



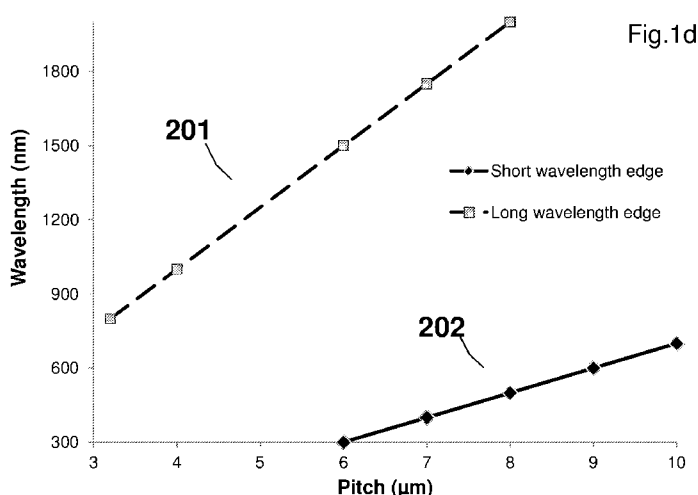
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(54) **Title:** A DELIVERY FIBER ASSEMBLY AND A BROAD BAND SOURCE

(57) **Abstract:** The invention comprises a delivery fiber assembly suitable for delivering broad band light and comprising a delivery fiber and a connector member. The delivery fiber has a length, an input end for launching light and a delivery end for delivering light. The delivery fiber comprises along its length a core region and a cladding region surrounding the core region wherein the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index up to N_{inc} and extending in the length of the longitudinal axis of the delivery fiber, wherein $N_{inc} < N_{bg}$. The plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region. The connector member is mounted to the delivery fiber at a delivery end section of the delivery fiber comprising the delivery end. The delivery fiber has a transmission bandwidth of about 200 nm or more.



A DELIVERY FIBER ASSEMBLY AND A BROAD BAND SOURCE

TECHNICAL FIELD

The invention relates to a delivery fiber suitable for delivering light from as broad band source as well as a broad band source system, and an apparatus
5 comprising such broad band source.

BACKGROUND ART

Broad band sources and systems are well known in the art and are for example described in EP2081 074, WO15003714 and WO15003715.

WO15003714 discloses a supercontinuum light source comprising a
10 microstructured optical fiber and a pump light source, where the microstructured optical fiber comprises an intermediate tapered section. Thereby a very broad and stable supercontinuum of light is obtained.

US 8,731,009 discloses a super continuum light source comprising a pump source and a generator fiber for generating the supercontinuum, where the
15 refractive index profile of the core of the generator fiber is arranged to allow modal cleaning of the light as it propagates to provide an optical super continuum with relatively high spectral density and/or good beam quality.

In general most of the prior art broad band sources are focused on generating supercontinuum light of high quality and/or which is spanning over
20 increasingly broader band width, e.g. supercontinuum which is spanning further into the blue wavelength e.g. below 450 nm or even lower.

The generated light or fractions thereof are often used in high precision illumination procedures and/or high precision measuring procedures such as for stimulated emission depletion, for fluorescence imaging procedures for
25 Optical Coherence Tomography (OCT) and/or for industrial inspection, such as metrology.

Usually the light or fractions of light generated by the broad band source is transmitted via a delivery fiber to an apparatus, such as an illumination apparatus and/or a measuring apparatus for use in the measuring process of the apparatus. Generally it is desired that the delivery fiber is simple to
5 connect to the apparatus and it is well known in the art to use standard connectors such as connectors according to the standards IEC 61754-20, IEC 61754-15 or IEC 61754-13.

The prior art delivery fibers have usually been step index fibers having a relatively very narrow transmission band with because such fibers are easy to
10 handle, easy to connectorize and have low transmission loss. In order to be capable of transmitting a broader band width it has been suggested to use of photonic crystal fiber (PCF) with air holes in their cross-sections as delivery fiber has been introduced; thereby the delivery fiber is capable of transmitting a broader band width. However, such holey PCF generally is difficult to
15 connect and may result in undesired power loss.

DESCRIPTION OF THE INVENTION

An object of the present invention is to provide a delivery fiber assembly suitable for delivering broad band light from a broad band source and/or from two or more sources as well as a broad band source system where the
20 delivery fiber is simple to connect to an apparatus for transmitting light to the apparatus and where at least one of the problems discussed above is alleviated.

It is further an object to provide a broad band source and a broad band source system comprising a delivery fiber which is simple to connect e.g. to
25 an apparatus for transmitting light to the apparatus and where at least one of the problems discussed above is alleviated.

In an embodiment it is an object to deliver light by the delivery fiber from two or more light sources having different wavelength(s).

These and other objects have been solved by the invention or embodiments thereof as defined in the claims and as described herein below.

It has been found that the invention or embodiments thereof have a number of additional advantages which will be clear to the skilled person from the
5 following description.

According to the invention it has been found that by providing a new type of delivery fiber for delivering broad band light or selected portions of broad band light comprising wavelengths e.g. discrete wavelengths within a broad range. The delivery fiber can be connectorized in a relatively simple and
10 effective way and with a very low loss. Simultaneously it has been found that the novel delivery fiber assembly has a relatively high mechanical strength, which in fact is highly beneficial because such delivery fibers usually are subjected to mechanical disturbances such as bends and rough handling. Often the delivery is coiled and uncoiled repeatedly and with no control of
15 coiling diameter.

In an embodiment of the delivery fiber assembly of the invention it is adapted for delivering broad band light to an apparatus for transmitting light to the apparatus. The delivery fiber assembly comprises a delivery fiber and a connector member. The delivery fiber has a length, an input end for
20 launching light and a delivery end for delivering light. The delivery fiber comprises along its length a core region and a cladding region surrounding the core region wherein the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index of up to N_{inc} and
25 extending in the length of and preferably along the longitudinal axis of the delivery fiber, wherein $N_{inc} < N_{bg}$. The plurality of inclusions in the cladding region is arranged in a cross-sectional pattern (a pattern seen in a cross section of the delivery fiber) comprising at least two rings of inclusions surrounding the core region. The connector member is mounted to the

delivery fiber at a delivery end section of the delivery fiber comprising the delivery end. Further, the delivery fiber has a transmission bandwidth of about 200 nm or more, such as of about 300 nm or more, such as of about 400 nm or more, such as of about 500 nm or more for example at least an
5 octave (halving/doubling in frequency).
Generally it is desired that the core region has a diameter up to about 15 μm

In an embodiment the transmission bandwidth is defined as the wavelengths where the delivery fiber has a transmission loss of less than 0.5 dB/m. In an
10 embodiment the transmission bandwidth is defined as the wavelengths where the delivery fiber has a transmission loss of less than 0.1 dB/m.
Advantageously the transmission loss is measured when the fiber is bend with either a 16 cm or a 32 cm bending diameter.

15 Heretofore it has never been considered to use an all solid fiber comprising solid inclusions as delivery fiber for delivering light from a broad band source to an apparatus for measurement and/or illumination. In particular it has never been considered that such all solid fiber comprising solid inclusions could be constructed to have a transmission bandwidth of 200 nm or larger
20 and in particular it is surprising that the all solid fiber comprising solid inclusions can be constructed to have a transmission bandwidth of 200 nm or less, below 1800 nm or even below 900 nm.

The term "inclusions" means inclusions in a background material, wherein an inclusion has another refractive index than that of the background material
25 surrounding it. The solid inclusions can for example be inclusions of another glass type than the background material and/or an inclusion of doped material (index changing materials such as F, Ge, P, B,) a vacuum inclusion or any combinations thereof. The inclusions of a delivery fiber can be of equal or different material or structure. An inclusion may be of a homogeneous
30 material or it may have regions of different materials and/or refractive index. Where an inclusion comprises several regions of different refractive index the

refractive index of the inclusion is determined as the average refractive index of the inclusion.

In the context of the present application, the phrase "ring of inclusions" refers to the cladding inclusions typically having substantially equal radial distance to the core and being aligned in a ring configuration surrounding the core.

Typically, a ring of inclusions is not fully circular, but rather is shaped with a number of soft angles, such as in a hexagonal shape. Preferably all the inclusions of a ring of inclusions are of substantially the same size and preferably of same material.

The phrase "radial distance" means distance determined in radial direction from the longitudinal axis of the core of the delivery fiber.

The term "substantially" should herein be taken to mean that ordinary product variances and tolerances are comprised.

The diameter of the core and of an inclusion is determined as the characteristic diameter of the core/ inclusion. The core or the inclusions are not always entirely circular. The characteristic diameter is the diameter of the circle of the inclusion/core where it is circular or in case the inclusion is not circular, the characteristic diameter is determined as the average of the maximum and the minimum extent of the inclusion/core in question.

The inclusions may have equal or different diameters and the inclusion diameter of the respective inclusions may as mentioned be equal or differ along the length of the fiber.

In an embodiment the delivery end section of the delivery fiber comprising the delivery end, and the connector member is mounted at a mounting distance from the delivery end such that the delivery end is passing through the connector member for connecting the delivery end in physical contact with a receiver waveguide, preferably a receiver fiber, such as a receiver fiber incorporated in an apparatus for illumination and/or metrology and/or surgery.

- The delivery end of the fiber is the end facet. The mounting distance to the delivery end is usually a few mm e.g. at least 2 mm, such as up to 2 cm or preferably less than 1 cm. The mounting distance to the delivery end is usually given by the structure of the connector member. Preferably the
- 5 connector member is a standard connector member such as a standard connector member according to at least one of the standards IEC 61754-20, IEC 61754-15 or IEC 61754-13 or equivalent standards. The mounting distance from the delivery end is determined as the distance from the delivery end to the nearest physical contact to the connector member. Usually the
- 10 connector member has a connecting flange that extends beyond the delivery end for being mated with and connected to another connector member while simultaneously protecting the connected delivery end. Prior to being connected to the apparatus the delivery end is desirably protected by a removable cap. For optimal connection the delivery end is advantageously
- 15 polished and optionally arranged to have a facet which is angled e.g. up to 60 degrees, such as up to about 30 degrees, such as from about 3 to 10 degrees, such as about 8 degrees relative to the cross-section plan of the fiber so as to reduce undesired reflection of light at the end facet. For broad band operation the angle of the facet is often selected as a compromise. Thus it is generally
- 20 desired to have the facet angle sufficiently large enough to ensure that an undesired amount of light not to be reflected and thereby that a large amount of the light is collected within the NA of the fiber. On the other hand the facet angle should advantageously not be too large because that may result in an undesired angular dispersion.
- 25 In an embodiment the delivery end section of the delivery fiber is mounted to the connector member such that the delivery end of the delivery fiber is suitable for connectorisation, without changing the fiber waveguide structure.

According to the present invention it has been found that the delivery fiber of the delivery fiber assembly can be connected to an apparatus without the use

30 of free space optics – i.e. without the transmission at the connection site is

outside the fiber - and without undesired change of the phase front of the propagating mode. Further the delivery fiber of the delivery fiber assembly can be connected to an apparatus without undesired expansion of mode field and thereby loss of light can be reduced or entirely avoided.

5

In an embodiment the connector member is mounted to the delivery fiber at the delivery end section of the delivery fiber at a distance to the delivery end, such that the delivery end is passing through the connector member for connecting the delivery end in physical contact with a receiver waveguide, preferably a receiver fiber, such as a receiver fiber incorporated in an apparatus for illumination and/or metrology and/or surgery.

10

The connector member preferably comprises a ferrule and the delivery end section passes through the ferrule for being coupled to the receiver unit.

15

Advantageously the connector member is arranged such that the delivery end can be brought in physical contact with and connected to a receiving waveguide e.g. an optical fiber comprising a corresponding receiving waveguide connector member.

20

Advantageously the connector member is spring-loaded, so the delivery end facet can be mated to a receiving fiber in a butt coupling where fiber faces are pressed together when the connectors are mated. The resulting glass-to-glass contact eliminates signal losses that would be caused by an air gap between the joined fibers.

25

In an embodiment the delivery fiber has, at least along its delivery end section and optionally along the entire length of the fiber, a constant mode field diameter for at least one wavelength within the transmission bandwidth where the mode field is expanding the fiber may lose light. The delivery end section preferably comprises a length of the fiber of at least 2 mm, preferably

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at least about 5 mm, such as at least 1 cm. Preferably the delivery fiber has a constant mode field diameter to wavelength profile within the transmission bandwidth at least along the delivery end section. The phrase 'mode field diameter to wavelength profile' means the profile of the respective mode field diameters relative to the respective wavelengths within the transmission bandwidth. Thereby the delivery fiber can be connected to an apparatus for use with a minimum loss of light.

The mode field diameters of the delivery fiber are advantageously selected in dependence on the desired transmission wavelength bandwidth. It has been found that the mode field diameter for a wavelength range of wavelengths below 2 μm varies surprisingly little. Thus for a bandwidth of 100 nm the mode field diameter varies preferably less than 10 % based on the mode field diameter of the lowest wavelength.

It has been found that the relatively small core region i.e. about 15 μm or smaller is an important factor for keeping the mode field diameter range for the transmission bandwidth narrow. Thus, by selecting even smaller core region the mode field diameter range for the transmission bandwidth may be even narrower. Further it has been found that the mode field diameter variation is smaller for wavelength of about 900 nm or less than for larger wavelengths.

The delivery fiber may be tailored by selecting a mode field diameter range i.e. In an embodiment the delivery fiber at least along said delivery end section has a mode field diameter range for said transmission wavelength, wherein the mode field diameter range is about 30 % or less, such as about 20% or less, such than about 15 % or less, such as about 10 % or less of the lowest mode field diameter of the range. The mode field diameter range is the range of mode field diameters corresponding to the transmission band width and

the lowest mode field diameter of the range is the mode field diameter of the lowest wavelength of the transmission band width.

Advantageously the delivery fiber for at least one wavelength within said transmission bandwidth and at least along said delivery end section has a constant numerical aperture NA and a propagation loss less than 0.5 dB/m, such as less than about 0.2 dB/m, such as less than about 0.1 dB/m or even less than 0.05 dB/m.

Advantageously the delivery fiber is single mode for at least one wavelength within the transmission bandwidth. Generally the beam of light has a much higher quality for single mode light than for multimode light and for some applications single mode light is a requirement. Preferably the delivery fiber is single mode for at least about 50 %, such as at least about 80 % of the transmission bandwidth, such as for the entire transmission bandwidth of the delivery fiber.

In a preferred embodiment the delivery fiber is a polarization-maintaining optical fiber (PM fiber). The PM fiber may for example comprise one or more stress elements.

A PM fiber is a fiber in which linear polarization can be maintained if linearly polarized light is launched into the fiber. Advantageously the launched polarized light maintains a linear polarization during propagation along the PM delivery fiber and exits the fiber in a linear polarization state. Advantageously there is little or no cross-coupling of optical power between the two polarization modes. Preferably the PM delivery fiber is single-mode for at least one wavelength within the transmission bandwidth. By providing the delivery fiber as a PM fiber, the delivery fiber has an even lower bending loss.

The PM properties can for example be induced by incorporating stress elements e.g. such as described in US 7,289,709.

5 The core region may in principle have any core diameter depending on the power and the wavelengths to be transmitted. Advantageously the delivery fiber core region has a diameter of at least about 3 μm . The core region may vary along the length of the delivery fiber, but generally it is preferred that the core region has a substantially identical diameter along the major part of the delivery fiber, such as preferably along at least about 80 % of the length
10 of the delivery fiber. The most suitable core region diameters are up to about 15 μm , such as within the range of from about 3 μm to about 10 μm , such as from about 4 μm to about 12 μm .

Where the transmission bandwidth of the delivery fiber comprises
15 wavelengths below 500 nm or even below 450 nm, the delivery fiber core region advantageously has a diameter of less than about 10 μm because it has been found that where the core region of the delivery fiber is larger, such as larger than about 15 nm, there is an increased loss in the UV light region.

20 All structural details of the optical fiber, such as core region size, inclusion diameters and pattern are given in relation to a cross-sectional view of the fiber unless otherwise specified.

In an embodiment the core region diameter is substantially identical along the
25 length of the delivery fiber, optionally excluding one or more component sections of the delivery fiber.

Such component section(s) is/are further described below.

30 Preferably the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least four rings of inclusions surrounding

the core region, such as at least five rings of inclusions surrounding the core region. It has been found that by increasing the number of rings of inclusion the transmission bandwidth can be increased and further additional properties, such as single mode properties and/or reduced loss can be enhanced.

- 5 The rings of inclusions are advantageously arranged in a pitch pattern such that the distance between adjacent inclusions is P times the pitch, where P is 0.5 or an integer up to five, preferably up to 3, such as 1 or 2, and where P can have different value from different distances of nearest inclusions.
- 10 In an embodiment the inclusions are arranged in a pitch pattern, a double pitch pattern, a triple pitch pattern, a half pitch pattern or a combination thereof, where a pitch is determined as the smallest center to center distance between the core region and an inclusion.
- 15 It has been found that the pitch Λ can be used in tailoring the delivery fiber for a desired transmission band width and in particularly whether or not the transmission band width comprises wavelength in the blue range below 450 nm and/or in the red range above 800 nm. To reach into the blue wavelengths it is desired that the pitch is less than about 10 μm , preferably
- 20 less than about 9 μm , such as less than about 8 μm , such as less than about 7 μm , such as less than about 6 μm . To reach into the red wavelength the pitch is advantageously about 3.2 μm or larger, such as about 3.2 μm or larger, such as about 4 μm or larger, such as about 5 μm or larger, such as about 5 μm or larger, such as about 7 μm or larger, such as about 8 μm or
- 25 larger.

The core region diameter to pitch d/Λ may advantageously be about 0.7 or less, such as from about 0.3 to about 0.65, such as from about 0.4 to about 0.6.

Advantageously the core region has a refractive index N_{core} , the cladding region has an effective refractive index N_{clad} , and the refractive index N_{bg} of the cladding background material is substantially identical to the refractive index of the core region N_{core} .

5

In an embodiment the refractive index of the core region is homogeneous. In another embodiment the core region is microstructured e.g., as described in co-pending DK PA 2014 00545. Where the core region is microstructured the refractive index of the core region N_{core} is determined as the average refractive index.

10

In an alternative embodiment the refractive index N_{bg} of the cladding background material differs from the refractive index of the core region N_{core} , preferably such that the refractive index N_{bg} of the cladding background material is lower than the refractive index of the core region N_{core} .

15

In an embodiment the delivery fiber is a silica fiber and the solid inclusions are of down doped silica. Preferably the solid inclusions independently of each other are silica doped with at least one of fluorine and/or boron and/or component comprising F and/or B atoms.

20

The respective inclusions may have equal or different refractive indices and an inclusion may have several regions with different refractive indices in which situation the refractive index is determined as the average refractive index as described above.

25

In an embodiment, the difference between refractive indices of the respective inclusions independent from each other and the refractive index of the background material N_{bg} is from about 10^{-5} to about 0.1, such as from about 10^{-4} to about 10^{-2} , such as up to about 10^{-3} .

30

In an embodiment the inclusions have substantially identical refractive index N_{inc} .

5 In an embodiment n of the inclusions have different refractive indices $N_{inc(1)}, \dots, N_{inc(n)}$, where n is an integer up to the number of inclusions – in other words in principle all of the inclusions may have different refractive indices. However, from a practical point of view this embodiment is not preferred.

10 Advantageously up to 10, such as 2-4, preferably all of the inclusions of a ring of inclusion have substantially identical refractive indices.

In an embodiment the inclusions of one ring of inclusions have a refractive index different from that of the inclusions of another ring of inclusions.
15 Preferably the inclusions of the one ring of inclusions have higher refractive index than the inclusions of another ring of inclusions closer to the core region. By having rings of inclusions with different refractive indices, the delivery fiber can be designed to have a desired transmission bandwidth and at the same time higher order modes may be suppressed.

20

In an embodiment the inclusions of a ring of inclusions comprises two or more inclusions having different refractive index.

25 Advantageously the solid inclusions are substantially parallel to the core region. Thereby the fiber can be drawn in a relatively simple way.

In an embodiment the solid inclusions are helically surrounding the core region. Thereby the number of inclusions can be reduced and/or the bending loss can be reduced. However, the production of fiber with inclusions helically
30 surrounding the core region is more difficult than with inclusions parallel to the core region.

In an embodiment the delivery fiber comprises an inner cladding region and an outer cladding region, where the cladding background material may differ.

- 5 In an embodiment the delivery fiber comprises an inner cladding region and an outer cladding region, where the cladding background material has identical refractive index.

10 In an embodiment the delivery fiber comprises an inner cladding region and an outer cladding region, where the inclusions in the outer cladding region have higher index than the inclusions in the inner cladding region. In this embodiment the inner cladding region advantageously comprises the herein described inclusions of solid material having refractive index of up to N_{inc} and the inclusions in the outer cladding region are of solid material having
15 refractive index which is higher than N_{inc} . Preferably the inclusions in the outer cladding region are of solid material having refractive index which is higher than the background material of the outer cladding region. Thereby the inclusions of the outer cladding region may act to couple out higher order modes.

20

In an embodiment the delivery fiber is a double clad delivery fiber comprising an inner cladding region and an outer cladding region for example as described above, and wherein the delivery fiber is configured such that signals can be collected e.g. via free space optic or via a coupler e.g. a fused
25 coupler as described below.

The inclusion may in principle have any size, but generally it is desired that the inclusions are not too large unless where inclusions are used for making the fiber birefringent.

30

In an embodiment the solid inclusions have equal or different diameters, preferably the diameters is from about 0.2 to about 1 μm , such as from about 0.4-0.8 μm .

- 5 Preferably the inclusions of a ring of inclusions have equal diameter.

In an embodiment the inclusions in a ring of inclusions have a first diameter and the inclusions in another ring of inclusions have a second diameter that differs from the first diameter.

- 10 Advantageously the delivery fiber is an all solid fiber – i.e. a fiber entirely of solid material at 25 °C. Preferably the delivery fiber is an all silica fiber, wherein the core region, the cladding region and/or the inclusions are doped to reach their respective refractive indices.

- 15 In an embodiment the transmission bandwidth of the delivery fiber comprises wavelengths within the range of from about 400 nm to 900 nm. This range of wavelength is highly suitable for a plurality of high precision procedures, in particularly for microscopy based procedures. Preferably the transmission bandwidth of the delivery fiber comprises at least a bandwidth of about 100
20 nm, such as at least a bandwidth of about 200 nm such as at least a bandwidth of about 300 nm, such as at least a bandwidth of about 400 nm, such as the entire bandwidth within the range of from about 400 nm to 900 nm.

- 25 In an embodiment the transmission bandwidth comprises at least one wavelength in the visible range.

- In an embodiment the transmission bandwidth comprises wavelengths above the visible range, for example of 700 nm or larger. This is highly suitable for
30 illumination during eye surgery, in particular where transmission bandwidth is exclusively above 700 nm.

In an embodiment the transmission bandwidth comprises at least one wavelength below 450 nm, or even below 400 nm. Such wavelengths are very suitable for many microscopy illumination procedures.

5

In an embodiment the delivery fiber is configured for suppressing wavelengths above 1500 nm. This can be provided by the selection of the distance between the inclusions in the respective rings of inclusions and/or by the selection of the refractive index difference between the refractive index of the core region and the effective refractive index of the cladding region.

10

In an embodiment the delivery fiber is configured for suppressing wavelengths above 900 nm.

15 In an embodiment the transmission bandwidth of the delivery fiber comprises wavelengths within the range of from about 1100 nm to 2400 nm, preferably the transmission bandwidth of the delivery fiber comprises at least a bandwidth of about 100 nm, such as at least a bandwidth of about 200 nm such as at least a bandwidth of about 300 nm, such as at least a bandwidth of about 400 nm, such as the entire bandwidth within the range of from about 1100 nm to 2400 nm.

20

In an embodiment the transmission bandwidth of the delivery fiber comprises wavelengths within the range of from about 400 nm to 1100 nm.

25

In an embodiment the transmission bandwidth of the delivery fiber comprises wavelengths below 800 nm, such as below 700 nm, such as below 600 nm, such as below 500 nm.

30 The delivery fiber should not be too long because this may result in undesired bends and mechanical disturbance. However, neither should the delivery fiber

be too short. In preferred embodiments the delivery fiber assembly can be supplied in different lengths for the specific use.

A suitable length of the delivery fiber is for example from about 5 cm to about 100m, such as from about 10 cm to about 30 m, such as from about 20 cm to about 20 m, such as from about 30 cm to about 10 m.

Advantageously the delivery fiber comprises at least one component section, the component section is advantageously configured for splitting of light from the delivery fiber and/or for combining light in the delivery fiber, the component section preferably is an all fiber component section.

Advantageously the delivery fiber comprises a fused component, such as a fused coupler or a fused splitter. Such fused components are well known in the art, but have heretofore never been applied or fused to a delivery fiber. The principle of a fused element is that the core of the delivery fiber and the core of the fused component – usually a fiber component – are fused to be very close to each other so as to transfer light from one core to another. An advantage of the fused component(s) comprises an optical fiber with solid microstructures e.g. comprising a core region and a cladding region surrounding the core region wherein the cladding region comprises a cladding background material having a refractive index TN_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive indices of up to TN_{inc} and extending in the length of and preferably along the twin delivery fiber, wherein $TN_{inc} < TN_{bg}$ and the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region.

It has been found that by using all solid fibers comprising solid microstructures in form of inclusions as described, the coupling or splitting of light to or from the delivery fiber will be such that the fraction of light coupled

to or split from the delivery fiber has a substantially identical wavelength profile as the light from where it was coupled or split.

In an embodiment the delivery fiber assembly comprises a fused coupler,
5 wherein the fused coupler is fused to the delivery fiber at the component section.

Advantageously the fused coupler is a 2x2 coupler, comprising a coupling fiber fused to the delivery fiber at the component section. The coupling fiber comprises a first and a second fiber section on either side of the fused
10 component section and is arranged such the light is coupled between the delivery fiber and the coupling fiber at the fused component section.

In an embodiment the coupling fiber is arranged for coupling light into the delivery fiber and simultaneously coupling a light fraction from the delivery fiber to the coupling fiber. Such fused coupler is advantageous for use in OCT
15 as shown in the examples below.

In an embodiment the delivery fiber assembly comprises a fused splitter, wherein the fused splitter is fused to the delivery fiber at the component section for splitting a fraction of light from the delivery fiber. Preferably the
20 split off light fraction constitutes from 5 – 95 % by power of the light, wherein the split off light fraction has a wavelength profile substantially identical to the light fraction from which it was split.

In an embodiment the splitter is a 10-90 % ratio splitter in that the split off
25 light will constitute about 10 % by power or about 90 % by power. This type of splitter is e.g. suitable for use in OCT or wafer metrology or similar apparatus.

In general the splitter can be applied for splitting any desired power fraction
30 of light from the delivery fiber and the split off fraction can be used as a

reference. In an embodiment the delivery fiber with the splitter is configured for use in an interferometer apparatus.

5 In an embodiment the splitter is a 50-50 % ratio splitter in that the split off light will constitute about 50 % by power. This embodiment may be applied for providing interleaved pulses, e.g. as described in Advanced Fluorescence Fluctuation Spectroscopy with Pulsed Interleaved Excitation, Matthias Höller, Dissertation zur Erlangung des Doktorgrades der Fakultät für Chemie und Pharmazie der Ludwig-Maximilians-Universität München, 2011.

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In an embodiment the fused splitter comprises a twin delivery fiber for delivering light, the twin delivery fiber comprises a twin delivery end and a length extending from the component section to the twin delivery end and comprises along its length a core region and a cladding region surrounding
15 the core region wherein the cladding region comprises a cladding background material having a refractive index TN_{bg} and a plurality of microstructures in the form of inclusions of solid material having a refractive index of up to TN_{inc} and extending in the length of and preferably along the twin delivery fiber, wherein $TN_{inc} < TN_{bg}$ and the plurality of inclusions in the cladding region is
20 arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region, preferably a twin connector member being mounted to the twin delivery fiber at a twin delivery end section of the twin delivery fiber comprising the twin delivery end.

25 Advantageously the delivery fiber has a transmission bandwidth of about 200 nm or more, such as of about 300 nm or more, such as of about 400 nm or more, such as of about 500 nm or more.

30 In an embodiment the delivery fiber assembly comprises a fused coupler and a fused splitter, wherein the fused splitter is fused to the delivery fiber at a first component section and the fused coupler is fused to the delivery fiber at

a second component section closer to the delivery end of the delivery fiber, the fused splitter and fused coupler comprises a loop fiber configured for delaying a light pulse fraction split out via the splitter and recombined into the delivery fiber via the coupler such that a split off and recombined light pulse
5 fraction is delayed relative to the light pulse fraction from which it was split.

The loop fiber is advantageously an all solid fiber comprising inclusions e.g. as described above.

Advantageously the assembly comprises an input end connector member and
10 the input end connector member is mounted to the delivery fiber at an input end section of the delivery fiber comprising the input end, the connector member preferably being configured for connecting the input end in physical contact with a light launching unit, such as a microstructured optical fiber.

15 In an embodiment the assembly comprises a pre-delivery fiber, the pre-delivery fiber is coupled to the delivery fiber without free space optics.
In an embodiment the pre-delivery fiber is spliced to the delivery fiber, optionally by a splicing.

20 Advantageously the splicing is provided such that guiding one or more properties selected from mode field diameter, numerical aperture, low propagation loss or transmission band width are substantially unaltered from the pre-delivery fiber to the delivery fiber.

25 In an embodiment the delivery fiber assembly is configured for delivering light with single mode quality from a multiplex of multiplexed lasers with different wavelengths. Such multiplexed laser light is sometimes referred to as a spectral engine. The multiplexed laser light may e.g. be multiplexed from a
30 blue, a green and a red laser which are combined into a single beam path with e.g. a Keyoptics KineFLEX module. Prior art would either be using three

different delivery fibers or having a single delivery fiber which was single mode at the large wavelengths and multimode at the low wavelengths. Heretofore there has not been any solution that makes it possible to deliver single mode multiplexed light comprising different wavelengths, such as
5 wavelengths that differs with about 25 nm or more, such as about 100 nm or more, such as 200 nm or more, such as 300 nm or more by one single delivery fiber.

The invention also relates to a broad band source for supplying light to an
10 apparatus. The broad band source comprises

- an optical pump source operable to generate pump pulses
- a microstructured optical fiber for generating broad band light pulses upon feeding of pump light; and
- a delivery fiber arranged for receiving at least a portion of at least
15 some of the broad band light pulses and for delivering at least a part of the received portion of the broad band light pulses to the apparatus,

wherein the optical pump source is arranged to launch pump pulses to the microstructured optical fiber, and the delivery fiber has a length, an input end for launching light and a delivery end for delivering light, the delivery fiber
20 comprises along its length a core region and a cladding region surrounding the core region wherein the core region has a diameter of up to about 15 μm and the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having a refractive index of at least N_{inc} and extending in the
25 length of and preferably along the longitudinal axis of the delivery fiber, wherein $N_{inc} < N_{bg}$ and the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region.

The delivery fiber of the broad band source may advantageously be as the
30 delivery fiber described above.

In an embodiment the delivery fiber has a transmission bandwidth of about 200 nm or more, such as of about 300 nm or more, such as of about 400 nm or more, such as of about 500 nm or more.

5

Advantageously, the delivery fiber has a constant mode field diameter for at least one wavelength within the transmission bandwidth at least along the delivery end section, preferably the delivery fiber has a constant mode field diameter to wavelength profile within the transmission bandwidth at least

10 along the delivery end section. In one embodiment the delivery fiber has a substantially constant mode field diameter along its entire length including the delivery end section with the connector.

