[0020] In the case of reflective or diffractive axicons, Equation (1) is modified, but in all cases it is the diameter of the axial focus that determines the transverse resolution of the imaging system. A theme of the present invention is that the poor transverse resolution typical of current OCT systems can be improved by changing from a standard focusing geometry in which the focal volume (power distribution) is limited in both the transverse and the axial dimensions to one in which the focal volume is limited only in the transverse direction.

[0021] By combining the high transverse localization (and weak axial localization) of an axicon with OCT (see Fig. 2), an imaging system that provides high three-dimensional localization over large field sizes can be realized. Axial resolution for this imaging technique is determined solely by the coherence length of the light source (E.A. Swanson, D. Huang, M.R. Hee, J.G. Fujimoto, C.P. Lin, and C.A. Puliafito, Opt Lett. 17, 151 (1992)) and is given by Equation (4):

$$\Delta z = \frac{2Ln(2)}{\pi}\frac{\lambda^2}{\Delta\lambda}, \qquad (4)$$

where As is the spectral width (full-width half maximum ("FWHM"))of the light source.

[0022] In a preferred embodiment, the optical element has a transverse resolution defined as $\Delta r = d_0$ being less than or equal to about 5μm. The optical element has a $\Delta z = z_D$ of at least 50μm.

Image Formation.

[0023] Fig. 4A illustrates the entire OCT/axicon system of one embodiment of the present invention. All components, other than the axicon probe, are standard to OCT. The use of OCT to determine the backreflection as a function of distance along the axial line focus provides a one dimensional raster scan. This is typically accomplished by scanning the length of the interferometer reference arm. An axicon has the property each axial location of the focus corresponds to a unique annulus at the input aperture of the axicon (see Fig. 3). This relationship could allow the reference arm length scanning to be replaced by scanning an annulus of illumination at the axicon aperture.

[0024] Regardless of how the axial dimension is scanned, to obtain an image a scan of another axis must be performed. This second scanning dimension is usually performed at a slower rate. Methods of accomplishing this slow scanning of the secondary axis include moving the sample arm optics, including the optical fiber, collimating lens and axicon in the y direction (see Fig. 4B), rotating the entire probe around the optical fiber axis (see part C of Fig. 4B) or angularly deflecting the line focus in the x-y plane (see part D of Fig. 4B). See, (G.J. Tearney, S.A. Boppart, B.E. Bouma, M.E. Brezinski, N.J. Weissman, J.F. Southern, and J.G. Fujimoto, Opt. Lett. 21, 543 (1996)) and (S.A. Boppart, B.E. Bouma, C. Pitris, GJ. Tearney, J.G. Fujimoto, and M.E. Brezinski, Opt Lett. 22, 1618 (1997)). Both linear motion along the y or z axis and rotation are easily accomplished in a compact probe by use of piezoelectric transducers or mechanical or pneumatic actuators.

[0025] Fig. 5 is a schematic of an alternative apparatus used to perform high transverse resolution ranging with a high depth of field. The system comprises a light source, beam redirecting element, detector, and an optical element The optical element provides line focus and an array of focused spots on the sample.

[0026] Fig. 6 shows an offset fiber array are directed by the mirror through the objective and used to displace focused (imaged) spots in the longitudinal and transverse dimensions on the sample. The spots are scanned (scan direction being indicated by the horizontal line and arrows) to create a multidimensional image.

[0027] Fig. 7 is a schematic of a fiber array, microlens array and diffraction grating (array of mirrors) used to displace focused (imaged) spots in the longitudinal and transverse dimensions on the sample. Light from the light source (not shown) passes through the fibers in the array, and through the microlens array to the diffraction grating. Light directed by the grating passes through the objective lens and focused on the sample. The spots are scanned (scan direction being indicated by the horizontal line and arrows) to create a multidimensional image.

[0028] An alternative means for providing a high transverse resolution over a large depth of focus is the use of a filter in the back plane of the imaging lens. This technique, commonly termed apodization, allows the production of either a line focus as in the axicon or a multitude of focused spots positioned along the longitudinal dimension. The use of annular apodization to shape a beam focus has been previously described in the literature (M. Martinez-Corral, P. Andres, J. Ojeda-Castaneda, G. Saavedra, Opt. Comm. 119, 491 (1995)). However, use of apodization to create high transverse resolution over a large focal distance, where the longitudinal data is further resolved by OCT has not been previously described.