Advantageously the delivery fiber has a substantially constant mode field
15 diameter to wavelength profile along the major part of its length, preferably as described above e.g. at least including the end sections including 1 cm from delivery end.

The delivery fiber is preferably single mode for at least one wavelength within
20 the transmission bandwidth. Preferably the delivery fiber is single mode for at least about 50 %, such as at least about 80 % of the transmission bandwidth, such as for the entire transmission bandwidth of the delivery. The delivery fiber preferably has a transmission bandwidth of about 200 nm or more, such as of about 300 nm or more, such as of about 400 nm or more, such as of
25 about 500 nm or more.

Advantageously the delivery is a polarization-maintaining optical fiber (PM fiber) as described above.

30 In an embodiment the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least four rings of inclusions

surrounding the core region, such as at least five rings of inclusions surrounding the core region. The rings of inclusions are arranged in a pitch pattern, a double pitch pattern, a triple pitch pattern, a half pitch pattern or a combination thereof, e.g. as described above.

5

In an embodiment the fiber has a so called single cell core, which basically corresponds to a single missing inclusion. In this embodiment the core size is given by two times the pitch (Λ) minus the diameter of the inclusions (d).

10 Preferably the core region has a refractive index N_{core} , the cladding region has an effective refractive index N_{clad} , and the refractive index N_{bg} of the cladding background material is substantially identical to the refractive index of the core region N_{core} .

15 The delivery fiber is advantageously a silica fiber and the solid inclusions are of down doped silica, preferably the solid inclusions independently of each other are silica doped with at least one of fluorine and/or boron and/or component comprising F and/or B atoms.

20 In an embodiment the delivery fiber is a double clad fiber comprising an inner cladding region and an outer cladding region, where the inclusions in the outer cladding region have higher indices than the inclusions in the inner cladding region, preferably the inner cladding region comprises the at least two rings of inclusions of solid material having a refractive index of at least
25 N_{inc} and the outer cladding region has a higher effective refractive index than the inner cladding region.

The inclusions in the outer cladding region are preferably of solid material having a refractive index which is higher than N_{inc} , preferably the inclusions in
30 the outer cladding region are of solid material having a refractive index which

is higher than the background material of the outer cladding region. Thereby the inclusions of the outer cladding may act to couple out higher order modes.

In an embodiment the outer cladding is arranged to receive and transmit a
5 signal from an illuminated target. The light scattered from the target may be collimated by an optical element to be transmitted via the outer cladding e.g. to a spectrometer.

The delivery fiber is advantageously in form of a delivery fiber assembly as
10 described above.

The optical pump source can in principle be any kind of optical pump source, e.g. such as the optical pump source described in WO 2011/023201.

Advantageously the optical pump source comprises a mode-locked fiber
15 oscillator and preferably at least one amplifier. In an embodiment the optical pump source comprises a master oscillator power amplifier MOPA. MOPA configurations are well known in the art.

The microstructured optical fiber can be any microstructured optical fiber
20 suitable for supercontinuum generation e.g. as described in the above cited prior art documents.

Advantageously the optical pump source and the microstructured optical fiber of the broad band source are configured for generating broad band light
25 pulses spanning at least about 200 nm, preferably at least about 500 nm, such as an octave.

Advantageously the microstructured optical fiber comprises holes which are connected to a connector member connected to the delivery fiber preferably
30 without the use of free space optics.

In an embodiment the microstructured optical fiber comprising holes is spliced to the delivery fiber e.g. as described in US2012195554.

5 In an embodiment the microstructured optical fiber is connected to the delivery fiber by butt connection, optionally by connector members or by splicing, such as a cold splice or where the holes are collapsed at the end of the microstructured optical fiber.

10 In an embodiment the microstructured optical fiber is connected to the delivery fiber by using of a gradient index fiber arrangement (GRIN) as described in "Low-Loss High-Strength Microstructured Fiber Fusion Splices Using GRIN Fiber Lenses" by A. D. Yablon and R. Bise. 2004 Optical Society of America, OCIS codes: (060.2310) Fiber optics.

15 In an embodiment the broad band source comprises a band pas filter for filtering the broad band light pulses, the band pas filter is preferably a tunable band pass filter, preferably selected from a grating based filter, a prism, or an acousto-optic tunable filter (AOTF). Such band pass filters are well known to the skilled person.

20

Advantageously the band pass filter is positioned between the microstructured optical fiber and the delivery fiber.

25 In an embodiment the delivery fiber is arranged to receive the band pass filtered portion of the broad band light pulses and for delivering the at least a part of the received portion of the broad band light pulses to the apparatus without free space optics.

30 In an embodiment the filter is a tunable optical band pass filter, configured for selectively selecting a plurality of wavelengths or wavelength ranges and transmitting the selected wavelengths to the delivery fiber.

In an embodiment wherein the pump source is operable to generate pump pulses at a pump pulse repetition rate, and the broad band source comprises a pulse picker arranged between the pump source and the microstructured optical fiber, the pulse picker being operable to pick out pulses to reduce the pump pulse repetition rate generated by the pump source, such that the reduced pump pulse repetition rate is launched to the microstructured optical fiber.

10 The invention also comprises a broad band source system comprising the broad band source as described above and wherein the broad band source system comprises a plurality of delivery fiber assemblies having different transmitting properties, wherein each of the delivery fiber assemblies comprises an input end connector member and a delivery end connector member. Thereby the user can select a delivery fiber assembly for a specific use and switch to another delivery fiber assembly for another use. The respective delivery fiber assemblies are advantageously designed for the performance of different procedures and the user can relatively simply switch delivery fiber assembly.

20

The invention also relates to a spectral engine source for supplying light to an apparatus, the spectral engine source comprising

- two or more lasers emitting laser beams with wavelength(s) that differs with at least one wavelength
- 25 • a multiplexer, and
- a delivery fiber

Thus the spectral engine may comprise a multiplum of lasers emitting laser beams with distinct wavelength or band of wavelength.

The multiplexer is configured for receiving at least a portion of the laser beams of each of the lasers and for collimating the received light to a

30

5 multiplexed beam. The delivery fiber is arranged to receive the multiplexed beam and to delivering at least a part of the received multiplexed beam to the apparatus, and wherein the delivery fiber has a length, an input end for launching light and a delivery end for delivering light. The delivery fiber comprises along its length a core region and a cladding region surrounding the core region wherein the core region has a diameter of up to about 15 μm and the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index of up to N_{inc} and extending in the length of the longitudinal axis of the delivery fiber, wherein $N_{inc} < N_{bg}$ and the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region, preferably the delivery fiber has a transmission bandwidth comprising wavelengths comprising at least a part of the wavelengths of each of the two or more lasers.

The delivery fiber may be as described above.

20 The lasers may be any kind of lasers, such as fiber lasers or semiconductor diode lasers.

In an embodiment at least one of the laser beams emitted from the two or more lasers have a bandwidth of about 50 nm or less, such as about 25 nm or less, such as about 5 nm or less.

25

In an embodiment one of the laser beams emitted from the two or more lasers comprises at least one wavelength below 500 nm and one of the laser beams emitted from the two or more lasers comprises at least one wavelength above 800 nm.

30

In an embodiment the spectral engine comprises at least three lasers, wherein a first laser of the lasers is adapted for emitting a laser beam comprising at least one wavelength below 450 nm, a second laser of the lasers is adapted for emitting a laser beam comprising at least one
5 wavelength in the range from 500 nm to 700 nm, and a third of the lasers is adapted for emitting a laser beam comprising at least one wavelength above 800 nm.

- 10 The invention also relates to an apparatus comprising a broad band source or a spectral engine source comprising as described above. The apparatus comprises an optical waveguide arranged for receiving light from the delivery fiber, wherein the optical waveguide comprises a connector member configured for being mated with the delivery end connector member of the
15 delivery fiber, the optical wave guide preferably being an optical fiber.

The apparatus is for example an illumination apparatus configured for illuminating a target, the illumination apparatus is preferably selected from a microscope, a spectroscope or an endoscope.

20

- Advantageously the illumination source is adapted for fluorescence Imaging; Fluorescence Lifetime Imaging (FLIM); Total Internal Reflection Fluorescence (TIRF) Microscopy; fluorescence resonance energy transfer (FRET); pulse interleave excitation foster resonance energy transfer (PIE-FRET); broadband
25 Spectroscopy; nanophotonics; flow cytometry; industrial inspection, such as metrology; ringdown spectroscopy, such as gas sensing; analytical spectroscopy, such as hyperspectral spectroscopy, crop analysis e.g. of fruits and time of flight spectroscopy (TCSPC); single Molecule Imaging and/or combinations thereof. In one embodiment the delivery fiber serves as a so-
30 called light guide in the microscope.

In an embodiment the apparatus is a metrology apparatus, the apparatus preferably comprises a double clad delivery fiber configured for collecting signals from an illuminated target.

- 5 In an embodiment the apparatus comprises at least one delivery fiber assembly comprising a fused coupler and/or at least one delivery fiber assembly comprising a fused splitter.

- In an embodiment the illumination source comprises at least one delivery fiber assembly comprising a fused coupler and/or at least one delivery fiber
10 assembly comprising a fused splitter and wherein the delivery fiber has a transmission bandwidth of at least about 200 nm, preferably at least about 500 nm, such as an octave.

- All features of the inventions and embodiments of the invention as described above including ranges and preferred ranges can be combined in various
15 ways within the scope of the invention, unless there are specific reasons not to combine such features.

Brief description of the drawings

- The above and/or additional objects, features and advantages of the present invention, will be further elucidated by the following illustrative and non-limiting
20 detailed description of embodiments of the present invention, with reference to the appended drawings.

Fig. 1a shows a cross-section of a delivery fiber of an embodiment of a delivery fiber assembly of the invention.

- Fig. 1b shows a wavelength profile in form of a transmission loss spectrum for
25 a delivery fiber as shown in Fig. 1a.

Fig. 1c shows an example of a PM fiber, where the dark regions are inclusions doped with another material, such as e.g. boron

Fig. 1d shows an example of the long wavelength transmission edge and short wavelength transmission edge versus the pitch for a fiber according to the invention.

- 5 Fig. 2 shows a perspective view of a part of an embodiment of the delivery fiber assembly of the invention.

Fig. 3 is a schematic illustration of an embodiment of a broad band source of the invention.

- 10 Fig. 4 is a schematic illustration of another embodiment of a broad band source of the invention.

Fig. 5 is a schematic illustration of yet another embodiment of a broad band source of the invention.

Fig. 6 is a schematic illustration of an embodiment of an apparatus of the invention in form of an interferometer.

- 15 Fig. 7 is a schematic illustration of an embodiment of an apparatus of the invention in form of another type of interferometer.

Fig. 8 is a schematic illustration of an embodiment of a spectral engine source of the invention.

- 20 Fig. 9 is a schematic illustration of another embodiment of a spectral engine source of the invention.

Fig. 10 is an illustration of an apparatus of an embodiment of the invention

Fig. 11 is an illustration of another apparatus of an embodiment of the invention

- 25 The figures are schematic and may be simplified for clarity. Throughout, the same reference numerals are used for identical or corresponding parts.

Fig. 1a shows a cross-section of a delivery fiber 5 of a delivery fiber assembly. The delivery fiber 5 comprises a core region with a refractive index n_{core} . The core is surrounded by a cladding region comprising a background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions 2a, 2b of solid material having refractive index up to N_{inc} and extending in the length of the longitudinal axis of the delivery fiber, wherein $N_{\text{inc}} < N_{\text{bg}}$. The plurality of inclusions 2a, 2b in the cladding region is arranged in a cross-sectional pattern comprising at least 6 rings of inclusions surrounding the core region. In the shown embodiment, the 3 in radial direction innermost rings of inclusions 2a have a lower refractive index than the 3 in radial direction outermost rings of inclusions 2b. In the shown embodiments the inclusions have substantially equal diameter. As explained above it may for some applications be advantageous to have different diameters for one ring of inclusions relative to another ring of inclusions.

Fig. 1b shows a transmission loss spectrum of a fiber corresponding to the delivery fiber shown in fig. 1 with six rings of inclusions, but where all inclusions have same refractive index. In this example the core has a diameter of 10 μm , the inclusions have a refractive index which is 1.2% lower than the refractive index of the core and the cladding background silica material at 635 nm. The center to center distance between the inclusions in the cladding (also known as the pitch) is 6 μm and the diameter of the inclusions is 3 μm .

The spectrum is obtained by sending light from a broad band spectrum light source through the fiber and performing a cut-back to separate the coupling loss. The peak at around 1400 nm is due to water absorption. The delivery fiber is single-mode in the entire transmission bandwidth of the delivery fiber. It can be seen that the delivery fiber has a very broad transmission bandwidth extending from about 425 nm to about 1500 nm.

The delivery fiber shown in Fig. 1c is an example of a PM fiber comprising a core region with a refractive index n_{core} . The core is surrounded by a cladding

region comprising a background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions 7a, 8b of solid material having refractive index up to N_{inc} and extending in the length of the longitudinal axis of the delivery fiber, wherein $N_{inc} < N_{bg}$. The plurality of inclusions 7a, 7b in the cladding region is arranged in a cross-sectional pattern comprising at least 6 rings of inclusions surrounding the core region. In the shown embodiment, a number of inclusions b with a higher refractive index than the other inclusions 7a is arranged in two opposite clusters for forming stress elements. The inclusions 7b with the higher refractive index are e.g. doped with boron.

In an embodiment of the of the delivery fiber is has been found that the diameter(d) of the inclusions in the cladding relative to the pitch (Λ) may have large influence on the guiding properties of the delivery fiber. In an embodiment the transmission loss is large if the d/Λ is less than about 0.4. In an embodiment the fiber is multimode if d/Λ is more than about 0.6.

In an embodiment of the invention is has been found that the pitch (Λ) of the delivery fiber may have large influence on the spectral transmission bandwidth of the delivery fiber.

In particular it was found that the short wavelength transmission edge sets a upper limit to the pitch and where this limit increases with the required short wavelength edge, such that e.g. a short wavelength edge of 300 nm requires a pitch of less than 6 μm whereas a short wavelength edge of 600 nm requires a pitch of less than 9 μm .

Further it was found that the long wavelength transmission edge sets a lower limit to the pitch and where this limit increases with the required long wavelength edge, such that e.g. a long wavelength edge of 800 nm requires a pitch of at least 3.2 μm whereas a long wavelength edge of 1500 nm requires a pitch of at least 6 μm .

Fig. 1d shows the pitch shows an example of the long wavelength transmission edge (201) and short wavelength transmission edge (202) versus the pitch for a fiber according to the invention having a d/Λ of about 0.5.

In an example the mode field diameter of the delivery fiber varies from about 8.0 μm at 500 nm to about 9.0 μm at 900 nm. In an embodiment the mode filed diameter of the fiber varies by less than about 20% from 500 nm to 900 nm.

Fig. 2 shows a part of a delivery fiber assembly comprising the delivery fiber 5 and a connector member 6 mounted to the delivery fiber at a delivery end section of the delivery fiber comprising the delivery end 5a. As it can be seen the delivery fiber comprises a protection coating, such as a polymer protection coating.

The connector member is advantageously an optical fiber connector of the type which in the prior art is commonly used to terminate the end of an optical standard fiber to enable easy connection and disconnection of two standard optical fibers with low loss.

During mounting, the optical fiber is typically aligned inside the optical connector member, so that the core region of the optical delivery fiber is centered inside a connector plane of the connector member. For a polarizing or polarization maintaining fiber it is also possible to rotate the fiber so that the polarization axis is in a predetermined plane. Furthermore it is ensured that the end facet of the fiber is in the output plane of the connector member. This can e.g. be achieved by polishing the connector and fiber end facets.

If light is sent through the delivery fiber assembly with a connector member on the output end, then the position of the light being emitted from the output of the connector member is well known. For a standard all-solid single mode fiber the light will have its focal plane and thereby waist at the output plane of the connector.

Many different types of connectors have been introduced to the market, such as e.g. FC, E-2000, SMA connectors, as well as connectors with built in beam expansion.

It is desired to use fiber connector members having low loss and high power handling, as they should advantageously be capable of handling average powers such as up to 100 mW or even to several Watts.

The broad band source 10 shown in Fig. 3 comprises a broad band laser pulse generator 1 comprising a not shown optical pump source operable to generate pump pulses and a not shown microstructured optical fiber for generating broad band light pulses upon feeding of pump light where the optical pump source is arranged to launch pump pulses to the microstructured optical fiber. In the shown embodiment the broad band laser pulse generator 1 is in the form of a SuperKTM system marketed by NKT Photonics Denmark. The broad band source further comprises a delivery fiber 5 comprising solid inclusions as described above. The delivery fiber 5 is arranged for receiving at least a portion of at least some of said broad band light pulses. In the shown embodiment the broad band source 10 further comprises an optical component 3, preferably a filter 3 arranged between the broad band laser pulse generator 1 and the delivery fiber 5. The optical component 3 is for example a polarizer, a spectral filter (preferably tunable) and/or a beam splitter.

At the output end section of the delivery fiber 5, the delivery fiber comprises a connector member 6 e.g. as described above. The connector member 6 is advantageously configured for delivering at least a part of said received portion of said broad band light pulses to an apparatus as described above.

In the embodiment shown in Fig. 4 the broad band source 10 is coupled to an optical waveguide arranged for receiving light from the delivery fiber, here called the first delivery fiber. In this embodiment the optical waveguide arranged for receiving light from the first delivery fiber is in form of an additional delivery assembly comprising a second delivery optical fiber 22 and

a second delivery fiber inlet end connector member 21 and a second delivery fiber output end termination unit 23. The connector member 6 of the delivery fiber assembly 5, 6 in the following referred to as the first delivery fiber assembly 5,6 is connected to the second delivery fiber inlet end connector member 21 using a mating sleeve 20.

By using a mating sleeve the connectors mechanically couple the core regions of the first and the second delivery fibers 5, 22 so that light can pass from the first delivery fiber 5 to the second delivery fiber 22 with low loss. Preferably the connector members are spring-loaded, so the fiber faces are pressed together when the connector members 6, 21 are mated. The resulting glass-to-glass or plastic-to-plastic contact eliminates signal losses that would be caused by an air gap between the joined fibers.

The fiber termination unit 23 is advantageously a connector member, a collimator, a ball lens, grin lens or any other suitable termination unit.

The second optical delivery fiber 22 can in principle be any kind of optical fiber, preferably having a relative broad transmission bandwidth e.g. at least about 200 nm or more, and preferably the transmission bandwidth of the second optical delivery fiber 22 at least partially overlaps the transmission bandwidth of the first delivery fiber 5.

In an embodiment the second optical delivery fiber 22 is substantially identical to the first delivery fiber 5.

In an embodiment the broad band source 10 comprising the broad band laser pulse generator 1 and the first fiber delivery assembly 5,6 can be replaced without replacing the second fiber delivery assembly 21, 22, 23 or vice versa.

In an embodiment the broad band source 10 and said second fiber delivery assembly 21, 22, 23 is built into an apparatus or alternatively the second fiber delivery assembly 21, 22, 23 is built into an apparatus while the broad band source 10 is arranged to feed light to the apparatus via the connection between the connector members 6, 21. Examples of such apparatus are

microscopes, bio- imaging systems (such as e.g. OCT, SLO, STED, CARS and photoacoustic systems), alignment or overlay system and manufacturing equipment (such as e.g. semiconductor manufacturing equipment). This

embodiment of the invention enables that the broad band source 10 easily
5 can be disconnected for service and/or can be replaced independently of said second fiber assembly 21, 22, 23, which e.g. may be more difficult to disconnect from the remainder of the apparatus. For example the

supercontinuum source and first fiber delivery assemble constituting a broad band source of an embodiment of the invention can be comprised in a first

10 module, whereas the second fiber assembly 21, 22, 23 is part of a second module such as e.g. an alignment sensor in a semiconductor wafer scribing system. In this example the invention enables a modular build-up of the semiconductor wafer scribing system. If the semiconductor wafer scribing

system breaks down, then the error can be located to the specific module

15 which has failed, and this can be replaced independently of the other modules. This improves risk management for the semiconductor wafer scribing system compared to having to replace both modules at the same time.

In an embodiment the second fiber delivery assembly 21, 22, 23 is used in bio-medical imaging or surgical applications. Examples of such embodiments

20 include endoscopy, colonoscopy, rhinoscopy and bronoscopy as well as other applications where a part of the second optical fiber enters inside either a human or animal body. In such embodiments the broad band source 10 as shown in Fig. 3 can easily be connected to the connection member 21 as described above.

25 In an embodiment the second fiber delivery assembly is sterilized before use.

In an embodiment the second fiber delivery assembly is disposable.

Fig. 5 is a schematic illustration of another embodiment of a broad band source of the invention. The broad band system 10 may be as described above and the second optical delivery fiber assembly 21, 22, 23 may be as

30 described in Fig. 4.

The fiber termination unit 23 advantageously is or comprises a collimator for focusing light towards a sample 30.

Advantageously the second fiber delivery assembly 21, 22, 23 is built into an apparatus and the broad band source 10 is optionally arranged as a built in module in the apparatus and is arranged to feed light to the apparatus via the connection between the connector members 6, 21. The source 10 comprises or is optically connected to an optical detector 34, and the optical component 3 comprises an additional filter 32 arranged to direct a portion of light 33 reflected by the sample and guided by the fibers 5 and 22. The additional filter is advantageously a splitter.

In an embodiment the delivery fiber 5 and the second optical fiber 22 are double clad fibers. Thereby a portion of the light 31 reflected by the sample can be guided to the optical detector via the second optical delivery fiber assembly 21, 22, 23 and the first delivery fiber assembly 5, 6. In an embodiment the delivery fiber 5 and the second optical fiber 22 comprise a cladding with an NA of at least 0.1, such as at least 0.15, such as at least 0.22. Also in this embodiment the fibers 5, 22 will guide some of the light 31 which is being reflected from the sample under test.

In an embodiment the optical component 3 comprises means to separate the light that is reflected from the sample and guided by the fibers 33 from at least some of the light from the broad band source. Such means is for example a beam splitter 32.

In an alternative embodiment a double-clad fiber coupler is applied instead of a splitter for example by providing a double-clad fiber coupler at the input end of the first delivery fiber. The double-clad fiber coupler is advantageously configured for separating core and cladding light, e.g. by having a 2X2 port structure comprising multimode double clad fibers on two ports of the coupler and single mode double clad fibers on the other two ports, such as e.g. the DC1300 LEB offered by Thorlabs. In principle a portion or all of the reflected

light could be separated from the major part of the light from the broad band source but any other means known to the skilled person.

Advantageously the reflected and separated light is transmitted to an optical
5 detector 34, such as e.g. a photodiode or a spectrometer.

Fig. 6 is a schematic illustration of an embodiment of an apparatus of the invention in form of an interferometer e.g. for use in optical coherence tomography (OCT) e.g. for visualization of internal tissue. The interferometer comprises a first delivery fiber assembly 105a, 106a comprising a fused
10 coupler delivery fiber assembly 105b, 106b where the first delivery fiber assembly 105a, 106a and the fused coupler delivery fiber assembly 106b is fused in a component section 100. The interferometer comprises a broad band source comprising an optical pump source 101a operable to generate pump pulses an air hole microstructured optical fiber 101b for generating
15 broad band light pulses upon feeding of pump pulses from said optical pump source 101a and the first delivery fiber assembly 105a, 106a comprising a delivery fiber 105a comprising solid inclusions as described above and a connector member 106a also as described above. The first delivery fiber assembly 105a, 106a is connected to the microstructured optical fiber via a
20 delivery fiber connector member 106c which is advantageously as the connector member described above, and an end cap connection member 101c. In the end cap connection member 101c the air holes along less than a few mm of the air hole microstructured optical fiber 101b are collapsed and the light beam is collimated by a not shown lens. The delivery fiber connector
25 member 106c and the end cap connection member 101c are mated and held together by a mating sleeve 20c. In an alternative embodiment the air hole microstructured optical fiber 101b is spliced to the delivery fiber 105 by splicing and/or by using a GRIN lens as described above.

The interferometer comprises a second fiber assembly 21a, 22a, 23a which
30 advantageously is as the second fiber assembly 21, 22, 23 described above,

and the connector members 106a, 21a are connected and hold together by mating sleeve 20a.

The fused coupler delivery fiber assembly 105b, 106b is connected to a third fiber assembly 21b, 22b, 23b which advantageously is as the second fiber assembly 21, 22, 23 described above, and the connector members 106b, 21b are connected and held together by mating sleeve 20b. The interferometer further comprises a mirror 40 or another reference unit arranged to reflect light emitted via the fiber termination unit 23b. In an alternative embodiment the reference unit is not included in the apparatus but can be selected by the user.

- 10 The fused coupler delivery fiber assembly 105b is further connected to a detector 124, such as a spectrometer. The broad band source may comprise one or more tunable or non-tunable filters and or a pulse picker and one or more amplifiers such as it is well known in the art.

- 15 In general a coupler has a bar port, where the light goes straight through from one top arm to the other top arm (or from the bottom arm to the other bottom arm), and a cross port where the light goes from the top arm to bottom arm, or vice versa. Often couplers are close to have a very low loss such that all the light is send to the bar port or the cross port. In this embodiment the two top arms are provided by the delivery fiber 105a on either side of the component section 100 and the bottom arms are provided by the delivery fiber 105b on either side of the component section. The bar ports and the cross port are provided by the component section 100. The bar port has a transmission coefficient of x and the cross arm a transmission coefficient of $(1-x)$. The transmission coefficient is the same irrespective of which direction the coupler is traversed.
- 20
- 25

In use broad band light pulses are transmitted to the delivery fiber 105a and as marked on the illustration in the end of the delivery fiber 105a nearest to the microstructured optical fiber the light pulses power is set to be 100 % = "1". At the fused component section 100, some of the light (x) is transmitted

further via the delivery fiber 105a and some of the light $(1-x)$ is transmitted further via the fused coupler delivery fiber 105b.

The light portion (X) transmitted from the fused component section 100 and via the delivery fiber 105a is transmitted to the second fiber assembly 21a, 22a, 23a and via the fiber termination unit 23a the light pulses are emitted towards a sample 30 and reflected light 31a is transmitted in the opposite direction via the second fiber 22a and the delivery fiber 105a until the remitted light reaches the fused component section 100. From there a portion of remitted light is transmitted further via the fused coupler delivery fiber 105b to the detector 104.

The light portion $(1-X)$ transmitted from the fused component section 100 and via the fused coupler delivery fiber 105b is transmitted to the third fiber assembly 21b, 22b, 23b and via the fiber termination unit 23b the light pulses are emitted towards a mirror 40 and reflected light 31b is transmitted in the opposite direction via the third fiber 22b and the fused coupler delivery fiber 105b until the remitted light reaches the fused component section 100. From there a portion of remitted light is transmitted further via the fused coupler delivery fiber 105b to the detector 104. Advantageously the mirror reflects substantially all of the light that is incident on it.

As explained the interferometer thereby has two interferometer arms, one that is guiding light to a sample and re-transmit reflected light and one that is guiding light to a reference unit (e.g. a mirror) and re-transmits reflected light. In an embodiment one interferometer arm is configured for being focused onto a tissue sample and for scanning the sample in an X-Y longitudinal raster pattern. The other interferometer arm is bounced off the reference mirror. Reflected light from the tissue sample is combined with reflected light from the reference.

As mentioned above in the embodiment shown in fig. 6 the light goes from the broad band laser goes through the cross port of the coupler to reach the mirror 40. It is reflected from the mirror and goes back through the bar port of

the coupler to reach the detector 124. Assuming that the reflection is loss less the transmission coefficient for the entire path is the product of the two transmission coefficients, i.e. $x(1-x)$.

Fig. 7 is a schematic illustration of an embodiment of a delivery fiber of the invention comprising a combiner.

Advantageously all of the delivery fibers 105a, 105b, 22a, 22b are all solid fibers comprising microstructures in form of inclusions as described above and preferably all of the delivery fibers 105a, 105b, 22a, 22b have a transmission bandwidth of 200 nm or more, preferably the transmission bandwidths are overlapping or identical.

Fig. 7 is a schematic illustration of an embodiment of an apparatus of the invention in form of another type of interferometer e.g. for use in optical metrology e.g. for thin film, wafer, optical critical dimension (OCD), overlay and wafer stress for transistor and interconnect metrology applications.

Parts of the interferometer of Fig. 7 are similar to corresponding parts of the interferometer of Fig.6. The interferometer comprises a first delivery fiber assembly 105a, 106a comprising a fused splitter delivery fiber assembly 105b, 106b where the first delivery fiber assembly 105a, 106a and the fused splitter delivery fiber assembly 106b is fused in a component section 100. The interferometer comprises a broad band source comprising an optical pump source 101a operable to generate pump pulse, a microstructured optical fiber 101b for generating broad band light pulses upon feeding of pump pulses from said optical pump source 101a and the first delivery fiber assembly 105a, 106a comprising a delivery fiber 105a comprising solid inclusions as described above and a connector member 106a also as described above. The first delivery fiber assembly 105a, 106a is connected to the microstructured optical fiber via a filter 32 arranged to directing a portion of reflected light 33 reflected by the sample 30e and the reference unit 40 towards an optical detector 34. The remaining parts are as in the example of Fig. 7.

Fig. 8 illustrates a spectral engine source suitably for supplying light to an apparatus. The spectral engine source comprises three lasers 121, 222, 123 emitting laser beams 121a, 122a, 123a respectively. The laser beams 121a, 122a, 123a differs from each other with at least one wavelength as described
5 above.

The lasers 121, 222, 123 may be of same or of different types, such as one or more gas lasers, one or more chemical lasers, one or more metal-vapor lasers and/or one or more semiconductor lasers.

The spectral engine source further comprises a multiplexer M here illustrated
10 by a number of mirrors arranged to combine the beams 121a, 122a, 123a into one single multiplexed beam M. It should be understood that the multiplexer may be any kind of multiplexer or combiner capable of combining least a portion of the laser beams of each of the lasers and for collimating the received light to a multiplexed beam. The multiplexer M collimates the 121a,
15 122a, 123a sufficiently close to be received by the delivery fiber of the spectral engine source of the invention. For simplification the delivery fiber is not shown of the spectral engine source, however the delivery fiber is arranged to collect the multiplexed beam M and to delivering at least a part of the received multiplexed beam M to the apparatus,

20 Fig. 9 illustrates another spectral engine source suitably for supplying light to an apparatus. The spectral engine source comprises 5 lasers 131, 232, 133, 134, 135 emitting laser beams 131a, 132a, 133a, 134a, 135a respectively. The laser beams 131a, 132a, 133a, 134a, 135a differs from each other with at least one wavelength. For example laser beam 131a may comprise
25 wavelength (s) in the range of 400-500nm, laser beam 132a may comprise wavelength (s) in the range of 500-600nm, laser beam 133a may comprise wavelength (s) in the range of 600-700nm, laser beam 135a may comprise wavelength (s) in the range of 800-900nm.