[0029] Fig. 8 shows an embodiment of an apodized pupil plane filter.

[0030] Fig. 9 shows a schematic of the use of an apodizer in front of an imaging lens the output of which is focused in the axial line.

METHOD OF IMAGING

[0031] The present invention also provides a method of obtaining a high resolution and high depth of focus image of a sample, the method being defined by claim 10.

[0032] An advantage of the present invention is that the OCT imaging apparatus is capable of enabling sub-cellular resolution imaging along transverse and longitudinal dimensions of the sample in a compact, optical fiber-based package. Other advantages include the potential compact size and low cost of axial line focus optical elements such as the apodizer-lens combination or axicon.

[0033] Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims.

Claims

1. An OCT apparatus for imaging at least a portion of a sample, comprising:

a first interferometric arrangement configured to provide an electro-magnetic radiation; and
a second arrangement configured to receive the electro-magnetic radiation, and configured to generate a resultant electro-magnetic intensity distribution,
wherein the second arrangement comprises an optical element having a configuration to provide

i) a transverse resolution of the resultant electro-magnetic intensity distribution that is less than or equal to 5 μm, and
ii) a depth of focus of at least 50 μm;

wherein the optical element is configured to generate the resultant electro-magnetic intensity distribution as at least one of (i) an axial line focus, or (ii) a multitude of focused spots along a longitudinal dimension parallel to the optical axis.

2. The apparatus according to claim 1, wherein the intensity distribution is approximately constant for at least 50μm within the axial line focus along the longitudinal dimension, and
wherein a wavelength of the electro-magnetic radiation remains approximately the same for at least the predetermined distance at which the intensity distribution is approximately constant.

3. The apparatus according to any one of claims 1 to 2, wherein the second arrangement is one of an optical arrangement which is configured to optically image the sample, an axicon lens, a defractive optical element, or includes a combination of a diffractive element and a lens, or includes a plurality of lenses.

4. The apparatus according to any one of claims 1 to 2, wherein the intensity distribution is a Bessel beam.

5. The apparatus according to any one of claims 1 to 2, further comprising a third arrangement configured to cooperate with the second arrangement so as to translate at least one of the intensity distribution and the sample relative to the other.

6. The apparatus according to claim 5, wherein the translation of the at least one of the intensity distribution and the sample produces an image which has two or more dimensions.

7. The apparatus according to any one of the preceding claims, wherein at least a portion of the intensity distribution includes a non-Gaussian distribution.

8. The apparatus according to any one of the preceding claims, further comprising a fourth arrangement configured to receive information that is associated with the intensity distribution, and display an OCT image based on the received information.

9. The apparatus according to claim 2, wherein the apparatus is configured such that resultant electro-magnetic intensity distribution is constant in the longitudinal dimension within the sample.

10. An OCT method for imaging at least a portion of a sample, comprising:

a) providing an electro-magnetic radiation using a first interferometric arrangement;
b) receiving the electro-magnetic radiation and generating a resultant electro-magnetic intensity distribution at a second arrangement wherein the second arrangement comprises an optical element having a configuration that provides

i) a transverse resolution of the resultant electro-magnetic intensity distribution that is less than or equal to

5 μm, and
ii) a depth of focus of at least 50 μm; and

wherein the optical element generates the resultant electro-magnetic intensity distribution as at least one of: (i) an axial line focus; or (ii) a multitude of focused spots along a longitudinal direction parallel to the optical axis.

Patentansprüche

1. OCT-Vorrichtung zum Abbilden wenigstens eines Abschnitts einer Probe, die Folgendes umfasst:

   eine erste interferometrische Anordnung, die konfiguriert ist, eine elektromagnetische Strahlung bereitzustellen; und
   eine zweite Anordnung, die konfiguriert ist, die elektromagnetische Strahlung zu empfangen, und konfiguriert ist, eine resultierende elektromagnetische Intensitätsverteilung zu erzeugen,
   wobei die zweite Anordnung ein optisches Element umfasst, das eine Konfiguration aufweist, um Folgendes bereitzustellen:

   i) eine Querauflösung der resultierenden elektromagnetischen Intensitätsverteilung, die kleiner oder gleich 5 μm ist, und
   ii) eine Schärfentiefe von wenigstens 50 μm;

   wobei das optische Element konfiguriert ist, die resultierende elektromagnetische Intensitätsverteilung als wenigstens eines aus (i) einem axialen Strichfokus oder (ii) mehreren fokussierten Lichtflecken entlang einer Längsausdehnung parallel zu der optischen Achse zu erzeugen.

2. Vorrichtung nach Anspruch 1, wobei die Intensitätsverteilung für wenigstens 50 μm innerhalb des axialen Strichfokus entlang der Längsausdehnung ungefähr konstant ist, und
   wobei eine Wellenlänge der elektromagnetischen Strahlung für wenigstens den vorbestimmten Abstand, an dem die Intensitätsverteilung ungefähr konstant ist, ungefähr gleich bleibt.

3. Vorrichtung nach einem der Ansprüche 1 bis 2, wobei die zweite Anordnung eine optische Anordnung, die konfiguriert ist, die Probe optisch abzubilden, oder eine Axicon-Linse oder ein brechendes optisches Element ist oder eine Kombination eines beugenden Elements und einer Linse enthält oder mehrere Linsen enthält.

4. Vorrichtung nach einem der Ansprüche 1 bis 2, wobei die Intensitätsverteilung ein Bessel-Strahl ist.

5. Vorrichtung nach einem der Ansprüche 1 bis 2, die ferner eine dritte Anordnung enthält, die konfiguriert ist, mit der zweiten Anordnung zusammenzuwirken, um die Intensitätsverteilung und/oder die Probe relativ zueinander zu verschieben.

6. Vorrichtung nach Anspruch 5, wobei die Verschiebung der Intensitätsverteilung und/oder der Probe ein Bild erzeugt, das zwei oder mehr Dimensionen aufweist.

7. Vorrichtung nach einem der vorhergehenden Ansprüche, wobei wenigstens ein Abschnitt der Intensitätsverteilung eine Nicht-Gauss-Verteilung enthält.

8. Vorrichtung nach einem der vorhergehenden Ansprüche, die ferner eine vierte Anordnung umfasst, die konfiguriert ist, Informationen zu empfangen, die der Intensitätsverteilung zugeordnet sind, und basierend auf den empfangenen Informationen ein OCT-Bild anzuzeigen.

9. Vorrichtung nach Anspruch 2, wobei die Vorrichtung so konfiguriert ist, dass die resultierende elektromagnetische Intensitätsverteilung in der longitudinalen Ausdehnung innerhalb der Probe konstant ist.

10. OCT-Verfahren zum Abbilden wenigstens eines Abschnitts einer Probe, das Folgendes umfasst:

    a) Bereitstellen einer elektromagnetischen Strahlung unter Verwendung einer ersten interferometrischen Anordnung;

b) Empfangen der elektromagnetischen Strahlung und Erzeugen einer resultierenden elektromagnetischen Intensitätsverteilung an einer zweiten Anordnung, wobei die zweite Anordnung ein optisches Element umfasst, das eine Konfiguration aufweist, die Folgendes bereitstellt:

i) eine Querauflösung der resultierenden elektromagnetischen Intensitätsverteilung, die kleiner oder gleich 5 μm ist, und
ii) eine Schärfentiefe von wenigstens 50 μm; und

wobei das optische Element die resultierende elektromagnetische Intensitätsverteilung als wenigstens eines des Folgenden erzeugt: (i) einen axialen Strichfokus; oder (ii) mehrere fokussierte Lichtflecke entlang einer Längsrichtung parallel zu der optischen Achse.

Revendications

1. Appareil OCT pour imager au moins une partie d'un échantillon, comprenant :

un premier dispositif interférométrique configuré pour émettre un rayonnement électromagnétique ; et
un deuxième dispositif configuré pour recevoir le rayonnement électromagnétique, et configuré pour générer une distribution d'intensité électromagnétique résultante,
dans lequel le deuxième dispositif comprend un élément optique ayant une configuration permettant d'apporter

i) une résolution transversale de la distribution d'intensité électromagnétique résultante qui est inférieure ou égale à 5 μm, et
ii) une profondeur de champ d'au moins 50 μm ;

dans lequel l'élément optique est configuré pour générer la distribution d'intensité électromagnétique résultante comme (i) un foyer linéaire axial, et/ou (ii) une multitude de points focalisés le long d'une dimension longitudinale parallèle à l'axe optique.