The spectral engine source further comprises a multiplexer M here illustrated by a number of mirrors arranged to combine the beams 131a, 132a, 133a, 134a, 135a into one single multiplexed beam M. The spectral engine source also comprises a not shown delivery fiber as described above for receiving the multiplexed beam and to delivering at least a part of the received multiplexed beam M to an apparatus,

Fig. 10 illustrates an apparatus of an embodiment of the invention comprising a light source LS selected from a broad band source, a broad band source system or a spectral engine source with a delivery fiber DL as described above. The apparatus is a lithographic apparatus and comprises an illumination system (illuminator) IL arranged to receive the light from the delivery fiber of the light source LS. The illuminator IL may comprise an adjuster AD for adjusting the angular intensity distribution of the radiation beam received from the light source LS. In addition, the illuminator IL may comprise various other components, such as an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

The radiation beam B is incident on a patterning device (e.g., mask MA), which is held on the support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor (which is not explicitly depicted in Fig. 1) can be used to accurately position the mask MA with respect to the path of the radiation beam B, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse

positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner) the mask table MT may be connected to a short-stroke actuator only, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies. The apparatus may for example operate as described in US2007013921

Fig. 11 illustrates an apparatus of an embodiment of the invention comprising scanning microscope that is embodied as a confocal scanning microscope and a light source LS selected from a broad band source, a broad band source system or a spectral engine source with a delivery fiber DL as described above. The light source LS delivers an illuminating light beam 211 via the delivery fiber DL

The scanning microscope comprises an acoustooptical component 213 that is embodied as AOTF 215. From acoustooptical component 213, light 212, selected out of illuminating light beam 211, arrives at a beam deflection device 17 that contains a gimbal-mounted scanning mirror 19 and that guides illuminating light beam 211 through scanning optical system 221, tube optical system 223, and objective 225 over or through specimen 227. Detected light beam 229 coming from the specimen travels in the opposite direction through scanning optical system 221, tube optical system 223, and objective 225, and arrives via scanning mirror 219 at acoustooptical component 213 which conveys detected light beam 229 to detector 231, which is embodied as a multi-band detector. Illuminating light beam 211 is depicted as a solid line in

the drawing, and detected light beam 229 as a dashed line. Illumination pinhole 233 and detection pinhole 235 that are usually provided in a confocal scanning microscope are schematically drawn in for the sake of completeness. Omitted in the interest of better clarity, however, are certain optical elements for guiding and shaping the light beam. Acoustooptical component 213, which serves to select the wavelength spectrum that is chosen, is configured as AOTF 215, through which an acoustic wave passes. The acoustic wave is generated by an electrically activated piezo acoustic generator 237. Activation is accomplished by a high-frequency source 239 that generates an electromagnetic high-frequency wave that exhibits an adjustable HF spectrum. The HF spectrum is chosen in such a way that only those portions of illuminating light beam 211 having the desired wavelength arrive at beam deflection device 217. The other portions of illuminating light beam 211 not influenced by the acoustic excitation are directed into a beam trap 241. The power level of the illuminating light beam 211 can be selected by varying the amplitude of the acoustic wave. The crystal sectioning and orientation of acoustooptical component 213 are selected in such a way that with a single coupling-in direction, different wavelengths are deflected in the same direction. A computer 243 is used to choose a second or third wavelength spectrum. Monitor 247 of computer 243 serves as the display for the spectral composition. Selection of the wavelength spectrum together with its spectral composition is accomplished on the basis of a graph G within a coordinate system having two coordinate axes X, Y. The wavelength of the light is plotted on coordinate axis X, and its power level on coordinate axis Y. Computer 243 controls high-frequency source 239 in accordance with the user's stipulation. The user makes adjustments using computer mouse 257. Depicted on monitor 247 is a slider 259 that serves for adjustment of the overall light power level of illuminating light beam 11 or detected light beam 229.

Although embodiments have been described and shown in detail, the invention is not restricted to them, but may also be embodied in other ways

within the scope of the subject matter defined in the following claims. In particular, it is to be understood that other embodiments may be utilized and structural and functional modifications may be made without departing from the scope of the present invention.

PATENT CLAIMS

1. A delivery fiber assembly suitable for delivering broad band light and comprising a delivery fiber and a connector member, said delivery fiber has a length, an input end for launching light and a delivery end for delivering light,
5 said delivery fiber comprises along its length a core region and a cladding region surrounding the core region wherein the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index up to N_{inc} and extending in the length of the longitudinal axis of the
10 delivery fiber, wherein $N_{inc} < N_{bg}$ and the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region, said core region has a diameter up to about 15 μm , said connector member being mounted to said delivery fiber at a delivery end section of the delivery fiber comprising said delivery end, said
15 delivery fiber has a transmission bandwidth of about 200 nm or more, such as of about 300 nm or more, such as of about 400 nm or more, such as of about 500 nm or more.
2. The delivery fiber assembly of claim 1, wherein the said connector
20 member being mounted to said delivery fiber at said delivery end section of the delivery fiber at a distance to said delivery end, such that the delivery end is passing through the connector member for connecting said delivery end in physical contact with a receiver waveguide, preferably a receiver fiber, such as a receiver fiber incorporated in an apparatus for illumination and/or
25 metrology and/or surgery.
3. The delivery fiber assembly of claim 1 or claim 2, wherein the delivery fiber for at least one wavelength within said transmission bandwidth and at least along said delivery end section has a constant mode field diameter,
30 preferably said delivery fiber, at least along said delivery end section has a

constant mode field diameter to wavelength profile within said transmission bandwidth.

4. The delivery fiber assembly of any one of the preceding claims,
5 wherein the delivery fiber at least along said delivery end section has a mode field diameter range for said transmission wavelength, wherein the mode field diameter range is about 30 % or less, such as less than about 20 % or less, such than about 15 % or less, such as about 10 % or less of the lowest mode field diameter of the range.

10

5. The delivery fiber assembly of any one of the preceding claims,
wherein the delivery fiber for at least one wavelength within said transmission bandwidth and at least along said delivery end section has a constant
15 numerical aperture NA and a propagation loss less than 0.5 dB/m, such as less than about 0.2 dB/m.

6. The delivery fiber assembly of any one of the preceding claims,
wherein said delivery fiber is single mode for at least one wavelength within
20 said transmission bandwidth, preferably said delivery fiber is single mode for at least about 50 %, such as at least about 80 % of the transmission bandwidth, such as for the entire transmission bandwidth of said delivery fiber.

25 7. The delivery fiber assembly of any one of the preceding claims,
wherein said delivery fiber is a polarization-maintaining optical fiber (PM fiber), preferably said delivery fiber comprises one or more stress elements.

8. The delivery fiber assembly of any one of the preceding claims,
30 wherein the core region has a diameter of up to about 10 μm , such as from about 3 μm to about 8 μm , such as from about 4 to about 6 μm , preferably

the core region has a substantially identical diameter along the major part of the delivery fiber, such as preferably along at least about 80 % of the length of the delivery fiber.

- 5 9. The delivery fiber assembly of any one of the preceding claims, wherein the core region diameter is substantially identical along the length of the delivery fiber, optionally excluding one or more component sections of the delivery fiber.
- 10 10. The delivery fiber assembly of any one of the preceding claims, wherein the delivery fiber has a core region diameter to pitch d/Λ which is about 0.7 or less, such as from about 0.3 to about 0.65, such as from about 0.4 to about 0.6.
- 15 11. The delivery fiber assembly of any one of the preceding claims, wherein the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least four rings of inclusions surrounding the core region, such as at least five rings of inclusions surrounding the core region, said rings of inclusions are arranged in a pitch pattern, a double pitch
20 pattern, a triple pitch pattern, a half pitch pattern or a combination thereof, where a pitch is determined as the smallest center to center distance between the core region and an inclusion.
12. The delivery fiber assembly of any one of the preceding claims,
25 wherein the core region has a refractive index N_{core} , and the cladding region has an effective refractive index N_{clad} , and the refractive index N_{bg} of the cladding background material is substantially identical to the refractive index of the core region N_{core} .
- 30 13. The delivery fiber assembly of any one of the preceding claims, wherein the delivery fiber is a silica fiber and the solid inclusions are of down

doped silica, preferably the solid inclusions independently of each other are silica doped with at least one of fluorine and/or boron and/or component comprising F and/or B atoms, preferably said solid inclusions for at least one wavelength within the transmission bandwidth and independently from each other have a refractive index difference relative to the refractive index N_{bg} of the cladding background material of from about 10^{-3} to about 10^{-2} .

14. The delivery fiber assembly of any one of the preceding claims, wherein the inclusions have substantially identical refractive index N_{inc} .

15. The delivery fiber assembly of any one of the preceding claims 1-10, wherein n of the inclusions have different refractive index $N_{inc(n)}$, where n is an integer up to the number of inclusions, such as up to 10, such as 2-4.

16. The delivery fiber assembly of claim 15, wherein the inclusions of a ring of inclusions comprises two or more inclusions having different refractive index.

17. The delivery fiber assembly of claim 15, wherein the inclusions of a ring of inclusions have substantially identical refractive index, optionally inclusions of one ring of inclusion have a different refractive index than the inclusions of another ring of inclusions, preferably the inclusions of said one ring of inclusion have higher refractive index than the inclusions of another ring of inclusions closer to the core region.

18. The delivery fiber assembly of any one of the preceding claims, wherein the solid inclusions have equal or different diameters, preferably the diameter(s) is/are up to about 5 μm , such as up to about 3 μm , such as from about 0.2 to about 1 μm , such as from about 0.4-0.8 μm .

19. The delivery fiber assembly of any one of the preceding claims, wherein the delivery fiber is an all solid fiber, preferably the delivery fiber is an all silica fiber, wherein the core region, the cladding region and/or the inclusions are doped to reach their respective refractive indices.

5

20. The delivery fiber assembly of any one of the preceding claims, wherein the transmission bandwidth of the delivery fiber comprises wavelengths within the range of from about 400 nm to 900 nm, preferably the transmission bandwidth of the delivery fiber comprises at least a
10 bandwidth of about 100 nm, such as at least a bandwidth of about 200 nm, such as at least a bandwidth of about 300 nm, such as at least a bandwidth of about 400 nm, such as the entire bandwidth within the range of from about 400 nm to 900 nm.

15 21. The delivery fiber assembly of claim 20, wherein the transmission bandwidth of the delivery fiber comprises wavelengths below 800 nm, such as below 700 nm, such as below 600 nm, such as below 500 nm.

22. The delivery fiber assembly of any one of the preceding claims,
20 wherein the transmission bandwidth of the delivery fiber comprises wavelengths within the range of from about 1100 nm to 2400 nm, preferably the transmission bandwidth of the delivery fiber comprises at least a bandwidth of about 100 nm, such as at least a bandwidth of about 200 nm, such as at least a bandwidth of about 300 nm, such as at least a bandwidth
25 of about 400 nm, such as the entire bandwidth within the range of from about 1100 nm to 2400 nm.

23. The delivery fiber assembly of any one of the preceding claims, wherein the delivery fiber has a length of from about 5 cm to about 100 m,
30 such as from about 10 cm to about 30 m, such as from about 20 cm to about 20 m, such as from about 30 cm to about 10 m.

24. The delivery fiber assembly of any one of the preceding claims, wherein the delivery fiber comprises at least one component section, said component section is configured for splitting off light from the delivery fiber and/or for combining light into the delivery fiber, said component section preferably is an all fiber component section.

25. The delivery fiber assembly of claim 19, wherein said assembly comprises a fused coupler, wherein said fused coupler is fused to the delivery fiber at said component section optionally for coupling light into the delivery fiber.

26. The delivery fiber assembly of claim 19 or claim 20, wherein said assembly comprises a fused splitter, wherein said fused splitter is fused to the delivery fiber at said component section for splitting a fraction of light from the delivery fiber, preferably said split off light fraction constitutes from 5 – 95 % by power of the light, wherein the said split off light fraction has a wavelength profile substantially identical to that of the light fraction from which it was split.

20

27. The delivery fiber assembly of claim 21, wherein said fused splitter comprises a twin delivery fiber for delivering light, said twin delivery fiber comprises a twin delivery end and a length extending at least from said component section to said twin delivery end and comprises along its length a core region and a cladding region surrounding the core region wherein the cladding region comprises a cladding background material having a refractive index TN_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index of up to N_{inc} and extending in the length of the twin delivery fiber, wherein $TN_{inc} < TN_{bg}$ and the plurality of inclusions in the cladding region are arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region, preferably a twin

30

connector member being mounted to said twin delivery fiber at a twin delivery end section of the twin delivery fiber comprising said twin delivery end.

5 28. The delivery fiber assembly of any one of claims 19-21, wherein said assembly comprises a fused coupler and a fused splitter, wherein said fused splitter is fused to the delivery fiber at a first component section and said fused coupler is fused to the delivery fiber at a second component section closer to the delivery end of the delivery fiber, said fused splitter and fused
10 coupler comprising a loop fiber configured for delaying a light pulse fraction split out via the splitter and recombined into the delivery fiber via the coupler such that a split off and recombined light pulse fraction is delayed relative to the light pulse fraction from which it was split.

15 29. The delivery fiber assembly of any one of the preceding claims, wherein the assembly comprises an input end connector member, the input end connector member being mounted to said delivery fiber at an input end section of the delivery fiber comprising said input end, said connector member preferably being configured for connecting said input end in physical
20 contact with a light launching unit.

30. The delivery fiber assembly of any one of the preceding claims, wherein the assembly comprises a pre-delivery fiber, said pre-delivery fiber is coupled to said delivery fiber without free space optics.

25

31. The delivery fiber assembly of claim 25, wherein the pre-delivery fiber is connected to said delivery fiber, optionally by a splicing, preferably by a splicing where guiding one or more properties selected from mode field diameter, numerical aperture, low propagation loss or transmission band
30 width are substantially unaltered from the pre-delivery fiber to the delivery fiber.

32. A broad band source for supplying light to an apparatus, the broad band source comprising

- an optical pump source operable to generate pump pulses
- 5 • a microstructured optical fiber for generating broad band light pulses upon feeding of pump light; and
- a delivery fiber arranged for receiving at least a portion of at least some of said broad band light pulses and for delivering at least a part of said received portion of said broad band light pulses to said
- 10 apparatus,

wherein said optical pump source is arranged to launch pump pulses to said microstructured optical fiber, and said delivery fiber has a length, an input end for launching light and a delivery end for delivering light, said delivery fiber comprises along its length a core region and a cladding region

15 surrounding the core region wherein the core region has a diameter of up to about 15 μm and the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index of up to N_{inc} and extending in the length of the longitudinal axis of the delivery fiber, wherein

20 $N_{inc} < N_{bg}$ and the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the core region, preferably said delivery fiber has a transmission bandwidth of about 200 nm or more, such as of about 300 nm or more, such as of about 400 nm or more, such as of about 500 nm or more.

25

33. The broad band source of claim 32, wherein for at least one wavelength within said transmission bandwidth the delivery fiber has a constant mode field diameter at least along said delivery end section,

30 preferably said delivery fiber has a substantially constant mode field diameter

to wavelength profile within said transmission bandwidth at least along said delivery end section.

34. The broad band source of claim 32 or claim 33, wherein the delivery
5 fiber is single mode for at least one wavelength within said transmission
bandwidth, preferably said delivery fiber is single mode for at least about
50 %, such as at least about 80 % of the wavelengths of the transmission
bandwidth, such as for the entire transmission bandwidth of said delivery
fiber, said delivery fiber preferably has a transmission bandwidth of about as
10 at least an octave.

35. The broad band source of the preceding claims 32-34, wherein the
delivery is a polarization-maintaining optical fiber (PM fiber), preferably said
delivery fiber comprises one or more stress elements.
15

36. The broad band source of any one of the preceding claims 32-35,
wherein the plurality of inclusions in the cladding region is arranged in a
cross-sectional pattern comprising at least four rings of inclusions surrounding
the core region, such as at least five rings of inclusions surrounding the core
20 region, said rings of inclusions are arranged in a pitch pattern, a double pitch
pattern, a triple pitch pattern, a half pitch pattern or a combination thereof,
where a pitch is determined as the smallest center to center distance between
the core region and an inclusion.

25 37. The broad band source of any one of the preceding claims 32-36,
wherein the delivery fiber has a core region diameter to pitch d/Λ which is
about 0.7 or less, such as from about 0.3 to about 0.65, such as from about
0.4 to about 0.6.

30

38. The broad band source of any one of the preceding claims 32-37, wherein the core region has a refractive index N_{core} , the cladding region has an effective refractive index N_{clad} , and the refractive index N_{bg} of the cladding background material is substantially identical to the refractive index of the
5 core region N_{core} .

39. The broad band source of any one of the preceding claims 32-38, wherein the delivery fiber is a silica fiber and the solid inclusions are of down
10 doped silica, preferably the solid inclusions independently of each other are silica doped with at least one of fluorine and/or boron and/or component comprising F and/or B atoms.

40. The broad band source of any one of the preceding claims 32-39, wherein the delivery fiber is a double clad fiber comprising an inner cladding
15 region and an outer cladding region, where the inclusions in the outer cladding region have higher index than the inclusions in the inner cladding region, preferably the inner cladding region comprises said at least two rings of inclusions of solid material having refractive index of at least N_{inc} and the outer cladding region has a higher effective refractive index than the inner
20 cladding region.

41. The broad band source of any one of the preceding claims 32-40, wherein the delivery fiber is in form of a delivery fiber assembly of any one of
25 claims 1-31.

42. The broad band source of any one of the preceding claims 32-41, wherein the optical pump source comprises a mode-locked fiber oscillator and preferably at least one amplifier.

43. The broad band source of any one of the preceding claims 32-42, wherein the microstructured optical fiber comprising holes is connected to said delivery fiber without the use of free space optics.

5 44. The broad band source of any one of the preceding claims 32-43, wherein the microstructured optical fiber is connected to said delivery fiber by butt connection.

45. The broad band source of any one of the preceding claims 32-44,
10 wherein said broad band source comprises a band pas filter for filtering the broad band light pulses, said band pas filter is preferably a tunable band pass filter, preferably selected from a grating based filter, a prism, or an acousto-optic tunable filter (AOTF).

15 46. The broad band source of claim 45, wherein said band pass filter is positioned between said microstructured optical fiber and said delivery fiber.

47. The broad band source of claim 46, wherein said delivery fiber is arranged to receive said band pass filtered portion of said broad band light
20 pulses and for delivering said at least a part of said received portion of said broad band light pulses to said apparatus without free space optics.

48. The broad band source of any one of the preceding claims 32-47, wherein said filter is a tunable optical band pass filter, configured for
25 selectively selecting a plurality of wavelengths or wavelength ranges and transmitting said selected wavelengths to the delivery fiber.

49. The broad band source of any one of the preceding claims 32-48, wherein said pump source is operable to generate pump pulses at a pump
30 pulse repetition rate, and said broad band source comprises pulse picker arranged between said pump source and said microstructured optical fiber,

said pulse picker being operable to pick out pulses to reduce the pump pulse repetition rate generated by the pump source, such that the reduced pump pulse repetition rate is launched to said microstructured optical fiber.

5

50. A broad band source system comprising the broad band source of any one of the preceding claims 32-49, wherein said broad band source system comprises a plurality of delivery fiber assemblies having different transmitting properties, wherein each of said delivery fiber assemblies comprises an input
10 end connector member and an delivery end connector member.

51. A spectral engine source for supplying light to an apparatus, the spectral engine source comprising

- two or more lasers emitting laser beams with wavelength(s) that
15 differs with at least one wavelength
- a multiplexer, and
- a delivery fiber as claimed in any one of claims 1-31

wherein the multiplexer is configured for receiving at least a portion of the laser beams of each of the lasers and for collimating the received light to a
20 multiplexed beam, said delivery fiber is arranged to receive said multiplexed beam and to delivering at least a part of said received multiplexed beam to said apparatus, and wherein said delivery fiber has a length, an input end for launching light and a delivery end for delivering light, said delivery fiber comprises along its length a core region and a cladding region surrounding
25 the core region wherein the core region has a diameter of up to about 15 μm and the cladding region comprises a cladding background material having a refractive index N_{bg} and a plurality of microstructures in the form of inclusions of solid material having refractive index of up to N_{inc} and extending in the length of the longitudinal axis of the delivery fiber, wherein $N_{inc} < N_{bg}$ and
30 the plurality of inclusions in the cladding region is arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the

core region, preferably said delivery fiber has a transmission bandwidth comprising wavelengths comprising at least a part of the wavelengths of each of the two or more lasers.

- 5 52. The spectral engine source of claim 50, wherein at least one of said laser beams emitted from said two or more lasers have a bandwidth of about 50 nm or less, such as about 25 nm or less, such as about 5 nm or less.

- 10 53. The spectral engine source of claim 51 or claim 52, wherein one of said laser beams emitted from said two or more lasers comprises at least one wavelength below 500 nm and one of said laser beams emitted from said two or more lasers comprises at least one wavelength above 800 nm.

- 15 54. The spectral engine source of any one of claims 51-53, wherein said spectral engine comprises at least three lasers, wherein a first laser of the lasers is adapted for emitting a laser beam comprising at least one wavelength below 450 nm, a second laser of the lasers is adapted for emitting a laser beam comprising at least one wavelength in the range from 500 nm to 700 nm, and a third of the lasers is adapted for emitting a laser
20 beam comprising at least one wavelength above 800 nm.

- 25 55. An apparatus comprising a broad band source of any one of claims 32-49, a spectral engine source of any one of claims 51-54 or a broad band source system of claim 50, said apparatus comprising an optical waveguide arranged for receiving light from said delivery fiber, wherein said optical waveguide comprises a connector member configured for being mated with said delivery end connector member of said delivery fiber, said optical waveguide preferably being an optical fiber.

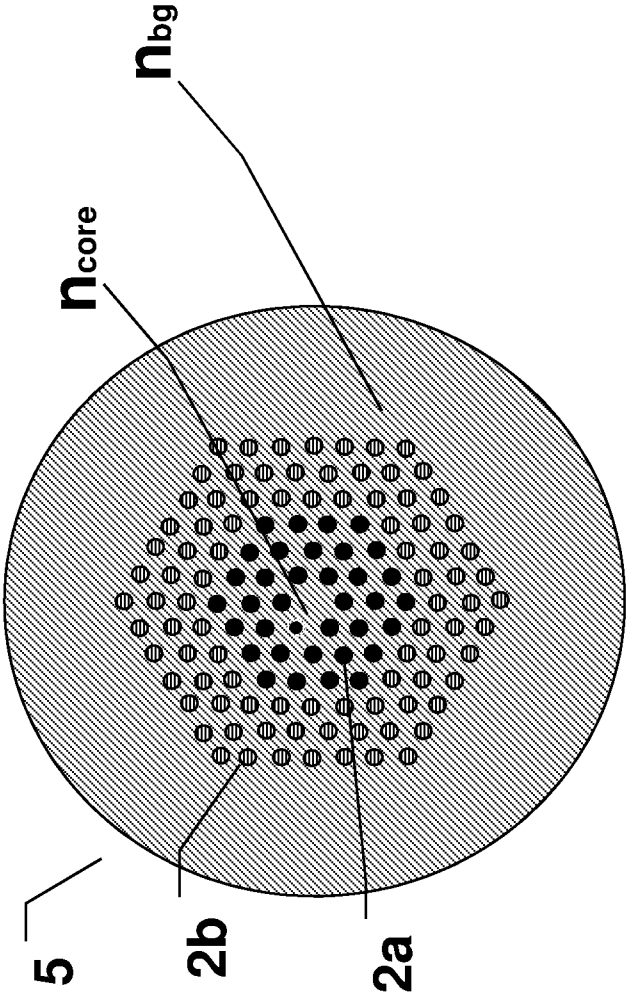
56. The apparatus of claim 55, wherein the apparatus is an illumination apparatus configured for illuminating a target, said illumination apparatus is preferably selected from a microscope, a spectroscope or an endoscope.

5 57. The apparatus of claim 55 or claim 56, wherein the illumination source is adapted for fluorescence Imaging; Fluorescence Lifetime Imaging (FLIM); Total Internal Reflection Fluorescence (TIRF) Microscopy; fluorescence resonance energy transfer (FRET); pulse interleaved excitation Foster Resonance Energy Transfer (PIE-FRET); broadband Spectroscopy;
10 nanophotonics; flow cytometry; industrial inspection, such as metrology; ringdown spectroscopy, such as gas sensing; analytical spectroscopy, such as hyperspectral spectroscopy, crop analysis e.g. of fruits and time of flight spectroscopy (TCSPC); single Molecule Imaging and/or combinations thereof.

15 58. The apparatus of any one of claims 55-56, wherein the apparatus is a metrology apparatus, said apparatus preferably comprising double clad delivery fiber configured for collecting signals from an illuminated target.

59. The apparatus of any one of claims 55-58, wherein the apparatus
20 comprises at least one delivery fiber assembly comprising a fused coupler and/or at least one delivery fiber assembly comprising a fused splitter.