2. Appareil selon la revendication 1, dans lequel la distribution d'intensité est approximativement constante sur au moins 50 μm à l'intérieur du foyer linéaire axial le long de la dimension longitudinale, et
dans lequel la longueur d'onde du rayonnement électromagnétique reste approximativement la même au moins sur la distance prédéterminée sur laquelle la distribution d'intensité est approximativement constante.

3. Appareil selon l'une quelconque des revendications 1 à 2, dans lequel le deuxième dispositif est un dispositif optique qui est configuré pour imager optiquement l'échantillon, ou une lentille axicon, ou un élément optique diffractif, ou comporte une combinaison d'un élément diffractif et d'une lentille, ou comporte une pluralité de lentilles.

4. Appareil selon l'une quelconque des revendications 1 à 2, dans lequel la distribution d'intensité est un faisceau de Bessel.

5. Appareil selon l'une quelconque des revendications 1 à 2, comprenant en outre un troisième dispositif configuré pour coopérer avec le deuxième dispositif de manière à translater la distribution d'intensité et/ou l'échantillon l'un par rapport à l'autre.

6. Appareil selon la revendication 5, dans lequel la translation de la distribution d'intensité et/ou de l'échantillon produit une image qui a au moins deux dimensions.

7. Appareil selon l'une quelconque des revendications précédentes, dans lequel au moins une partie de la distribution d'intensité comporte une distribution non gaussienne.

8. Appareil selon l'une quelconque des revendications précédentes, comprenant en outre un quatrième dispositif configuré pour recevoir des informations qui sont associées à la distribution d'intensité, et afficher une image OCT basée sur les informations reçues.

9. Appareil selon la revendication 2, dans lequel l'appareil est configuré de telle sorte que la distribution d'intensité électromagnétique soit constante dans la dimension longitudinale à l'intérieur de l'échantillon.

10. Procédé OCT pour imager au moins une partie d'un échantillon, comprenant :

a) l'émission d'un rayonnement électromagnétique à l'aide d'un premier dispositif interférométrique ;
b) la réception du rayonnement électromagnétique et la production d'une distribution d'intensité électromagnétique résultante au niveau d'un deuxième dispositif, le deuxième dispositif comprenant un élément optique ayant une configuration qui apporte

i) une résolution transversale de la distribution d'intensité électromagnétique résultante qui est inférieure ou égale à 5 μm, et
ii) une profondeur de champ d'au moins 50 μm ; et

dans lequel l'élément optique génère la distribution d'intensité électromagnétique résultante comme : (i) un foyer linéaire axial ; et/ou (ii) une multitude de points focalisés le long d'une direction longitudinale parallèle à l'axe optique.

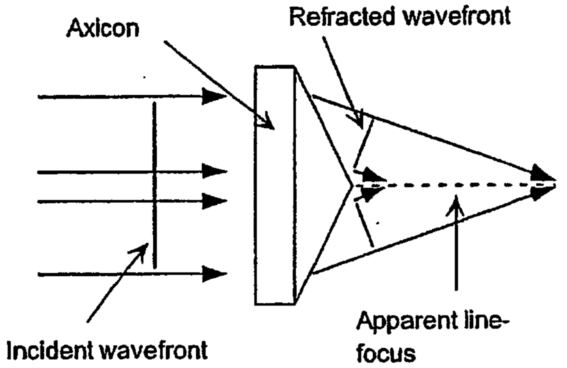
Axicon
Refracted wavefront
Incident wavefront
Apparent line-focus

FIG. 1

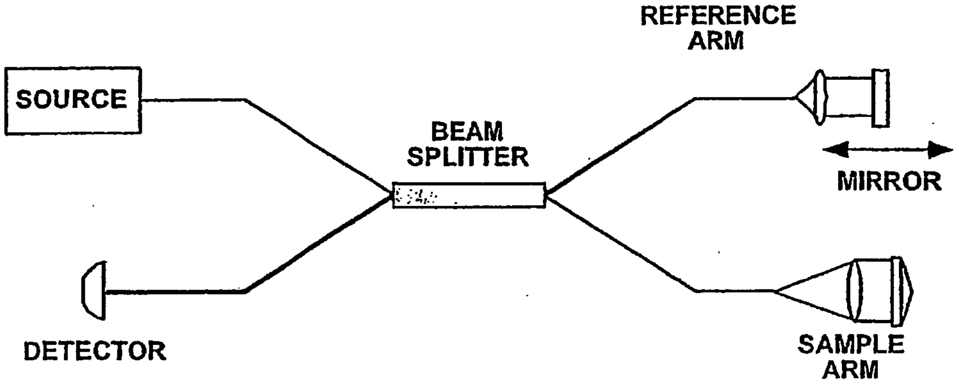
REFERENCE ARM
SOURCE
BEAM SPLITTER
MIRROR
DETECTOR
SAMPLE ARM

FIG. 2

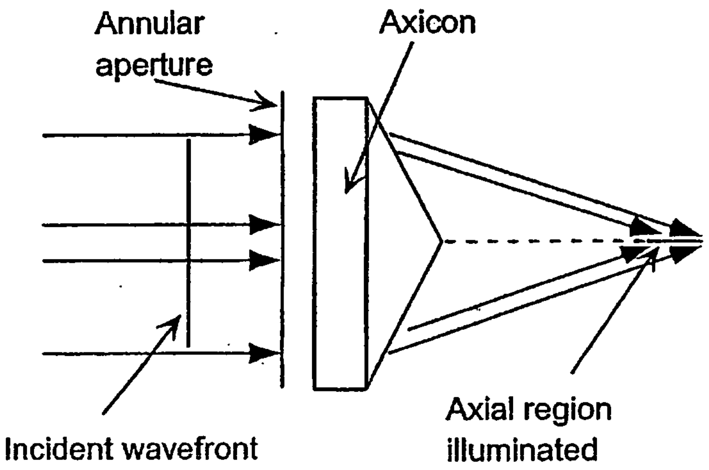
Annular aperture
Axicon
Incident wavefront
Axial region illuminated

FIG. 3

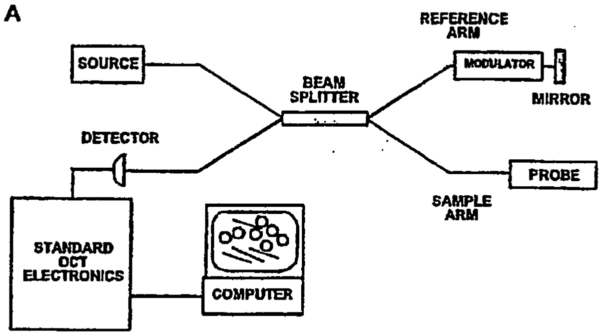
A
REFERENCE ARM
SOURCE
MODULATOR
MIRROR
BEAM SPLITTER
DETECTOR
PROBE
SAMPLE ARM
STANDARD OCT ELECTRONICS
COMPUTER

FIG. 4A

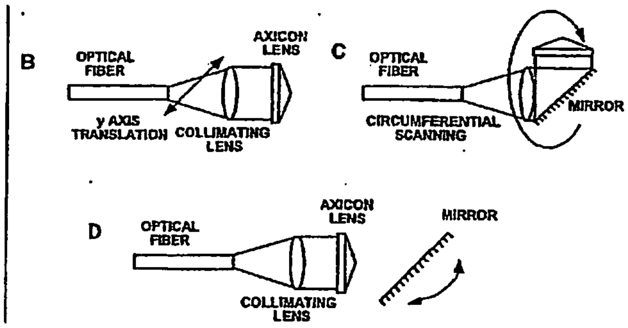
B
OPTICAL FIBER
AXICON LENS
y AXIS TRANSLATION
COLLIMATING LENS
C
OPTICAL FIBER
MIRROR
CIRCUMFERENTIAL SCANNING
D
OPTICAL FIBER
AXICON LENS
MIRROR
COLLIMATING LENS