Fig.1a



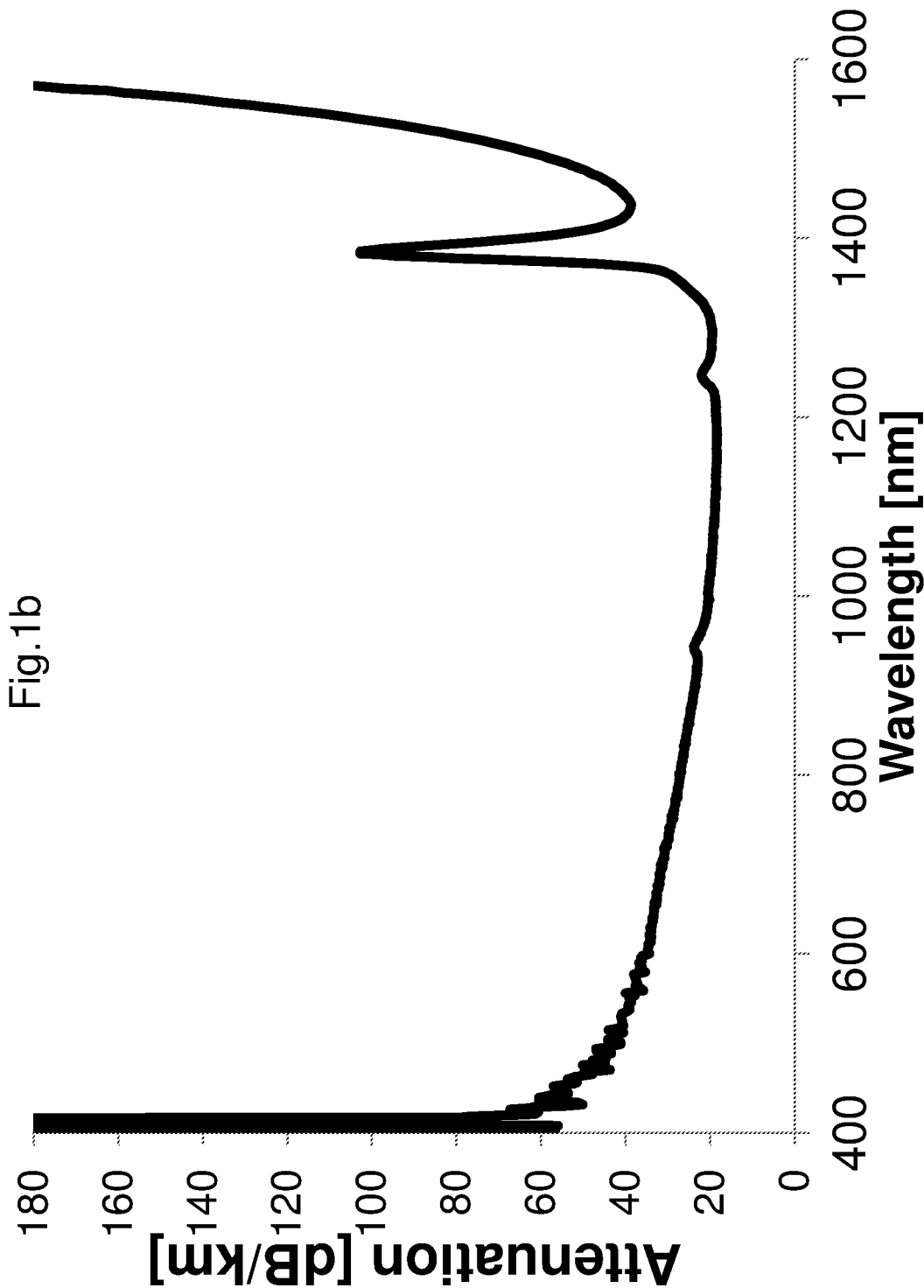


Fig.1c

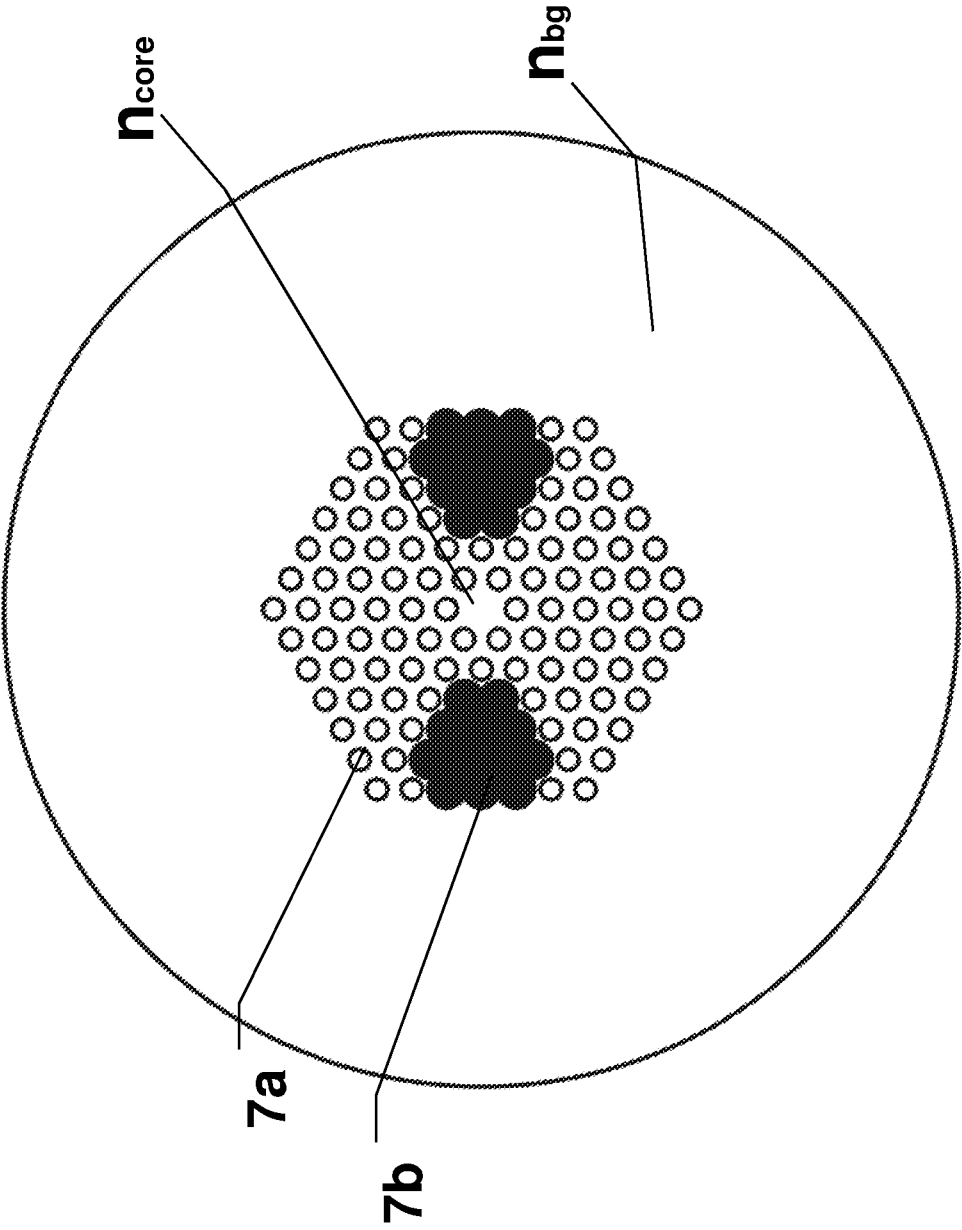


Fig.1d

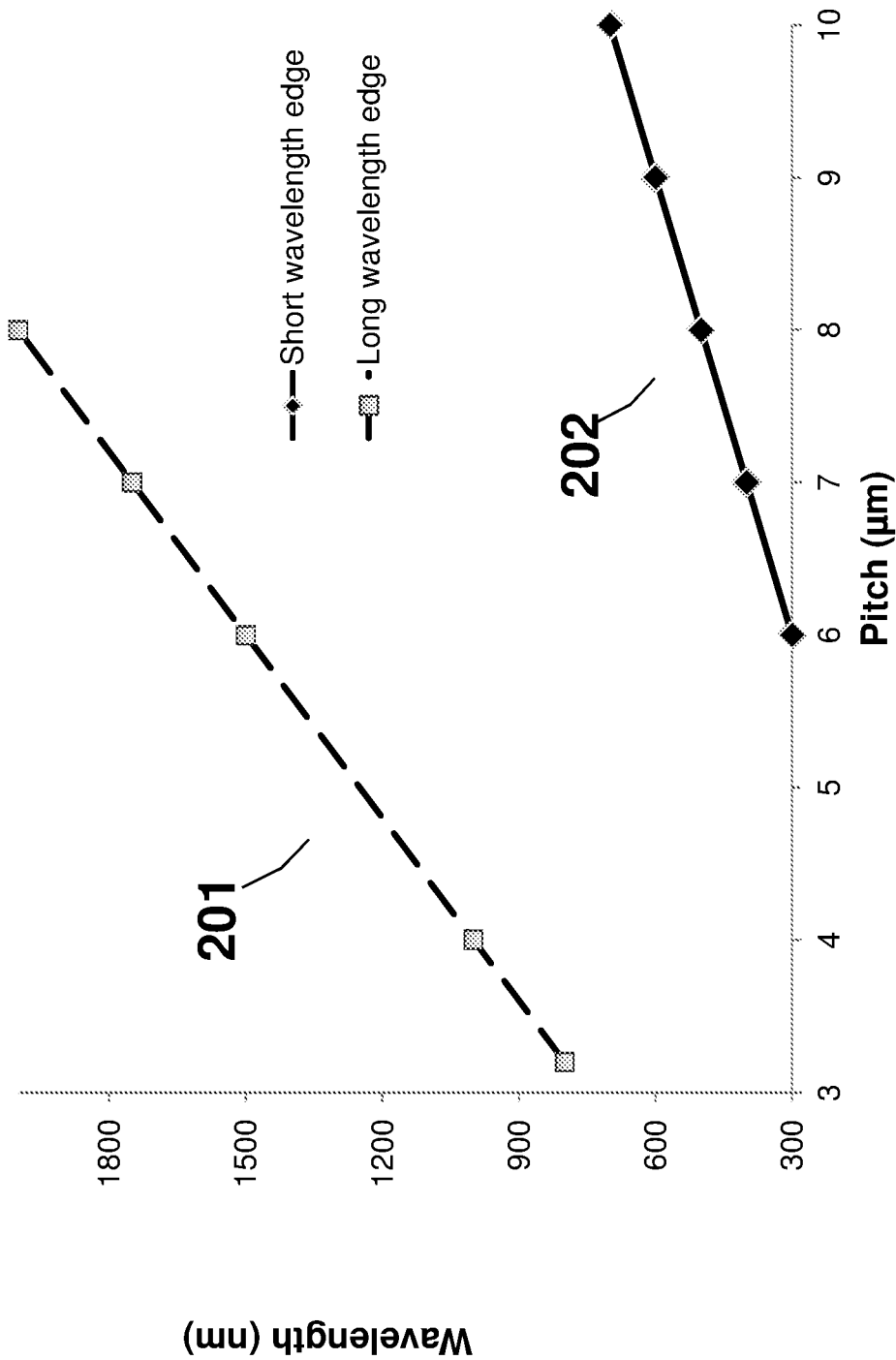


Fig.2

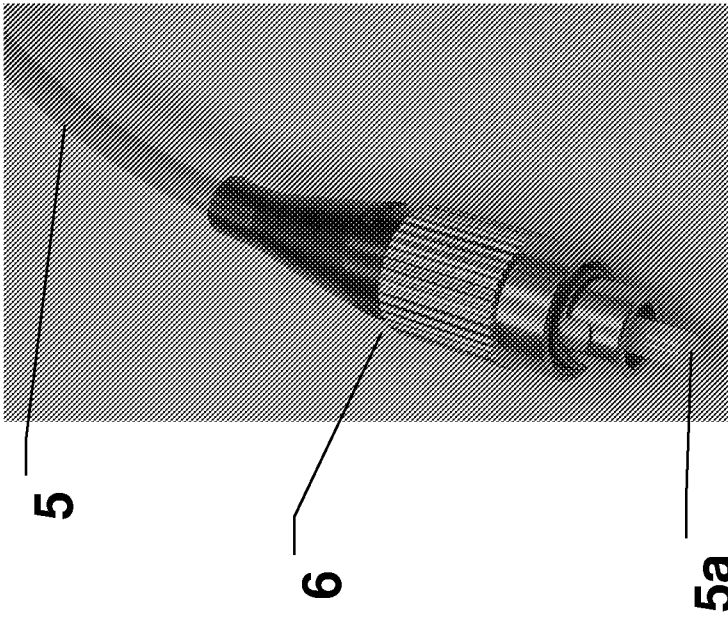


Fig.3

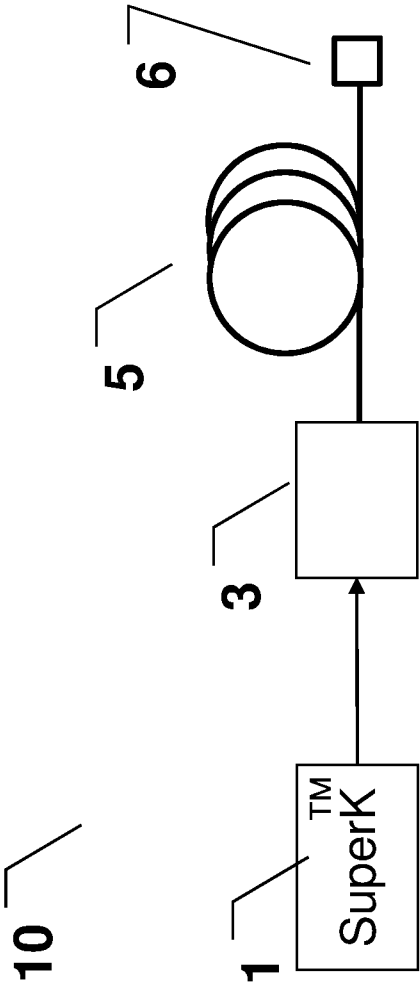


Fig.4

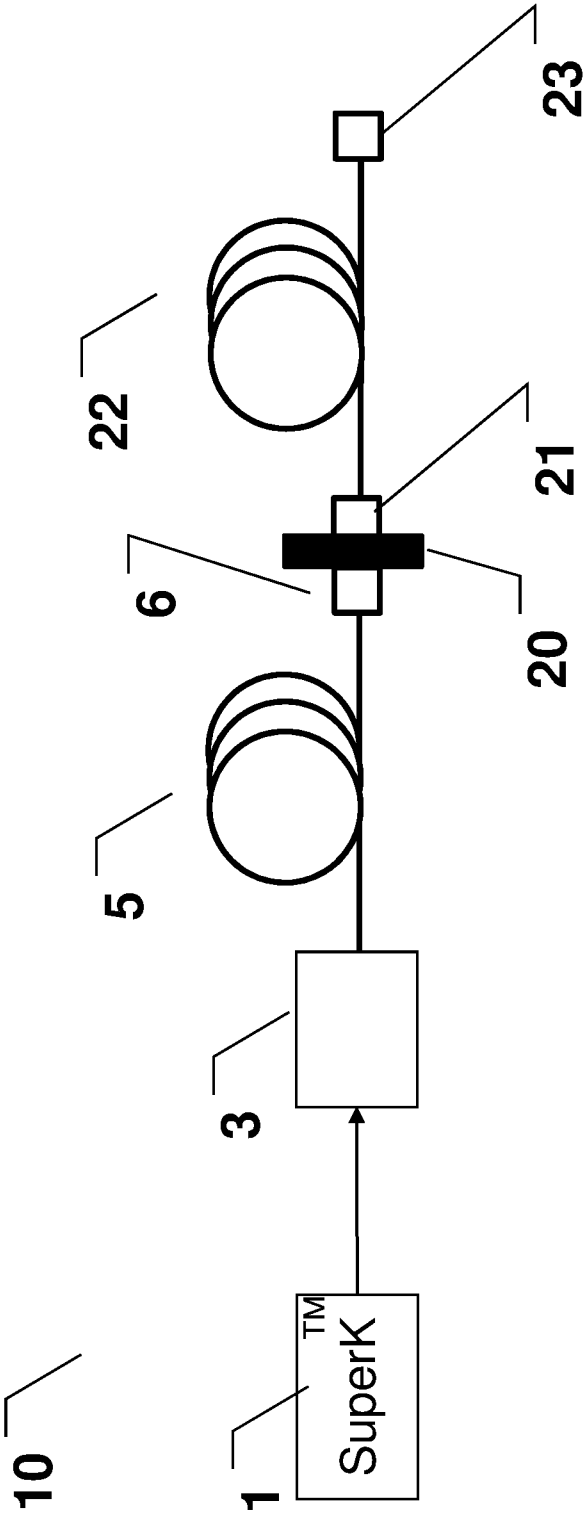


Fig.5

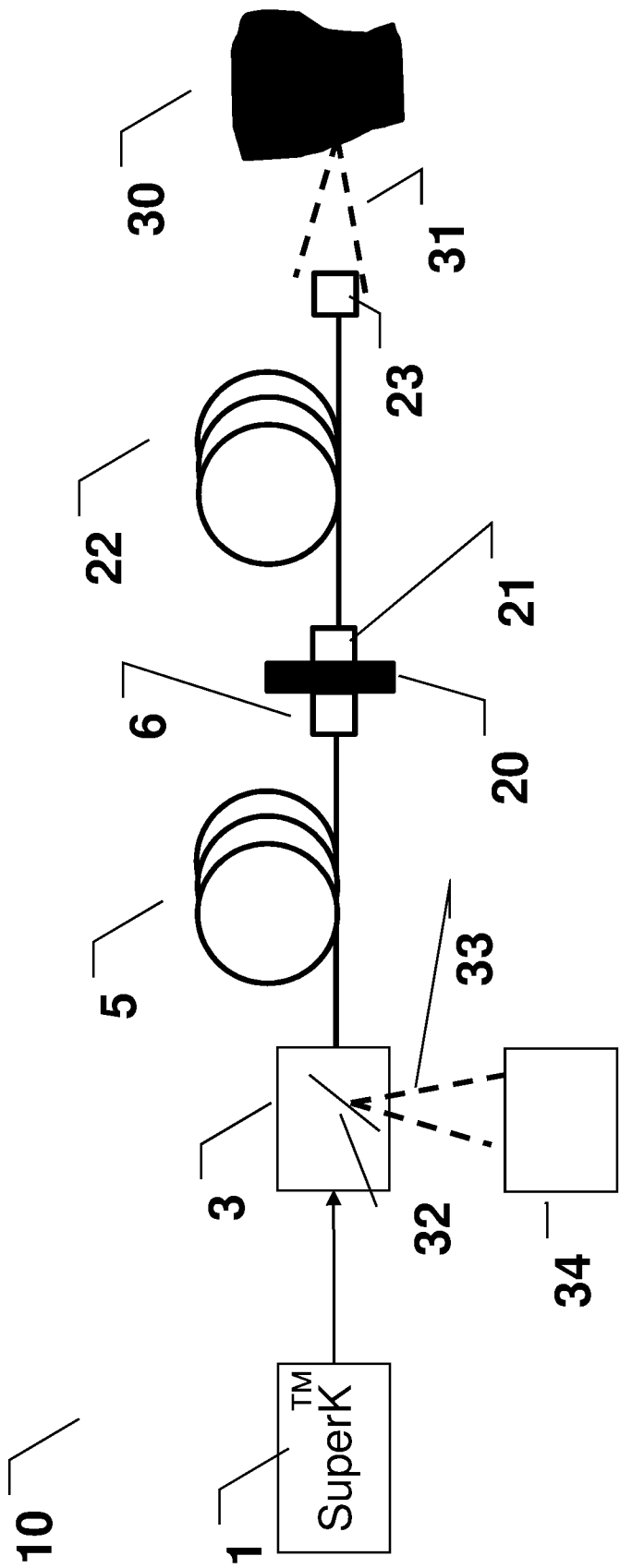


Fig. 6

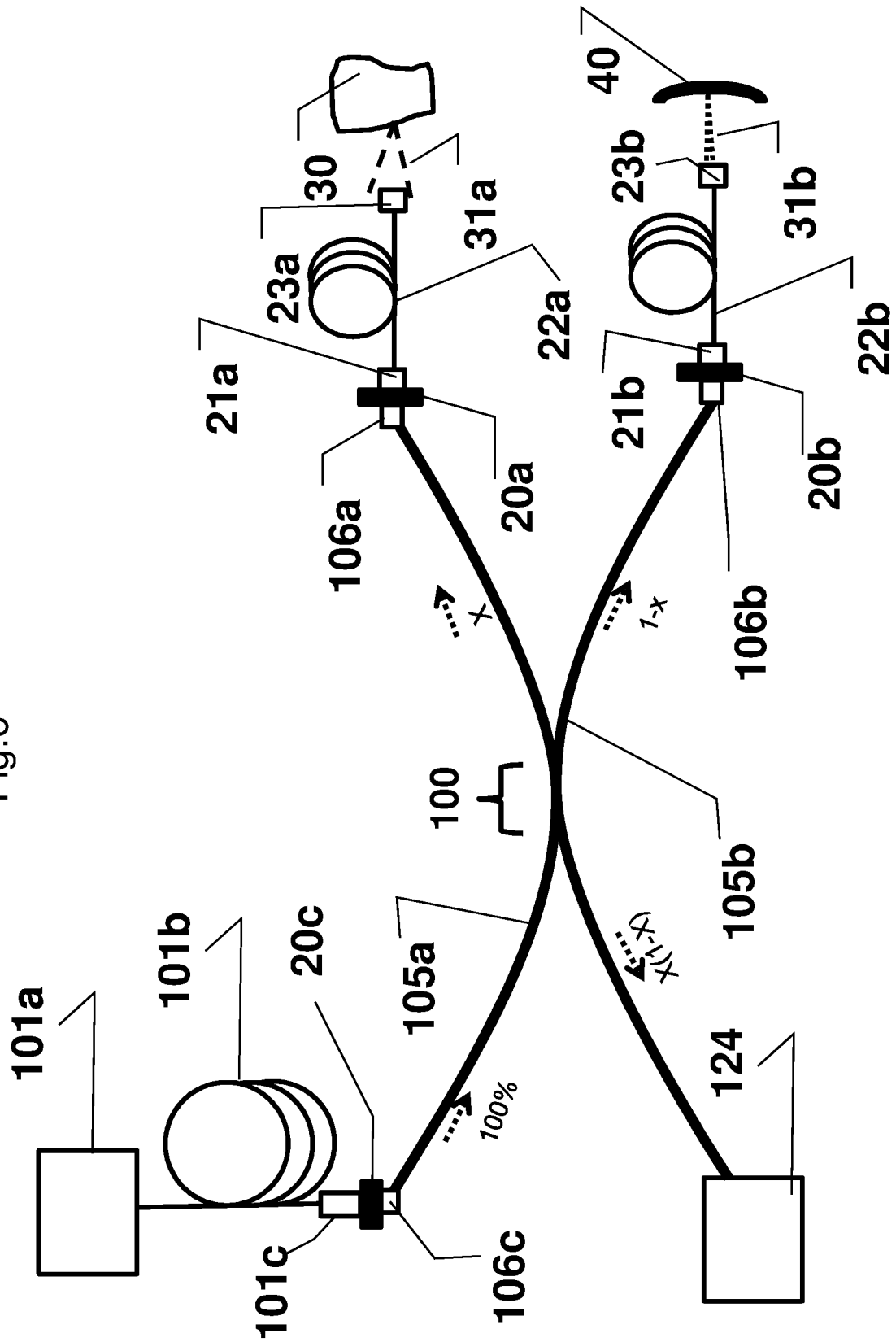


Fig.7

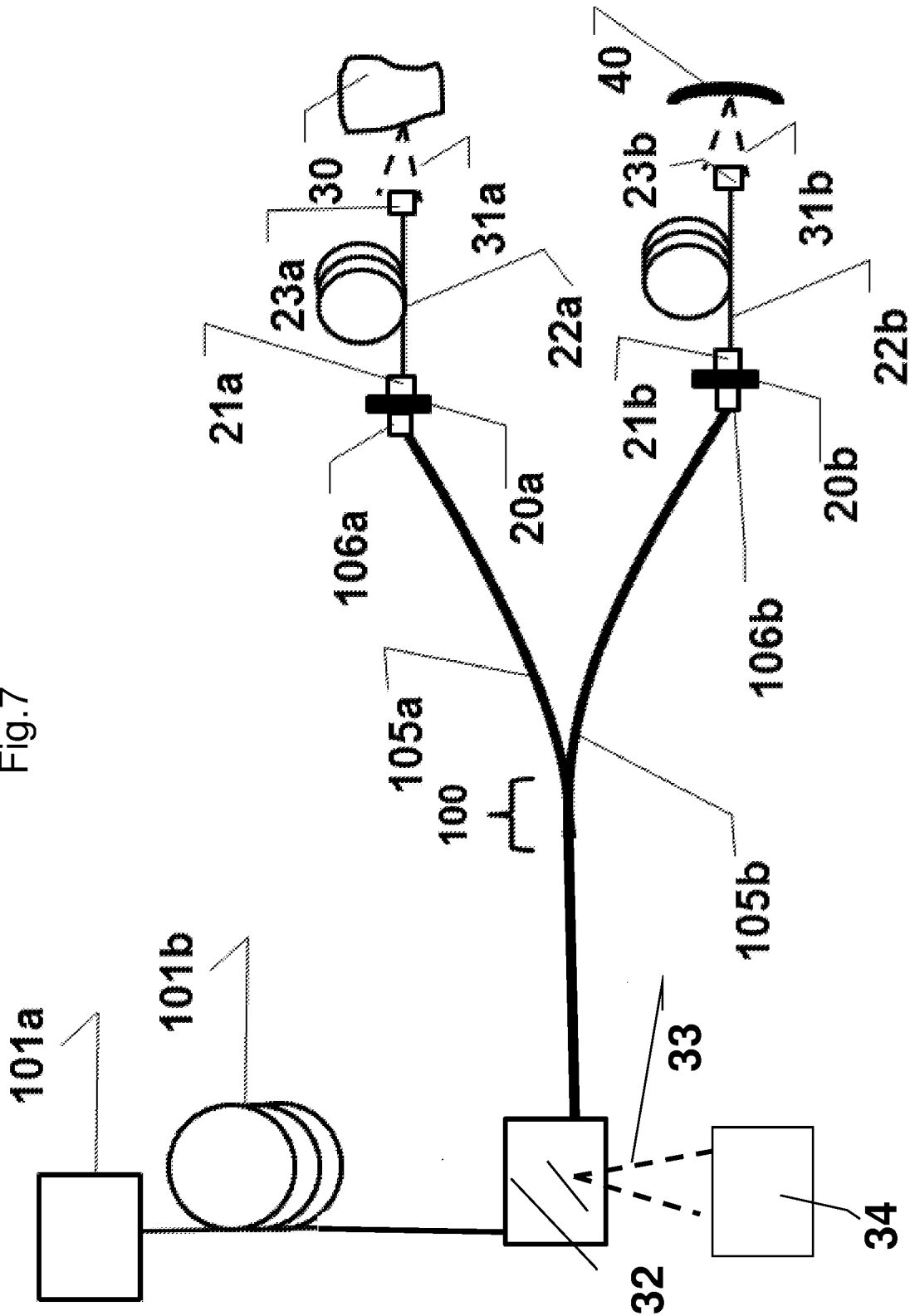


Fig.8

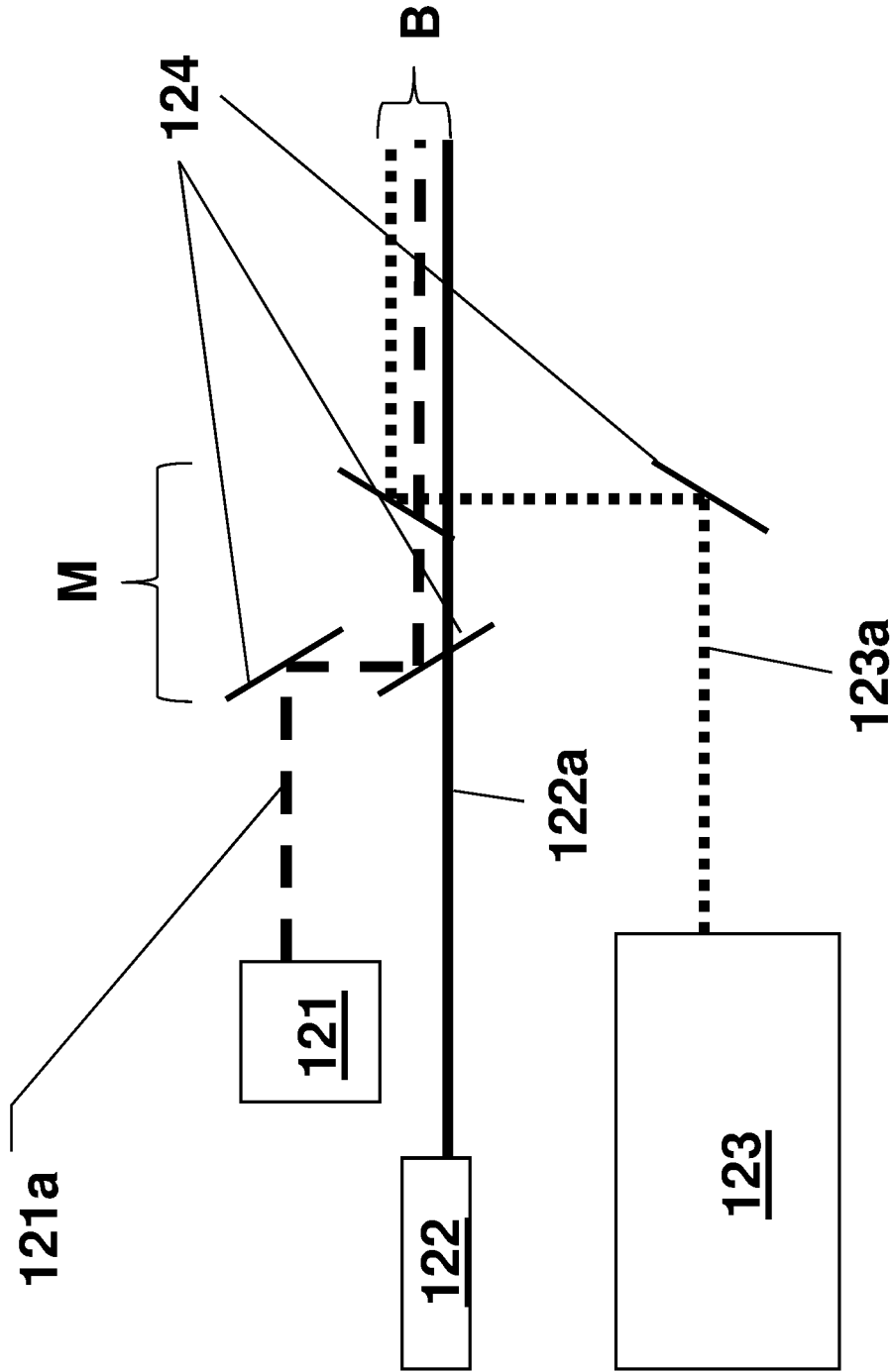


Fig.9

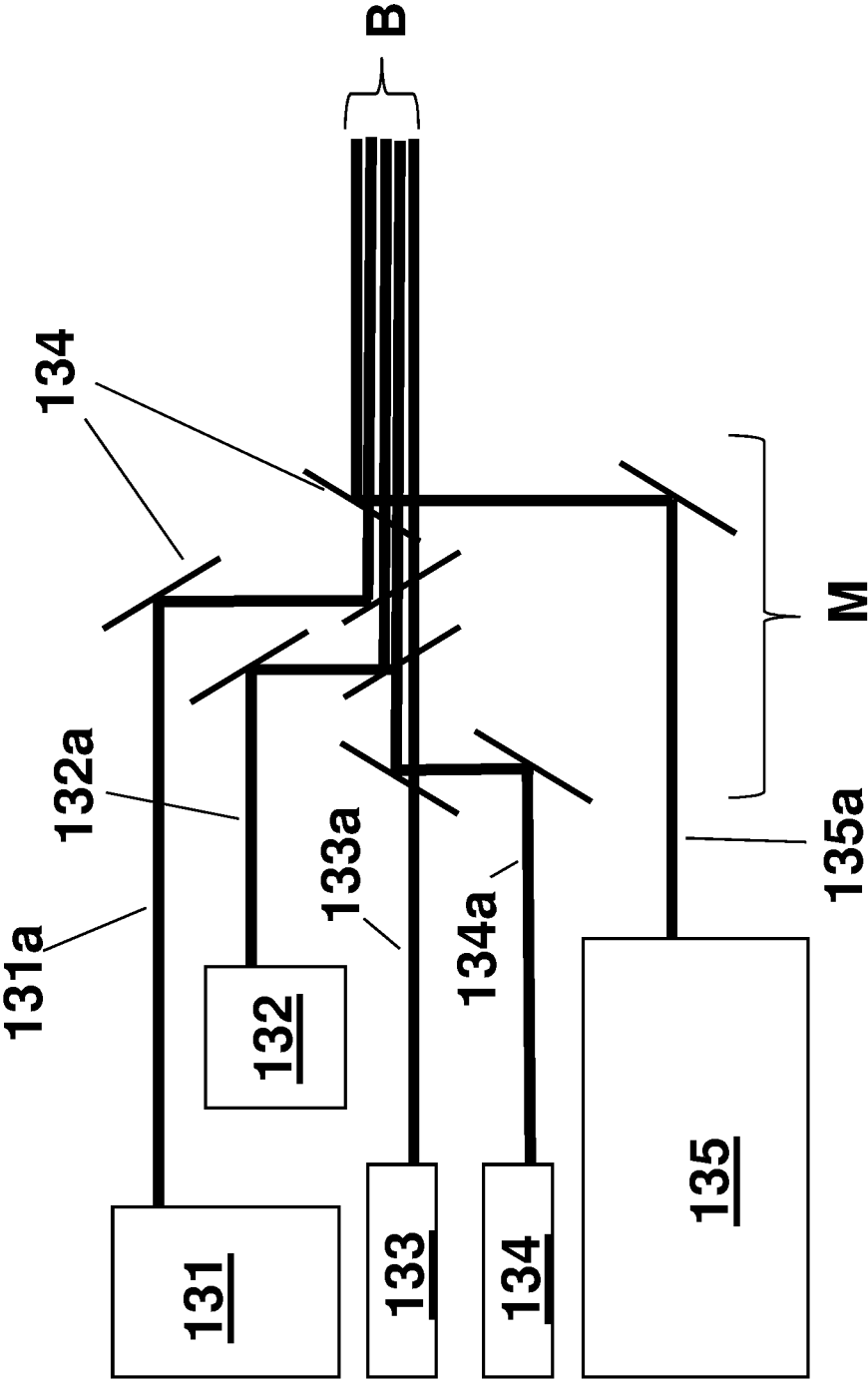
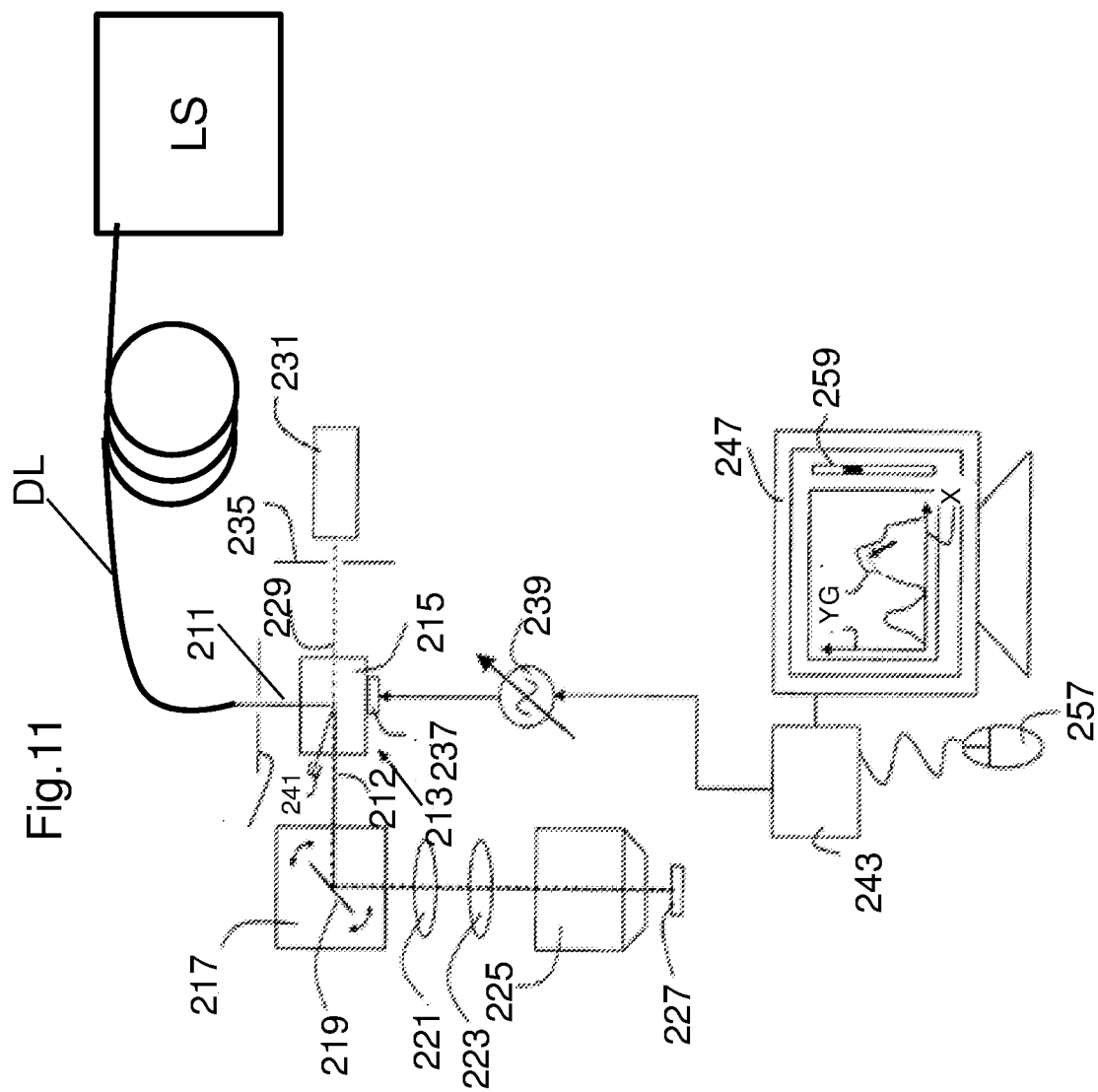


Fig. 11



INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK2016/050221

A. CLASSIFICATION OF SUBJECT MATTER G02B 6/032 (2006.01) 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) IPC/CPC: G02B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched DK, NO, SE, FI: Classes as above.		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPODOC, WPI, FULLTEXT: ENGLISH		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/077021 A1 IMRA AMERICA INC 2015.05.28 See abstract and [004 – 11] and [0095].	1 – 59
A	US 8849083 B1 (SAMSON et al.) 2014.09.30 See col. 1, l. 24 – col. 3, l. 14, col. 5, l. 20 – 30, and col. 10, l. 37 – 55.	1 – 59
A	WO 2015/084198 A1 (FUNDACJA POLSKIE CT FOTONIKI I ŚWIATŁOWODÓW) 2015.06.11 See front page and p. 8, l. 13 - p. 9, l. 10.	1 – 59
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “E” earlier application or patent but published on or after the international filing date “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) “O” document referring to an oral disclosure, use, exhibition or other means “P” document published prior to the international filing date but later than the priority date claimed “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 “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 “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 “&” document member of the same patent family		
Date of the actual completion of the international search 21/09/2016		Date of mailing of the international search report 21/09/2016
Name and mailing address of the ISA Nordic Patent Institute Helgeshøj Allé 81 DK - 2630 Taastrup, Denmark. Facsimile No. + 45 43 50 80 08		Authorized officer Thorkild Sørensen Telephone No. +45 43 50 85 44

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/DK2016/050221

Patent document cited in search report / Publication date	Patent family member(s) / Publication date
WO 2015/077021 A1 IMRA AMERICA INC 2015.05.28	US 2016245989 A1 2016.08.25
US 8849083 B1 (SAMSON et al.) 2014.09.30	None.
WO 2015/084198 A1 (FUNDACJA POLSKIE CT FOTONIKI I ŚWIATŁOWODÓW) 2015.06.11	PL 406372 A1 2015.06.08



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代理人 王勇

(51)Int.Cl.

G02B 6/032(2006.01)

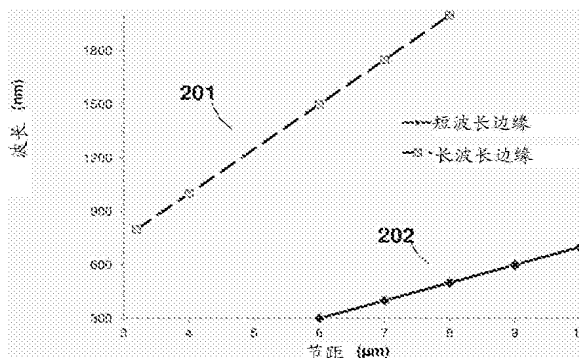
权利要求书6页 说明书19页 附图13页

(54)发明名称

传输光纤组件和宽带光源

(57)摘要

本发明包括一种传输光纤组件,其适于传输宽带光并包括传输光纤和连接器构件。传输光纤具有一定长度、用于发射光的输入端和用于传输光的传输端。传输光纤沿其长度包括纤芯区和围绕纤芯区的包层区,其中包层区包括具有折射率 N_{bg} 的背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在传输光纤的纵轴长度上延伸,其中 $N_{inc} < N_{bg}$ 。包层区中的多个内含物在横截面模式上布置以包括围绕纤芯区的至少两圈内含物。连接器构件在包括传输端的传输光纤的传输端部分处安装至传输光纤。传输光纤具有约200nm或更大的传输带宽。



1. 一种传输光纤组件,其适于传输宽带光并包括传输光纤和连接器构件,所述传输光纤具有一定长度、用于发射光的输入端和用于传输光的传输端,所述传输光纤沿其长度包括纤芯区和围绕所述纤芯区的包层区,其中所述包层区包括具有折射率 N_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在所述传输光纤的纵轴长度上延伸,其中 $N_{inc} < N_{bg}$,以及所述包层区中的多个内含物以横截面模式布置以包括围绕所述纤芯区的至少两圈内含物,所述纤芯区具有不超过约 $15\mu\text{m}$ 的直径,所述连接器构件在包括所述传输端的传输光纤的传输端部分处安装至所述传输光纤,所述传输光纤具有约 200nm 或更大的、诸如约 300nm 或更大的、诸如约 400nm 或更大的、诸如约 500nm 或更大的传输带宽。

2. 根据权利要求1所述的传输光纤组件,其中所述连接器构件在所述传输光纤的所述传输端部分、距离所述传输端的一定距离处安装至所述传输光纤,以使得所述传输端穿过所述连接器构件,所述连接器构件用于以物理接触连接所述传输端与接收器波导,优选地接收器光纤,诸如合并在于照明和/或计量和/或外科手术的装置中的接收器光纤。

3. 根据权利要求1或权利要求2所述的传输光纤组件,其中针对所述传输带宽内的至少一个波长并沿至少所述传输端部分的传输光纤具有恒定模场直径,优选地,所述传输光纤至少沿所述传输端部分具有所述传输带宽内的恒定模场直径与波长分布。

4. 根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤至少沿所述传输端部分具有针对所述传输波长的模场直径,其中所述模场直径的范围是所述范围的最低模场直径的约30%或更小,诸如约20%或更小,诸如约15%或更小,诸如约10%或更小。

5. 根据前述权利要求中任一项所述的传输光纤组件,其中针对所述传输带宽内的至少一个波长并沿至少所述传输端部分的传输光纤具有恒定数值孔径NA和小于 0.5dB/m 、诸如小于约 0.2dB/m 的传播损耗。

6. 根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤针对所述传输带宽内的至少一个波长是单模的,优选地,所述传输光纤针对传输带宽的至少约50%,诸如至少约80%、诸如针对所述传输光纤的整个传输带宽是单模的。

7. 根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤是偏振保持光纤(PM光纤),优选地所述传输光纤包括一个或多个应力元件。

8. 根据前述权利要求中任一项所述的传输光纤组件,其中所述纤芯区具有不超过约 $10\mu\text{m}$ 的直径,诸如从约 $3\mu\text{m}$ 至约 $8\mu\text{m}$,诸如从约 $4\mu\text{m}$ 至约 $6\mu\text{m}$,优选地所述纤芯区具有沿大部分传输光纤、诸如优选沿所述传输光纤的80%长度的基本相同直径。

9. 根据前述权利要求中任一项所述的传输光纤组件,其中所述纤芯区的直径沿可选地除所述传输光纤的一个或多个组成段之外的传输光纤的长度基本相同。

10. 根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤具有约0.7或更少、诸如从约0.3至约0.65、诸如从约0.4至约0.6的纤芯区直径与节距比 d/Λ 。

11. 根据前述权利要求中任一项所述的传输光纤组件,其中所述包层区中的多个内含物以横截面模式布置以包括围绕所述纤芯区的至少四圈内含物、诸如围绕所述纤芯区的至少五圈内含物,所述各圈内含物以节距模式、双节距模式、三节距模式、半节距模式、或其组合来布置,其中所述节距被确定为所述纤芯区和所述内含物之间的最小中心至中心距离。

12. 根据前述权利要求中任一项所述的传输光纤组件,其中所述纤芯区具有折射率

N_{core} ,以及所述包层区具有有效折射率 N_{clad} ,以及所述包层背景材料的折射率 N_{bg} 基本等于所述纤芯区的折射率 N_{core} 。

13.根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤是硅纤维以及所述实心内含物是下掺杂硅,优选地,彼此独立的实心内含物是掺杂有氟和/或硼和/或包括F和/或B原子的组分中的至少一种的硅,优选地针对所述传输带宽内的至少一个波长并彼此独立的所述实心内含物具有从约 10^{-3} 至约 10^{-2} 的关于所述包层背景材料的折射率 N_{bg} 的折射率差异。

14.根据前述权利要求中任一项所述的传输光纤组件,其中所述内含物具有基本相同的折射率 N_{inc} 。

15.根据前述权利要求1-10中任一项所述的传输光纤组件,其中所述内含物的 n 具有不同折射率 $N_{\text{inc}(n)}$,其中 n 是不超过内含物个数的整数,诸如不超过10,诸如2-4。

16.根据权利要求15所述的传输光纤组件,其中一圈内含物中的内含物包括具有不同折射率的两个或多个内含物。

17.根据权利要求15所述的传输光纤组件,其中一圈内含物中的各内含物具有基本相同的折射率,可选地一圈内含物的各内含物具有不同于另一圈内含物的各内含物的折射率,优选地,一圈内含物的各内含物具有相比更靠近所述纤芯区的另一圈内含物的各内含物来说更高的折射率。

18.根据前述权利要求中任一项所述的传输光纤组件,其中所述实心内含物具有相同或不同的直径,优选地直径不超过约 $5\mu\text{m}$ 、诸如不超过约 $3\mu\text{m}$ 、诸如从约 0.2 至约 $1\mu\text{m}$ 、诸如从约 0.4 – $0.8\mu\text{m}$ 。

19.根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤是全实心光纤,优选地所述传输光纤是完全硅纤维,其中所述纤芯区、所述包层区和/或所述内含物被掺杂以达到它们各自的折射率。

20.根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤的传输带宽包括从约 400nm 至约 900nm 范围内的波长,优选地,所述传输光纤的传输带宽包括至少约 100nm 的带宽,诸如至少约 200nm 的带宽,诸如至少约 300nm 的带宽,诸如至少约 400nm 的带宽,诸如在从约 400nm 至约 900nm 范围内的整个带宽。

21.根据权利要求20所述的传输光纤组件,其中所述传输光纤的传输带宽包括低于 800nm 、诸如低于 700nm 、诸如低于 600nm 、诸如低于 500nm 的波长。

22.根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤的传输带宽包括约 1100nm 至 2400nm 范围内的波长,优选地,所述传输光纤的传输带宽包括至少约 100nm 的带宽,诸如至少约 200nm 的带宽、诸如至少约 300nm 的带宽、诸如至少约 400nm 的带宽、诸如在从约 1100nm 至 2400nm 范围内的整个带宽。

23.根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤具有从约 5cm 至约 100m ,诸如从约 10cm 至约 30m ,诸如从约 20cm 至约 20m ,诸如从约 30cm 至约 10m 的长度。

24.根据前述权利要求中任一项所述的传输光纤组件,其中所述传输光纤包括至少一个组成段,所述组成段被配置用于分离来自所述传输光纤的光和/或用于将光组合至所述传输光纤中,所述组成段优选地是全光纤组成段。

25.根据权利要求19所述的传输光纤组件,其中所述传输光纤包括熔接式耦合器,其中

所述熔接式耦合器在所述组成段处熔接至所述传输光纤以可选地用于将光耦合至所述传输光纤。

26. 根据权利要求19或权利要求20所述的传输光纤组件,其中所述传输光纤组件包括熔接式分束器,其中所述熔接式分束器在所述组成段处熔接至所述传输光纤以用于分离来自所述传输光纤的一部分光,优选地,所述分离出的光部分占5-95%功率的光,其中所述分离出的光部分具有与光被分离处的光部分基本相同的波长分布。

27. 根据权利要求21所述的传输光纤组件,其中所述熔接式分束器包括用于传输光的双传输光纤,所述双传输光纤包括双传输端以及从所述组成段至所述双传输端延伸的长度,并且包括沿其长度的纤芯区和围绕所述纤芯区的包层区,其中所述包层区包括具有折射率 TN_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 TN_{inc} 的折射率并且在所述双传输光纤的长度上延伸,其中 $TN_{inc} < TN_{bg}$,以及所述包层区中的多个内含物以横截面模式布置以包括围绕所述纤芯区的至少两圈内含物,优选地,双连接器构件在包括所述双传输端的双传输光纤的双传输端部分处安装至所述双传输光纤。

28. 根据权利要求19-21中任一项所述的传输光纤组件,其中所述传输光纤组件包括熔接式耦合器和熔接式分束器,其中所述熔接式分束器在第一组成段处熔接至所述传输光纤以及所述熔接式耦合器在更加靠近所述传输光纤的传输端的第二组成段处熔接至所述传输光纤,所述熔接式分束器和所述熔接式耦合器包括环路光纤,其被配置用于延迟通过所述分束器分离出以及通过所述耦合器重新组合至所述传输光纤的光脉冲部分,从而使得分离出并重新组合的光脉冲部分相对于光分离处的光脉冲部分被延迟。

29. 根据前述权利要求中任一项所述的传输光纤组件,其中所述组件包括输入端连接器构件,所述输入端连接器构件在包括所述输入端的传输光纤的输入端部分处安装至所述传输光纤,所述连接器构件优选地被配置用于将所述输入端物理接触地连接光发射单元。

30. 根据前述权利要求中任一项所述的传输光纤组件,其中所述组件包括传输前光纤,所述传输前光纤耦合至所述传输光纤而无需自由空间光系统。

31. 根据权利要求25所述的传输光纤组件,其中所述传输前光纤连接至所述传输光纤,可选地通过拼接,优选地,通过拼接使得控制从模场直径、数值孔径、低传播损耗或传输带宽选择的一个或多个属性从所述传输前光纤至所述传输光纤基本不变。

32. 一种用于供应光至装置的宽带光源,所述宽带光源包括:

光学泵浦光源,其可操作以生成泵浦脉冲;

微结构光纤,其用于在供给泵浦光时生成宽带光脉冲;以及

传输光纤,其布置用于接收至少一些所述宽带光脉冲的至少一部分以及用于传输所述宽带光脉冲的所述接收部分的至少一部分至所述装置;

其中所述光学泵浦光源被布置以发射泵浦脉冲至所述微结构光纤,以及所述传输光纤具有一定长度、用于发射光的输入端和用于传输光的传输端,所述传输光纤沿其长度包括纤芯区和围绕所述纤芯区的包层区,其中所述纤芯区具有不超过 $15\mu m$ 的直径以及所述包层区包括具有折射率 N_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在所述传输光纤的纵轴长度上延伸,其中 $N_{inc} < N_{bg}$,以及所述包层区中的多个内含物以横截面模式布置以包括围绕所述纤芯区的至少两圈内含物,优选地所述传输光纤具有约200nm或更大的、诸如约300nm或更大的、诸如约400nm或更大的、诸如

约500nm或更大的传输带宽。

33. 根据权利要求32所述的宽带光源,其中针对所述传输带宽内的至少一个波长,所述传输光纤至少沿所述传输端部分具有恒定模场直径,优选地,所述传输光纤至少沿所述传输端部分具有所述传输带宽内的大致恒定的模场直径与波长分布。

34. 根据权利要求32或权利要求33所述的宽带光源,其中所述传输光纤针对所述传输带宽内至少一个波长是单模的,优选地,所述传输光纤针对所述传输带宽的至少约50%、诸如至少约80%、诸如所述传输光纤的整个传输带宽是单模的,所述传输光纤优选地具有约至少倍频的传输带宽。

35. 根据前述权利要求32-34中任一项所述的宽带光源,其中所述传输光纤是偏振保持光纤(PM光纤),优选地所述传输光纤包括一个或多个应力元件。

36. 根据前述权利要求32-35中任一项所述的宽带光源,其中所述包层区中的多个内含物以横截面模式布置以包括围绕所述纤芯区的至少四圈内含物、诸如围绕所述纤芯区的至少五圈内含物,所述内含物的各圈以节距模式、双节距模式、三节距模式、半节距模式、或其组合来布置,其中所述节距被确定为所述纤芯区和所述内含物之间的最小中心至中心距离。

37. 根据前述权利要求32-36中任一项所述的宽带光源,其中所述传输光纤具有约0.7或更少、诸如从约0.3至约0.65、诸如从约0.4至约0.6的纤芯区直径与节距比 d/Λ 。

38. 根据前述权利要求32-37中任一项所述的宽带光源,其中所述纤芯区具有折射率 N_{core} ,所述包层区具有有效折射率 N_{clad} ,以及所述包层背景材料的折射率 N_{bg} 基本等于所述纤芯区的折射率 N_{core} 。

39. 根据前述权利要求32-38中任一项所述的宽带光源,其中所述传输光纤是硅纤维以及所述实心内含物是下掺杂硅,优选地,彼此独立的实心内含物是掺杂有氟和/或硼和/或包括F和/或B原子的组分中的至少一种的硅。

40. 根据前述权利要求32-39中任一项所述的宽带光源,其中所述传输光纤是双包层光纤,其包括内包层区 and 外包层区,其中所述外包层区中的内含物相比所述内包层区中的内含物来说具有更高的折射率,优选地所述内包层区包括所述至少两圈实心材料内含物,其具有至少 N_{inc} 的折射率,以及所述外包层区具有相比所述内包层区来说更高的有效折射率。

41. 根据前述权利要求32-40中任一项所述的宽带光源,其中所述传输光纤是根据权利要求1-31中任一项所述的传输光纤组件的形式。

42. 根据前述权利要求32-41中任一项所述的宽带光源,其中所述光学泵浦光源包括锁模光纤振荡器以及优选地至少一个放大器。

43. 根据前述权利要求32-42中任一项所述的宽带光源,其中所述微结构光纤包括孔,其连接至所述传输光纤而无需使用自由空间光系统。

44. 根据前述权利要求32-43中任一项所述的宽带光源,其中所述微结构光纤通过端接连接至所述传输光纤。

45. 根据前述权利要求32-44中任一项所述的宽带光源,其中所述宽带光源包括用于对宽带光脉冲进行滤光的带通滤光器,所述带通滤光器优选地是可调谐带通滤光器,其优选地选自光栅滤光器、棱镜、或声光可调滤光器(AOTF)。

46. 根据权利要求45所述的宽带光源,其中所述带通滤光器定位在所述微结构光纤和

所述传输光纤之间。

47. 根据权利要求46所述的宽带光源,其中所述传输光纤被布置以接收所述宽带光脉冲的所述带通滤光部分以及用于在没有自由空间光系统的情况下将所述宽带光脉冲的所述接收部分的至少一部分传输至所述装置。

48. 根据前述权利要求32-47中任一项所述的宽带光源,其中所述滤光器是可调谐光学带通滤光器,其被配置用于可选择地选择多个波长或波长范围并将所述选择的波长传输至所述传输光纤。

49. 根据前述权利要求32-48中任一项所述的宽带光源,其中所述泵浦光源可操作以泵浦脉冲重复率生成泵浦脉冲,以及所述宽带光源包括布置于所述泵浦光源和所述微结构光纤之间的脉冲选择器,所述脉冲选择器可操作以选择脉冲以减小由所述泵浦光源所生成的泵浦脉冲重复率,从而使得减小的泵浦脉冲重复率被发射至所述微结构光纤。

50. 一种宽带光源系统,其包括根据前述权利要求32-49中任一项所述的宽带光源,其中所述宽带光源系统包括具有不同传输属性的多个传输光纤组件,其中所述传输光纤组件的每个包括输入端连接器构件和传输端连接器构件。

51. 一种用于供给光至装置的光谱引擎源,所述光谱引擎源包括:

两个或多个激光器,其发射具有在至少一个波长上不同的各波长的激光束;

多路复用器;以及

根据权利要求1-31中任一项所述的传输光纤;

其中所述多路复用器被配置用于接收每个激光器的激光束的至少一部分以及用于将所接收的光准直为多路复用光束,所述传输光纤布置用于接收所述多路复用光束以及用于将所述接收的多路复用光束的至少一部分传输至所述装置,以及其中所述传输光纤具有一定长度、用于发射光的输入端和用于传输光的传输端,所述传输光纤沿其长度包括纤芯区和围绕所述纤芯区的包层区,其中所述纤芯区具有不超过 $15\mu\text{m}$ 的直径以及所述包层区包括具有折射率 N_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在所述传输光纤的纵轴长度上延伸,其中 $N_{\text{inc}} < N_{\text{bg}}$,以及所述包层区中的多个内含物以横截面模式布置以包括围绕所述纤芯区的至少两圈内含物,优选地所述传输光纤具有其波长包括所述两个或多个激光器中每个的至少一部分波长的传输带宽。

52. 根据权利要求50所述的光谱引擎源,其中从所述两个或多个激光器发射的至少一个所述激光束具有约50nm或更小、诸如约25nm或更小、诸如约5nm或更小的带宽。

53. 根据权利要求51或权利要求52所述的光谱引擎源,其中从所述两个或多个激光器发射的所述激光束中的一个包括至少一个低于500nm的波长,以及从所述两个或多个激光器发射的所述激光束中的一个包括至少一个高于800nm的波长。

54. 根据权利要求51-53中任一项所述的光谱引擎源,其中所述光谱引擎包括至少三个激光器,其中各激光器中的第一激光器适于发射包括至少一个低于450nm的波长的激光束,各激光器中的第二激光器适于发射包括至少一个在500nm至700nm范围内的波长的激光束,以及各激光器中的第三激光器适于发射包括至少一个高于800nm的波长的激光束。

55. 一种装置,其包括根据权利要求32-49中任一项所述的宽带光源、根据权利要求51-54中任一项所述的光谱引擎源或根据权利要求50所述的宽带光源系统,所述装置包括光波导,其布置用于从所述传输光纤接收光,其中所述光波导包括连接器构件,其被配置用于与

所述传输光纤的所述传输端连接器构件匹配,所述光波导优选地是光纤。

56. 根据权利要求55所述的装置,其中所述装置是被配置用于照射目标的照明装置,所述照明装置优选地选自显微镜、分光镜或内窥镜。

57. 根据权利要求55或权利要求56所述的装置,其中所述照明源适用于荧光成像;荧光寿命成像 (FLIM);全内反射荧光 (TIRF) 显微术;荧光共振能量转移 (FRET);脉冲交错激发促进共振能量转移 (PIE-FRET);宽带光谱学;纳米光子学;流式细胞术;工业检测,诸如计量学;衰荡光谱学,诸如气体感测;分析光谱学,诸如高光谱学,例如水果的作物分析,以及飞行时间质谱仪 (TCSPC);单分子成像和/或它们的组合。

58. 根据权利要求55-56中任一项所述的装置,其中所述装置是计量装置,所述装置优选地包括双包层传输光纤,其被配置用于从被照射目标收集信号。

59. 根据权利要求55-58中任一项所述的装置,其中所述装置包括至少一个传输光纤组件,其包括熔接式耦合器;和/或至少一个传输光纤组件,其包括熔接式分束器。

传输光纤组件和宽带光源

技术领域

[0001] 本发明涉及一种适用于从宽带光源传输光的传输光纤以及宽带光源系统,以及包括这种宽带光源的装置。

背景技术

[0002] 宽带光源和系统是本领域所公知的并且例如在EP2081074、W015003714和W015003715中描述。

[0003] W015003714公开了一种超连续谱光源,其包括微结构光纤和泵浦光源,其中微结构光纤包括中间锥形部分。由此获得光的非常宽且稳定的超连续谱。

[0004] US 8,731,009公开了一种超连续谱光源,其包括泵浦光源和用于生成超连续谱的发生器光纤,其中发生器光纤的纤芯的折射率分布图布置为随着光传播允许光的模态清洗以提供具有相对高的光谱强度和/或良好光束质量的光学超连续谱。

[0005] 通常,大多数现有技术的宽带光源聚焦于生成高质量的和/或在越来越宽的带宽上跨度的超连续谱光,例如进一步跨度到蓝色波长、例如低于450nm或甚至更低的超连续谱。

[0006] 所生成的光或其一部分通常用于高精度照明程序和/或高精度测量程序,诸如用于受激发射损耗、用于光学相干断层成像(OCT)的荧光成像程序、和/或用于工业检测,诸如计量学。

[0007] 通常,由宽带光源生成的光或光的一部分经由传输光纤传送至装置,诸如照明装置和/或在该装置的测量过程中使用的测量装置。通常,期望的是传输光纤简单地连接至装置并且本领域公知的是使用标准连接器,诸如根据标准IEC 61754-20、IEC 61754-15或IEC 61754-13的连接器。

[0008] 现有技术的传输光纤通常是阶梯折射率光纤,其具有相对非常窄的传输频带,这是因为这种光纤易于操作、易于连接且具有低传输损耗。为了可以传输较宽带宽,已经提出了使用光子晶体光纤(PCF),在它们的横截面上具有空气孔,由此引入了传输光纤;进而传输光纤可以传输较宽带宽。然而,这种多孔PCF通常难以连接并且可能导致不期望的功率损耗。

发明内容

[0009] 本发明的目的是提供一种传输光纤组件,其适于从宽带光源和/或从两个或多个光源传输宽带光,以及一种宽带光源系统,其中传输光纤简单地连接至装置以用于将光传输至该装置,并且减轻了如上所述问题中的至少一个。

[0010] 再一个目的是提供包括传输光纤的宽带光源和宽带光源系统,所述传输光纤简单地例如连接至装置以用于将光传输至该装置,并且减轻了如上所述问题中的至少一个。

[0011] 在一个实施方式中,目的是通过传输光纤从具有不同波长的两个或多个光源传输光。

[0012] 这些和其他目的已经通过如权利要求书中所限定并如下面本文中所描述的本发明或其实施方式来解决。

[0013] 已经发现,本发明或其实施方式具有多个另外的优点,其通过下面描述对于本领域技术人员是明显的。

[0014] 根据本发明,已经发现通过提供一种新型的传输光纤,用于传输宽带光或宽带光的选择部分,其包括例如宽范围内的离散波长的波长。传输光纤可以以相对简单且有效的方式连接并具有非常低的损耗。同时,已经发现,这种新的传输光纤组件具有相对高的机械强度,这实际上是非常有益的,因为这种传输光纤通常承受机械扰动,诸如弯曲和粗暴处理。通常,运输是重复地卷起和展开且不对缠绕直径进行控制。

[0015] 在本发明的传输光纤组件的实施方式中,它适于将宽带光传输至装置以用于将光传输至该装置。传输光纤组件包括传输光纤和连接器构件。传输光纤具有长度、用于发射光的输入端和用于传输光的传输端。传输光纤沿其长度包括纤芯区和围绕纤芯区的包层区,其中所述包层区包括具有折射率 N_{bg} 的包层背景材料,和以实心材料内含物形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在传输光纤的纵轴长度上和优选地沿传输光纤的纵轴延伸,其中 $N_{inc} < N_{bg}$ 。包层区中的多个内含物以横截面模式(在传输光纤的横截面中看出的模式)布置以包括围绕纤芯区的至少两圈内含物。连接器构件在包括传输端的传输光纤的传输端部分处安装至传输光纤。此外,传输光纤具有约200nm或更大的、诸如约300nm或更大的、诸如约400nm或更大的、诸如约500nm或更大的传输带宽,举例来说至少倍频(一半/两倍频率)。

[0016] 通常,期望的是,纤芯区具有不超过约15 μ m的直径。

[0017] 在一个实施方式中,传输带宽被限定为其中传输光纤具有小于0.5dB/m的传输损耗的波长。在一个实施方式中,传输带宽被限定为其中传输光纤具有小于0.1dB/m的传输损耗的波长。有利地,当光纤以16cm或32cm的弯曲直径弯曲时来测量传输损耗。

[0018] 迄今为止,从来没有人考虑使用包括实心内含物的全实心光纤作为传输光纤来从宽带光源传输光至用于测量和/或照明的装置。特别地,从来没有人考虑这种包括实心内含物的全实心光纤可以构造为具有200nm或更大的传输带宽,以及特别地,令人惊讶的是,包括实心内含物的全实心光纤可以构造为具有200nm或更小、低于1800nm或甚至低于900nm的传输带宽。

[0019] 术语“内含物”指代背景材料中的内含物,其中内含物具有不同于围绕内含物的背景材料的折射率的另一折射率。实心内含物可以例如是与背景材料不同的另一玻璃型内含物和/或掺杂材料内含物(指数变化材料,诸如F、Ge、P、B)、真空内含物或其任意组合。传输光纤的内含物可以具有相同或不同的材料或结构。内含物可以是均质材料或它可以具有不同材料和/或折射率的区域。在内含物包括多个不同折射率的区域的情况下,内含物的折射率被确定为内含物的平均折射率。

[0020] 在本申请的上下文中,短语“一圈内含物”指代通常具有与纤芯基本相同的半径距离并以围绕纤芯的环构造排列的包层内含物。通常,一圈内含物不是完全圆形的,而是成形为具有多个软角,诸如以六边形形状。优选地,一圈内含物的所有内含物具有基本相同尺寸和优选相同材料。

[0021] 短语“径向距离”指代在径向方向上从传输光纤的纤芯的纵轴确定的距离。

[0022] 术语“基本上”在本文中应该指代为包括普通产品差异和公差。

[0023] 纤芯和内含物的直径被确定为纤芯/内含物的特征直径。纤芯或内含物并非总是完全圆形的。特征直径是内含物/纤芯是圆形时圆的直径,或在内含物不是圆形时,特征直径确定为讨论中的内含物/纤芯的最大和最小程度的平均。

[0024] 内含物可具有相同或不同的直径,以及各个内含物的内含物直径可以如所述沿光纤的长度为相同或不同的。

[0025] 在一个实施方式中,包括传输端的传输光纤的传输端部分,以及连接器构件在距离传输端的安装距离处安装以使得传输端穿过连接器构件,连接器构件用于以物理接触连接传输端与接收器波导,优选地接收器光纤,诸如合并在用于照明和/或计量和/或外科手术的装置中的接收器光纤。

[0026] 光纤的传输端是端面。与传输端的安装距离通常是几mm,例如至少2mm,诸如不超过2cm或优选地小于1cm。与传输端的安装距离通常由连接器构件的结构给定。优选地,连接器构件是标准连接器构件,诸如根据标准IEC 61754-20、IEC 61754-15或IEC 61754-13或其等效标准中的至少一个的标准连接器构件。与传输端的安装距离被确定为从传输端至与连接器构件的最接近物理接触的距离。通常,连接器构件具有连接凸缘,其超出传输端延伸以用于与另一连接器构件配对并连接,同时保护所连接的传输端。在连接至所述装置之前,传输端期望地由可移除帽防护。为了最佳连接,传输端有利地被抛光并可选地布置为具有平面,其关于光纤的横截面成例如不超过60度、诸如不超过约30度、诸如从约3至10度、诸如约8度的角度,从而减少端面处的不期望光反射。对于宽带操作,平面的角度通常被选择为折衷的。因此,通常期望的是使得面角充分地足够大以确保不反射不期望量的光并由此大量光被收集在光纤的NA中。另一方面,面角应该有利地不太大,因为这会导致不期望的角色散。

[0027] 在一个实施方式中,传输光纤的传输端部分安装至连接器构件以使得传输光纤的传输端适于连接,而不会改变光纤波导结构。

[0028] 根据本发明,已经发现传输光纤组件的传输光纤可以在不使用自由空间光系统的情况下连接至装置——即在光纤外连接部位处没有传输——以及没有传播模式的波阵面的不期望改变。此外,传输光纤组件的传输光纤可以连接至装置而没有模场的不期望扩张并因此可以减少或完全避免光损耗。

[0029] 在一个实施方式中,连接器构件在传输光纤的传输端部分、距离传输端的一距离处安装至传输光纤以使得传输端穿过连接器构件,连接器构件用于以物理接触连接传输端与接收器波导,优选地接收器光纤,诸如合并 in 用于照明和/或计量和/或外科手术的装置中的接收器光纤。

[0030] 连接器构件优选地包括金属箍以及传输端部分穿过该金属箍用于耦合至接收器单元。

[0031] 有利地是,连接器构件布置为使得传输端可以与接收波导物理接触并连接,接收波导例如是包括相应接收波导连接器构件的光纤。

[0032] 有利地,连接器构件是弹簧装载的,从而传输端面可以以对接耦合匹配至接收光纤,其中光纤面在连接器配对时按压在一起。所产生的玻璃至玻璃接触消除了将由接合纤维之间的空气间隙导致的信号损耗。

[0033] 在一个实施方式中,传输光纤至少沿其传输端部分以及可选地沿光纤的整个长度具有针对传输带宽内至少一个波长的恒定模场直径,在模场扩张时,光纤会损失光。传输端部分优选地包括至少2mm、优选地至少约5mm、诸如至少1cm的光纤长度。优选地,传输光纤至少沿传输端部分具有传输带宽内恒定模场直径与波长分布曲线。短语“模场直径与波长分布曲线”指代各自模场直径相对于传输带宽内各个波长的分布曲线。由此传输光纤可以连接至装置以最小的光损耗进行使用。