FIG. 4B

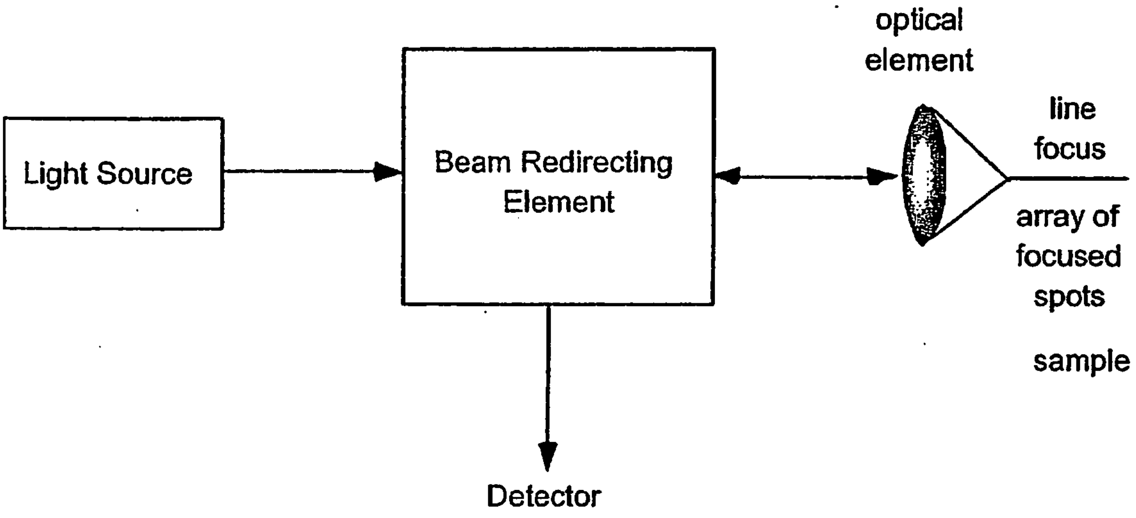
Light Source
Beam Redirecting Element
optical element
line focus
array of focused spots
sample
Detector

FIG. 5

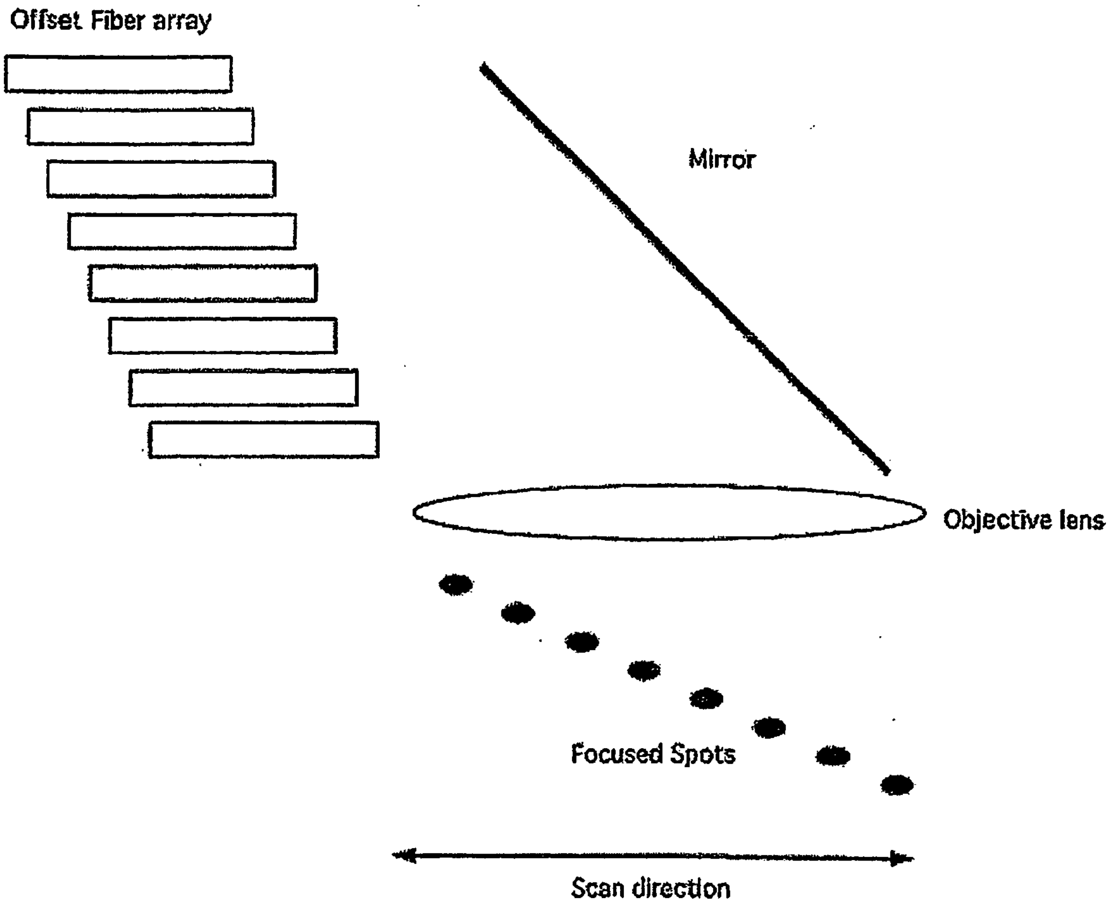
Offset Fiber array
Mirror
Objective lens
Focused Spots
Scan direction