[0034] 传输光纤的模场直径有利地基于期望传输波长带宽进行选择。已经发现,针对低于2 μ m波长的波长范围的模场直径变化出奇地小。因此针对100nm带宽,模场直径基于最低波长的模场直径优选地变化小于10%。

[0035] 已经发现,相对小的纤芯区,即约15 μ m或更小的纤芯区,是用于保持针对传输带宽的模场直径范围窄的重要因素。因此,通过选择甚至更小的纤芯区,针对传输带宽的模场直径范围可以甚至更窄。此外,已经发现,模场直径变化针对约900nm或更小的波长相比较大大波长来说更小。

[0036] 可通过选择模场直径范围制作传输光纤。在一个实施方式中,传输光纤至少沿所述传输端部分具有针对所述传输波长的模场直径范围,其中模场直径范围是该范围的最低模场直径的约30%或更小,诸如约20%或更小,诸如约15%或更小,诸如约10%或更小。模场直径范围是对应于传输带宽的模场直径的范围,以及该范围的最小模场直径是传输带宽的最低波长的模场直径。

[0037] 有利地,针对所述传输带宽内至少一个波长并至少沿所述传输端部分的传输光纤具有恒定数值孔径NA和小于0.5dB/m、诸如小于约0.2dB/m、诸如小于约0.1dB/m或甚至小于0.05dB/m的传播损耗。

[0038] 有利地,传输光纤针对传输带宽内至少一个波长是单模的。通常,相对于多模光来说,光束具有针对单模光的高的多的质量,以及针对一些应用,单模光是需要的。优选地,传输光纤针对传输带宽的至少约50%,诸如至少约80%、诸如针对传输光纤的整个传输带宽是单模的。

[0039] 在优选实施方式中,传输光纤是偏振保持光纤(PM光纤)。PM光纤可例如包括一个或多个应力元件。

[0040] PM光纤是其中在线性偏振光被发射到光纤中时可以保持线性偏振的光纤。有利地是,所发射的偏振光在传播期间沿PM传输光纤保持线性偏振并以线性偏振状态离开光纤。有利地是,在两个偏振模式之间光学功率的交叉耦合很小或没有。优选地,PM传输光纤针对传输带宽内的至少一个波长是单模的。通过提供传输光纤为PM光纤,传输光纤具有甚至更低的弯曲损耗。

[0041] PM属性可以例如通过结合应力元件来诱发,诸如举例来说在US7,289,709中描述的。

[0042] 纤芯区原理上可基于待传输的功率和波长具有任意纤芯直径。有利地,传输光纤芯区具有至少约3 μ m的直径。纤芯区可沿传输光纤的长度变化,但通常优选的是纤芯区具有沿大部分传输光纤、诸如优选地沿传输光纤80%长度的基本相同直径。最合适的纤芯区直径不超过约15 μ m,诸如在约3 μ m至约10 μ m、诸如约4 μ m至约12 μ m的范围内。

[0043] 在传输光纤的传输带宽包括低于500nm或甚至低于450nm的波长时,传输光纤芯区

有利地具有小于约 $10\mu\text{m}$ 的直径,因为已经发现在传输光纤的芯区较大时,诸如大于约 15nm ,在UV光区具有增加的损耗。

[0044] 光纤的所有结构细节,诸如纤芯区尺寸、内含物直径和模式关于光纤的横截面视图给出,除非另有规定。

[0045] 在一个实施方式中,纤芯区直径沿可选地除传输光纤的一个或多个组成段之外的传输光纤的长度基本相同。

[0046] 这些组成段在下文中进一步描述。

[0047] 优选地,包层区中的多个内含物以横截面模式布置以包括围绕纤芯区的至少四圈内含物、诸如围绕纤芯区的至少五圈内含物。已经发现,通过增加内含物的圈数,可以增加传输带宽以及可以增强其他额外属性,诸如单模属性和/或降低损耗。内含物的圈有利地以节距模式布置以使得相邻内含物之间的距离是节距的P倍,其中P是0.5或不超过5的整数、优选地不超过3的整数、诸如1或2,以及其中P可以根据最接近内含物的不同距离具有不同数值。

[0048] 在一个实施方式中,内含物以节距模式、双节距模式、三节距模式、半节距模式、或其组合来布置,其中节距被确定为纤芯区和内含物之间的最小中心至中心距离。

[0049] 已经发现,节距 Λ 可以用于定制针对期望传输带宽的传输光纤以及特别是不论传输带宽是否包括低于 450nm 的蓝光范围和/或高于 800nm 的红光范围的波长。为了达到蓝光波长,期望的是节距小于约 $10\mu\text{m}$,优选地小于约 $9\mu\text{m}$,诸如小于约 $8\mu\text{m}$,诸如小于约 $7\mu\text{m}$,诸如小于约 $6\mu\text{m}$ 。为了达到红光波长,节距有利地是约 $3.2\mu\text{m}$ 或更大,诸如约 $3.2\mu\text{m}$ 或更大,诸如约 $4\mu\text{m}$ 或更大,诸如约 $5\mu\text{m}$ 或更大,诸如约 $5\mu\text{m}$ 或更大,诸如约 $7\mu\text{m}$ 或更大,诸如约 $8\mu\text{m}$ 或更大。

[0050] 纤芯区直径与节距 d/Λ 可以有利地是约0.7或更小,诸如从约0.3至约0.65,诸如从约0.4至约0.6。

[0051] 有利地,纤芯区具有折射率 N_{core} ,包层区具有有效折射率 N_{clad} ,以及包层背景材料的折射率 N_{bg} 基本等于纤芯区的折射率 N_{core} 。

[0052] 在一个实施方式中,纤芯区的折射率是均匀的。在另一实施方式中,纤芯区是微结构的,例如如共同未决DK PA 2014 00545中描述的。在纤芯区是微结构时,纤芯区的折射率 N_{core} 被确定为平均折射率。

[0053] 在一个可替代实施方式中,包层背景材料的折射率 N_{bg} 不同于纤芯区的折射率 N_{core} ,优选地使得包层背景材料的折射率 N_{bg} 低于纤芯区的折射率 N_{core} 。

[0054] 在一个实施方式中,传输光纤是硅纤维以及实心内含物是下掺杂硅。优选地,彼此独立的实心内含物是掺杂有氟和/或硼和/或包括F和/或B原子的组分中的至少一种的硅。

[0055] 各个内含物可以具有相同或不同的折射率以及内含物可具有数个区域,它们具有不同折射率,在该情形中,折射率如上所述被确定为平均折射率。

[0056] 在一个实施方式中,彼此独立的各个内含物的折射率和背景材料的折射率 N_{bg} 之间的差异是从约 10^{-5} 至约0.1,诸如从约 10^{-4} 至约 10^{-2} ,诸如不超过约 10^{-3} 。

[0057] 在一个实施方式中,内含物具有基本相同的折射率 N_{inc} 。

[0058] 在一个实施方式中,内含物的n具有不同的折射率 $N_{\text{inc}(1)} \cdots N_{\text{inc}(n)}$,其中n是不超过内含物数量的整数,换言之,原理上所有内含物可具有不同折射率。然而,从实用观点来说,这样的实施方式不是优选的。

[0059] 有利地,不超过10个内含物,诸如2-4个内含物,优选地一圈内含物的所有内含物具有基本相同的折射率。

[0060] 在一个实施方式中,一圈内含物的各内含物具有不同于另一圈内含物的各内含物的折射率。优选地,一圈内含物的各内含物具有相比更靠近纤芯区的另一圈内含物的各内含物来说更高的折射率。通过使得各圈内含物具有不同折射率,传输光纤可以被设计为具有期望的传输带宽,并且同时可以抑制高阶模式。

[0061] 在一个实施方式中,一圈内含物的各内含物包括具有不同折射率的两个或多个内含物。

[0062] 有利地,实心内含物基本平行于纤芯区。由此光纤可以以相对简单的方式拉制。

[0063] 在一个实施方式中,实心内含物螺旋地缠绕纤芯区。由此可以减少内含物的数量和/或可以减少弯曲。然而,相比内含物平行于纤芯区来说,内含物螺旋缠绕纤芯区的纤维的制造更加困难。

[0064] 在一个实施方式中,传输光纤包括内包层区 and 外包层区,其中包层背景材料可不同。

[0065] 在一个实施方式中,传输光纤包括内包层区 and 外包层区,其中包层背景材料具有相同折射率。

[0066] 在一个实施方式中,传输光纤包括内包层区 and 外包层区,其中外包层区中的内含物具有相比内包层区的内含物来说更高的折射率。在该实施方式中,内包层区有利地包括本文中描述的具有不超过 N_{inc} 的折射率的实心材料内含物,以及外包层区中的内含物是具有大于 N_{inc} 的折射率的实心材料。优选地,外包层区中的内含物是具有高于外包层区的背景材料的折射率的实心材料。由此,外包层区的内含物可用于耦合进高阶模式。

[0067] 在一个实施方式中,传输光纤是双包层传输光纤,其包括例如如上所述的内包层区 and 外包层区,以及其中传输光纤被配置为使得信号可以例如经由自有空间光系统或经由例如如上所述的熔接式耦合器的耦合器来收集。

[0068] 内含物可以在原理上具有任意尺寸,但通常期望的是内含物不能太大,除非其中内含物用于使得光纤双折射。

[0069] 在一个实施方式中,实心内含物具有相同或不同的直径,优选地直径是从约0.2至约 $1\mu\text{m}$,诸如从约0.4-0.8 μm 。

[0070] 优选地,一圈内含物的各内含物具有相同直径。在一个实施方式中,一圈内含物的各内含物具有第一直径,以及另一圈内含物的各内含物具有第二直径,第二直径与第一直径不同。

[0071] 有利地,传输光纤是全实心光纤——即,在25℃时完全实心材料的光纤。优选地,传输光纤是完全硅纤维,其中纤芯区、包层区 and /或内含物被掺杂以达到它们各自的折射率。

[0072] 在一个实施方式中,传输光纤的传输带宽包括从约400nm至约900nm范围内的波长。波长范围非常适于多种高精度程序,特别地适于基于显微镜的程序。优选地,传输光纤的传输带宽包括至少约100nm的带宽,诸如至少约200nm的带宽,诸如至少约300nm的带宽,诸如至少约400nm的带宽,诸如在从约400nm至约900nm范围内的整个带宽。

[0073] 在一个实施方式中,传输带宽包括可见光范围内的至少一个波长。

[0074] 在一个实施方式中,传输带宽包括大于可见光范围的波长,例如700nm或更大。这非常适于眼科手术期间的照明,特别是传输带宽完全地高于700nm的情况。

[0075] 在一个实施方式中,传输带宽包括低于450nm、或甚至低于400nm的至少一个波长。这些波长非常适于诸多显微镜照明程序。

[0076] 在一个实施方式中,传输光纤被配置用于抑制高于1500nm的波长。这可以通过选择相应圈的内含物中各内含物之间的距离和/或通过选择纤芯区的折射率和包层区的有效折射率之间的折射率差异来设置。

[0077] 在一个实施方式中,传输光纤被配置用于抑制高于900nm的波长。

[0078] 在一个实施方式中,传输光纤的传输带宽包括约1100nm至2400nm范围内的波长,优选地,传输光纤的传输带宽包括至少约100nm的带宽,诸如至少约200nm的带宽、诸如至少约300nm的带宽、诸如至少约400nm的带宽、诸如从约1100nm至2400nm范围内的整个带宽。

[0079] 在一个实施方式中,传输光纤的传输带宽包括从约400nm至1100nm范围内的波长。

[0080] 在一个实施方式中,传输光纤的传输带宽包括低于800nm、诸如低于700nm、诸如低于600nm、诸如低于500nm的波长。

[0081] 传输光纤不应该太长,因为这会导致不期望的弯曲和机械扰动。然而,传输光纤也不应该太短。在优选实施方式中,传输光纤组件可以以不同长度提供用于具体用途。

[0082] 传输光纤的合适长度例如从约5cm至约100m,诸如从约10cm至约30m,诸如从约20cm至约20m,诸如从约30cm至约10m。

[0083] 有利地,传输光纤包括至少一个组成段,该组成段有利地被配置用于分离来自传输光纤的光和/或用于结合传输光纤中的光,该组成段优选地是全光纤组成段。

[0084] 有利地,传输光纤包括熔接式元件,诸如熔接式耦合器或熔接式分束器。这种熔接式元件是本领域公知的,但迄今为止还没有被应用或熔接到传输光纤。熔接式元件的原理是传输光纤的纤芯和熔接式元件的芯——通常是光纤元件——彼此非常靠近地熔接从而将光从一个芯传输至另一个芯。熔接式元件的优点包括具有实心微结构的光纤,其例如包括纤芯区和围绕纤芯区的包层区,其中包层区包括具有折射率 TN_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 TN_{inc} 的折射率并且在双传输光纤的长度上和优选地沿双传输光纤延伸,其中 $TN_{inc} < TN_{bg}$,以及包层区中的多个内含物以横截面模式布置以包括围绕纤芯区的至少两圈内含物。

[0085] 已经发现,通过使用包括以所述的内含物形式的实心微结构的全实心光纤,到达或来自传输光纤的光的耦合或分离将使得耦合至传输光纤或从传输光纤分离出的光部分具有与来自光被耦合或分离处的光基本相同的波长分布。

[0086] 在一个实施方式中,传输光纤组件包括熔接式耦合器,其中熔接式耦合器在组成段处熔接至传输光纤。

[0087] 有利地,熔接式耦合器是 2×2 耦合器,其包括在组成段处熔接至传输光纤的耦合光纤。耦合光纤包括在熔接式组成段的任一侧上的第一和第二光纤段,并布置为使得光在传输光纤和熔接式组成段处的耦合光纤之间耦合。

[0088] 在一个实施方式中,耦合光纤布置用于将光耦合至传输光纤并同时将来自传输光纤的光部分耦合至耦合光纤。该熔接式耦合器有利地用于OCT中,如下面示例中所示出的。

[0089] 在一个实施方式中,传输光纤组件包括熔接式分束器,其中熔接式分束器在组成

段处熔接至传输光纤用于分离来自传输光纤的一部分光。优选地,分离出的光部分占5-95%功率的光,其中分离出的光部分具有与光被分离处的光部分基本相同的波长分布。

[0090] 在一个实施方式中,分束器是10-90%比率分束器,其中分离出的光将占约10%功率或约90%功率。这种类型的分束器例如适于用在OCT中或晶片测量或类似装置中。

[0091] 通常,分束器可以适于从传输光纤分离任意期望功率比例的光,以及所分离出的部分可以作为基准。在一个实施方式中,具有分束器的传输光纤被配置用于干涉仪装置中。

[0092] 在一个实施方式中,分束器是50%-50%比率分束器,其中分离出的光将占约50%功率。该实施方式可适用于提供交错脉冲,例如如在“Advanced Fluorescence Fluctuation Spectroscopy with Pulsed Interleaved Excitation, Matthias Höller, Dissertation zur Erlangung des Doktorgrades der Fakultät für Chemie und Pharmazie der Ludwig-Maximilians-Universität München, 2011”中所描述的。

[0093] 在一个实施方式中,熔接式分束器包括用于传输光的双传输光纤,所述双传输光纤包括双传输端以及从组成段至双传输端延伸的长度,并且包括沿其长度的纤芯区和围绕纤芯区的包层区,其中包层区包括具有折射率 TN_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 TN_{inc} 的折射率并且在双传输光纤的长度上和优选地沿双传输光纤延伸,其中 $TN_{inc} < TN_{bg}$,以及包层区中的多个内含物以横截面模式布置以包括围绕纤芯区的至少两圈内含物,优选地,双连接器构件在包括双传输端的双传输光纤的双传输端部分处安装至双传输光纤。

[0094] 有利地,传输光纤具有约200nm或更大、诸如约300nm或更大、诸如约400nm或更大、诸如约500nm或更大的传输带宽。

[0095] 在一个实施方式中,传输光纤组件包括熔接式耦合器和熔接式分束器,其中熔接式分束器在第一组成段处熔接至传输光纤以及熔接式耦合器在更加靠近传输光纤的传输端的第二组成段处熔接至传输光纤,熔接式分束器和熔接式耦合器包括环路光纤,其被配置用于延迟通过分束器分离出以及通过耦合器重新组合至传输光纤的光脉冲部分,从而使得分离出并重新组合的光脉冲部分相对于光被分离处的光脉冲部分被延迟。

[0096] 环路光纤有利地是包括如上所述的内含物的全实心光纤。

[0097] 有利地,该组件包括输入端连接器构件,以及输入端连接器构件在包括输入端的传输光纤的输入端部分处安装至传输光纤,连接器构件优选地被配置用于将输入端物理接触地连接光发射单元,诸如微结构光纤。

[0098] 在一个实施方式中,该组件包括传输前光纤,传输前光纤耦合至传输光纤而无需自由空间光系统。在一个实施方式中,传输前光纤拼接至传输光纤,可选地通过拼接。

[0099] 有利地,拼接被设置为使得控制从模场直径、数值孔径、低传播损耗或传输带宽选择的一个或多个属性从传输前光纤至传输光纤基本不变。

[0100] 在一个实施方式中,传输光纤组件被配置用于从具有不同波长的多个多路复用激光器以单模质量传输光。该多路复用激光器的光有时称作为光谱引擎。多路复用激光器的光可例如由蓝、绿和红色激光器多路复用,它们例如通过Keyoptics KineFLEX模块组合为单光束路径。现有技术将使用三个不同传输光纤或具有单传输光纤,其在大的波长处是单模的以及在低的波长处是多模的。迄今为止,还没有任何解决方案使得可以通过一个单传输光纤来传输包括不同波长的单模多路复用光,诸如差别约25nm或更大、诸如约100nm或更

大、诸如约200nm或更大、诸如约300nm或更大的波长。

[0101] 本发明还涉及一种用于供应光至装置的宽带光源。所述宽带光源包括：

[0102] 光学泵浦光源，其可操作以生成泵浦脉冲；

[0103] 微结构光纤，其用于在进给泵浦光时生成宽带光脉冲；以及

[0104] 传输光纤，其布置用于接收至少一些宽带光脉冲的至少一部分以及用于传输宽带光脉冲的所接收部分的至少一部分至所述装置；

[0105] 其中所述光学泵浦光源布置以发射泵浦脉冲至微结构光纤，以及传输光纤具有一定长度、用于发射光的输入端和用于传输光的传输端，传输光纤沿其长度包括纤芯区和围绕纤芯区的包层区，其中所述纤芯区具有不超过约15 μ m的直径以及所述包层区包括具有折射率 N_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构，其具有至少 N_{inc} 的折射率并且在传输光纤的纵轴长度上和优选地沿传输光纤的纵轴延伸，其中 $N_{inc} < N_{bg}$ ，以及包层区中的多个内含物以横截面模式布置以包括围绕纤芯区的至少两圈内含物。

[0106] 宽带光源的传输光纤可有利地是如上所述的传输光纤。

[0107] 在一个实施方式中，传输光纤具有约200nm或更大的、诸如约300nm或更大的、诸如约400nm或更大的、诸如约500nm或更大的传输带宽。

[0108] 有利地，传输光纤在至少沿其传输端部分具有针对传输带宽内至少一个波长的恒定模场直径，优选地，传输光纤在至少沿其传输端部分具有传输带宽内恒定模场直径与波长分布。在一个实施方式中，传输光纤沿其包括传输端部分和连接器的整个长度具有基本恒定模场直径。

[0109] 有利地，传输光纤沿其长度的大部分具有基本恒定的模场直径与波长分布，优选地如上所述，长度的大部分例如至少包括距离传输端1cm的末端部分。

[0110] 传输光纤优选地针对传输带宽内至少一个波长是单模的。优选地，传输光纤针对传输带宽的至少约50%、诸如至少约80%、诸如传输光纤的整个传输带宽是单模的。传输光纤优选地具有约200nm或更大的、诸如约300nm或更大的、诸如约400nm或更大的、诸如约500nm或更大的传输带宽。

[0111] 有利地，传输光纤是如上所述的偏振保持光纤(PM光纤)。

[0112] 在一个实施方式中，包层区中的多个内含物以横截面模式布置以包括围绕纤芯区的至少四圈内含物、诸如围绕纤芯区的至少五圈内含物。内含物的各圈以节距模式、双节距模式、三节距模式、半节距模式、或其组合来布置，例如如上所述。

[0113] 在一个实施方式中，光纤具有所谓的单核纤芯，其基本对应于单个缺失内含物。在该实施方式中，纤芯尺寸由节距(Λ)的两倍减去内含物的直径(d)得到。

[0114] 优选地，纤芯区具有折射率 N_{core} ，包层区具有有效折射率 N_{clad} ，以及包层背景材料的折射率 N_{bg} 基本等于纤芯区的折射率 N_{core} 。

[0115] 传输光纤有利地是硅纤维以及实心内含物是下掺杂硅，优选地，彼此独立的实心内含物是掺杂有氟和/或硼和/或包括F和/或B原子的组分中的至少一种的硅。

[0116] 在一个实施方式中，传输光纤是双包层光纤，其包括内包层区 and 外包层区，其中所述外包层区中的内含物相比内包层区中的内含物来说具有更高折射率，优选地内包层区包括至少两圈实心材料内含物，其具有至少 N_{inc} 的折射率，以及外层区具有相比内包层区来说更高的有效折射率。

[0117] 外包层区中的内含物优选是具有高于 N_{inc} 的折射率的实心材料,优选地外包层区中的内含物是具有比外包层区的背景材料更高的折射率的实心材料。由此外包层区的内含物可用于耦合高阶模。

[0118] 在一个实施方式中,外包层被布置用于从照明目标接收并传输信号。从目标散射的光可由光学元件准直以经由外包层传输至例如光谱仪。

[0119] 传输光纤有利地以如上所述的传输光纤组件的形式。

[0120] 光学泵浦光源可以原理上是任意类型的光学泵浦光源,例如诸如在WO 2011/023201中描述的光学泵浦光源。有利地,光学泵浦光源包括锁模光纤振荡器以及优选地至少一个放大器。在一个实施方式中,光学泵浦光源包括主振荡功率放大器MOPA。MOPA构造是本领域公知的。

[0121] 微结构光纤可以是适于超连续谱生成的任意微结构光纤,例如如上引用的现有技术文献中描述的。

[0122] 有利地,光学泵浦光源和宽带光源的微结构光纤被配置为生成跨度至约200nm、优选地至少约500nm、诸如倍频的宽带光脉冲。

[0123] 有利地,微结构光纤包括孔,其连接至连接器构件,连接器构件优选地无需使用自由空间光系统连接至传输光纤。

[0124] 在一个实施方式中,包括孔的微结构光纤拼接至传输光纤,例如如US2012195554中描述的。

[0125] 在一个实施方式中,微结构光纤通过端接、可选地通过连接器构件或通过拼接、诸如冷拼接来连接至传输光纤,或其中各孔在微结构光纤末端处坍塌。

[0126] 在一个实施方式中,微结构光纤通过使用梯度折射率光纤排列 (GRIN) 来连接至传输光纤,如A.D.Yablon和R.Bise的“Low-Loss High-Strength Microstructured Fiber Fusion Splices Using GRIN Fiber Lenses”.2004Optical Society of America,OCIS codes: (060.2310)Fiber optics中描述的。

[0127] 在一个实施方式中,宽带光源包括带通滤光器用于对宽带光脉冲进行滤光,带通滤光器优选地是可调谐带通滤光器,其优选地选自光栅滤光器、棱镜、或声光可调滤光器(AOTF)。这些带通滤光器对于本领域技术人员来说是公知的。

[0128] 有利地,带通滤光器定位在微结构光纤和传输光纤之间。

[0129] 在一个实施方式中,传输光纤被布置以接收宽带光脉冲的带通滤光部分以及用于在没有自由空间光系统的情况下传输宽带光脉冲的所接收部分的至少一部分至所述装置。

[0130] 在一个实施方式中,滤光器是可调谐光学带通滤光器,其被配置用于可选择地选择多个波长或波长范围并将所选择的波长传输至传输光纤。

[0131] 在一个实施方式中,其中泵浦光源可操作以泵浦脉冲重复率生成泵浦脉冲,以及宽带光源包括布置于泵浦光源和微结构光纤之间的脉冲选择器,所述脉冲选择器可操作以选择脉冲以减小由泵浦光源所生成的泵浦脉冲重复率,从而使得减小的泵浦脉冲重复率被发射至微结构光纤。

[0132] 本发明还包括宽带光源系统,其包括如上所述的宽带光源以及其中所述宽带光源系统包括具有不同传输属性的多个传输光纤组件,其中每个传输光纤组件包括输入端连接器构件和传输端连接器构件。由此使用者可以选择用于具体用途的传输光纤组件以及切换

为另一传输光纤组件用于另一用途。各个传输光纤组件有利地设计用于不同程序性能,并且使用者可以相第简单地切换传输光纤组件。

[0133] 本发明还涉及一种用于供给光至装置的光谱引擎源,该光谱引擎源包括:

[0134] 两个或多个激光器,其发射具有在至少一个波长上不同的各波长的激光束;

[0135] 多路复用器;以及

[0136] 传输光纤。

[0137] 因此,光谱引擎源可包括多个激光器,其发射具有不同波长或波长带的激光束。

[0138] 多路复用器被配置用于接收每个激光器的激光束的至少一部分以及用于将所接收的光准直为多路复用光束。传输光纤布置用于接收多路复用光束以及用于将所接收多路复用光束的至少一部分传输至所述装置,以及其中所述传输光纤具有一定长度、用于发射光的输入端和用于传输光的传输端。传输光纤沿其长度包括纤芯区和围绕纤芯区的包层区,其中所述纤芯区具有不超过约 $15\mu\text{m}$ 的直径以及所述包层区包括具有折射率 N_{bg} 的包层背景材料和以实心材料内含物形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在传输光纤的纵轴长度上延伸,其中 $N_{\text{inc}} < N_{\text{bg}}$,以及包层区中的多个内含物以横截面模式布置以包括围绕纤芯区的至少两圈内含物,优选地传输光纤具有其波长包括所述两个或多个激光器中每个的至少一部分波长的传输带宽。

[0139] 传输光纤可以如上所述。

[0140] 激光器可以是任意类型的激光器,诸如光纤激光器或半导体二极管激光器。

[0141] 在一个实施方式中,从所述两个或多个激光器发射的至少一个激光束具有约50nm或更小、诸如约25nm或更小、诸如约5nm或更小的带宽。

[0142] 在一个实施方式中,从所述两个或多个激光器发射的激光束中的一个包括至少一个低于500nm的波长,以及从所述两个或多个激光器发射的激光束中的一个包括至少一个高于800nm的波长。

[0143] 在一个实施方式中,光谱引擎包括至少三个激光器,其中各激光器中的第一激光器适于发射包括至少一个低于450nm波长的激光束,各激光器中的第二激光器适于发射包括至少一个在500nm至700nm范围内波长的激光束,以及各激光器中的第三激光器适于发射包括至少一个高于800nm波长的激光束。

[0144] 本发明还涉及一种包括宽带光源或包括如上所述的光谱引擎源的装置。所述装置包括光波导,其布置用于从传输光纤接收光,其中所述光波导包括连接器构件,其被配置用于与传输光纤的传输端连接器构件匹配,所述光波导优选地是光纤。

[0145] 该装置例如是被配置用于照射目标的照明装置,所述照明装置优选地选自显微镜、分光镜或内窥镜。

[0146] 有利地,照明源适用于荧光成像;荧光寿命成像 (FLIM);全内反射荧光 (TIRF) 显微术;荧光共振能量转移 (FRET);脉冲交错激发促进共振能量转移 (PIE-FRET);宽带光谱学;纳米光子学;流式细胞术;工业检测,诸如计量学;衰荡光谱学,诸如气体感测;分析光谱学,诸如高光谱学,例如水果的作物分析,以及飞行时间质谱仪 (TCSPC);单分子成像和/或它们的组合。在一个实施方式中,传输光纤用作为显微镜中的所谓导光管。

[0147] 在一个实施方式中,所述装置是计量装置,所述装置优选地包括双包层传输光纤,其被配置用于从被照射目标收集信号。

[0148] 在一个实施方式中,所述装置包括至少一个传输光纤组件,其包括熔接式耦合器;和/或至少一个传输光纤组件,其包括熔接式分束器。

[0149] 在一个实施方式中,照明源包括至少一个传输光纤组件,其包括熔接式耦合器;和/或至少一个传输光纤组件,其包括熔接式分束器,以及其中所述传输光纤具有至少约200nm、优选地至少约500nm、诸如倍频的传输带宽。

[0150] 如上所述的包括各范围和优选范围的本发明的所有特征和本发明的各实施方式可以在本发明的范围内以各种方式组合,除非具有特别原因不能组合这些特征。

附图说明

[0151] 本发明的上述和/或另外目的、特征和优点将通过本发明的各实施方式的下面示意性和非限制性详细描述并参照附图来进一步阐明。

[0152] 图1a示出了本发明的传输光纤组件的实施方式的传输光纤的横截面。

[0153] 图1b示出了针对图1a中所示的输送光纤的以传输损耗谱形式的波长分布图;

[0154] 图1c示出了PM光纤的示例,其中黑色区域是掺杂有诸如硼的另一材料的内含物。

[0155] 图1d示出了针对根据本发明的光纤的关于节距的长波长传输边缘和短波长传输边缘的示例。

[0156] 图2示出了本发明的传输光纤组件的实施方式的透视图。

[0157] 图3是本发明的宽带光源的实施方式的示意图。

[0158] 图4是本发明的宽带光源的另一实施方式的示意图。

[0159] 图5是本发明的宽带光源的又一实施方式的示意图。

[0160] 图6是以干涉仪形式的本发明的装置的实施方式的示意图。

[0161] 图7是以另一类型的干涉仪形式的本发明的装置的实施方式的示意图。

[0162] 图8是本发明的光谱引擎源的实施方式的示意图。

[0163] 图9是本发明的光谱引擎源的另一实施方式的示意图。

[0164] 图10是本发明的实施方式的装置的示意图。

[0165] 图11是本发明的实施方式的另一装置的示意图。

具体实施方式

[0166] 附图是示意性的并且为了清楚可以简化。贯穿全文,相同的附图标记用于相同或相应的部件。

[0167] 图1a示出了传输光纤组件的传输光纤5的横截面。传输光纤5包括具有折射率 n_{core} 的纤芯区。纤芯由包层区围绕,包层区包括具有折射率 N_{bg} 的背景材料和以实心材料内含物2a、2b形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在传输光纤的纵轴长度上延伸,其中 $N_{\text{inc}} < N_{\text{bg}}$ 。包层区中的多个内含物2a、2b以横截面模式布置,其包括围绕纤芯区的至少6圈内含物。在所示实施方式中,径向方向上最内圈的3圈内含物2a具有相比径向方向上最外圈的3圈内含物2b来说更低的折射率。在所示实施方式中,内含物具有基本相同的直径。如上所说明的,针对一些应用,可能有利的是对于一圈内含物相比另一圈内含物来说具有不同的直径。

[0168] 图1b示出了对应于图1中所示的具有六圈内含物但其中全部内含物具有相同折射

率的传输光纤的光纤的传输损耗谱。在该示例中,纤芯具有 $10\mu\text{m}$ 直径,内含物具有比纤芯的折射率低1.2%的折射率,以及包层背景硅材料在 635nm 。包层内含物之间中心至中心距离(也公知为节距)为 $6\mu\text{m}$ 以及内含物的直径为 $3\mu\text{m}$ 。

[0169] 通过从宽带光谱光源发送光穿过光纤并执行截断来分离耦合损耗来获得光谱。 1400nm 附近的峰值是由吸水产生。传输光纤在传输光纤的整个传输带宽中是单模的。可以看出的是,传输光纤具有从约 425nm 至约 1500nm 延伸的非常宽的传输带宽。

[0170] 图1c中示出的传输光纤是PM光纤的示例,其包括具有折射率 n_{core} 的纤芯区。纤芯由包层区围绕,包层区包括具有折射率 N_{bg} 的背景材料和以实心材料内含物7a、7b形式的多个微结构,所述内含物具有不超过 N_{inc} 的折射率并且在传输光纤的纵轴长度上延伸,其中 $N_{\text{inc}} < N_{\text{bg}}$ 。包层区中的多个内含物7a、7b以横截面模式布置,其包括围绕纤芯区的至少6圈内含物。在所示实施方式中,相比其他内含物7a来说具有更高折射率的多个内含物7b以两个相对的簇布置用于形成应力元件。具有较高折射率的内含物7b例如掺杂有硼。

[0171] 在传输光纤的实施方式中,已经发现包层中内含物的直径(d)相对于节距(Λ)可能对传输光纤的导光特性具有大的影响。在一个实施方式中,在 d/Λ 小于约0.4时,传输损耗大。在一个实施方式中,在 d/Λ 大于约0.6时,光纤是多模的。

[0172] 在本发明的实施方式中,已经发现传输光纤的节距(Λ)可能对传输光纤的光谱传输带宽具有大的影响。

[0173] 特别地,发现短波长传输边缘对于节距设置了上限,以及其中该限制随着所需的短波长边缘增加,以使得例如 300nm 的短波长边缘需要小于 $6\mu\text{m}$ 的节距,而 600nm 的短波长边缘需要小于 $9\mu\text{m}$ 的节距。

[0174] 此外,发现长波长传输边缘对于节距设置了下限,以及其中该限制随着所需的长波长边缘增加,以使得例如 800nm 的长波长边缘需要至少 $3.2\mu\text{m}$ 的节距而 1500nm 的长波长边缘需要至少 $6\mu\text{m}$ 的节距。

[0175] 图1d示出了关于根据本发明的具有约0.5的 d/Λ 的光纤的节距的长波长传输边缘(201)和短波长传输边缘(202)的示例。

[0176] 在一个示例中,传输光纤的模场直径从 500nm 处的约 $8.0\mu\text{m}$ 至 900nm 处的约 $9.0\mu\text{m}$ 变化。在一个实施方式中,光纤的模场直径从 500nm 至 900nm 变化小于约20%。

[0177] 图2示出了传输光纤组件的一部分,其包括传输光纤5和连接器构件6,连接器构件6在包括传输末端5a的传输光纤的传输末端段处安装至传输光纤。可以看出的是,传输光纤包括防护涂层,诸如聚合物防护涂层。

[0178] 连接器构件有利地是以下类型的光纤连接器,其在现有技术中通常用于终止标准光纤的末端以使得两个标准光纤以低损耗简单连接和断开。

[0179] 在安装期间,光纤通常在光学连接器构件的内侧对齐,以使得光学传输光纤的纤芯区处于连接器构件的连接器平面的内侧中心。对于偏振或偏振保持光纤,还可以转动光纤从而使得偏振轴处于预定平面中。此外,确保的是光纤的端面处于连接器构件的输出平面。这例如可以通过对连接器和光纤端面抛光来实现。

[0180] 如果光被发送穿过在输出端上具有连接器构件的传输光纤组件,则从连接器构件输出端发射的光的位置是公知的。针对标准全实心单模光纤,光将使得其焦面以及由此腰线处于连接器的输出平面处。

[0181] 许多不同类型的连接器已经引入到市场,诸如举例来说,FC、E-2000、SMA连接器,以及具有内置光束展宽的连接器。

[0182] 期望的是使用具有低损耗和高功率容量的光纤连接器构件,这是因为它们应当有利地能够处理诸如不超过100mW或甚至不超过数瓦的平均功率。

[0183] 图3中所示的宽带光源10包括宽带激光脉冲发生器1,其包括可操作以生成泵浦脉冲的未示出的光学泵浦光源以及用于在进给泵浦光后生成宽带光脉冲的未示出的微结构光纤,其中光学泵浦光源布置以发射泵浦脉冲至微结构光纤。在所示的实施方式中,宽带激光脉冲发生器1是以丹麦NKT Photonics市售的SuperK™系统的形式。宽带光源还包括传输光纤5,其包括如上所述的实心内含物。传输光纤5布置用于接收至少一些所述宽带光脉冲的至少一部分。在所示的实施方式中,宽带光源10还包括光学元件3,优选地是布置在宽带激光脉冲发生器1和传输光纤5之间的滤光器3。光学元件3例如是偏振器、光谱滤光器(优选可调谐)和/或分束器。

[0184] 在传输光纤5的输出端部分,传输光纤包括连接器构件6,例如如上所述的。连接器构件6有利地配置为用于传输所述宽带光脉冲的所述接收部分的至少一部分至如上所述的装置。

[0185] 在图4中所示的实施方式中,宽带光源10耦合至光波导,其布置用于从传输光纤(这里称为第一传输光纤)接收光。在该实施方式中,布置用于从第一传输光纤接收光的光波导是以附加传输组件的形式,附加传输组件包括第二传输光纤22以及第二传输光纤入口端连接器构件21和第二传输光纤输出端终止单元23。在下文中称为第一传输光纤组件5、6的传输光纤组件5、6的连接器构件6使用匹配套筒20连接至第二传输光纤入口端连接器构件21。

[0186] 通过使用匹配套筒,连接器机械地耦合第一和第二传输光纤5、22的纤芯区,以使得光可以以低损耗从第一传输光纤5传递至第二传输光纤22。优选地,连接器构件是弹簧装载的,从而在连接器构件6、21配对时光纤面被按压在一起。所产生的玻璃至玻璃或塑料至塑料接触消除了将由接合纤维之间的空气间隙引起的信号损耗。

[0187] 光纤终止单元23有利地是连接器构件、准直器、球透镜、自聚焦透镜或任意其他合适的终止单元。

[0188] 第二光纤传输光纤22可以在原理上是任意类型的光纤,优选地具有相对宽的传输带宽,例如至少约200nm或更大,以及优选地第二光学传输光纤22的传输带宽与第一传输光纤5的传输带宽至少部分地重叠。

[0189] 在一个实施方式中,第二光学传输光纤22与第一传输光纤5基本相同。

[0190] 在一个实施方式中,可以在不需要更换第二光纤传输组件21、22、23的情况下更换包括宽带激光脉冲发生器1和第一光纤传输组件5、6的宽带光源10,反之亦然。

[0191] 在一个实施方式中,宽带光源10和所述第二光纤传输组件21、22、23内置到装置中或可替代地,第二光纤传输组件21、22、23内置到装置中,而宽带光源10布置以经由连接器构件6、21之间的连接将光供给至该装置。该装置的示例是显微镜、生物成像系统(诸如举例来说OCT、SLO、STED、CARS和光声系统)、对准或重叠系统以及制造设备(诸如举例来说半导体制造设备)。本发明的该实施方式使得宽带光源10可以容易地断开以用于维修和/或可以独立于所述第二光纤组件21、22、23进行更换,其例如会更加难以从该装置的其余部分断

开。例如，构成本发明的实施方式的宽带光源的超连续谱光源和第一光纤传输组件可以被包括在第一模块中，而第二光纤组件21、22、23是第二模块的一部分，诸如举例来说半导体晶片划线器中的对准传感器。在该示例中，本发明能够实现半导体晶片划线器的模块化构建。在半导体晶片划线器发生故障时，故障可以定位至发生故障的具体模块，并且这可以独立于其他模块进行更换。相比于需要同时更换两个模块，这改进了半导体晶片划线器的风险管理。

[0192] 在一个实施方式中，第二光纤传输组件21、22、23在生物学成像或外科手术应用中使用。该实施方式的示例包括内窥镜、结肠镜、鼻镜和支气管镜以及其他应用，其中第二光纤的一部分进入人体或动物体内。在这些实施方式中，如图3中所示的宽带光源10可以容易地连接至如上所述的连接构件21。

[0193] 在一个实施方式中，第二光纤传输组件在使用前消毒。

[0194] 在一个实施方式中，第二光纤传输组件是一次性的。

[0195] 图5是本发明的宽带光源的另一实施方式的示意图。宽带系统10可以是如上所述的以及第二光学传输光纤组件21、22、23可以是如图4中所描述的。

[0196] 光纤终止单元23有利地是或包括准直器，用于朝向样本30聚焦光。

[0197] 有利地，第二光纤传输组件21、22、23内置到装置中以及宽带光源10可选地布置为该装置中的内置模块并布置用于经由连接器构件6、21之间的连接将光供给至该装置。光源10包括或光学地连接至光检测器34，以及光学元件3包括附加滤光器32，其布置以指引由样本反射并由光纤5和22引导的光33的一部分。附加滤光器有利地是分束器。

[0198] 在一个实施方式中，传输光纤5和第二光纤22是双包层光纤。由此由样本反射的一部分光31可以经由第二光学传输光纤组件21、22、23和第一传输光纤组件5、6被引导至光检测器。在一个实施方式中，传输光纤5和第二光纤22包括具有至少0.1、诸如至少0.15、诸如至少0.22的NA的包层。同样在该实施方式中，光纤5、22将引导在测试时正在从样本反射的一些光31。

[0199] 在一个实施方式中，光学元件3包括工具来分离从样本反射并由光纤33引导的光和来自宽带光源的至少一些光。该工具例如是分束器32。

[0200] 在可替代实施方式中，应用双包层光纤耦合器来替代分束器，例如通过在第一传输光纤的输入端提供双包层光纤耦合器。双包层光纤耦合器有利地被配置用于分隔纤芯和包层光，例如通过具有2×2端口结构，其包括耦合器的两个端口上的多模双包层光纤和其他两个端口上的单模双包层光纤，诸如举例来说由Thorlabs提供的DC1300LEB。原理上，通过对于本领域技术人员来说已知的任意其他手段，反射光的部分或全部可以与宽带光源的大部分光分离。

[0201] 有利地，反射和分离的光被传输至光检测器34，诸如举例来说光电二极管和分光计。

[0202] 图6是以干涉仪形式的本发明的装置的实施方式的示意图，例如用于光学相干断层成像(OCT)，例如用于内部组织可视化。干涉仪包括第一传输光纤组件105a、106a，它们包括熔接式耦合器传输光纤组件105b、106b，其中第一传输光纤组件105a、106a和熔接式耦合器传输光纤组件106b在组成段100中熔接。干涉仪包括具有可操作以生成泵浦脉冲的光学泵浦光源101a的宽带光源，和用于从所述光学泵浦光源101a进给泵浦脉冲时生成宽带光脉

冲的气孔微结构光纤101b,以及第一传输光纤组件105a、106a,其包括具有如上所述的实心内含物的传输光纤105a和同样如上所述的连接器构件106a。第一传输光纤组件105a、106a经由传输光纤连接器构件106c和端帽连接构件101c连接至微结构光纤,光纤连接器构件106c有利地是如上所述的连接器构件。在端帽连接构件101c中,沿比气孔微结构光纤101b小于几mm延伸的气孔坍塌并且光束由未示出的透镜准直。传输光纤连接器构件106c和端帽连接构件101c由匹配套筒20c配对并保持在一起。在可替代实施方式中,气孔微结构光纤101b通过拼接和/或通过使用如上所述的GRIN透镜被拼接至传输光纤105。

[0203] 干涉仪包括第二光纤组件21a、22a、23a,其有利地是如上所述的第二光纤组件21、22、23,以及连接器构件106a、21a通过匹配套筒20a连接并保持在一起。

[0204] 熔接式耦合器传输光纤组件105b、106b连接至第三光纤组件21b、22b、23b,其有利地是如上所述的第二光纤组件21、22、23,以及连接器构件106b、21b通过匹配套筒20b连接并保持在一起。干涉仪还包括反射镜40或另一基准单元,布置以反射经由光纤终止单元23b发射的光。在可替代实施方式中,基准单元不包括在该装置中而可以由使用者进行选择。

[0205] 熔接式耦合器传输光纤组件105b还连接至检测器124,诸如分光仪。宽带光源可包括一个或多个可调谐或不可调谐滤光器和/或脉冲选择器以及一个或多个放大器,诸如本领域中所公知的。

[0206] 通常,耦合器具有阻挡端口,其中光直接从一个顶臂至另一顶臂(或从一个底臂至另一底臂),以及交叉端口,其中光纤从顶臂至底臂,或反之亦然。通常,耦合器靠近以具有非常低的损耗以使得所有光被发送至阻挡端口或交叉端口。在该实施方式中,两个顶臂由组成段100的任一侧上的传输光纤105a来提供以及底臂由组成段100的任一侧上的传输光纤105b来提供。阻挡端口和交叉端口由组成段100提供。阻挡端口具有x的传输系数以及交叉臂具有(1-x)的传输系数。不论穿过耦合器的方向,传输系数是相同的。

[0207] 在使用时,宽带光脉冲被传输至传输光纤105a并如在最靠近微结构光纤的传输105a末端的示图上所标记的,光脉冲功率被设置为 $100\% = "1"$ 。在熔接式组成段100处,一些光(x)经由传输光纤105a进一步传输以及一些光(1-x)经由熔接式耦合器传输光纤105b进一步传输。

[0208] 从熔接式组成段100并经由传输光纤105a传输的光部分(x)被传输至第二光纤组件21a、22a、23a,以及经由光纤终止单元23a,光脉冲朝向样本30发射,以及反射光31a在相反方向上经由第二光纤22a和传输光纤105a传输直至所传送光到达熔接式组成段100。从那里,所传送光的一部分经由熔接式耦合器传输光纤105b进一步传输至检测器104。

[0209] 从熔接式组成段100并经由熔接式耦合器传输光纤105b传输的光部分(1-x)被传输至第三光纤组件21b、22b、23b,以及经由光纤终止单元23b,光脉冲朝向反射镜40发射,以及反射光31b在相反方向上经由第三光纤22b和熔接式耦合器传输光纤105b传输直至所传送光到达熔接式组成段100。从那里,所传送光的一部分经由熔接式耦合器传输光纤105b进一步传输至检测器104。有利地,反射镜基本反射入射在其上的全部光。

[0210] 如所说明的,干涉仪因此具有两个干涉臂,一个臂引导光至样本并转发反射光以及一个臂引导光至基准单元(例如,反射镜)并转发反射光。在一个实施方式中,一个干涉臂被配置为聚焦在组织样本上并用于以X-Y纵向光栅模式扫描样本。另一个干涉臂从基准反射镜反弹。来自组织样本的反射光与来自基准的反射光组合。

[0211] 如上所提及的,在图6中所示的实施方式中,光从宽带激光器出发穿过耦合器的交叉端口以到达反射镜40。它从反射镜反射并穿过耦合器的阻挡端口返回以到达检测器124。假定反射是无损耗的,整个路径的传输系数是两个传输系数的乘积,即 $x(1-x)$ 。

[0212] 图7是包括组合器的本发明的传输光纤的实施方式的示意图。

[0213] 有利地,全部传输光纤105a、105b、22a、22b是全实心光纤,其包括以如上所述的内含物形式的微结构,并且优选地,全部传输光纤105a、105b、22a、22b具有200nm或更大的传输带宽,优选地传输带宽是重叠的或相同的。

[0214] 图7是以另一类型的干涉仪的形式的本发明的装置的实施方式的示意图,该另一类型的干涉仪例如用于例如薄膜、晶片、光学线宽测量仪(OCD)、晶体管的重叠和晶片应力以及互连计量应用的光学计量。

[0215] 图7的干涉仪的部件与图6的干涉仪的对应部件相似。干涉仪包括第一传输光纤组件105a、106a,它们包括熔接式分束器传输光纤组件105b、106b,其中第一传输光纤组件105a、106a和熔接式分束器传输光纤组件106b在组成段100中熔接。干涉仪包括具有可操作以生成泵浦脉冲的光学泵浦光源101a的宽带光源、用于在从所述光学泵浦光源101a进给泵浦脉冲时生成宽带光脉冲的微结构光纤101b、以及第一传输光纤组件105a、106a,其包括具有如上所述的实心内含物的传输光纤105a和同样如上所述的连接器构件106a。第一传输光纤组件105a、106a经由滤光器32连接至微结构光纤,滤光器32布置以将由样本30e和基准单元40反射的反射光33的一部分引向光检测器34。其余部件如图7中的示例。

[0216] 图8示出了适于提供光至装置的光谱引擎源。光谱引擎源包括三个激光器121、122、123,它们分别发射激光束121a、122a、123a。激光束121a、122a、123a在至少一个波长上彼此不同,如上所述。

[0217] 激光器121、122、123可以是相同或不同的类型,诸如一个或多个气体激光器、一个或多个化学激光器、一个或多个金属蒸气激光器和/或一个或多个半导体激光器。

[0218] 光谱引擎源还包括多路复用器M,这里由多个反射镜示意,它们布置以将光束121a、122a、123a组合为一个单条多路复用光束M。应该理解的是,多路复用器可以是任意类型的多路复用器或组合器,其能够将每个激光器的至少一部分激光束组合以及用于将所接收光准直至多路复用光束。多路复用器M将121a、122a、123a足够接近地准直以被本发明的光谱引擎源的传输光纤接收。为了简化起见,光谱引擎源的传输光纤未示出,然而,传输光纤被布置以收集多路复用光束M并用于将所接收的多路复用光束M的至少一部分传输至装置。

[0219] 图9示出了适用于提供光至装置的另一光谱引擎源。光谱引擎源包括5个激光器131、132、133、134、135,它们分别发射激光束131a、132a、133a、134a、135a。激光束131a、132a、133a、134a、135a在至少一个波长上彼此不同。例如,激光束131a可包括400–500nm范围内的波长,激光束132a可包括500–600nm范围内的波长,激光束133a可包括600–700nm范围内的波长,激光束135a可包括800–900nm范围内的波长。

[0220] 光谱引擎源还包括多路复用器M,这里由多个反射镜示意,它们布置以将光束131a、132a、133a、134a、135a组合为一个单条多路复用光束M。光谱引擎源还包括未示出的传输光纤,如上所述,用于接收多路复用光束并用于所接收的多路复用光束M的至少一部分传输至装置。

[0221] 图10示出了包括光源LS的本发明的实施方式的装置,光源LS选自宽带光源、宽带光源系统或光谱引擎源,具有如上所述的传输光纤DL。该装置是平板印刷装置并包括照明系统(照明器)IL,其布置用于从光源LS的传输光纤接收光。照明器IL可包括调节器AD,用于调节从光源LS接收的辐射束的光强度分布。另外,照明器IL可包括各种其他元件,诸如积分器IN和聚光器CO。照明器可用于调节辐射束,以在其横截面上具有期望的均匀性和强度分布。

[0222] 辐射束B入射在由支撑结构(例如,掩模台MT)保持的模式设备(例如,掩模MA)上,并由模式设备形成图案。横穿掩模MA,辐射束B穿过投影系统PS,投影系统PS将光束聚焦在基底W的目标部分C上。借助于第二定位器PW和位置传感器IF(例如,干涉仪设备、线性编码器或电容传感器),基底台WT可以精确地移动,例如使得在辐射束B的路径上定位不同目标部分C。类似地,第一定位器PM和另一位置传感器(其在图1中未明确描绘)可以用于例如在从掩模库机械检索后、或在扫描期间将掩模MA关于辐射束B的路径精确地定位。通常,掩模台MT的移动可借助于长冲程模块(粗定位)和短冲程模块(细定位)来实现,这形成第一定位器PM的一部分。类似地,基底台WT的移动可使用长冲程模块和短冲程模块来实现,这形成第二定位器PW的一部分。在步进器(与扫描器相对)的情形中,掩模台MT可仅连接至短冲程致动器,或可以是固定的。掩模MA和基底W可使用掩模对准标记M1、M2和基底对准标记P1、P2来对齐。尽管所示意的基底对准标记占据了专用目标部分,它们可以定位在目标部分之间的空间中(这些称作为线通道对准标记)。类似地,在其中多于一个模具设置于掩模MA的情形中,掩模对准标记可以定位在模具之间。该装置可例如如US2007013921中所述的来操作。

[0223] 图11示出了包括扫描显微镜和光源LS的本发明的实施方式的装置,扫描显微镜体现为共焦扫描显微镜,光源LS选自宽带光源、宽带光源系统或光谱引擎源,具有如上所述的传输光纤DL。光源LS经由传输光纤DL传输照明光束211。

[0224] 扫描显微镜包括声光元件213,其体现为AOTF 215。通过声光元件213,从照明光束211中选出的光212到达射束偏转设备17,其包含万向架固定的扫描镜19并且引导照明光束211穿过扫描光学系统221、管路光学系统223、以及物镜225、到达或穿过样本227。来自样本的检测光束229在相反方向上行进,穿过扫描光学系统221、管路光学系统223、以及物镜225,并经由扫描镜219到达声光元件213,其将检测光束229传输至检测器231,检测器体现为多波段检测器。照明光束211在附图中描绘为实线,以及检测光束229为虚线。为了完整,示意性地绘出了通常设置于共焦扫描显微镜中的照明针孔233和检测针孔235。然而为了更加清楚,省略了用于引导并形成光束的某些光学元件。声光元件213,其用于选择被选定的波长谱,被配置为AOTF 215,声波穿过它。声波由电激发压电发声器237生成。通过高频源239实现激发,高频源239生成呈现可调节HF谱的电磁高频波。HF谱被选择为使得仅具有期望波长的照明光束211的那些部分到达射束偏转设备217。未被声激发影响的照明光束211的其他部分被引导至射束阱241。照明光束211的功率水平可以通过改变声波的振幅来选择。声光元件213的晶体切片和定向被选择以使得通过单耦合方向,不同波长在相同方向上偏转。计算机243用于选择第二或第三波长谱。计算机243的监视器247用作为光谱组成的显示器。波长谱的选择连同其光谱组成基于具有两个坐标轴X、Y的坐标系中的曲线G来实现。光波长绘制于坐标轴X上,以及其功率水平绘制于坐标轴Y上。计算机243根据使用者的规定来控制高频源239。使用者使用计算机鼠标257进行调节。滑块259描绘于监视器247上,用于

照明光束11或检测光束229的整体光功率水平的调节。

[0225] 尽管已经详细描述和示出了各个实施方式,本发明不限制于它们,而是还可以在下面权利要求书中限定的主题的范围内以其他方式体现。特别地,应该理解的是,可以利用其他实施方式,以及可以在不偏离本发明的范围的情况下做出结构和功能改变。