FIG. 6

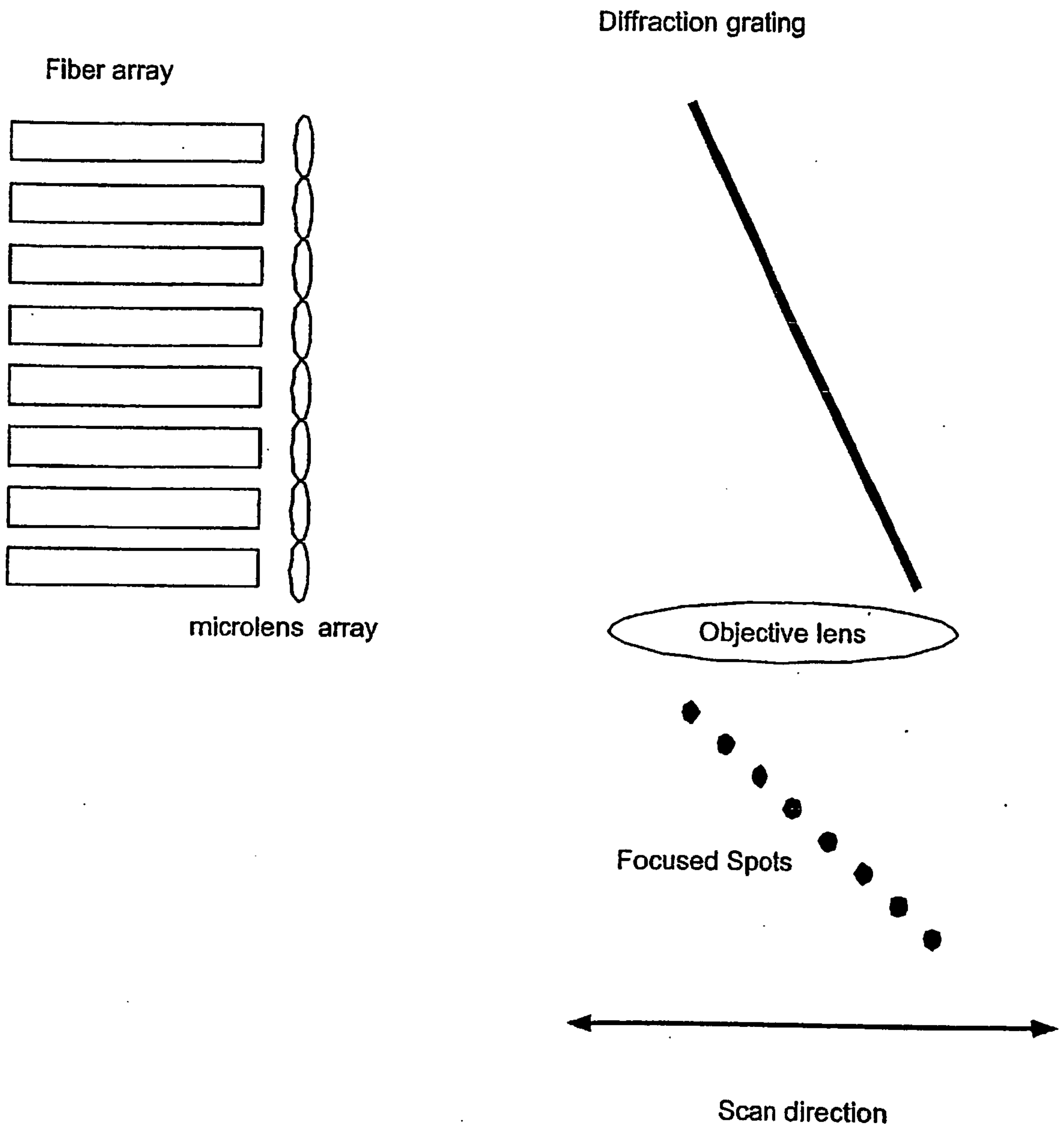
Diffraction grating
Fiber array
microlens array
Objective lens
Focused Spots
Scan direction