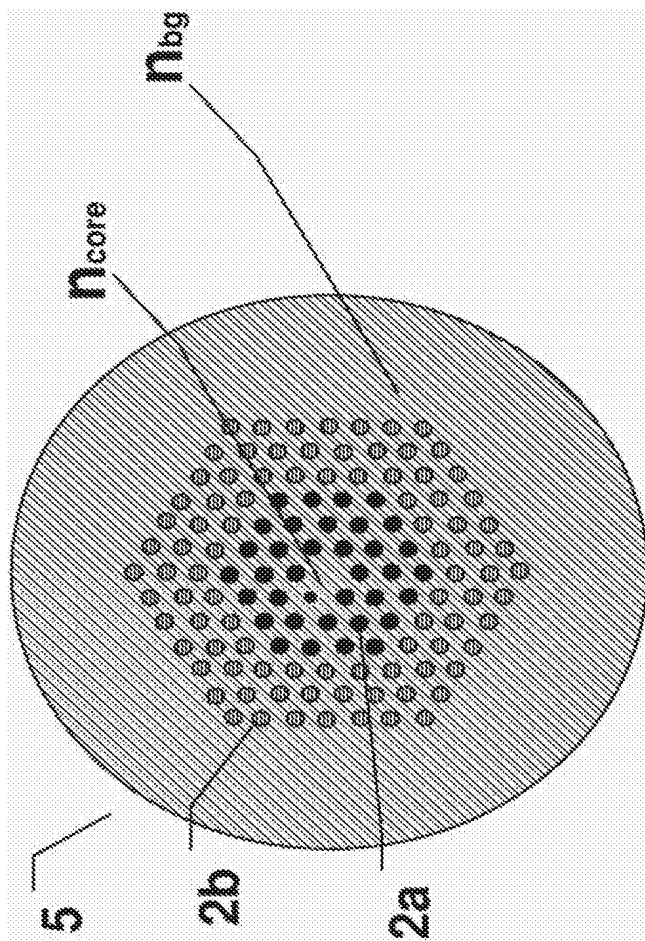


图1a

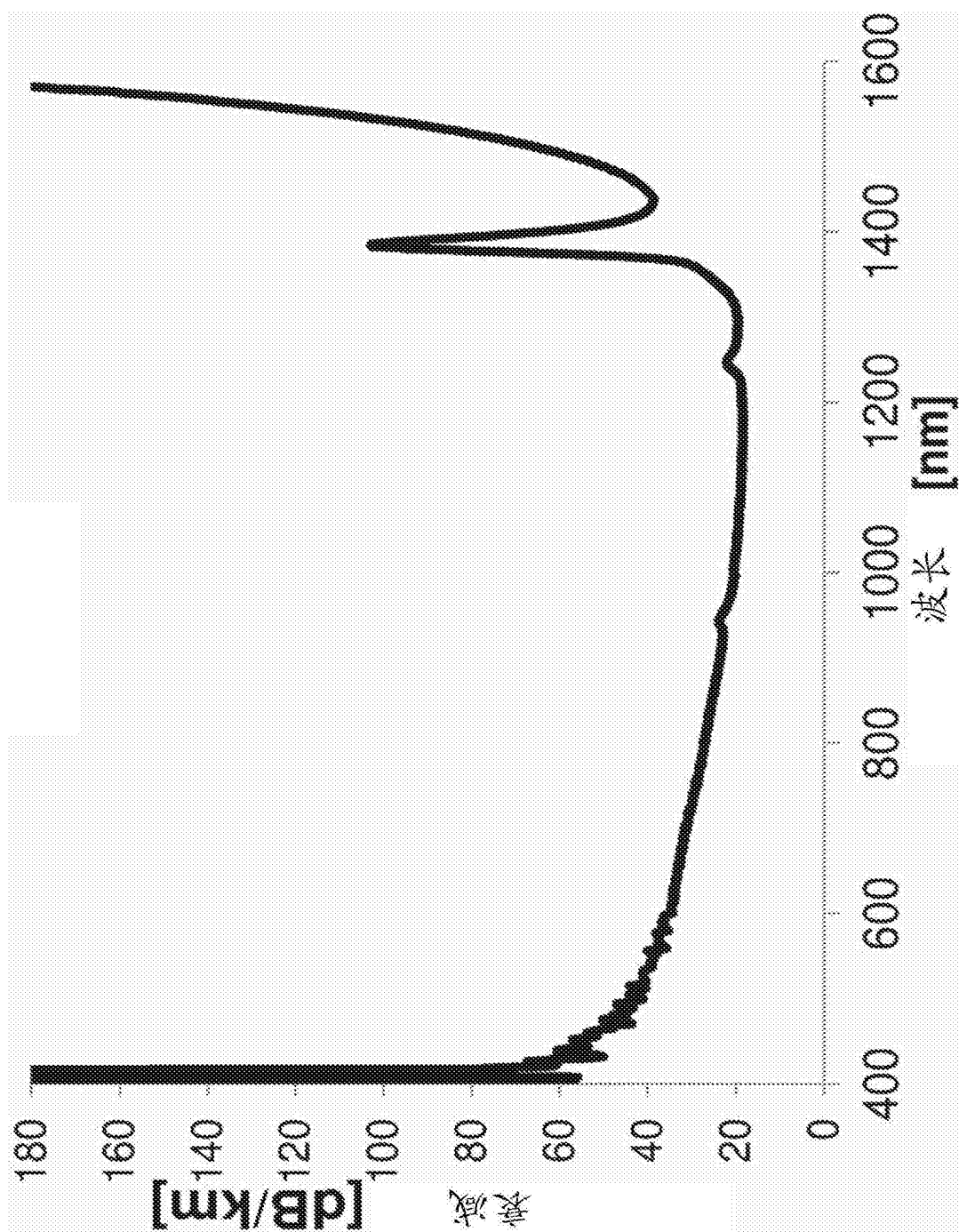


图1b

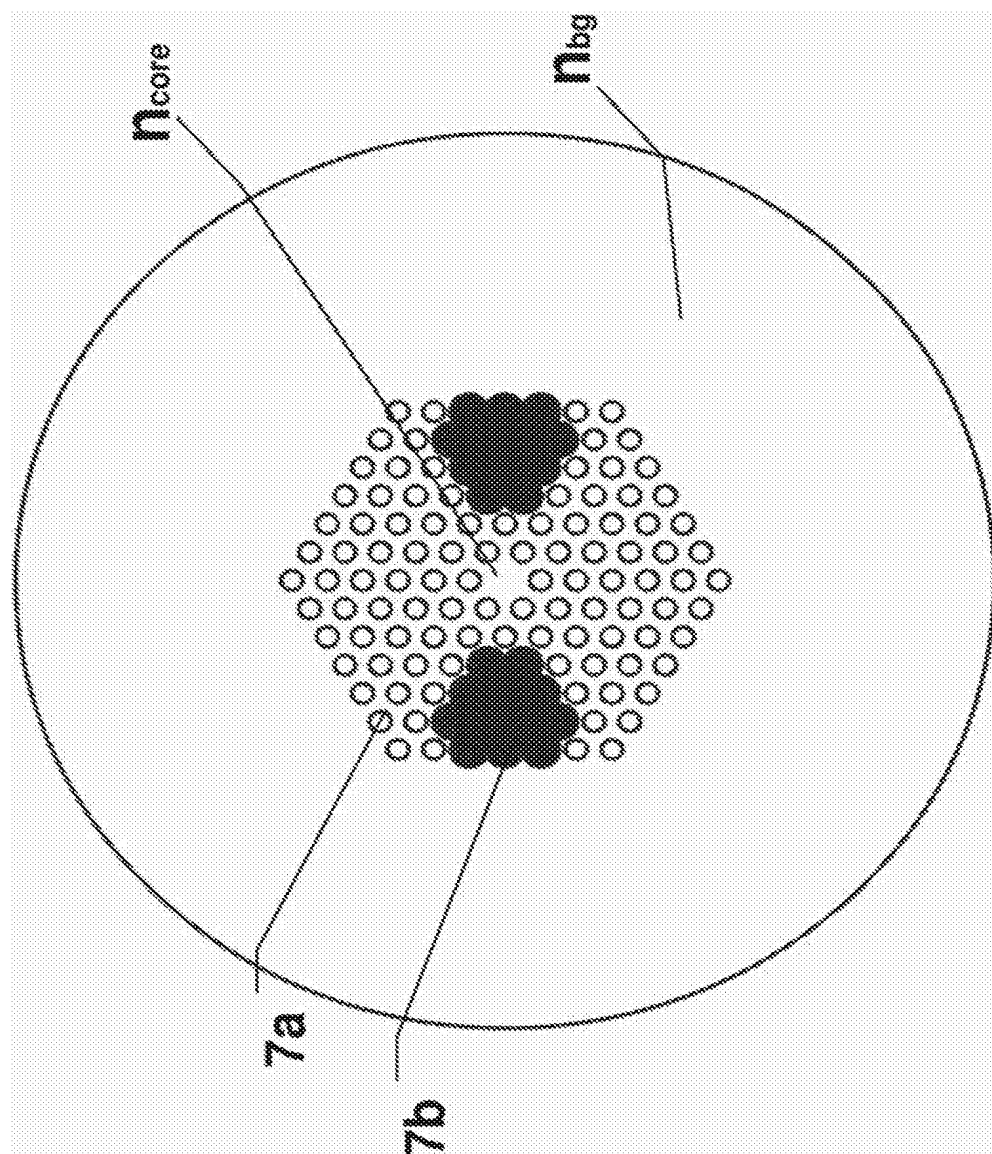


图1c

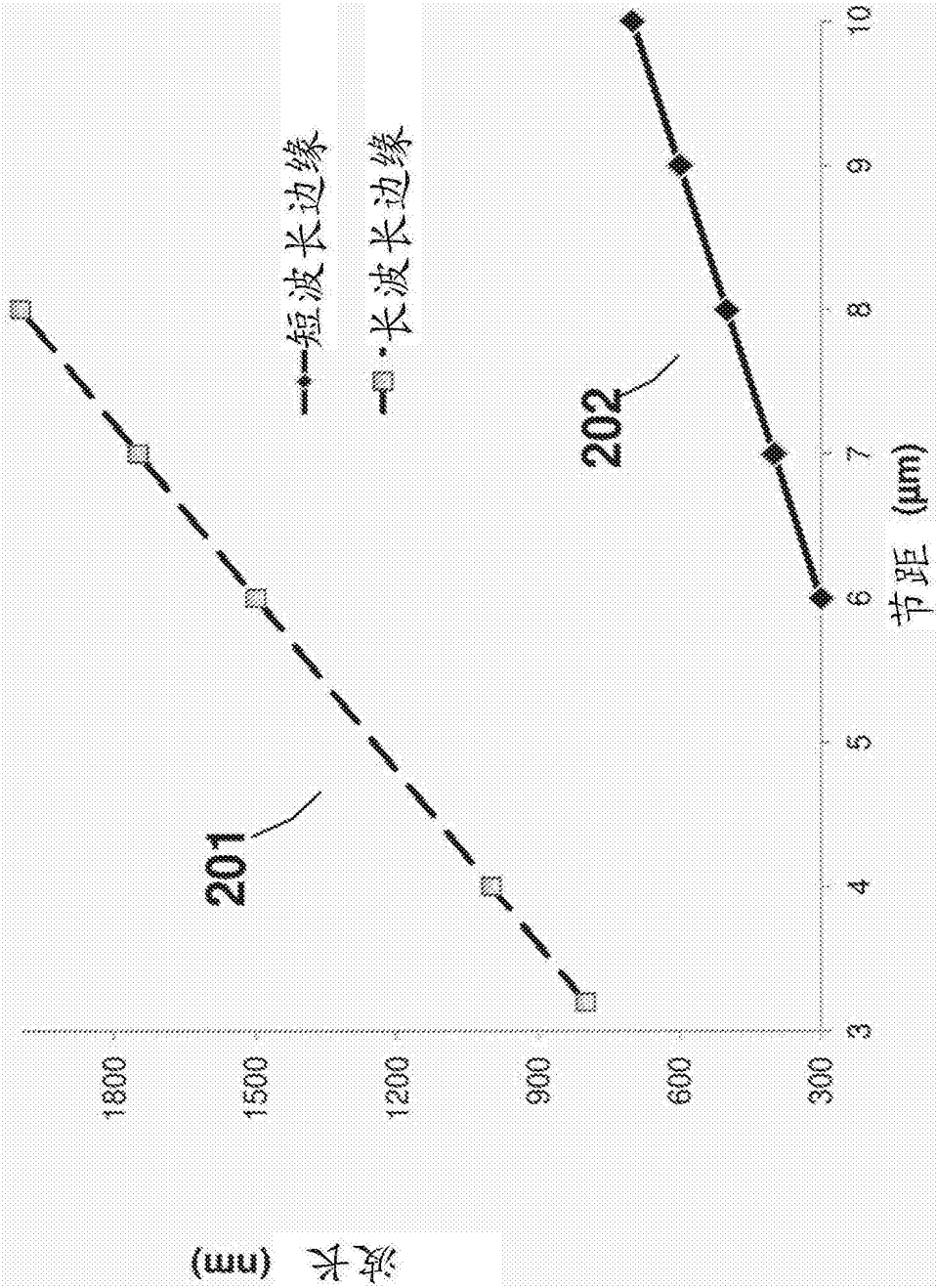


图1d

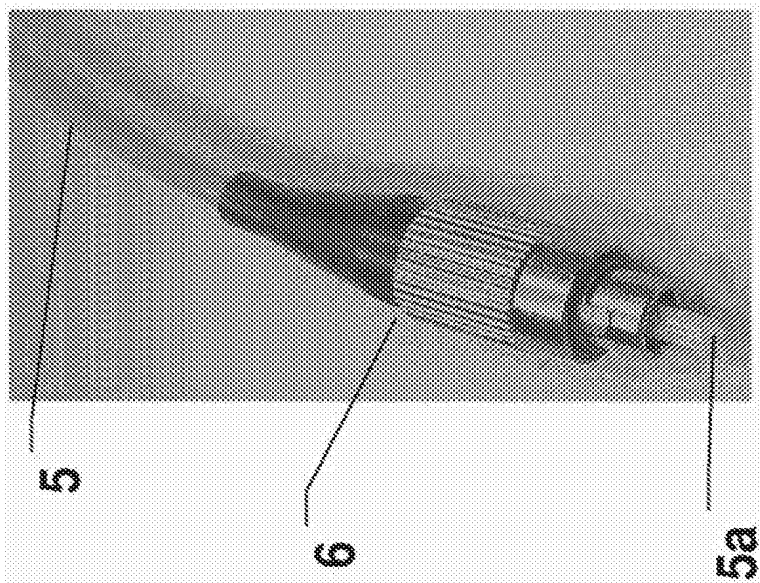


图2

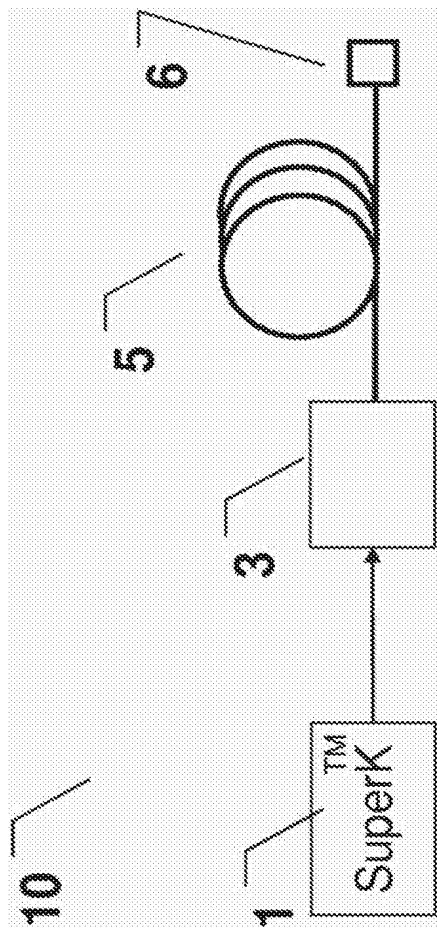


图3

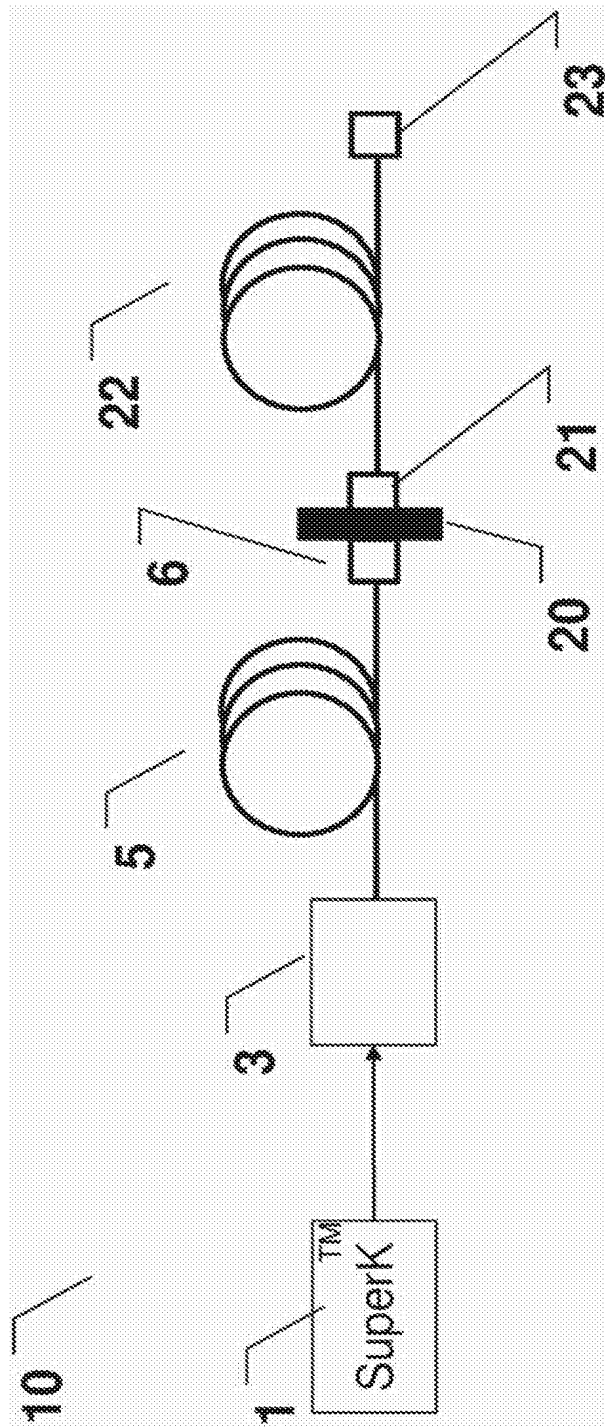


图4

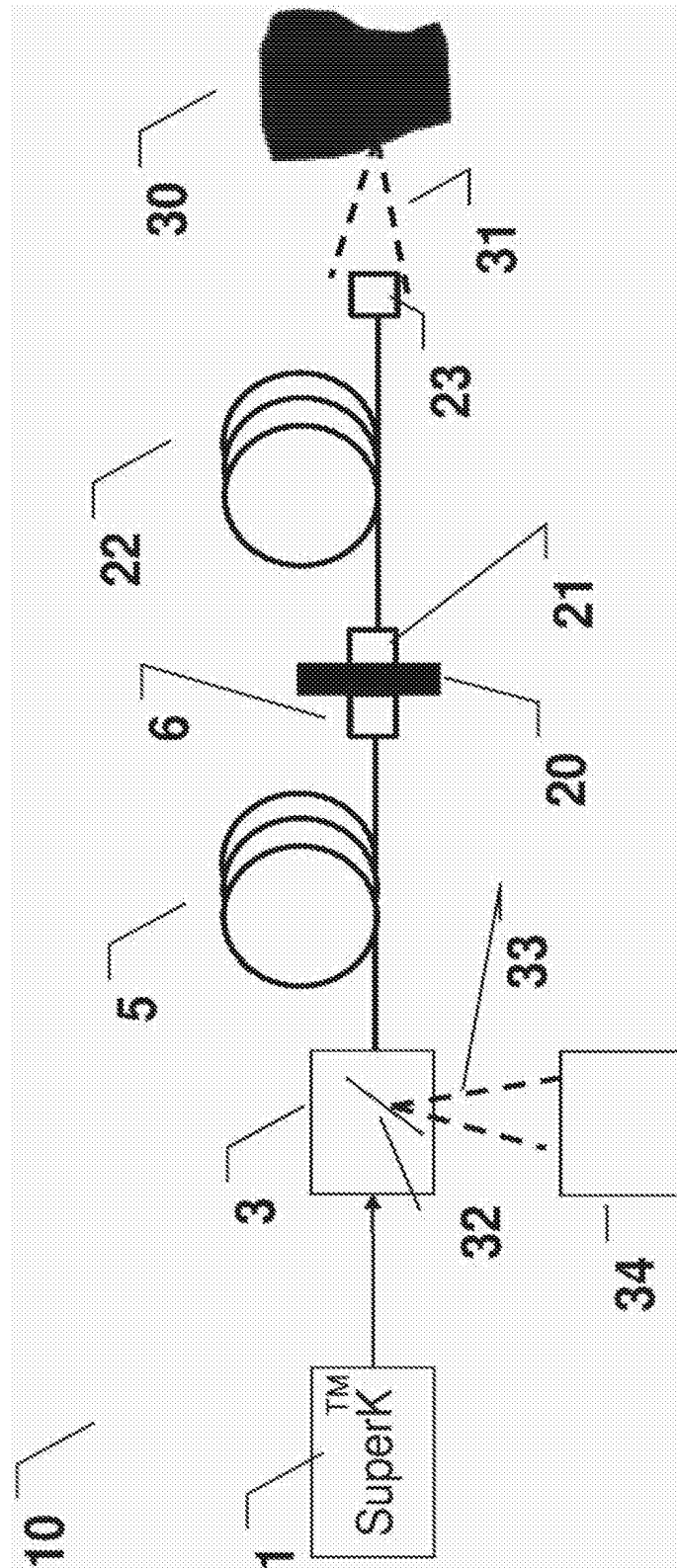


图5

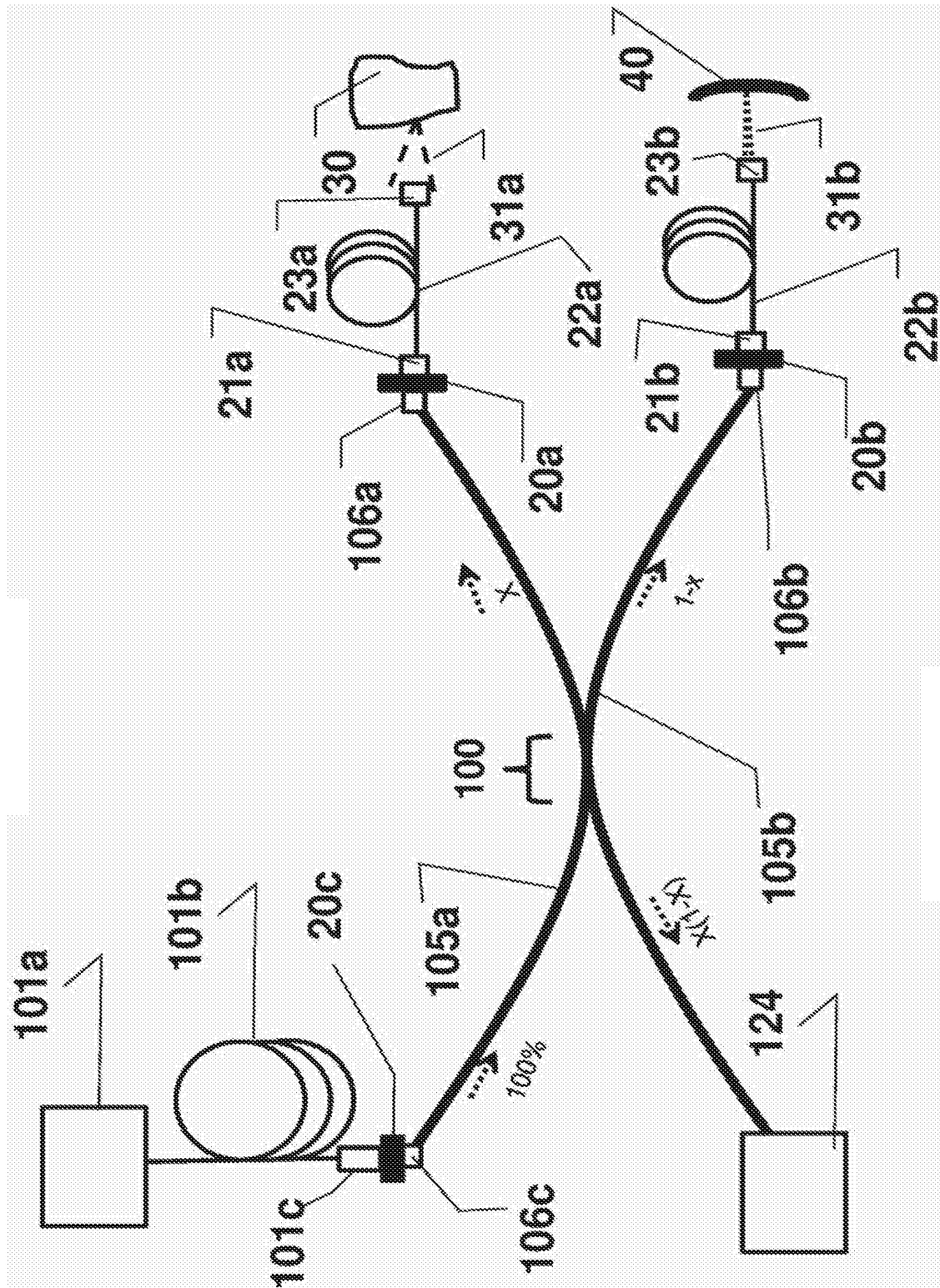


图6

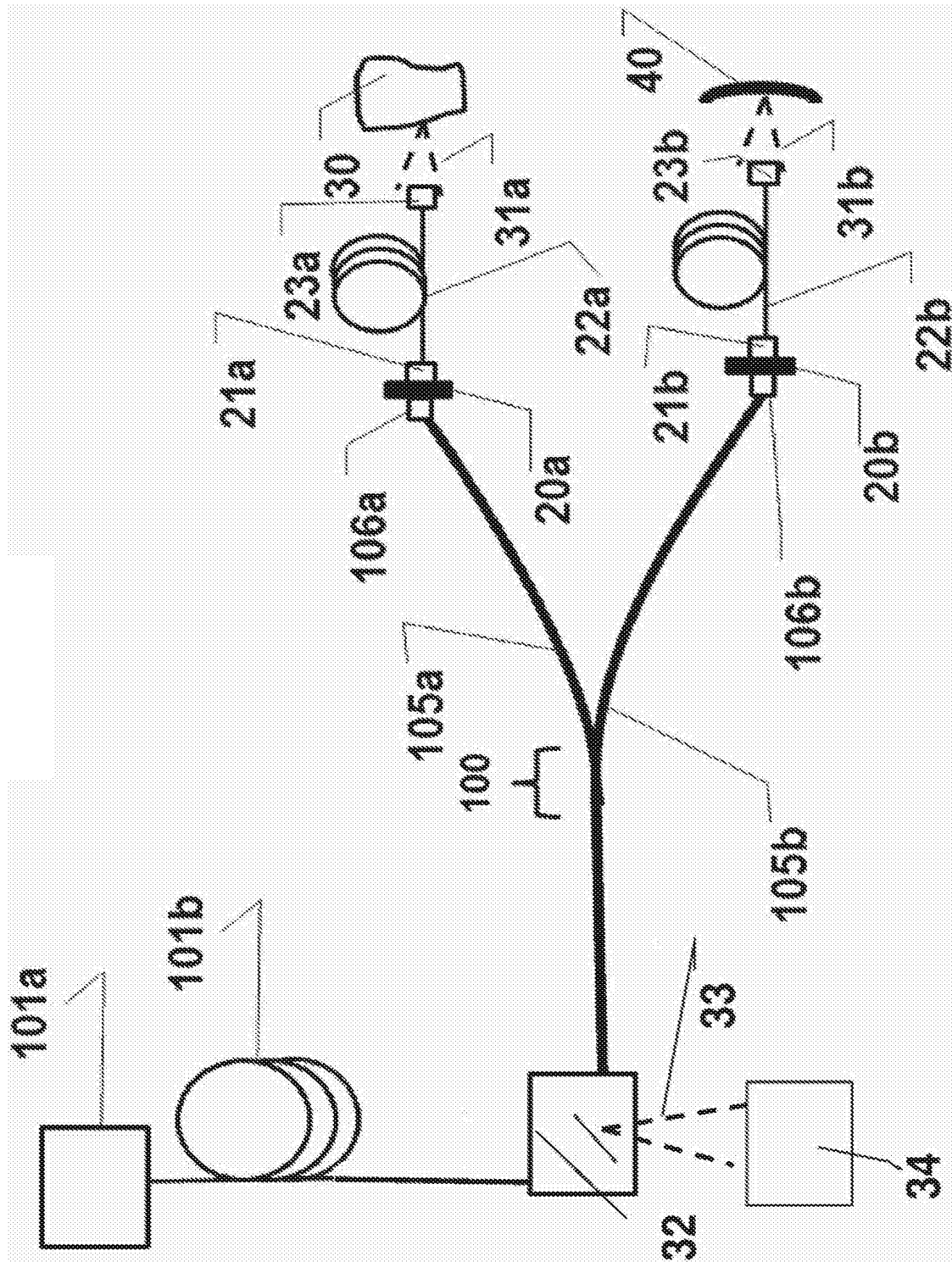


图7

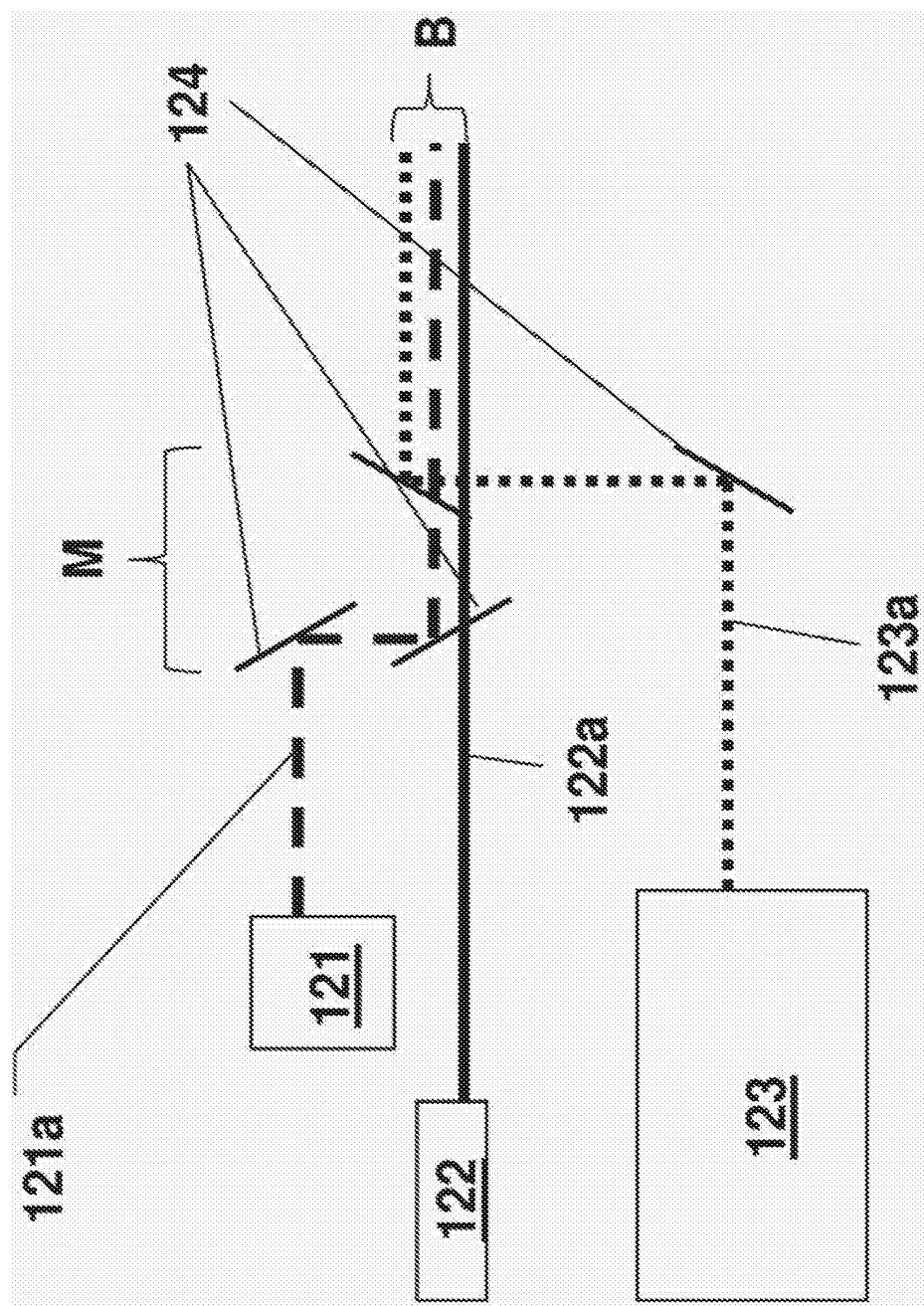


图8

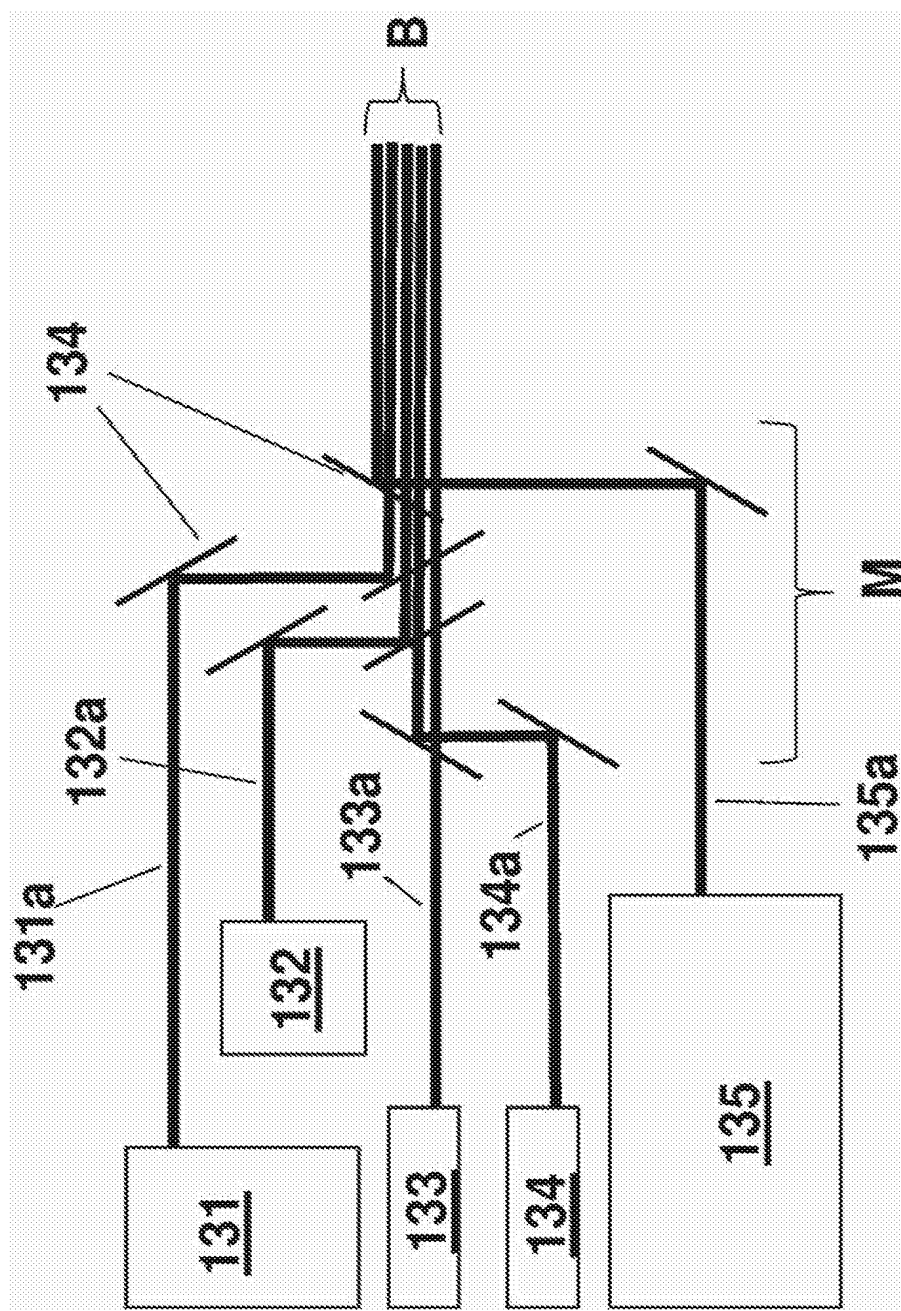


图9

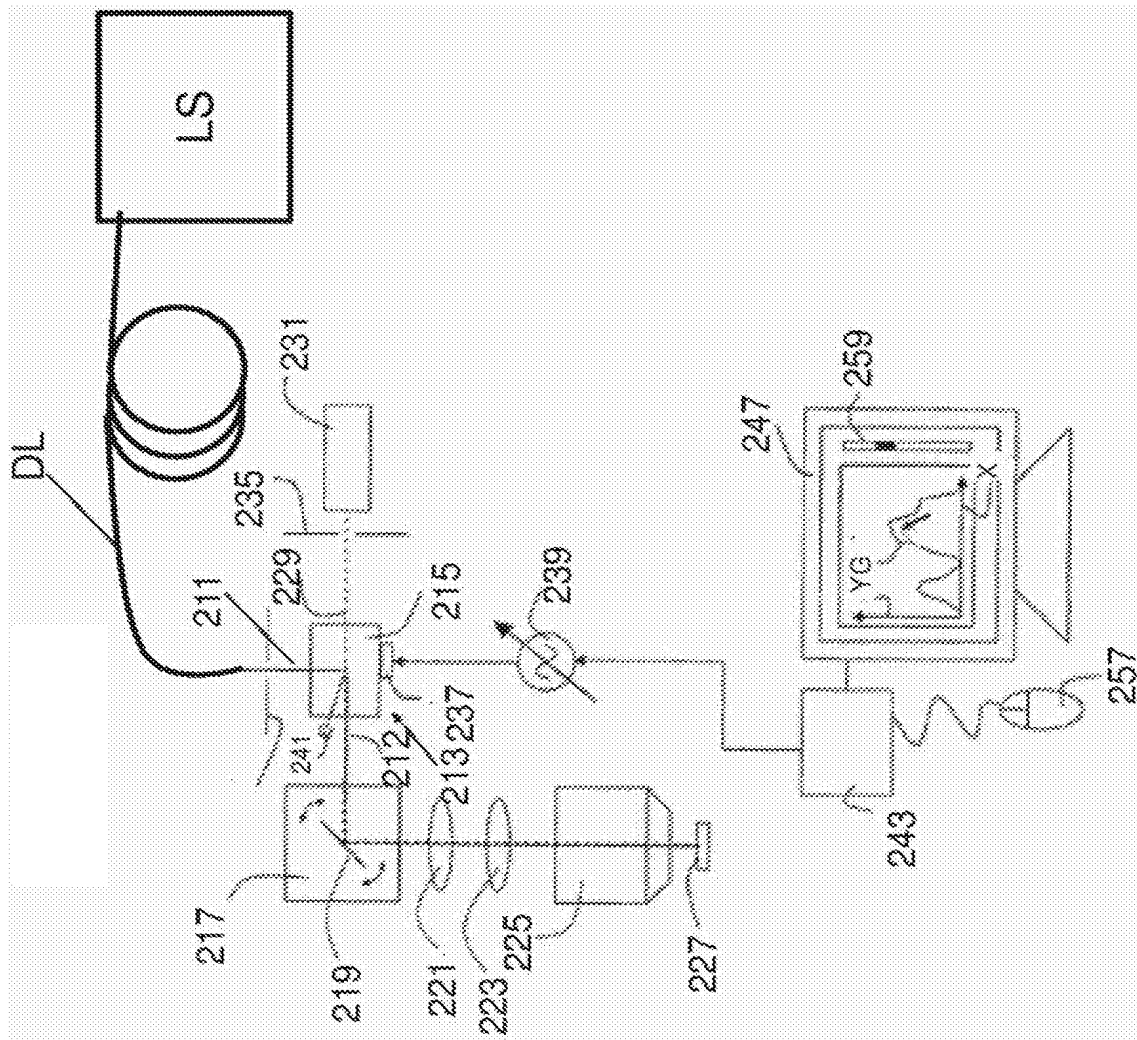


图11