FIG. 7

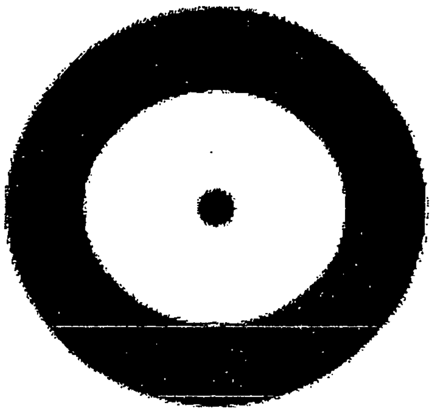

FIG. 8

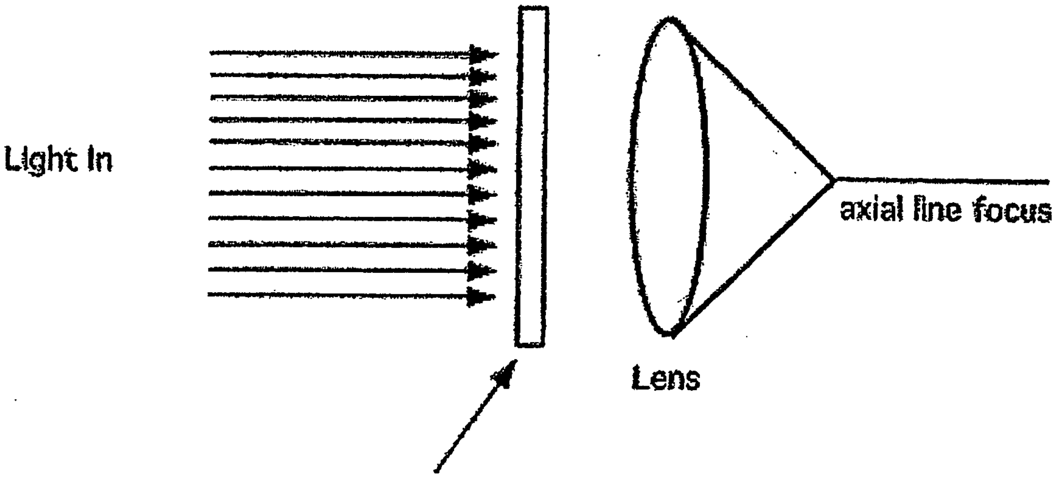

FIG. 9

REFERENCES CITED IN THE DESCRIPTION

Non-patent literature cited in the description

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专利名称(译)	用于具有轴线聚焦的OCT成像的装置，用于改善分辨率和景深		
公开(公告)号	EP2290318B1	公开(公告)日	2015-08-26
申请号	EP2010181734	申请日	2003-01-10
[标]申请(专利权)人(译)	通用医疗公司		
申请(专利权)人(译)	总医院CORPORATION		
当前申请(专利权)人(译)	总医院CORPORATION		
[标]发明人	TEARNEY GUILLERMO BOUMA BRETT		
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代理机构(译)	ðYOUNG & CO LLP		
优先权	60/347528 2002-01-11 US		
其他公开文献	EP2290318A1		
外部链接	Espacenet		

摘要(译)

一种用于执行具有高横向分辨率和大焦深的样本的低相干测距的装置，包括光学测距系统，该光学测距系统包括光源，用于将光从光源引导到样本的装置，用于引导来自光源的反射光的装置样品品到检测器，至少一个检测器，用于处理由检测器接收的光数据并产生图像的装置和具有被定义为DELTAris小于或等于约5μm的横向分辨率的光学元件，以及焦深DELTAz至少约50 microm。

$$2z_R = \frac{2\pi\left(\frac{d}{2}\right)^2}{\lambda}.$$